National Engineering Policy Centre

Royal Academy of Engineering

October 2024

Critical materials:

demand-side resource efficiency measures for sustainability and resilience

Summary for policymakers

IChemE

I·M3 Institute of Materials, Minerals & Mining

1. Executive summary

This report provides an overview of the underutilised policy options for achieving reductions in our demands for critical materials and therefore our dependency on imports of scarce materials. This includes both existing uses of critical materials, and future ones associated with low-carbon technologies.

The UK is economically and physically dependent on many materials that are mined elsewhere, and specific technological components that are not made here. Recent supply chain crises have driven increasing concern about the growing need for 'critical' materials, as the projected demands for these are likely to outstrip available supplies. This poses a risk to the resilience of the UK; if material demand significantly exceeds supply, it would interfere with not only economic prosperity but also the capacity of the UK to achieve the infrastructure transformation required to reach net zero. Expansion of demand for critical materials also comes with environmental and social harm that would work against global goals of mitigating climate change and of a just transition to net zero. These impacts are often not visible to the public or decision-makers.

This report presents a range of proactive policy and engineering innovations that can reduce the UK's dependency on critical materials and therefore its risk exposure. Despite increasing attention on critical materials, these 'demand-side' measures have been underutilised, and discussion has been largely limited to what can be done to ensure the UK has access to supplies ('supply-side' measures). Demand-side measures include:

Infrastructure and technology planning: considering material requirements during the upstream planning of future energy, transport and digital systems.

Design and design skills: design changes that minimise or eliminate the need for critical materials and the requisite design skills and cultures that enable this.

Circular economy: ensuring that where such materials are used, they can be recovered and reused or recycled.

Barriers to achieving these policy outcomes include a lack of suitable policy and regulatory frameworks, unclear responsibilities in government, and a lack of basic data. In addition, the UK has limited manufacturing capabilities or influence over the design of products made for global markets such as automobiles and wind turbines. Addressing this requires new skills and approaches to planning, innovation in engineering and design, and new economic structures that value resource efficiency and the resilience of our vital infrastructures.

1.1 Critical materials and the UK's transition to net zero

Materials are designated as critical when their anticipated uses go beyond the expected available supplies. Often supplies are limited because:

- they are less valuable by-products of other mining activities
- their trade may be particularly subject to geopolitics due to geographical concentration
- they are difficult and environmentally damaging to extract.

Developing new extraction infrastructure is slow and often risks worsening the environmental and social harms associated with their extraction. There is currently very little or no recycling capacity for most critical materials.

The Global Resources Outlook 2024, prepared by the United Nations Environment Programme, identified the still-increasing global resource use as the "main driver" of climate change, biodiversity loss and pollution. The report shows that current policy approaches focus almost exclusively on increasing and securing the supply of these materials, and says there must be a much stronger focus on demand-side measures that reduce consumption while improving the provision of essential human needs.

The need to build large amounts of renewable energy technologies is among the major drivers of the forecast increase in demand, as these technologies currently contain critical materials. These technologies are not the only driver of demand and it is vital that we continue to prioritise decarbonisation at national and global levels. However, there are many choices to be made about *how* to reach net zero and the consideration of materials therein. Currently, we are making decisions about how to transform UK infrastructure without considering the material dependencies and demands being created. Unknowingly locking in high reliance on critical materials risks supply shortages and increases the environmental cost of achieving the crucial goal of net zero.

Decarbonisation is essential, but we must also find ways of accomplishing it that do not trade carbon emissions in the UK for chemical pollution, biodiversity loss, drought, and land-use change elsewhere in the world. These effects reduce our capacity to adapt and accelerate the harms caused by greenhouse gases.

1.2 Infrastructure and technology planning

The policy focus on reducing territorial carbon emissions without considering broader material sustainability may 'lock in' infrastructure pathways that mean the UK will be dealing with these risks for decades to come. Infrastructure planning is the most important tool at the UK's disposal to control the volume of critical materials the UK will demand. Decisions made now are crucial due to the 'infrastructure lock-in' effect which would mean that resilience issues and risk of resource scarcity may persist for decades.

