Cleantech for Europe

Cleantech Group

Doing more with less:

A European **Critical Raw Materials Strategy** fit for Cleantech Competitiveness

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Breakthrough Energy

ACKNOWLEDGEMENTS

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Executive summary

As the EU Green Deal agenda comes into force, the European Union is setting out to profoundly transform its energy and transportation systems, industry, and overall technological landscape. Recent developments suggest that Europe is competing in the cleantech race on a solid regulatory footing. This once-in-a-century opportunity heavily relies on the availability of critical raw materials (CRMs), which are input materials of foundational importance to specific technologies linked to both existing and future growth trajectories of the EU's economic prosperity and competitiveness.

Critical raw materials (CRMs) such as lithium, graphite, cobalt, nickel, manganese and rare earths, carry a high risk of supply disruption, due to geographic concentration of supply coupled with a dearth of equally effective and affordable substitutes. A potential severe disruption at any stage of the CRM value chain – which includes exploration, mining, processing, recovery and recycling – could jeopardize both the green and digital transitions. Innovative clean technologies can enable a decrease in projected CRM demand as well as improve sustainability at every stage of the value-chain. Technologies are being developed to reduce the need for critical materials and increase their supply through better mining and recovery. A resilient and autonomous Europe can lead the world in technological, environmental, and social standards in this sector.

To date, the EU's focus has been on security of supply, and achieving it through accelerated permitting, small amounts of financial support for certain projects, and building partnerships with mineral-rich countries. While these are important steps, the EU is missing out on another lever: innovation.

In this report, we review the clean technologies that could change the EU's critical materials dependency into an asset, ushering in a new era of materials innovation, efficiency, and recovery. By failing to put cleantech innovation at the center of its CRM strategy, the EU risks falling short in both its security of supply goals as well as its climate and environmental goals.

Priority must be given to innovative ways of overcoming current barriers, increasing efficiency of materials used so that 'less' becomes 'more', while securing long-term competitiveness and security of supply for the foreseeable future. Similar to investing in efficiency improvements in home heating, while an initial investment is required, the return over the longer-term is what counts. In the field of CRM, only with a clear innovation strategy and sufficient funding can the EU reach its long-term goals.

To this end, there have been numerous policy initiatives in recent years, such as the Batteries Regulation and Critical Raw Materials Act (CRMA) in the EU, the Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA) in the US, and Critical Minerals Strategies in Australia and Canada, among others. This has led to a surge in venture investment into critical mineral start-ups developing and scaling clean technologies and solutions across the value chain.

In 2022, despite a fall in overall cleantech venture funding globally, CRM innovators around the world raised unprecedented amounts of equity ($1.6bn, of which $0.25bn was for higher risk early-stage ventures, according to the IEA). This 160% year-on-year increase led CRMs to account for 4% of all cleantech venture funding in 2022, according to the IEA.

While the global picture is optimistic, a look at funding by region reveals a more worrying trend: Europe is falling behind in

developing and scaling cutting-edge CRM cleantech. This report zooms in on the comparison between the US and the EU regarding one particular sector that has attracted much venture investment – battery recycling. The results are sobering for Europe, a continent which has for decades been a global leader in recycling.

The disparity between the EU and North America is primarily observable in terms of amounts invested. Average deal size in North America is significantly larger, providing pivotal scale-up capital to growth-stage innovators for CRM projects, which tend to be highly capital-intensive. This observation backs up our multiple recommendations on additional and better targeted funding to support positive synergies between innovations along the value chain so that investing more now can help us optimise our cleantech economy, with increasingly less CRM supply-chain uncertainties.

The report shows that venture investments have already responded positively to growing CRM demand as well as increasingly strategic and sophisticated government policies. This should encourage policymakers to pursue regulations and supportive instruments for critical raw materials.

Recommendations for an EU Cleantech Strategy for Critical Raw Materials:

Proposal 1: Enhance short- and long-term EU Public Funding

In order to close the investment gap between the Net Zero Industry Act and the CRMA we recommend the EU:

→ Utilize the expanded EU Innovation Fund to make innovative

CRM-cleantech projects eligible, and explore the possibility of replicating the European Hydrogen Bank model for quick- and cost-effective scaling-up of innovative projects.

→ Establish a European Critical Minerals Fund that is designed with speed, scale, and simplicity in mind to support European CRM innovators, and develops instruments designed to maximize the crowding-in of private investment. This Fund could eventually be bolstered by revenues from the EU Carbon Border Adjustment Mechanism (CBAM).

Proposal 2: Turbocharge innovation in clean technologies that sustainably boost primary CRM supply

We recommend the following actions be taken to develop and deploy supply-side innovations across the first three stages of the CRM value chain, namely exploration, mining, and processing:

→ **Exploration:** require EU countries to develop national CRM exploration programs for CRM resources and mandate large vertically integrated mining incumbents to disclose their environmental footprint.

→ **Mining:** Enhance incentives to mine more sustainably, thereby encouraging the uptake of mining practices and technologies which reduce environmental impact and local resistance to projects. Mandate and support the use of all electric mining equipment and develop a standard or label around “responsible mining”.

→ **Processing:** Develop standards to reduce waste, recover materials, as well as reduce the use of harmful chemicals in processing, and use water more efficiently. Use public funding to catalyze private-led investment into expanding domestic processing capacity for innovations which improve the productivity of CRM processing and refining while reducing its environmental impacts.

Proposal 3: Scale up innovation in clean technologies that reduce the need for additional primary CRM supply

Promising emerging clean technologies can improve resource use efficiency, thereby decreasing demand for CRM inputs as well as improving the sustainability of demand. To encourage the scale up of these innovations we propose the EU focuses on **recycling** salvageable materials from, e.g., lithium-ion batteries, **substituting** for non-critical materials where possible, and embracing the principles of **ecodesign**:

→ **Recycling:** Harmonise waste management rules for waste streams with significant CRM recovery potential, and ensure that all European end-of-life batteries and waste battery materials remain in Europe. Impose traceability disclosure on materials suppliers beyond battery manufacturers.

→ **Substitution:** The EU must encourage investment in substitute materials to reduce mineral intensity of clean technologies. Public support could be mobilised for R&D and demonstration projects aimed at reducing and replacing CRM in electrolysis, for example.

→ **Ecodesign:** Thoroughly mapping the landscape of mature and nascent clean technologies for opportunities to promote ecodesign would provide a strong foundation. It is critical that the EU support research and development into ecodesign, such as more recyclable alloys.

Whereas the EU has set clear goals for the phase-out of Russian oil and gas, in addition to swift investments and legislative actions to diminish its dependence on natural gas imports, the EU has yet to treat its CRM dependency with the same degree of urgency. We hope that this report will contribute to making this possible.

