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OF **CHEMISTRY**

Not out of thin air

The need for a strategic approach to materials in the UK wind energy industry

December 2024

Executive summary

This report explores the material requirements for offshore and onshore wind farms in the UK in a scenario that takes us from the present day to 2050. The scenario modelled here assumes a nationwide scale-up of wind energy, in line with the Government's stated ambitions to quadruple our offshore and double our onshore capacity by 2030.

The additional wind energy capacity that needs to be in place by 2050 will require substantial amounts of critical minerals, particularly of rare earth elements (REEs) and those needed in the production of steel (e.g. vanadium and niobium). Concerningly, our data reveals a similar picture for the materials that constitute the bulk of the footprint of wind turbines, primarily concrete and steel, but also others such as composites and copper. The amount of these materials we need to reach our 2050 ambitions for wind energy is vast, in weight terms far outstripping that of critical minerals by many orders of magnitude.

In practice, primary sourcing of all of these materials will have to be increased substantially, unless extensive effort is put into developing our recycling capabilities and capacity to unlock secondary sources. There is high global demand for many of these materials. Understanding the 'anthropogenic stocks' of these materials – i.e. the amounts that are already circulating in our economy (both in households and in industry) – will be crucial in developing recycling capabilities and capacity, and must be supported by better mapping and tracking of material streams. Efforts to secure a sufficient supply of critical minerals, foundation materials and other key inputs into wind technology will be in competition with equally pressing material needs in several other sectors. These range from solar energy to electric vehicle technology, construction and healthcare – all of which are central to society. Potential supply versus demand imbalances may threaten the UK's capacity to grow the wind sector, especially at the scale and pace that is required to meet our legally binding net zero commitments and our ambitions for energy security.

While promising recycling scenarios exist for some of these materials (such as copper and steel), routes for others (such as concrete and composites) remain elusive. Similarly, the UK's recycling capacity for critical minerals is minimal. We need strategic investment in selective recovery technologies and the required infrastructure, as well as incentives or regulatory requirements for manufacturers to use secondary raw materials, for example via minimum recycled content targets. There is no clear path to increase the primary extraction of critical minerals closer to home to meaningful levels, due to their geological distribution. However, there is significant scope to strengthen the secondary supply of these minerals through the recovery of decommissioned wind turbines and other end-of-life products.

Increasing the recovery and recycling of materials is just one part of establishing a more circular wind industry. A key principle of a circular economy is to keep materials circulating at their highest possible value for the maximum time. Reuse, re-manufacturing and re-powering, therefore, are all important in helping to achieve this and must be enabled by policy interventions. In addition, shifting towards greater durability and extending the lifespan of wind farms as standard will be another way to maximise the material lifespan. There may be trade-offs that will need to be considered carefully to increase circularity, for example between durability and recyclability, and to avoid 'burden shifting' of environmental impacts or emissions to different parts of the lifecycle. Data and evidence will be important in understanding these trade-offs and making high quality policy decisions. Ultimately, a more circular wind industry should help reduce primary resource demand, increase resource efficiency and minimise waste and pollution, while potentially also leading to the creation of more high value jobs in the industry.

Our main conclusion from this data is that without a coherent national strategy that prioritises material circularity, and that looks across the different critical minerals and other materials integral to wind energy, the UK is highly unlikely to succeed in scaling-up wind energy in order to transition to net zero within the next two and a half decades. Crucially, **a meaningful materials strategy for the UK** must not be limited to wind energy alone, but rather must serve all relevant growth sectors relying on critical minerals, cement and steel.

Furthermore, in the face of an accelerating triple planetary crisis, any sustainable strategic approach to materials must not only **look at infrastructural requirements, resource efficiency and supply resilience** as demand for these materials increases, but also strive to **drastically limit fossil carbon inputs, waste creation, greenhouse gas emissions and release of pollutants** into the environment across the entire material lifecycle.

Material circularity will be integral to realising our ambitious plans for wind, but also for other green technologies. Therefore, transitioning to **a circular economy of materials has to become a main priority for the Government**, as outlined in the Royal Society of Chemistry's **materials strategy action plan**. In our view, stakeholders from across concerned sectors need to collaborate to minimise silo formation and build a consensus on the materials required for this transition.

Introduction

The unsustainable use of resources such as fossil fuels, metals and non-metallic minerals is driving the triple planetary crisis of climate change, biodiversity loss and pollution.[i] Crucial to meeting the UK's obligation to be net zero by 2050[ii], the clean energy transition away from fossil fuels has a significant material demand.[iii] This increase is anticipated in both absolute quantities of material and the relative proportion required by low-carbon development. To meet current climate pledges, the International Energy Agency estimates that lithium demand will see at least a fourfold increase by 2030, with the proportion of demand from clean energy rising from about 50% to 80%.[iii] These material demands must be met in a way that minimises environmental and social impacts and ensures a just and equitable transition. In addition, some of the materials that are vital not only for renewable technologies, but also for healthcare, electronics, defence and many other essential industrial processes, are at risk of supply shortages, with 34 classified as 'critical minerals' due to their economic importance to the UK coupled with risk to their supply chains.[iv]

Set against a backdrop of a global commitment to triple renewable energy capacity by 2030[v] , the UK has put ambitious targets in place to double onshore wind and quadruple offshore wind by 2030. The UK Government will need to balance the material requirements to deliver these targets with the needs of other industrial sectors and technologies, while also managing supply chain risks which threaten economic security and growth, and minimising the environmental impacts of these materials. A clear overarching strategy is needed to enable a circular economy of materials in the UK.