In the **energy system**, areas of concern are chiefly related to:

- larger wind turbines, which rely on neodymium magnets
- solar panels, which can use a variety of critical materials
- batteries for energy storage, which are primarily lithium-based and often include materials such as cobalt, manganese and nickel
- nuclear power, which requires chromium as well as other critical materials
- and hydrogen electrolysers, which can use a variety of rare metals.

While copper is not considered a critical material in the UK, it is in the US, in part due to the huge demand from electricity grid upgrades. It may present similar risks despite being more abundant than materials considered critical within the UK.

In many areas there are alternative technologies or strategies for achieving the same outcome using fewer or no critical materials, or using different ones – albeit these currently tend to come with performance trade-offs. There are also higher-level choices around energy system architecture and the technology mix which impact the energy system's critical material demands, such as the degree of decentralisation, the approach to siting and

> Increasingly valuable and strategically important volumes of critical materials are being built into the infrastructure and technologies around us. Too often this is done without planning for their recovery or due attention to material sustainability

transmission, and most importantly the priority placed on energy demand reduction. Reducing overall energy demand, and especially smoothing out peak demand, reduces infrastructure requirements and therefore the requirements for critical materials. This is a stated policy goal of UK government but requires much more focus and prioritisation to achieve.

In the **transport system**, the primary critical material demands are from batteries for electric vehicles (EVs). Infrastructure planning can ensure that more efficient modes of travel are more widely available, enabling greater use of mass transit, active travel, and smaller batteries enabled by reliable charging infrastructure, as well as schemes for vehicle sharing.

The **digital system**, including both consumer goods and large operations such as data centres, is a particular challenge due to the difficulty in recovering the diverse critical materials, which are spread thinly through digital technology, and the often short lifespans of the components. Data centres require greater planning to align the emergence of this new infrastructure with goals for energy demand reduction, co-location, and also the development and implementation of best practices for resource efficiency, especially regarding reuse and recycling.

1.3 Design and design skills

Increasingly valuable and strategically important volumes of critical materials are being built into the infrastructure and technologies around us. Too often this is done without planning for their recovery or due attention to material sustainability. Critical material resource efficiency is undervalued in design incentives, and even if it is incentivised during the design process, progress is limited by a lack of access to reliable data on the sustainability, ethics, and supply chain risks of different materials.

Innovative design approaches can and should be deployed to:

- reduce critical material demands in the short-term
- ensure cheaper and easier access and recovery of the stocks of material accumulated in technology and infrastructure – creating an easily recoverable source of materials in the long-term.

However, designing products, buildings and infrastructure in more sustainable ways requires a paradigm shift in the way engineers and designers think and work. The core requirements are the incorporation of resource efficiency and global perspectives of sustainability and ethics, as well as designing in a way that enables reuse and recycling.

This section of the report gives an overview of design approaches for critical material resource efficiency, including material substitution, material reduction, extended product life, reuse, material recovery, and remanufacturing. It also considers the role of engineering research into novel materials which can displace critical materials without compromising on performance.

The UK has limited influence over the design of imported goods and components, though much of our import market is influenced by European Union regulations which are increasingly targeting material sustainability. However, the UK has significant influence domestically and globally through the production of standards for technologies and processes, an important lever for embedding new design practices. This includes the option of early sponsoring of standards which are important for emerging technologies with potentially high critical material costs. The UK also has existing ecodesign regulations focused on energy efficiency that could be expanded, alongside improvements to monitoring and enforcement.

Design skills are currently a key barrier but also can be enabler. UK design education and research are globally influential. However, less than half of UK designers feel that they have the skills to meet the demand for environmental design, or that their education prepared them for it.[1] Environmental design skills need to be more widespread across the design and engineering professions.