STATE OF PLAY

01. Booming demand and growing supply risk

02. Growing investment into innovations that could upend the CRM race

03. Lagging behind: the EU's under-investment in CRM technologies

Booming demand and growing supply risk

Booming demand for CRMs and geopolitical supply risk have emphasized the need for democracies to reduce their current reliance on unreliable authoritarian states for sourcing CRMs and not replace one dependency with another in the cleantech race to net-zero.

Whereas the EU has set clear goals for the phase-out of Russian oil and gas, in addition to swift investments and legislative actions to diminish its dependence on natural gas imports, the EU has yet to treat its CRM dependency with the same degree of urgency.

Booming demand: As the global race to develop and scale the deployment of cleantech heats up we are witnessing increasing demand for the CRMs that power clean technologies such as wind turbines (e.g., neodymium), electric vehicle (EV) batteries (e.g., lithium), solar panels (e.g., gallium), and electrolysers (e.g., iridium).

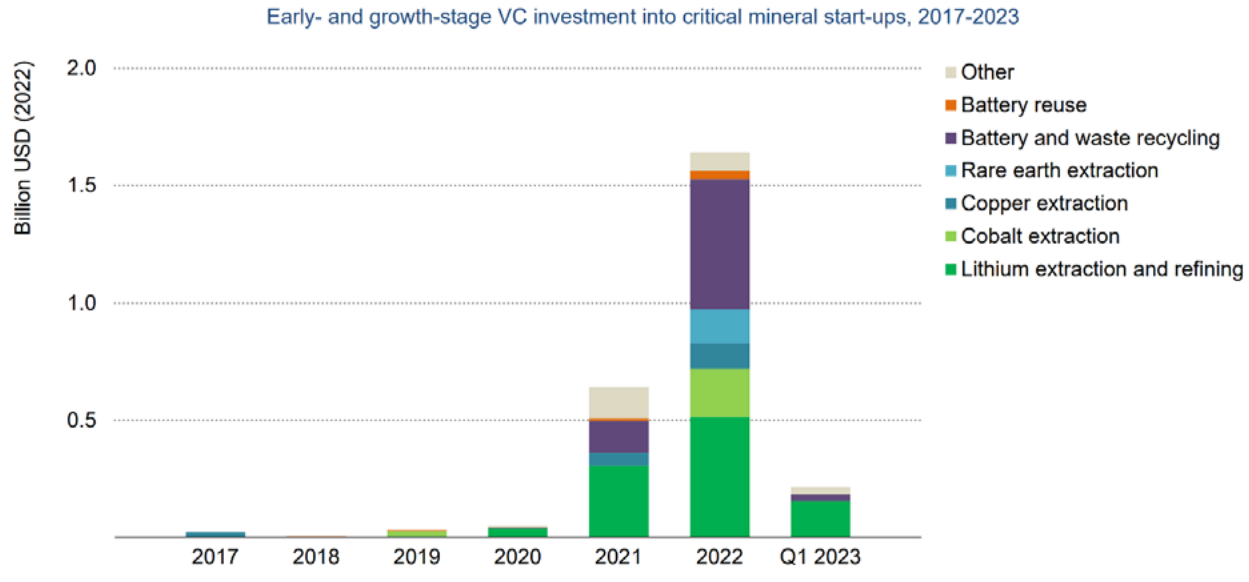
Growing supply risk: Firstly, more frequent and intense natural disasters made worse by climate change represent a real supply risk. Secondly, landmark developments, including Russia's illegal war of aggression against Ukraine and China's export restrictions on germanium, gallium, and graphite, have awakened leaders to the fact that under Europe's current policy trajectory, the global cleantech race is increasing Europe's reliance on undemocratic states for supplying CRMs. More so than even fossil fuels, the extraction and processing of CRMs is geographically concentrated in undemocratic countries. Notably, China is a dominant supplier

of most CRMs across most stages of the value chain. For example, China processes upwards of 60% of lithium and cobalt, and around 90% of rare earths. China's use of CRM export restrictions is rapidly increasing, putting Europe at significant risk.

Growing investment into innovations that could upend the CRM race

In response to this challenge to secure CRM supplies, there have been numerous policy initiatives in recent years, such as the Batteries Regulation and Critical Raw Materials Act (CRMA) in the EU, the Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA) in the US, and Critical Minerals Strategies in Australia and Canada, among others.

This has led to a surge in venture investment into critical mineral start-ups developing and scaling clean technologies and solutions across the value chain.



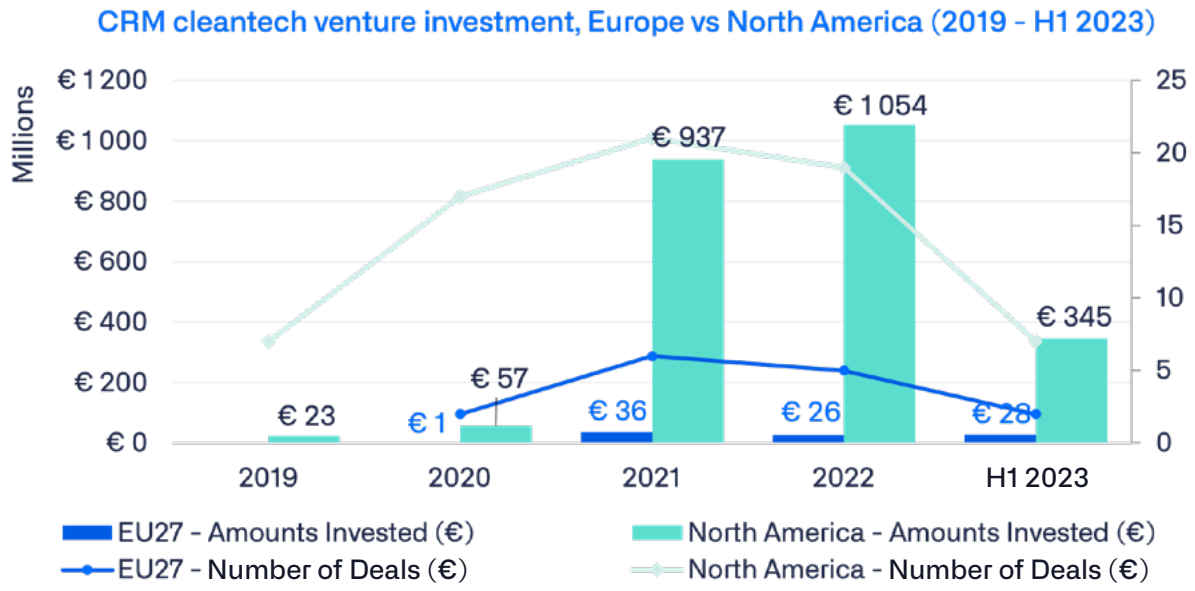
Source: IEA, based on Cleantech Group data

The graph above shows venture investment responded to increasingly strategic and sophisticated government policies by placing greater emphasis on battery recycling and lithium supply cleantech start-ups.