Material requirements of UK wind energy targets

Wind turbines require a diverse selection of materials (see illustration on page five). Many of these materials are required in significant quantities. In 2022, the UK had a total of 27.4 GW turbine capacity from onshore and offshore wind. By 2030, the target is to double onshore wind (27.6 GW capacity) and quadruple offshore wind (54.4 GW capacity).[vi]

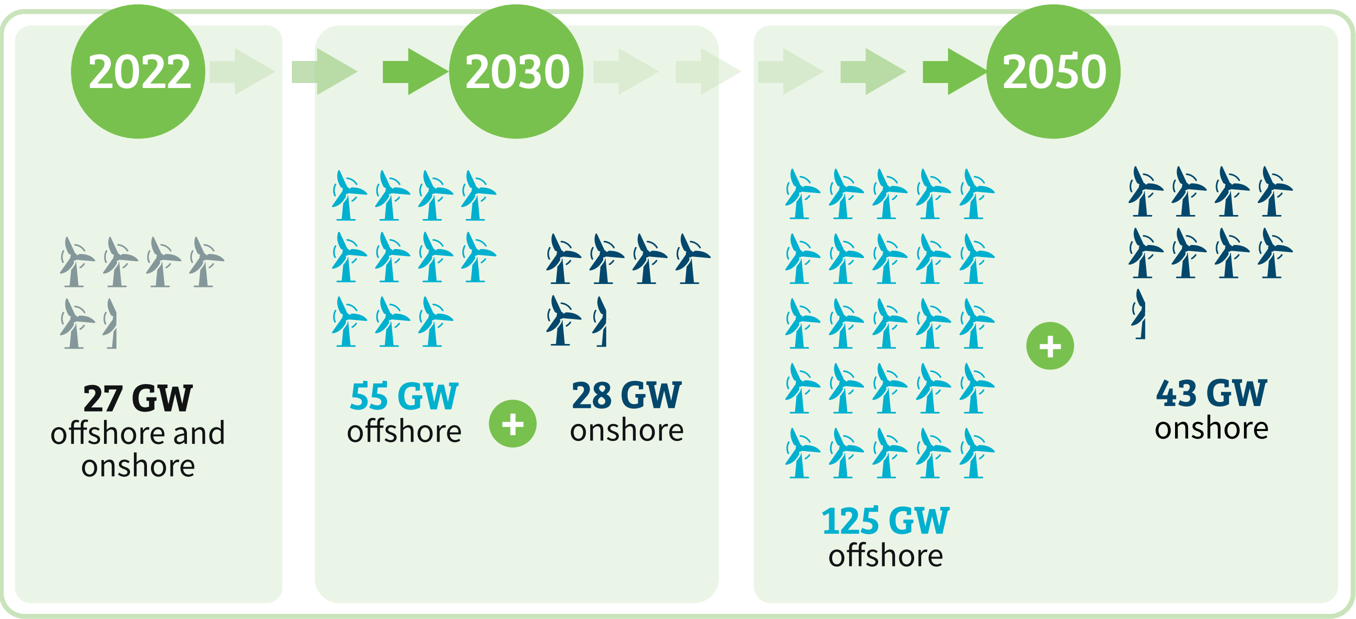
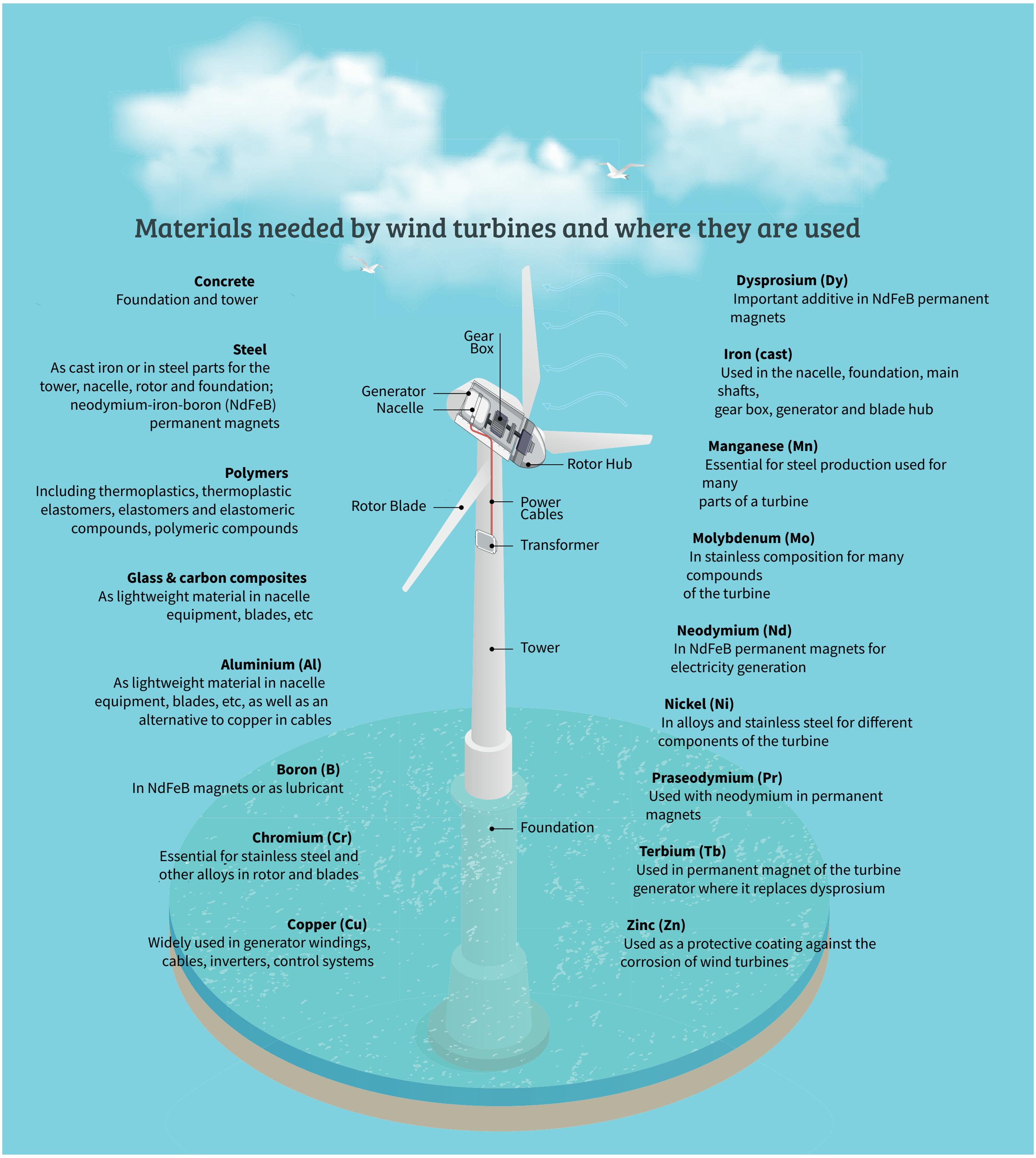