This report presents case studies on wind turbines and EVs that identify barriers to reuse and recycling originating from design, as well as important opportunities to reduce the critical material requirements of batteries through changing vehicle design and battery chemistry. Sodium-ion batteries can be produced without the use of critical materials and can utilise existing battery manufacture and recycling equipment.

1.4 Circular economy

Most critical materials in the global economy are not recycled at the end of their life, nor expected to be. This linear economy means that there is greater

CASE STUDY | Offshore wind turbines

This case study presents an example of the underutilised potential for circular economy in the UK.

Large offshore wind turbines can contain a significant amount of critical materials, for example one current design for a 6MW turbine uses 5,800kg of neodymium magnets. Neodymium has a high value and the magnets can be reused in applications such as electric vehicle motors. However, decisionmakers lack information on the exact volume of neodymium magnets within UK wind farms and when it will be available.

There is too little capacity for decommissioning wind turbines in terms of ports, equipped yards, and specialist engineers.

Work is ongoing to understand the costs and yields of neodymium recovery, informing what recycling capacities are needed. These have not been designed for end-of-life, presenting engineering challenges to recovering the critical material. However, the UK will have immediate access to a large future supply of neodymium, which there are currently few plans to take advantage of. To maximise the future opportunity from material recovery in the future, the UK needs to ensure new turbines are designed for end-of-life and materials recovery.

CASE STUDY | Electric vehicles

EVs are a particularly significant source of forecast demand for critical materials. Novel analysis for this report finds that the EVs projected to be sold in the UK from 2018–2040 would require 268,000 tonnes of lithium.

This case study quantifies the potential for critical material demand reduction in UK EVs through two design choices:

1. Battery size reduction: A 30% reduction in vehicle battery sizes in the largest EVs sold in the UK by 2040 could save 46,000 tonnes of lithium (which to mine would require excavating 75,000,000 tonnes of earth, enough to fill Wembley Stadium 19 times). Smaller battery size does impact vehicle performance, however, this could be partly offset by lightweighting designs and innovation in battery technology, and enabled through provision of reliable charging infrastructure.

2. Material substitution: Sodium-ion batteries are a prime example of an emerging technology for material substitution. These currently have lower performance compared to lithium-ion, but cutting-edge models completely avoid including critical materials. A shift to prioritising sustainable designs requires support, incentives, and engineering research and development. The UK has an opportunity to build on its strengths in these areas to make a domestic sector for sodium-ion battery production and recycling.

demand for extraction, increasing supply risks and adding to environmental and social harm. A circular economy by contrast uses as few materials as possible and maintains them in the economy at their highest possible value. Stocks of critical materials in existing and future infrastructure and technologies should represent future sources of material to meet future demands. Achieving this requires both changes in design practices to enable life extension and recovery, and the emergence of far more comprehensive and mature recycling sectors for critical materials.

Recycling of critical materials is of vital importance to achieving a plateau in material demand. As they become more common in goods, assets and infrastructures that are coming to the end of their lifespan, there will be increasing opportunity to source critical materials from the infrastructure assets and technologies in which they have been used. It is crucial that these recycling sectors begin to grow now in order to meet future needs.

1.5 Conclusion and recommendations

Strategic policymaking for sustainable materials consumption across infrastructure planning and engineering design has been lacking in the UK for many years. Replacing fossil-fuel-powered infrastructure and technologies is a crucial and deliberate shift requiring sustained pace and scale of deployment normally reserved for acute crises such as the COVID-19 pandemic. It will require a new policy approach to materials in order to assure the decarbonisation process as well as the sustainability of the new infrastructure.