In 2022, despite a fall in overall cleantech venture funding globally, CRM innovators around the world raised unprecedented amounts of equity ($1.6bn, of which $0.25bn was for higher risk early-stage ventures, according to the IEA). This 160% year-on-year increase led CRMs to account for 4% of all cleantech venture funding in 2022 (IEA). Global venture investments in the first half of 2023 put CRMs on track to overtake 2022 levels by year's end. This momentum indicates that investors increasingly anticipate supportive market and policy environments.

Lagging behind: the EU's under-investment in CRM technologies

While the global picture is optimistic, a comparison between venture funding in the EU and North America reveals a more worrying trend: Europe falling behind in developing and scaling cutting-edge CRM cleantech.



Data Source: Cleantech for Europe

Technology areas covered by the above graph: CRM exploration, mining and processing, and battery recycling. Note: the manufacturing of batteries and battery components is excluded from the table, but reshoring production thereof is also essential given the amount of critical raw materials they contain.

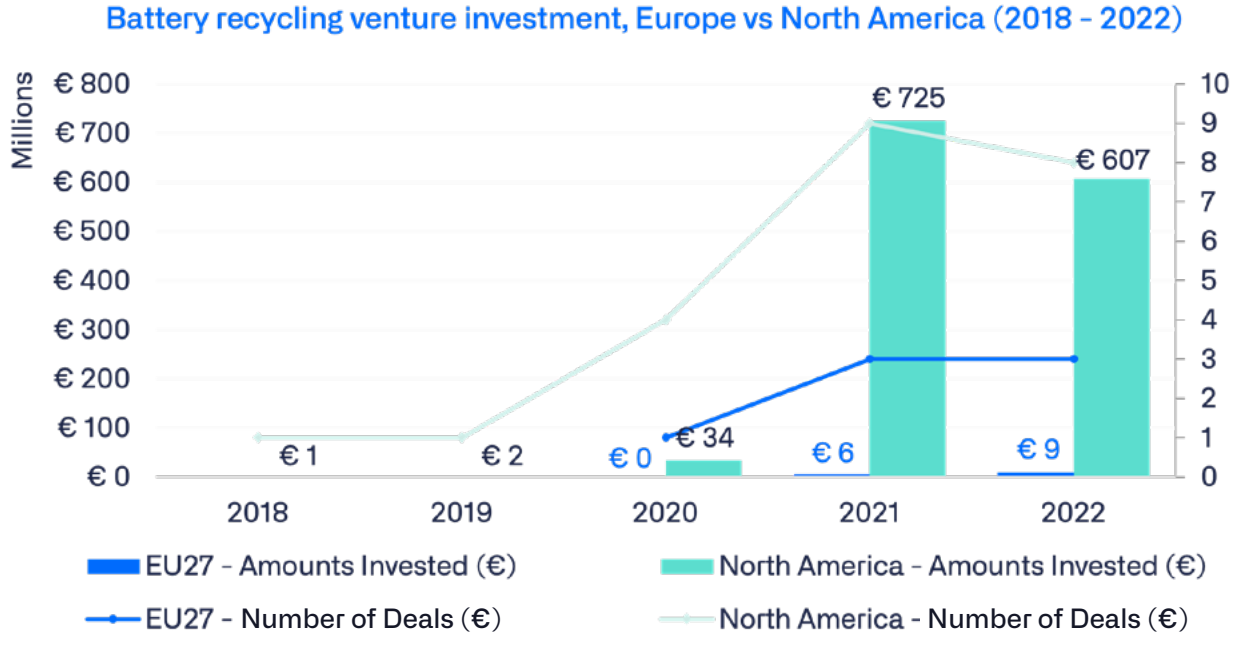
The graph above shows that the EU consistently significantly underperforms the US in both number of deals and amounts invested. CRM venture deals were on average 3.5 times larger in

the US (€49 million) than in the EU (€14 million) in the first half of 2023. That represents an improvement from 2022, when average US deal size was almost 10 times larger. Yet, the growth prospects of European CRM innovators remain hampered by a less favorable venture funding landscape.

Early-stage funding data reveals there is an abundance of ideas and innovation in Europe's CRM cleantech community, but as with cleantech more broadly, European innovators struggle to scale their technologies.

US-based innovators have raised 45% of global venture investment in critical minerals between 2018 and 2022, according to IEA-analysis based on Cleantech Group data. The graph above clearly shows US CRM venture investment skyrocketing, whereas EU CRM venture investment is increasing much more modestly.

Zooming in on a sector that has attracted much venture investment – battery recycling – is sobering for Europe, a continent which has for decades been a global leader in recycling. The graph below illustrates a stark difference in venture investment and deal sizes in battery recycling between Europe and North America.



Data Source: Cleantech for Europe

The US' BIL and IRA support CRM cleantech innovations at various stages, but crucially, do not neglect their scale up. Given that the disparity between the EU and North America is much smaller in terms of number of CRM deals than in terms of amounts invested, average deal size in North America is significantly larger, providing pivotal scale-up capital to growth-stage innovators for CRM projects, which tend to be highly capital-intensive.

This calls for Europe to develop a comprehensive CRM Strategy fit for cleantech competitiveness. To achieve its strategic goals for securing its CRM supply, Europe must send adequate market signals along every aspect of the CRM value chain, from exploration to recycling.

RECOMMENDATIONS

01. Enhance short- and long-term EU Public Funding

02. Turbocharge innovation in clean technologies that sustainably boost primary CRM supply

03. Scale up innovation in clean technologies that reduce the need for additional primary CRM supply

PROPOSAL 1

Enhance short- and long-term EU Public Funding

Why is the US so far ahead in CRM-cleantech venture funding?

Unlike the Net Zero Industry Act (NZIA), which, like IRA, is focused on boosting *domestic manufacturing* of cleantech with some financial support coming from revenues from the EU's carbon market, the CRMA lacks funding and relies more heavily on international partnerships to secure its domestic supply needs. In contrast, the US is aggressively funding foreign and domestic CRM projects alike. For example, the IRA mandates that from 2027, 80% of the market value of CRMs used to make EV batteries must be extracted or processed in the US or countries with which the US has a Free Trade Agreement (this excludes the EU).

The IRA allotted $500 million to secure domestic CRM production and $40 million in loan guarantees to domestic projects including manufacturing of rare earth elements. The Bipartisan Infrastructure Law (BIL) and IRA collectively allocated more than $8.5 billion for CRM projects and $600 million for CRM recycling, innovation, material efficiency and substitutes programs. North American innovators such as Redwood Materials, Li-Cycle and Ascend Elements receive billions of dollars in public and private funding to innovate in the batteries recycling space.