Figure 1: Potential growth in UK onshore and offshore wind capacity until 2050. Capacities are estimated based on the Government's targets and projections to meet net zero goals.

The UK is not the only country aiming to significantly grow their offshore and onshore wind capacity, so global demand for many of the same materials will be high, with some reports estimating demand growth in the EU to triple or even quadruple by 2030.[vii]

Our analysis suggests that to meet the UK's targets for wind capacity by 2030, 40 million tonnes of material will be required (see Figure 1 and Figure 2). If wind capacity continues to grow according to the recommendation set out by the UK Climate Change Committee to deliver a decarbonised power system[viii], a cumulative 95 million tonnes of material will be needed by 2050 (Figure 4 and Figure 5). It is possible that the actual material demand will be higher since there is currently no target defined for onshore wind capacity in 2050.



Materials needed by wind turbines and where they are used

Concrete
Foundation and tower

Steel
As cast iron or in steel parts for the tower, nacelle, rotor and foundation; neodymium-iron-boron (NdFeB) permanent magnets

Polymers
Including thermoplastics, thermoplastic elastomers, elastomers and elastomeric compounds, polymeric compounds

Glass & carbon composites
As lightweight material in nacelle equipment, blades, etc

Aluminium (Al)
As lightweight material in nacelle equipment, blades, etc, as well as an alternative to copper in cables

Boron (B)
In NdFeB magnets or as lubricant

Chromium (Cr)
Essential for stainless steel and other alloys in rotor and blades

Copper (Cu)
Widely used in generator windings, cables, inverters, control systems

Dysprosium (Dy)
Important additive in NdFeB permanent magnets

Iron (cast)
Used in the nacelle, foundation, main shafts, gear box, generator and blade hub

Manganese (Mn)
Essential for steel production used for many parts of a turbine

Molybdenum (Mo)
In stainless composition for many compounds of the turbine

Neodymium (Nd)
In NdFeB permanent magnets for electricity generation

Nickel (Ni)
In alloys and stainless steel for different components of the turbine

Praseodymium (Pr)
Used with neodymium in permanent magnets

Terbium (Tb)
Used in permanent magnet of the turbine generator where it replaces dysprosium