Developing a materials strategy within UK government will be complex and far-reaching, with implications for many policy areas. This report sets out a mixture of recommendations:

Build capacity for UK government, businesses and civil society to better understand material flows in the UK and enable strategic decision-making for resource efficiency

Build governance structures that ensure the UK government has an integrated materials strategy, with critical materials considered as part of the net zero strategy. This should sit across infrastructure planning, design regulation, market regulation, industrial strategy, trade policy, and recycling and waste policy, and align these policy areas towards strategic goals such as reducing dependency on critical materials and reducing embodied carbon. ▸ **Recommendation 1**

Target halving the UK's overall materials footprint to drive knowledge, skills, practices and implementation experience of resource efficiency. ▸ **Recommendation 3**

Establish monitoring and forecasting of supply chains, material flows, material requirements of particular technologies, and forecast material use across different scenarios for net zero infrastructure systems. This should be centralised in a National Materials Data Hub. ▸ **Recommendation 4**

Reduce the scale of infrastructure deployment needs by targeting and achieving whole-system energy demand reduction, in line with the 15% reduction target introduced as part of the net zero strategy. ▸ **Recommendation 12**

Build opportunities for engineering education and training that deliver a transformation of UK engineering skills, emphasising resource efficiency and build a global understanding of sustainability so that UK engineers, designers and others are prepared to build, maintain and recycle future technologies. ▸ **Recommendation 21**

Outline approaches for achieving critical material resource efficiency in design, circularity, and especially planning for future infrastructure systems

Incorporate assessment of critical material demands and resulting risks into energy policy, both in whole-system planning and individual decisionmaking. This should aim to deliver a diverse decarbonised energy system which meets public needs and is also resource efficient and resilient to critical material shortages. ▸ **Recommendations 7 and 10**

Include critical-material demand reduction as a goal of transport planning, in particular aimed at the role of batteries, especially through providing enabling infrastructure for more efficient and sustainable mobility solutions such as mass transit, active travel, and the use of smaller electric vehicles. ▸ **Recommendations 7 and 8**

As digital infrastructure such as data centres are being planned, review policy options and required standards for minimising critical material demands arising from e-waste and energy requirements. ▸ **Recommendation 14**

Expand existing ecodesign regulations, as well as monitoring and enforcement capacity, to include material efficiency; encourage design for durability, upgradeability, and disassembly; codify a right to repair; and expand ecolabelling regulations to reflect this.
▸ **Recommendation 18**

Invest in UK and international capacity for recycling critical material intensive products, in particular wind turbines and batteries, reducing dependence on existing supply chains and providing domestic sources of critical materials.
▸ **Recommendations 22–25**

Give examples of specific policies currently available to government that would improve UK critical-material resilience and global sustainability

Support accelerated development of key alternative technologies for reducing critical material use such as sodium-ion batteries, potentially including targeted research funding, supporting facilities to test manufacturing processes, sponsoring standards production, and building connections to industry to ensure take-up. ▸ **Recommendation 16**

The UK government, using existing expertise on net zero innovation, should identify strategic areas where the production of standards and innovation guardrails would accelerate innovation and adoption of goods, products and infrastructure assets that use less critical materials and sponsor the development of these standards. ▸ **Recommendation 17**

Commit to implementing the ban on single-use vapes in England proposed in January 2024 but not implemented prior to the July 2024 general election. ▸ **Recommendation 15**

Policy recommendations

1. Government should have a resource strategy for critical materials. This should be integrated into existing net zero strategy with the aim of managing the necessary trade-offs and reducing unsustainable material consumption, and especially critical materials, in the UK. This should incorporate infrastructure planning, design and market regulation, industrial strategy, trade policy and recycling and waste.

2. Government should explicitly consider critical materials trade-offs and how they will be managed in future net zero strategies.

3. Government should implement an economy-wide target to halve the UK's material footprint, based on raw material consumption.

Consultation on this should also consider sector- or asset-specific targets on significant points of demand for critical materials, on a case-by-case basis.

4. Government should implement the National Materials Data Hub that has previously been committed to. The hub should capture data on the location, nature and recoverability of material stocks and flows to enable informed policymaking and underpin a materials sustainability strategy.

5. Government should work internationally to establish monitoring and evaluation for traceability and whole value-chain data collection on the sustainability of materials (including non-greenhouse gas (GHG) impacts such as pollution and social harms), such as through digital passporting, to ensure that reliable data can be used in decision-making.