The EU has not responded with comparable incentives. Notably, the CRMA is missing new financial resources – in particular, for technologies that reduce the environmental impact of mining and processing and reduce virgin CRM demand through recovery, reuse, and recycling.

Digging deep: the EU must enhance public funding to catalyze private investment into scaling up CRM innovations and bridge the investment gap between manufacturing targets and reality.

In addition to the loosened rules around national subsidies under the revised state aid framework, Europe first-and-foremost requires EU-level funding to close the investment gap between NZIA and the CRMA. For example, while billions of euros have gone towards building battery gigafactories in Europe, shockingly little investment is going towards European mining and processing of critical minerals. The European CRM project pipeline is insufficient to meet demand from announced gigafactories. There is a risk that a decade from now European gigafactories will struggle to compete because of tight supplies of battery materials and be acquired by Asian battery makers such as CATL, LG Chem and Panasonic.

However, the 'Strategic Technologies for Europe Platform' (STEP) falls significantly short in both scale, scope, and simplicity, standing no chance of bridging this investment gap. It mostly redistributes funds currently available under existing funding plans without making any real effort to expedite access. It fails to offer fresh, long-term, and targeted support to scale essential innovations along the CRM value chain.

Make sufficient EU funding available in the short- to medium-term term to cover the whole CRM value chain, and in the next political mandate, establish a European Critical Minerals Fund:

1. The expansion of the EU Innovation Fund, including via part of the STEP proposal, should provide funding in the short- to medium-term

→ Innovative CRM-cleantech projects should be eligible for funding.

→ The European Hydrogen Bank model could be replicated for the quick- and cost-effective support for innovative CRM-projects. Support of operational expenditure (opex) should prioritize sustainability and innovativeness.

However, looking beyond short-term solutions, Europe will need a permanent and CRM-focused instrument to provide innovators and investors with greater long-term confidence that will support the achievement European CRM and cleantech manufacturing goals.

Europe's current patchwork of almost 40 EU instruments and programs funding cleantech disproportionately hinders innovators, who do not have the resources incumbents do to navigate EU public funding sources. Slow and cumbersome application processes also discriminate against innovators, and – in stark contrast with the US – funds are often too focused on early stages of development such as R&D. Therefore:

2. A European Critical Minerals Fund should be set up, that:

→ Is designed with speed, scale, and simplicity in mind to support European CRM innovators along the entire value chain.

→ Develops instruments designed to maximize the crowding-in of private investment.

→ Pays particular attention to Europe's perennial cleantech scale-up problem by providing levels of funding commensurate with scaling up.

→ Can support projects within the EU as well as projects by European companies outside of the EU, provided EU social and environmental standards are met.

→ This Fund could eventually be bolstered by revenues from the EU Carbon Border Adjustment Mechanism (CBAM).

PROPOSAL 2

Turbocharge innovation in clean technologies that sustainably boost primary CRM supply

Clean technologies can enable an increase in primary CRM supply (i.e., from ore deposits, as opposed to secondary sources such as mine wastes and recycling) through greater efficiency, waste reduction, and improving the economics of production. Crucially, these innovations improve the sustainability of production.

This section explores opportunities to enhance the development and deployment of supply-side innovations across the first three stages of the CRM value chain: **exploration**, **mining**, and **processing**.

EXPLORATION

The IEA estimates that the world needs at least 100 new mines to meet net-zero goals. Hence, Europe must find new deposits quickly. However, ore grade (i.e., resource quality) is declining as the deposits which are easiest to access have already been exploited. Discovery rates are dwindling because exploration is becoming more costly, as well as time and resource intensive. Most future mines will therefore come from subsurface deposits.

In this context, technologies which enable cheaper, faster, and less invasive exploration are emerging. For example, technologies are being developed that enable the exploration of deposits deeper underground, and in a more environmentally sound way.

Most exploration innovations across remote sensing, artificial intelligence (AI) and machine learning, data analysis, autonomous exploration, and surgical drilling contribute to reducing time and cost and increasing success rates.

US-based **KoBold Metals** uses AI and machine learning to help determine where to survey and drill. This enables shifting from a largely field-based activity to a more desk-based activity, reducing operating expenditures, while increasing success rates and speed. KoBold has raised $407.5m in equity capital. Europe also has promising AI and machine learning exploration innovators such as Norway-based **Earth Science Analytics**, but these have raised considerably lower sums of money, limiting their ability to scale as fast as better funded North American counterparts.