Zinc (Zn)
Used as a protective coating against the corrosion of wind turbines

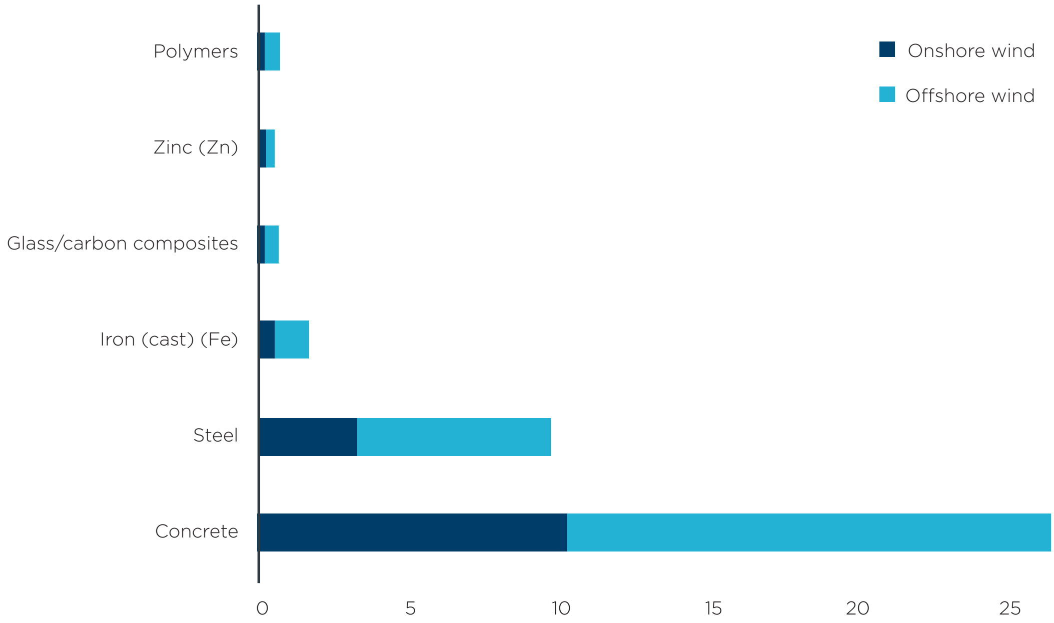


*Figure 2: Amount of material required to meet 2030 targets for onshore and offshore wind capacity, in **millions of tonnes**. NB: While other datasets vary in their estimates of material quantities, they are at the same order of magnitude. The differences are likely a result of the calculation method used between different methods.*

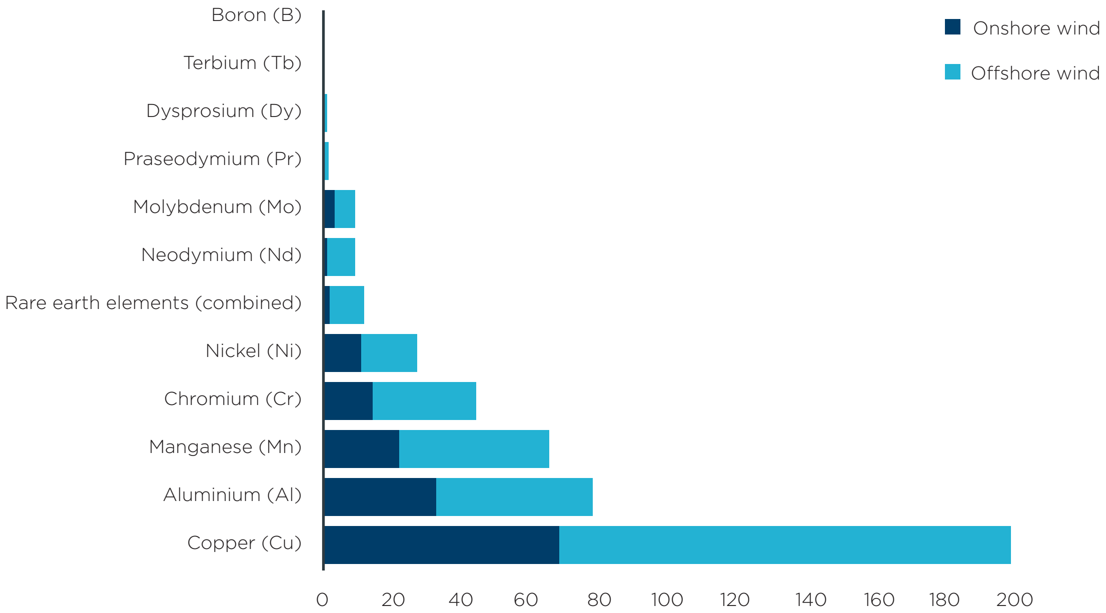


*Figure 3: Amount of material required to meet 2030 targets for onshore and offshore wind capacity, in **thousands of tonnes**.*

As Figure 3 highlights, a significant proportion of the cumulative 2050 material demand is required in the next six years in order to meet the Government's capacity targets by 2030. For example, 48.6% and 44.1% of the material demand for aluminium and nickel respectively is needed by 2030. This points to the urgency of taking a strategic approach to the sourcing and management of these materials.