6. Maintain the UK's support for a moratorium on sponsoring or supporting ISA licenses for deep seabed mining exploitation, and support the development of evidence on the impacts of deep seabed mining. In the meantime, the UK should encourage other states to adopt this position and ensure that no ISA mining code that allows for mining ahead of proper environmental evaluation is approved.

Policy recommendations

7. National infrastructure planning for energy, transport and digital systems should incorporate assessment of critical material requirements of different technology scenarios.

8. Reduce reliance on battery-electric vehicles in the future transport system through a widespread modal shift strategy for both passengers and freight.

9. Ensure a comprehensive, extensive, and reliable charging network, through the expansion and improvement of charging infrastructure throughout the UK.

10. Energy system governance, led by NESO, should include assessment of critical material requirements for energy system future scenarios and delivery risk assessments.

See related recommendations (22 and 23) on offshore wind procurement.

11. Government should drive the ongoing sharing of data on material usage in different key energy technologies (as well as in other sectors), currently held in the private sector only.

12. Target and achieve whole-system energy demand reduction, in line with the 15% reduction target introduced as part of the net zero strategy.

13. Reduce peak energy demand, including demand via demand-side response mechanisms.[2]

14. Government should review and consider policy options for minimising material demands of future digital systems, including through strategic planning and sustainability certification, with a focus on critical material consumption and e-waste management from data centres. This should be part of the foundations of a wider approach to managing the diverse environmental and energy-use impacts of digital infrastructure.

15. Commit to implementing the ban on single-use vapes in England proposed in January 2024 but not implemented prior to the July 2024 general election, and consider policy options for evaluating and monitoring new and existing products that may warrant similar prohibition due to inclusion of disposable batteries without appropriate end-of-life planning.

Policy recommendations

16. Government should support facilities to develop and test alternatives to critical materials across a range of uses.

An example of this support for research and development in material substitution would be to invest in sustainable battery technologies, and especially sodium-ion batteries, providing additional research funding and manufacturing/testing facilities, engineering standards, and connection to industry to ensure take-up. Investment should prioritise technologies that can utilise existing recycling infrastructure. This is discussed further in the case study analysis in Sections 5.3–5.4.

17. Government should work with BSI and relevant bodies to identify priority areas for the development of engineering standards, and directly sponsor the generation of standards, and safety cases and innovation guardrails for priority technologies such as sodium-ion batteries and battery recycling.[3]

18. Expand the ecodesign for energy-related products and energy information regulations 2021[4] to include material efficiency alongside energy efficiency in the regulations and standards for products currently covered under legislation. The existing list of products covered should also be expanded. This should additionally provide a right to repair, standards around upgradability, durability and design for disassembly, and apply to all categories of physical goods on the UK market.

Incentives to encourage the use of ecodesign practices should also be utilised by government – such as subsidies or economic incentives for products or assets that demonstrate good sustainable practice.

19. Expand the ecolabelling standards within the ecodesign for energy-related products and Energy Information Regulations 2021[5] to include more comprehensive sustainability indicators, such as material efficiency, repairability, ease of disassembly and recyclability.

20. Government should encourage enforcement and monitoring of ecodesign regulations through investment in surveillance networks, stronger disincentives and deterrents for those who do not keep to standards.

21. Government should work with leaders in the sector to develop and resource interventions to encourage a transformation in UK engineering skills that emphasises resource efficiency, and global perspectives on sustainability. This must ensure that engineers have the training to design the ability to maintain, replace and recover critical materials into future technologies and products.

Policy recommendations

22. Provide dynamic strategic planning for future engineering needs related to deployment and decommissioning of wind assets, and decommissioning of oil and gas assets. This should focus on developing sector capacity and skills for sustainable design, deployment, life extension, and decommissioning.

23. Build on attempts to consider design and material sustainability in CfD auctions by setting requirements for infrastructure design for end of life, considering the right places to embed this in procurement processes such as planning permission stages or CfD auctions.

24. Develop a sector-specific approach to improving circular economy for offshore wind to ensure the technical capability exists to more easily decommission, reuse and recycle wind turbines at end of life.