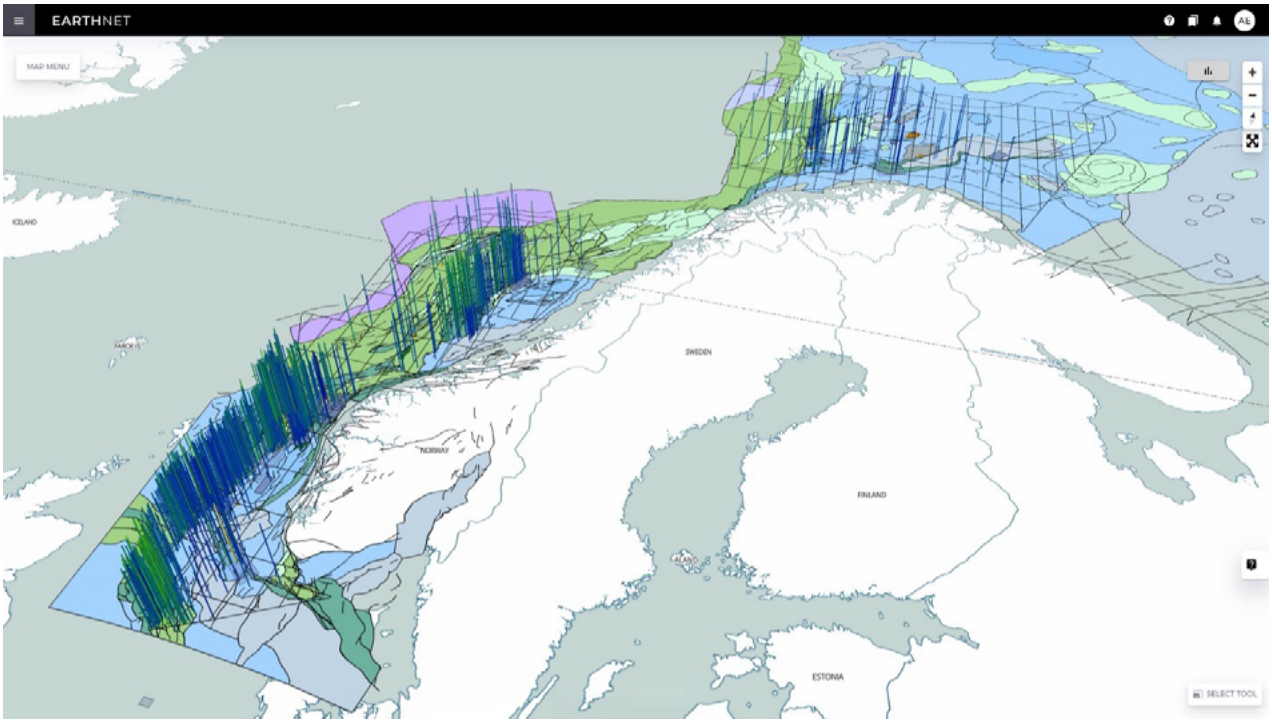


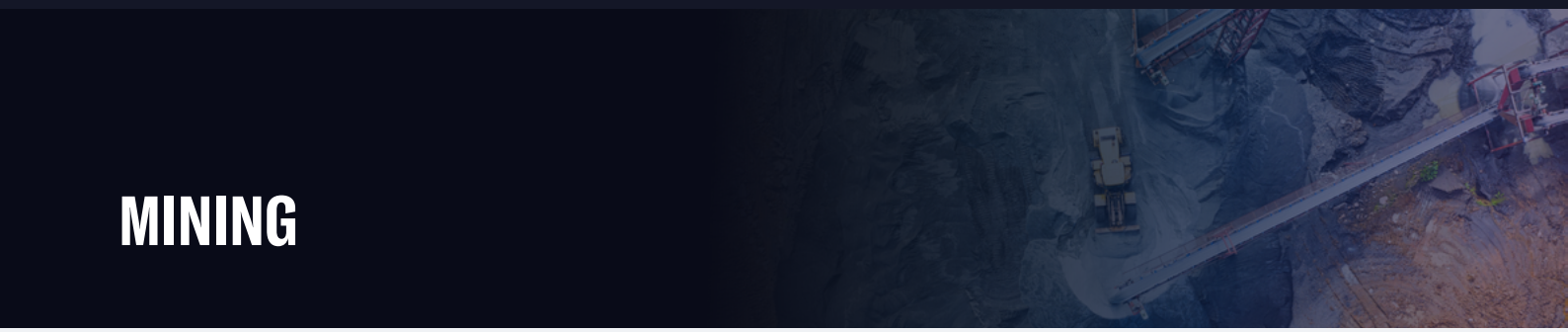
Image source: Earth Science Alaytics

Exploration technologies are underinvested in because of the risk and capital intensity associated with their development.

→ Requiring EU counties with relevant geological conditions to report on, develop and implement national exploration programs for CRM resources and extractive waste would stimulate investment in this crucial segment of the CRM value chain.

→ Policies such as mandatory environmental footprint declarations can also nudge huge vertically integrated mining incumbents to employ more sustainable exploration methods.

MINING



While recycling can reduce the need for additional primary CRM supply, substitution and ecodesign can reduce growth in CRM demand, and more efficient processing techniques can squeeze more CRMs out of less inputs, the need for more mining is unavoidable.

However, the environmental impacts and embodied carbon of CRM mining and processing are reducing the environmental and climate gains of the transition from fossil fuels to the emerging global clean economy.

Though Europe is rightly pursuing strategic partnerships with non-EU countries to achieve most of its primary-CRM supply needs, it will also have to mine more at home for **resilience**, **ethical**, **and environmental reasons**:

In addition to political risk (e.g., export restrictions), more frequent and intense natural disasters made worse by climate change represent a real supply risk, threatening our supply resilience. Moreover, there are strong ethical and environmental prerogatives, because for too long Europe has simply outsourced social and environmental concerns linked to mining by importing CRMs from the Global South, where far lower social and environmental safeguards are in place.

Contrary to popular belief, CRM mining can be done much more sustainably whilst increasing extraction rates and efficiency. The EU has non-negligible CRM reserves within its share of the earth's crust, and some EU countries are already substantial producers of certain CRMs: Germany produces gallium for thin film solar PV,

Finland produces germanium for multi-junction solar cells, and Spain produces strontium for solid oxide fuel cells.

Obtaining approval for a new mining project in Europe can take up to 15 years, so the EU's efforts to streamline and accelerate permitting are encouraging. More must be done, however, to nudge national permitting authorities to expedite permitting without diluting environmental safeguards, while also improving their capacities to do so. One complementary way to accelerate permitting currently overlooked by the EU is to **enhance incentives to mine more sustainably**, thereby encouraging the uptake of mining practices and technologies which reduce environmental impact and local resistance to new mines or to mine expansion projects. One such innovator is France-based **IROX**, which is developing a pulsed-power technology that can shatter rocks and mineral ores to reduce energy and carbon emissions.

Additionally, technologies exist that promise to leapfrog conventional mining altogether. German-Australian company **Vulcan Energy Resources** seeks to develop the world's first net-zero lithium project in Germany by combining a geothermal project with a lithium extraction project. It plans to extract lithium from hot brine pumped up from deep underground, while using the heat generated to power its operations.

Image source: Skeleton Technologies

Approximately 4-7% percent of global emissions are attributable to mining, and up to half of mining CO2 emissions come from the use of diesel vehicles for mining operations. UK-based **Savannah Resources** plans to electrify its mining equipment to develop Europe's largest lithium mine in Portugal, and France-based **Imerys** is considering this for its lithium mining projects. Yet, lithium-ion batteries cannot provide the fast-charging and high power that is needed for mining equipment. Estonia-based **Skeleton Technologies** is developing a high-powered SuperBattery that can be used to decarbonize heavy-duty vehicles in the mining sector, for which lithium-ion batteries are not ideally suited, due to longer charging times and, fewer life cycles, and inadequate amounts of power delivered. Skeleton's SuperBattery combines lithium with curved-graphene (a synthetic graphene made exclusively with non-critical locally produced materials), reducing lithium demand by 30%.

→ A complementary way to accelerate permitting currently overlooked by the EU is to enhance incentives to mine more sustainably, thereby encouraging the uptake of mining practices and technologies which reduce environmental impact and local resistance to projects.

→ It is imperative to mandate and support the use of all electric mining equipment in European mines as well as Strategic Projects the EU plans to support in resource-rich countries outside of the Union.

→ Equally so, developing a standard or label that defines "responsible mining" in terms of its effects on the environment (e.g., water pollution, biodiversity loss, and GHG emissions), following the model of the Batteries Regulation, would help ensure that Europe leads a global race to the top by fostering clean, sustainable, and ethical value chains.