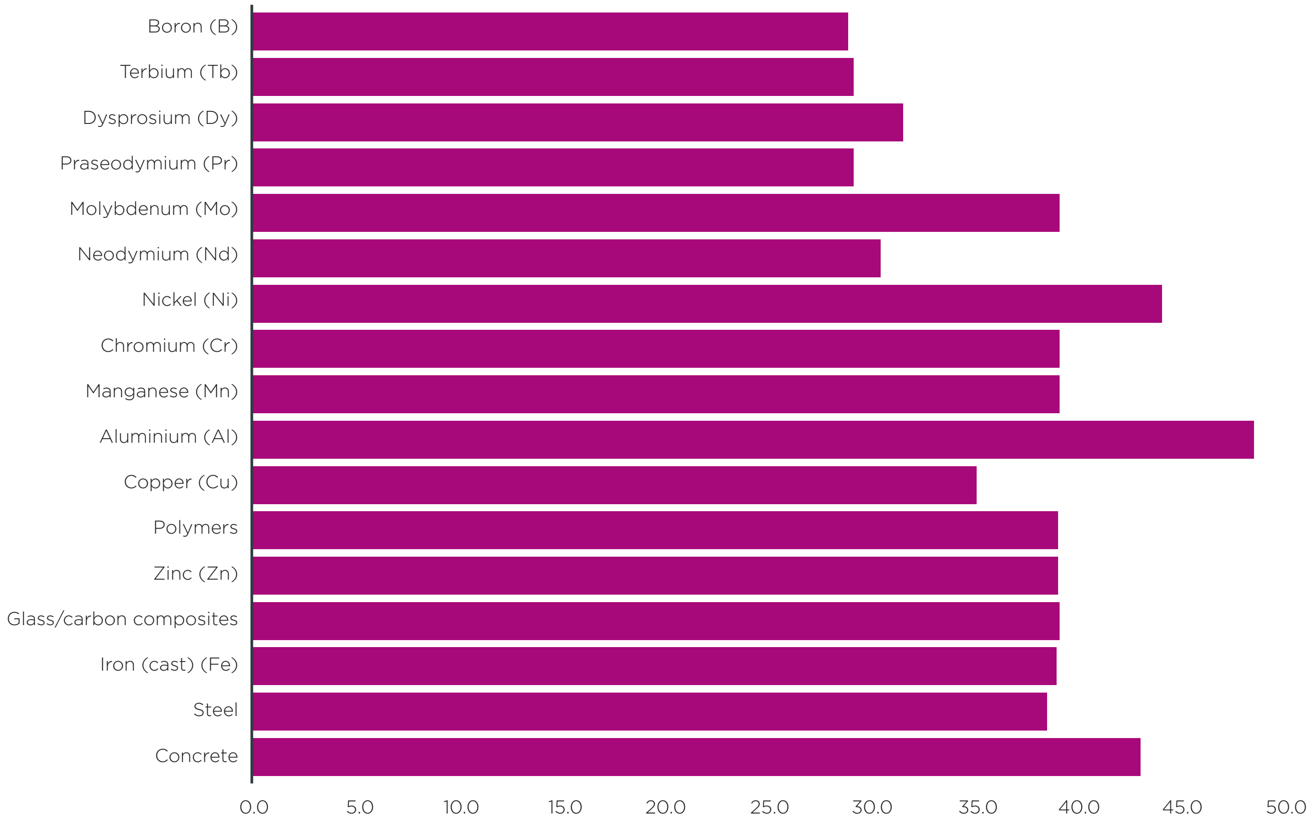


Figure 4: ***Percentage*** *of cumulative total required to meet 2030 capacity targets for each material.*

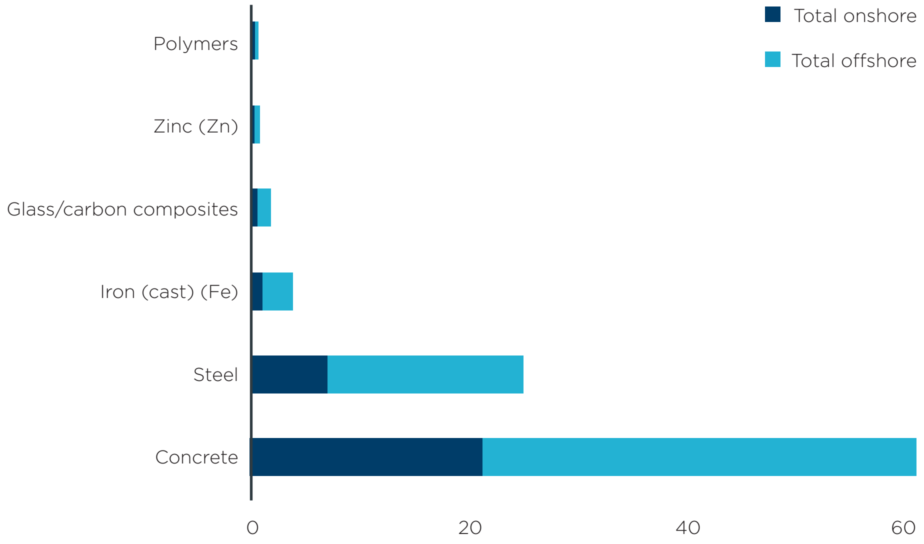


Figure 5: Cumulative material consumption forecast until 2050, in ***millions of tonnes****.*