25. Explore strategic opportunities for the UK in investing in domestic battery recycling capabilities and take an international approach to ensuring all EVs within the UK market have sufficient capacity to be safely and sustainably recycled at end of life.

References

1 The green designs skills gap: Insights into the scale and skills of environmental design in the UK, 2024, Design Council.
2 The NEPC Roundtable summary Consumers, flexibility and efficiency: How can consumption contribute to the decarbonisation of the electricity system?, discusses energy demand reduction in further detail.
3 BSI Faraday Battery Challenge Workshop 2-5 July, 2023, 2023, British Standards Institution.
4 Regulations: ecodesign of energy-consuming products: Guidance for manufacturers, their authorised representatives and importers, updated 2023, Department for Energy Security and Net Zero and Office for Product Safety and Standards.
5 Regulations: ecodesign of energy-consuming products: Guidance for manufacturers, their authorised representatives and importers, updated 2023, Department for Energy Security and Net Zero and Office for Product Safety and Standards.

Business as usual

END OF LIFE CHOICES

Insufficient investment in disassembly, re-use and recycling plants.

Insufficient engineering skills and capacity to recycle critical materials domestically.

Paying to export or landfill valuable critical-material rich waste.

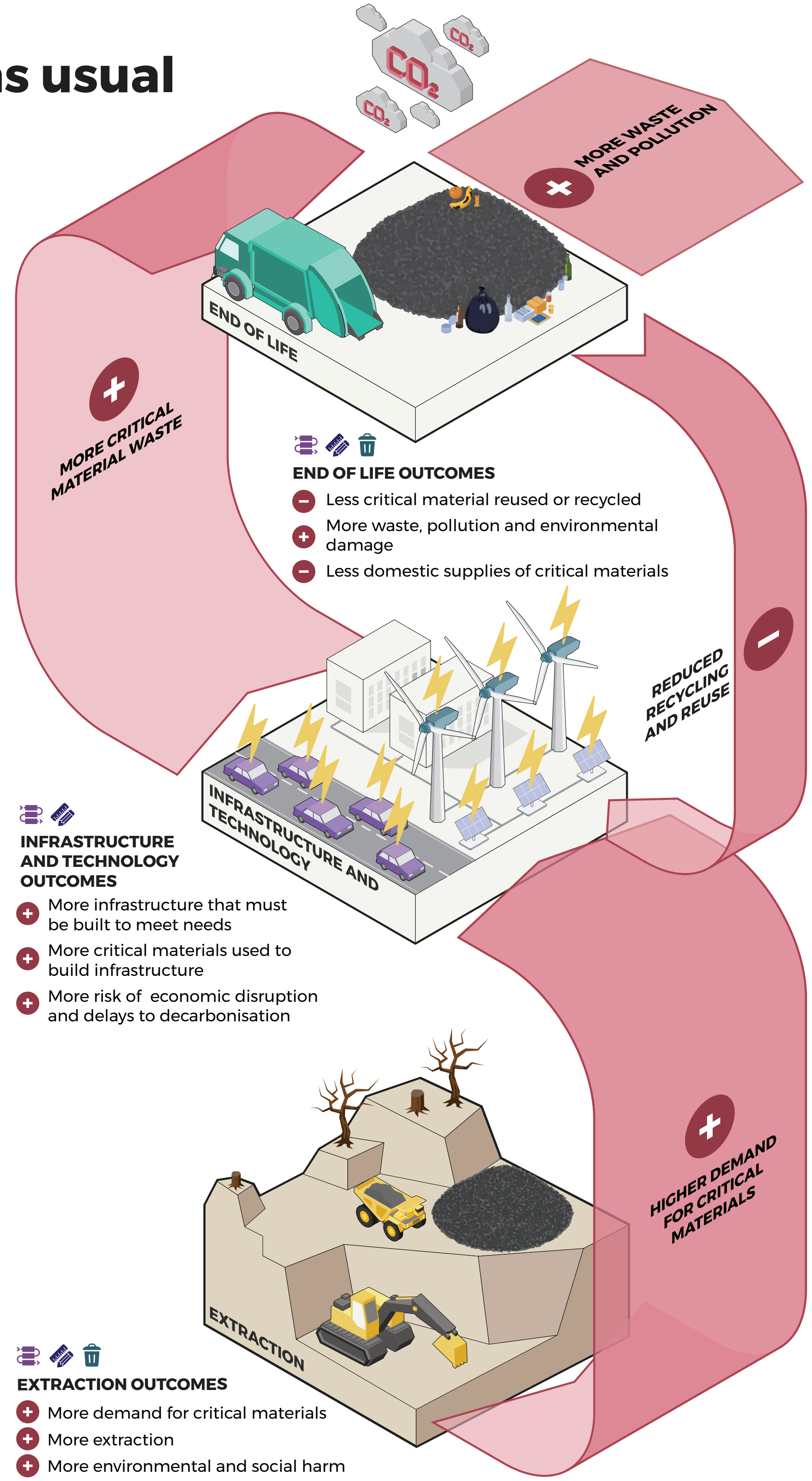
DESIGN AND DESIGN SKILLS CHOICES

Goods and infrastructure are designed only for least cost and highest performance.

INFRASTRUCTURE AND TECHNOLOGY PLANNING CHOICES

System planning doesn't consider reduction of critical material demand.

High critical materials requirements locked in.



END OF LIFE OUTCOMES

- (−) Less critical material reused or recycled
- (+) More waste, pollution and environmental damage
- (−) Less domestic supplies of critical materials

INFRASTRUCTURE AND TECHNOLOGY OUTCOMES

- (+) More infrastructure that must be built to meet needs
- (+) More critical materials used to build infrastructure
- (+) More risk of economic disruption and delays to decarbonisation

EXTRACTION OUTCOMES

- (+) More demand for critical materials
- (+) More extraction
- (+) More environmental and social harm

LEGEND: End of life choices — Design and design skills choices — Infrastructure and technology planning choices

A resource efficient economy

END OF LIFE CHOICES

UK investment and international collaboration delivers a network of recycling infrastructure enabled by circular design.

Engineering skills and capacity match demand required for increased recycling of materials.

Critical material rich waste is reused or recycled.

DESIGN AND DESIGN SKILLS CHOICES

Goods and infrastructure are designed for:

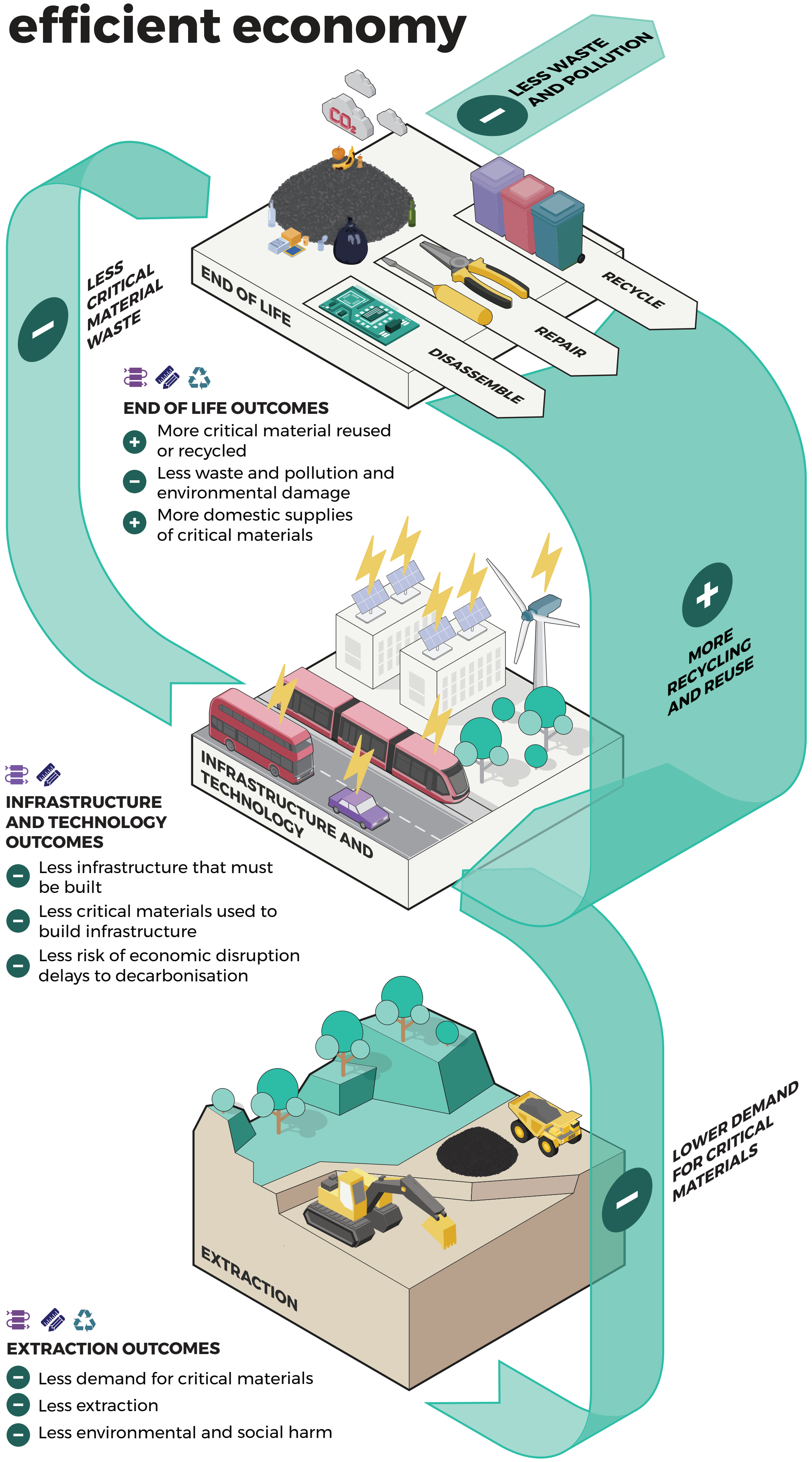
- repairability and longer life
- substitution of critical materials
- resource efficient design
- design for disassembly and re-use or recycling.

INFRASTRUCTURE AND TECHNOLOGY PLANNING CHOICES

Decisions made with materials in mind.

Resource-efficient system design.

Meetings needs in creative ways.



END OF LIFE OUTCOMES

- (+) More critical material reused or recycled
- (−) Less waste and pollution and environmental damage
- (+) More domestic supplies of critical materials

INFRASTRUCTURE AND TECHNOLOGY OUTCOMES

- (−) Less infrastructure that must be built
- (−) Less critical materials used to build infrastructure
- (−) Less risk of economic disruption delays to decarbonisation

EXTRACTION OUTCOMES

- (−) Less demand for critical materials
- (−) Less extraction
- (−) Less environmental and social harm

National
Engineering
Policy Centre

Royal Academy
of Engineering

THE ROYAL ACADEMY OF ENGINEERING

We are a charity delivering public benefit, a National Academy providing progressive leadership, and a Fellowship bringing together an unrivalled community of leaders from every part of engineering and technology.

Our Patron is His Majesty King Charles III.

NATIONAL ENGINEERING POLICY CENTRE

The National Engineering Policy Centre brings engineering thinking to the heart of policymaking, creating positive impacts for society.

We are a partnership of 42 professional engineering organisations that cover the breadth and depth of our profession, led by the Royal Academy of Engineering. Together we provide insights, advice, and practical policy recommendations on complex national and global challenges.

Royal Academy of Engineering
Prince Philip House
3 Carlton House Terrace
London SW1Y 5DG

Tel 020 7766 0600 www.raeng.org.uk
@RAEngNews

Registered charity number 293074