PROCESSING

CRM-supply is more geographically concentrated than oil and gas, and processing is the most geographically concentrated part of the global CRM supply chain. China's share of globally announced projects for processing and refining indicates that its domination of processing is set to continue. Setting aside the questions about geopolitical influence and supply risk raised by China's dominance of processing, the existing global pipeline of projects to expand processing capacity falls well short of what will be needed to reach net-zero.

For example, global lithium demand is expected to grow 40 times by 2040 mostly driven by demand for electric vehicles (EVs), but current supply projections fall short of meeting this demand. Today, lithium is mostly extracted from hard rock and to a lesser extent from brines in evaporation ponds. Estimates suggest that up to two-thirds of the world's lithium deposits are in these brines. Currently, evaporation ponds are the incumbent method of brine processing. However, evaporation ponds are land and water intensive, take a long time to permit as a result, can take years to evaporate, and only have a 40-60% material recovery rate. In contrast to evaporation ponds, Direct Lithium Extraction (DLE) takes hours to days and has a significantly higher material recovery. DLE speeds up refining and can be permitted more quickly because it reduces land, energy and water use considerably.

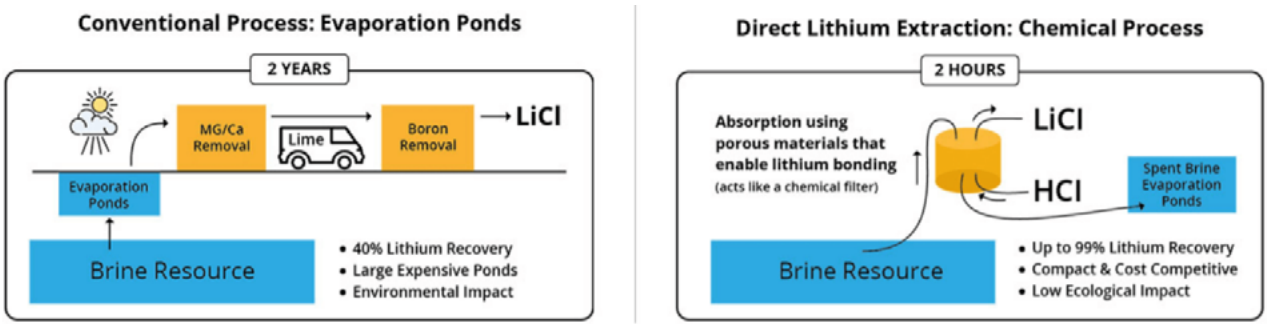


Image source: Lithium South Development Corp

DLE innovators are mostly concentrated in the US and raising huge and growing sums of equity from investors, with startups such as **Lilac Solutions** aiming to scale technologies that are up to 100 times less water intensive using current evaporation techniques.

→ Public funding to catalyze private-led investment into expanding domestic processing capacity should prioritize investments in innovations which improve the productivity of CRM processing and refining while reducing its environmental impacts.

→ Standards should be developed to reduce waste, recover materials, reduce the use of harmful chemicals in processing, and use water more efficiently.

Finally, in addition to the above stage-specific recommendations, we propose the following to stimulate investment across the supply-side innovation space more broadly:

- EU market regulators should collaborate with counterparts in the US, UK, Japan, and other countries with major commodities exchanges to improve CRM suppliers' access to so-called "derivatives" contracts, giving them the option to sell at a given price and time, as sellers of other commodities like agricultural products and oil do. This would greatly support market development and could be further elaborated to develop market-based incentives to encourage sustainable CRM production.
- The EU should offer non-EU countries which adopt EU labor and environmental standards tariff reductions and concessional financing for projects.

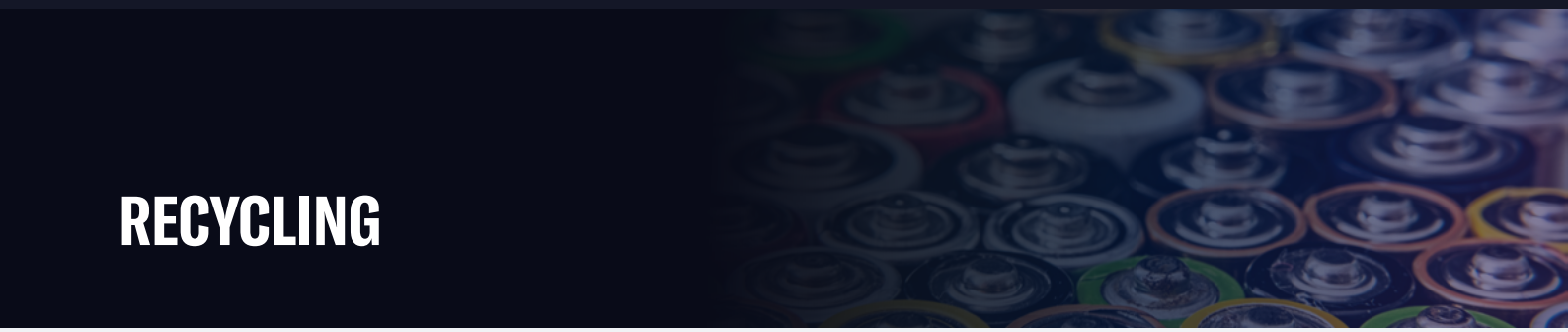
PROPOSAL 3

Scale up innovation in clean technologies that reduce the need for additional primary CRM supply

Despite the existence of the promising cleantech solutions explored above which have the potential to substantially lessen the environmental footprint of increasing CRM supply, the impact on the environment cannot be entirely eliminated. Primary supply cannot ramp up fast enough to achieve net-zero. Hence, demand-side innovation is essential for limiting the need to expand primary CRM supply.

Clean technologies can also enable a decrease in CRM demand as well as improve the sustainability of demand. This section will explore opportunities to enhance the development and deployment of demand-side innovations across three other stages of the CRM value chain: **recycling**, **substitution**, and **ecodesign**.

RECYCLING



Innovation is crucial to enhancing recycling rates and making recycling more sustainable and bankable. Increasing recycling rates would substantially slow the rate of growth in CRM mining needed for clean technologies. For example, boosting lithium recycling rates allows for an eight-fold expansion of mining capacity from 2021 to 2050 as opposed to a thirteen-fold expansion necessary if recycling rates remained constant (IEA).

According to the IEA, the global recycling rate for CRMs such as nickel, copper, and aluminum is around 40%, but could theoretically reach above 90%. Recycling will not eliminate the need for additional primary-CRM supply, but it can play a significant role if rates are raised for materials that can be recycled more easily, and if technology is developed for materials that are more difficult to recycle.