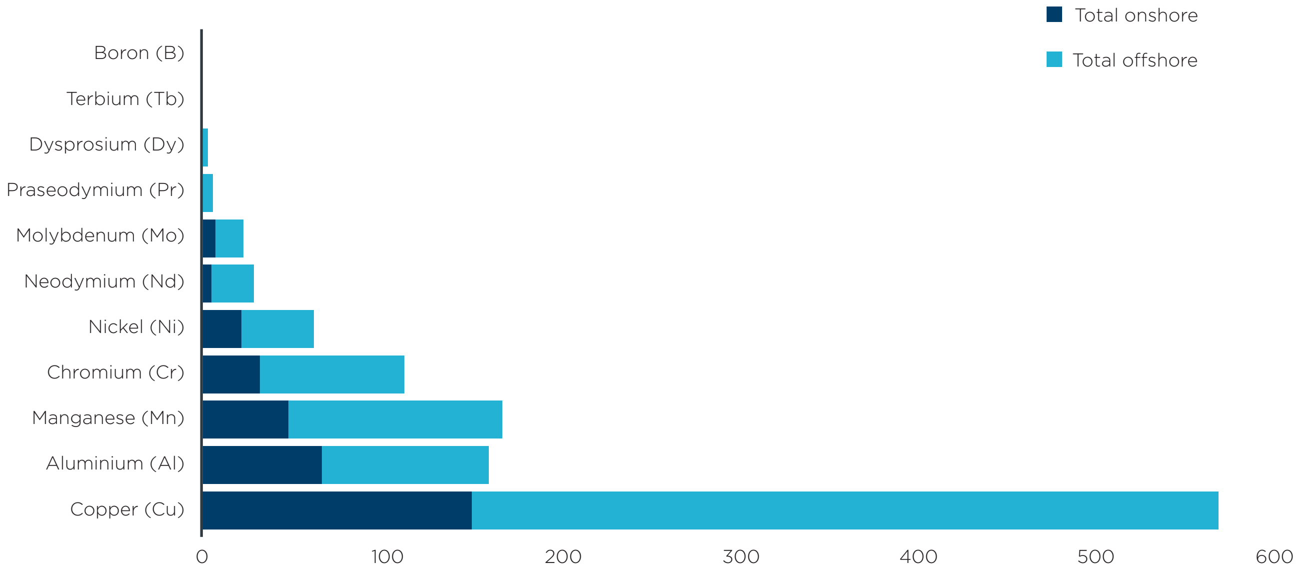


*Figure 6: Cumulative material consumption forecast for the wind industry until 2050, in **thousands of tonnes**.*

The balance of offshore and onshore wind capacity will affect the total material demand as the different turbine technologies require different quantities of materials (Figure 6 and Figure 7). For offshore wind, **direct drive** permanent magnet synchronous generator (PMSG) turbines held the market share in 2022 and are likely to continue to do so until 2050. Gearbox double-fed induction generator (DFIG) turbines comprised the market share of onshore wind in 2022, and this will likely change towards **gearbox** PMSG turbines by 2050.