In the US, the Bipartisan Infrastructure Law (BIL) has boosted the amount of grant funding available for US battery recycling. The BIL and IRA have allocated more than $8.5 billion for CRM projects & $600 million for CRM recycling and material efficiency, vastly improving the economics of US battery recyclers and drawing venture and private equity investors into the space.

For example, US-based **Redwood Materials** claims to be able to recover on average more than 95% of materials like nickel, cobalt, copper, aluminum, lithium and graphite in a lithium-ion battery. The company raised $1 billion in growth equity from investors in August after securing a $2 billion loan from the US Department of Energy (DOE) earlier this year. Another US-based battery recycling scale-up, **Ascend Elements**, which secured $480 million in grants from the DOE in 2022, has since raised $742 million in growth equity.

The EU has a global lead on implementing recycling regulations on batteries and solar panels. EU countries have been required to recycle 85% of the materials used in solar panels for a decade, and the cost of recycling is covered by upfront fees on panels entering the EU, while member state-level regulations govern how that recycling is managed. The EU has requirements for reuse and recycling of battery materials and requires manufacturers to design batteries to be more easily recycled and include a minimum amount of recycled content. The EU Batteries Regulation imposes new requirements for carbon intensity and recyclability. Nothing similar has been happening in the US so far, though US car manufacturers will follow EU standards.

The EU Batteries Regulation, which came into force this summer, introduces sustainability requirements for end-of-life batteries, including targets for collection, minimum levels of recovered content, and extended producer responsibility (EPR). This will encourage battery recycling but is not driving the same scale of investor interest into European battery recycling innovators is in the US. For example, Germany-based lithium-ion battery recycling startup **Cylib** – whose recycling efficiency rivals that of Redwood Materials, has raised a mere €11.6 million in equity compared to Redwood Materials' total of $1.8 billion in equity capital raised.

The EU aims to recycle 70% of lithium-ion batteries by 2030, but there may be feedstock issues as it takes about 15 years for an EV battery to reach end-of-life. Therefore, before the supply of old batteries becomes significant, the main feedstock for recycling battery materials will come from battery manufacturing scraps from gigafactories. It is encouraging that the EU intends to include pre-consumer waste in recycling targets to increase recycling of battery scraps. **Harmonising waste management rules for waste streams with significant CRM recovery potential is crucial.**

Norway-based **Hydrovolt** is a leading European innovator tapping the value of battery production scraps. Hydrovolt produces a powder called 'black mass' – a product which is a crucial step in the battery recycling process – from scraps and shredded batteries. Hydrovolt's black mass then undergoes a hydrometallurgical process (which is less energy-intensive and wasteful than the alternative pyrometallurgical process) to recover the raw materials. Today, black mass is still classified as hazardous waste by EU regulations, limiting the ability for Europe to recycle end-of-life batteries and scraps from battery production. Hence, the EU rightly intends to include the recovery of black mass in the CRMA's definition of EU recycling capacity, as well as in the waste codes the EU will develop. Yet cross-border transportation regulations for black mass remain very restrictive. Shipping black mass within and between countries in North America is much easier, putting European innovators at a competitive disadvantage because European innovators need more funding to operate their plants since they must store their black mass for months before being able to ship it across borders.

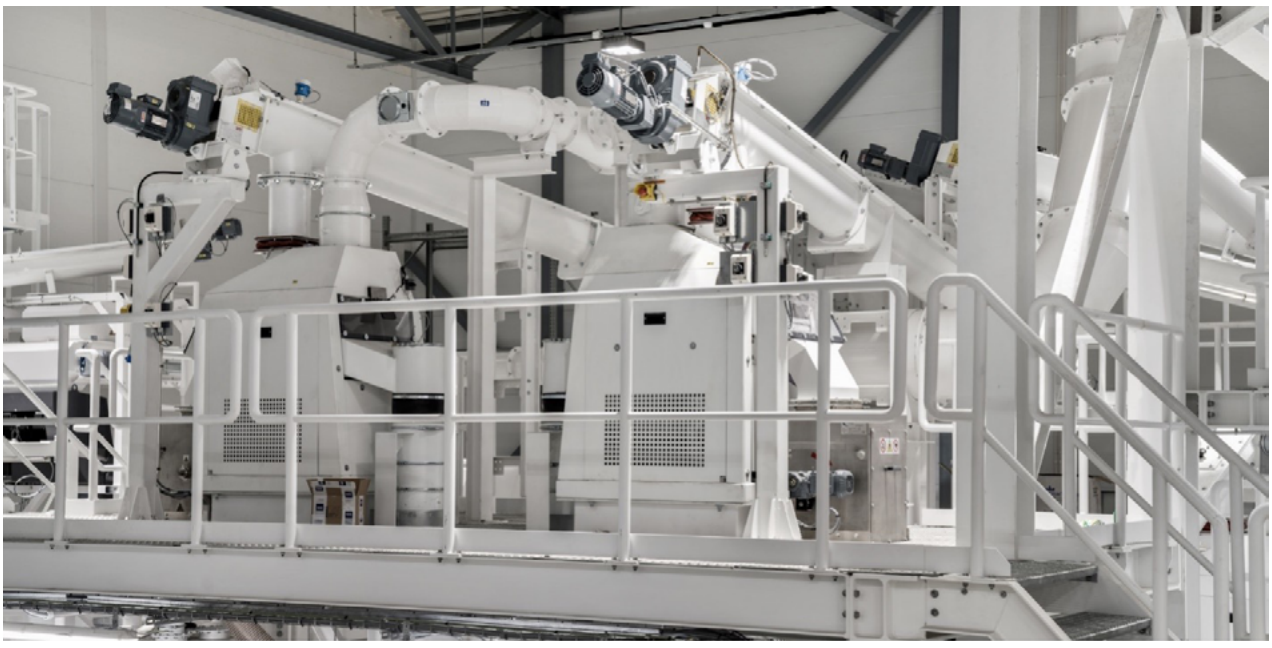


Image source: Hydrovolt

Millions of old EV batteries will come due for recycling in Europe over the next decade. Most of the waste that would be eligible for recycling is currently being shipped to other countries, most notably China. **Ensuring that all European end-of-life batteries and waste battery materials remain in Europe** would support its emerging circular battery economy while reducing dependency on primary CRMs and China.

Nickel-manganese-cobalt (NMC) and nickel-cobalt-aluminium (NCA) EV battery chemistries (popular in Europe and North America because of their high performance) are more attractive to recycle because they contain more valuable materials. To encourage the recycling of increasingly popular lithium-iron-phosphate (LFP) batteries, the environmental impact of lithium mining must be priced in through policy. Hence, it is vital to **ensure that CRM suppliers disclose adequate traceability data**. While the Batteries Regulation imposes traceability requirements on battery manufacturers, these standards must be passed down to the materials suppliers through specific requirements outlined in the off-take agreements that the CRMA encourages. Innovators like UK-based **Circulor** provide data tracking the environmental and circularity performance of the battery supply chain. Another innovator, Denmark-based ReFlow, is developing a bottom-up Life-Cycle Assessment (LCA) and carbon accounting platform and offers Environmental Product Declarations (EPD).