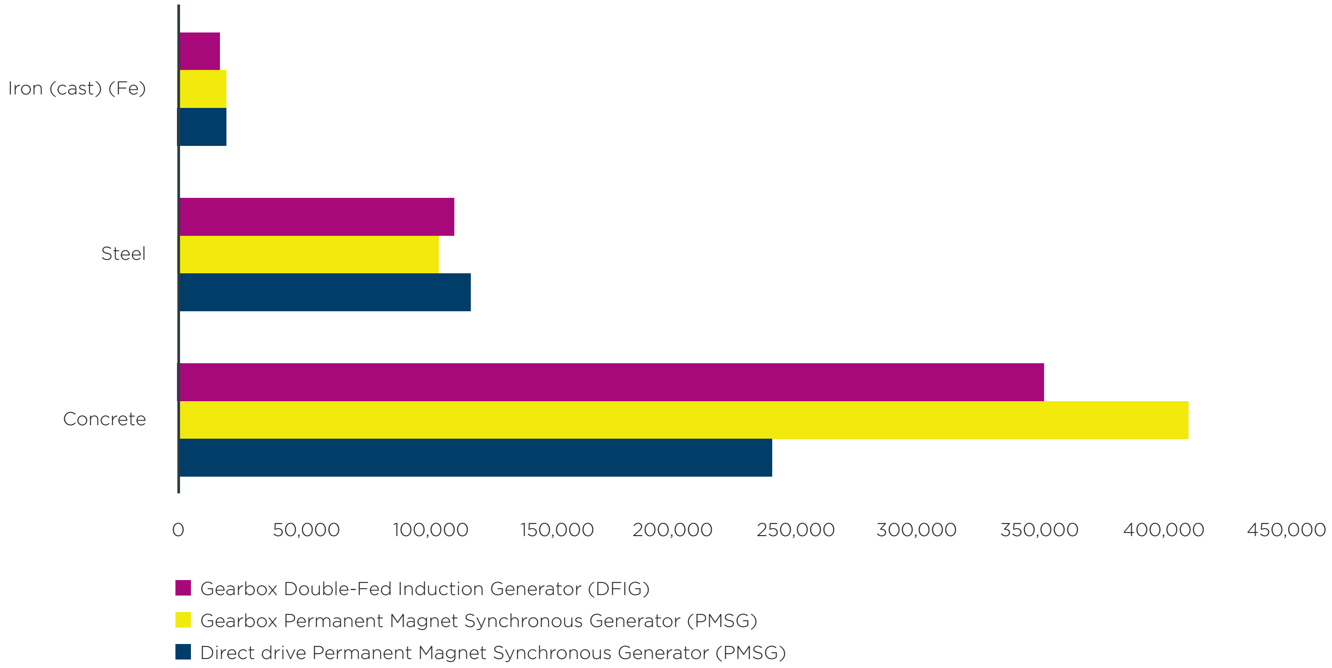


*Figure 7: Material usage estimates for the three technologies that are likely to dominate the market share either now, or by 2050, in **tonnes**.*

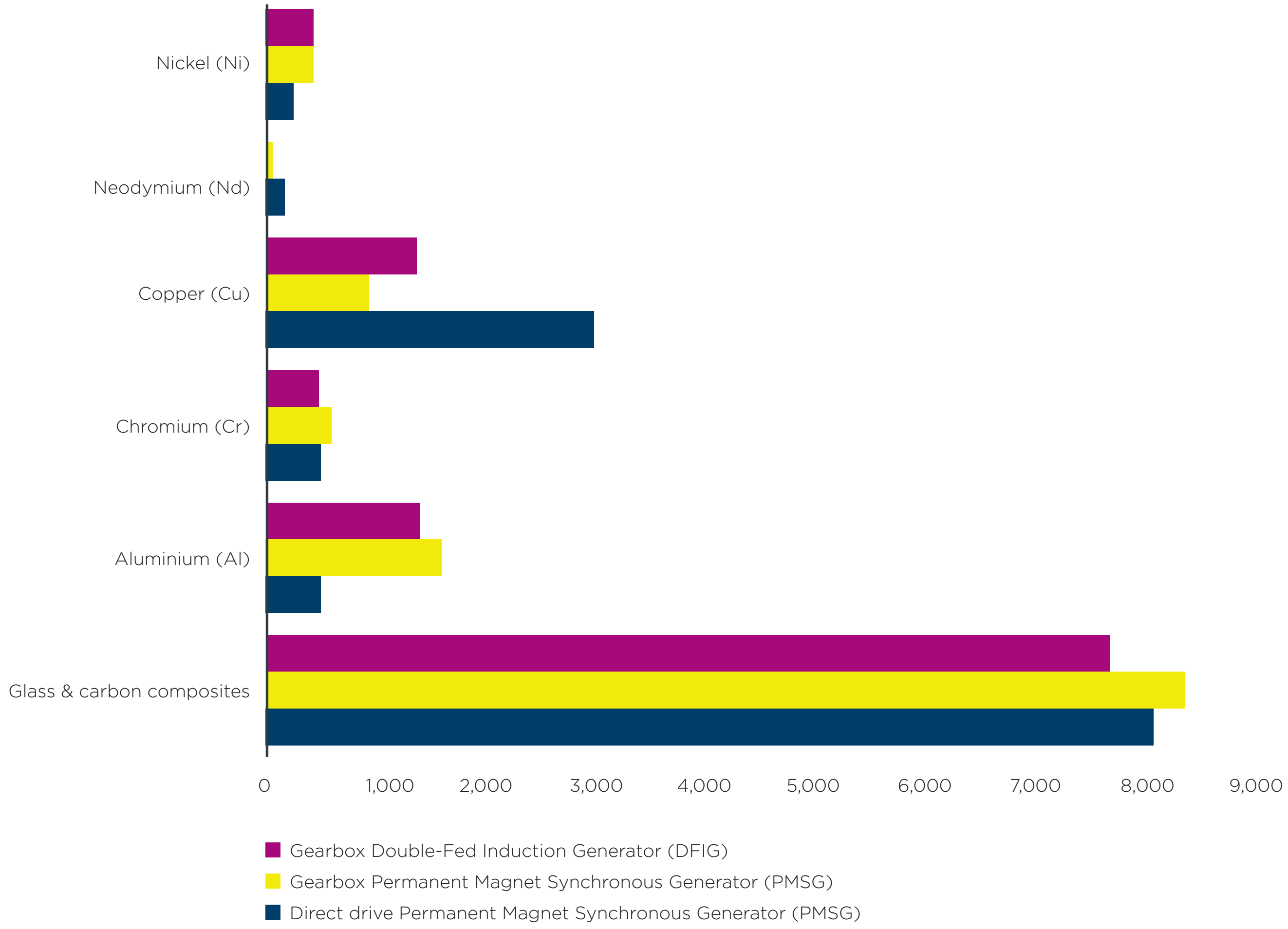


Figure 8: Material usage estimates for the three technologies that are likely to dominate the market share either now, or by 2050, in ***tonnes****. For this figure, only materials where there are notable differences between technologies have been displayed.*

The wind energy sector is just one of several sectors that require many of the same materials (see illustration on page 11). This means that their usage needs to be considered and evaluated over a number of different sectors to ensure that there is sufficient supply to meet the needs of all sectors. This is of particular importance for those that are classed as ‘critical minerals’ as outlined in the next section.