Finally, technologies are being developed to recover and upcycle minerals from mine waste (i.e., tailings) into valuable products. Canada-Based **Terra CO2** develops technologies for CO2 utilization including to remove acid generated from mine tailings and in CO2 reduced cement. Sweden-based **GreenIron** makes use of mine waste to provide a pellet-based fossil free reduction of metal oxides into metals.

Enhanced policy would encourage innovators to develop and scale-up such circular solutions, which would become economical over time. European technology leadership in this space could translate to substantial market opportunities globally.

→ Harmonise waste management rules for waste streams with significant CRM recovery potential.

→ Ease overly restrictive cross-border transportation regulations for black mass

→ Ensure that all European end-of-life batteries and waste battery materials remain in Europe, to support Europe's circular economy while reducing dependency on primary CRMs and China.

→ Ensure that CRM suppliers disclose adequate traceability data. Impose traceability disclosure on materials suppliers beyond just battery manufacturers.

→ Support the development of the tailings-to-value market

SUBSTITUTION

Substitution has huge potential to reduce CRM demand by reduce the need for additional CRM-supply across the board (i.e., primary *and* secondary supply). Substitution should be promoted for **economic**, **environmental**, and **security of supply** reasons.

Economic: A 40-50% reduction in the use of expensive silver and silicon in solar cells over the past decade has enabled the spectacular rise in solar panel deployment, according to the IEA.

Environmental: The quantity of copper required for an onshore wind farm is decreasing. Moreover, the quantity of rare earth elements (REEs) – the production of which is particularly environmentally harmful today – required to produce the powerful magnets used in wind turbines can be decreased by developing lighter, denser, superconducting magnets that do not require REEs. Superconductors may also minimize the requirement for copper in electricity transmission lines.

Security of supply: from the standpoint of geopolitical resilience, it is desirable that substitutes for CRMs with acute supply risks are scaled and deployed more widely. For example, carmakers' efforts, led by Tesla, to transition from existing EV motors to new ones that require fewer or no rare earth magnets, should encourage global efforts to provide alternatives.

The EU must encourage investment in substitute materials to reduce mineral intensity in further applications. For example, CRMs are also found in electrolysers – machines which enable green hydrogen production key to decarbonizing steel and fertilizers, among others. However, innovation is helping here, too. Germany-based **Sunfire** manufactures an electrolyser which

does not require rare earths. Yet, for other types of electrolysers, many manufacturers, including Sunfire, do require CRMs such as nickel and REEs such as scandium. Here, further public support for research and development into reducing and replacing CRM in electrolysis is needed. Latvia-based **Naco Technologies** is developing a nano-coating technology which increases efficiency and lifetime of critical components in electrolysers and fuel cells, and replaces the need for iridium and platinum.

Stationary energy storage is the second biggest driver of future lithium demand, after EVs. Hence, promoting energy storage innovations that do not require lithium or other CRMs – and can store electricity for much longer durations than lithium-ion batteries can – would reduce future lithium demand needs. One such innovator is **Energy Dome**, an Italy-based scale-up developing long-duration electricity storage (LDES) solutions using liquid CO2.

Another example is graphite, a material used in battery anodes due to its low-cost and its energy density, which is the biggest ingredient by weight in EV batteries. In June 2023, China imposed a quasi-export restriction on graphite to Sweden. Europe did not have the tools for a muscular response. However, shortly thereafter, US-based **Graphite One**, which produces high-grade anode materials, received a $37.5 million grant from the US Defense Department to accelerate the development of its Graphite Creek graphite mine in Alaska. The US government was able to make this substantial grant because in 2022 the Biden administration added CRMs used in EV batteries to a list of items covered by the Defense Production Act (DPA), a law that allows the US government to use public funding and procurement to spur innovation and supply of minerals domestically. This is a tool Europe could emulate, in addition to investing in graphite substitutes such as silicon.

→ The EU must encourage investment in substitute materials to reduce mineral intensity of clean technologies.

→ Enhance public support for research and development and demonstration projects aimed at reducing and replacing CRM in electrolysis.

→ Promote stationary energy storage technologies that do not require lithium or other CRMs and can store electricity for much longer durations than lithium-ion batteries

→ Consider developing a legal instrument enabling public funding and procurement to spur innovation and supply of minerals domestically.

ECODESIGN

In addition to enhancing recycling, enhancing the recyclability and material efficiency of cleantech supply chains is crucial to raising their sustainability and reducing CRM demand. Ecodesign improves the capacity for products containing CRMs to be recycled, and reduces their mineral intensity.

Policy and innovation are crucial for designing technologies that are more recyclable. For example, ecodesign could be game-changing for lithium-ion batteries and wind turbine blades.

Lithium-ion batteries: Smelting lithium-ion batteries to separate their metals does not recover lithium, and more energy is required to remanufacture the recovered metals into battery parts. Moreover, European smelters have struggled due to the high energy costs resulting from Russia's invasion of Ukraine. Direct recycling is a more efficient alternative where battery components are physically unpackaged, separated, and recycled or reused. This makes it possible to recover complete components, but doing so economically would require a lot of well-designed batteries, and greater standardization.

Wind turbine blades: Wind turbine blades can be difficult to recycle because they are made of composite materials. New recycling techniques, such as solvolysis and pyrolysis, are being developed, but they are expensive and energy-intensive. It is possible to design blades to be more recyclable to reduce end-of-life waste, and new additive manufacturing processes can reduce waste from the manufacturing process.

The EU's Ecodesign for Sustainable Products Regulation (ESPR), which is currently being negotiated by EU lawmakers, has the potential to reduce EU CRM demand by increasing recyclability and resource efficiency, thereby supporting EU strategic autonomy.

→ Raise the level of ambition of the proposed Ecodesign Regulation.

→ Thoroughly map the landscape of clean technologies for opportunities to mandate or promote ecodesign

→ Support research and development into ecodesign, such as more recyclable alloys

Finally, EU moves towards requiring carmakers to label the energy and material efficiency of EVs, as is the case for electric appliances, will stimulate investment across the demand-side innovation spectrum including recycling, substitution, *and* ecodesign. Promising emerging alternative battery chemistries, such as ones that use sodium instead of lithium, or reduce the need for cobalt and lithium, stand to benefit. For example, Denmark-based Topsoe has developed a battery that uses no cobalt or REEs and only requires half as much lithium.

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THANK YOU

Feel free to contact us with any questions you have.

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