Onshore and offshore wind both have significant infrastructure demands in their installation and connection phases. For example, the US estimates indicate that to deploy 30 GW of capacity by 2030, 6,800 miles of cables and just under 100 vessels (including specialised cable-laying, transport, installation and heavy-lift vessels) would be required.[ix] While the material demands of this infrastructure are not accounted for in our analysis of material consumption, it is likely to be a substantial additional requirement.

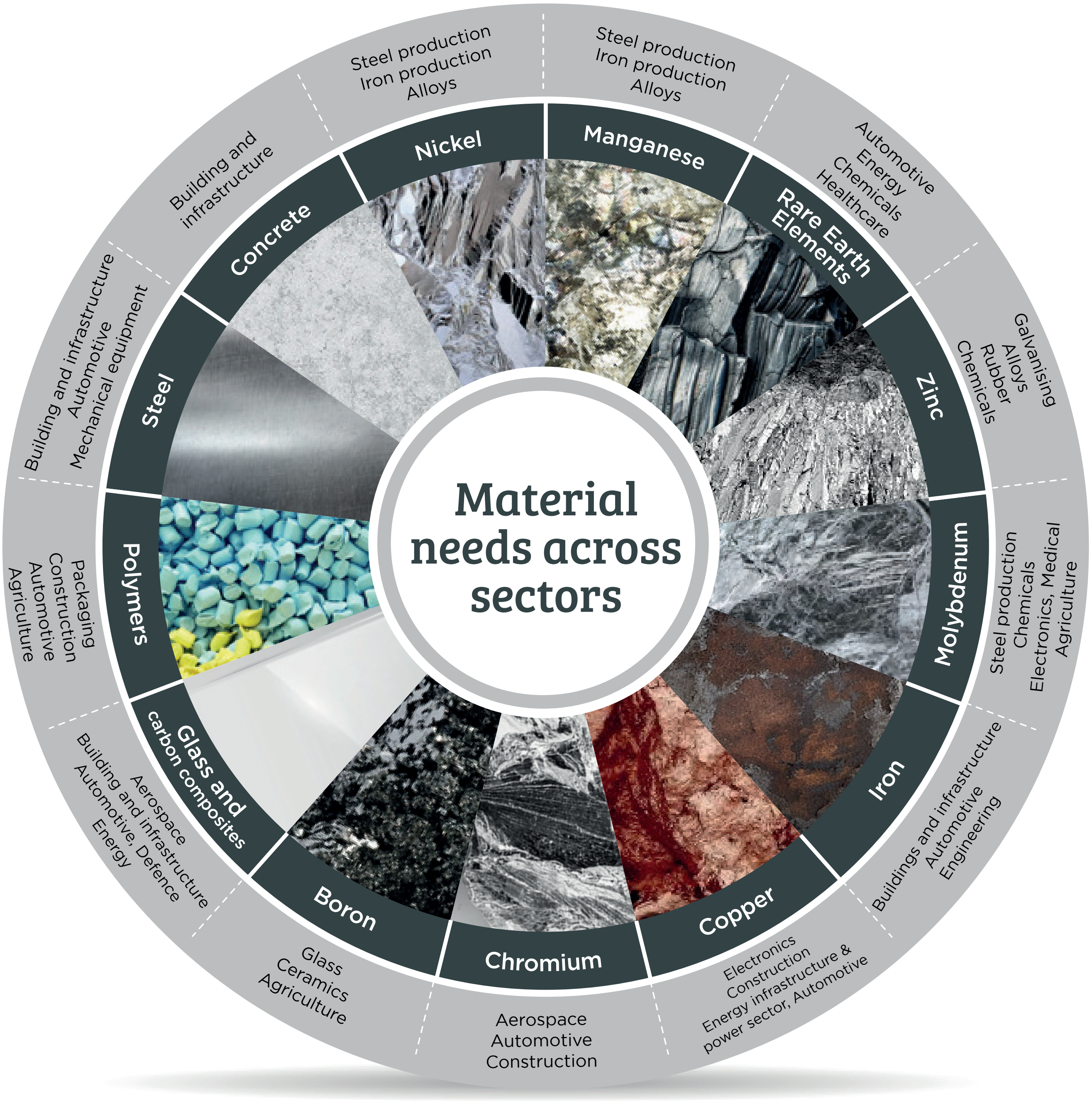


Figure 9: Many of the materials needed for wind energy are crucial in other sectors, showing the need for cross-sectoral evaluation of material demand in the UK.

Spotlight on composites[a]

Composite materials are utilised in wind turbines, currently in turbine blades and nacelles, as they are lightweight, strong and durable. The requirement to maximise energy production, by producing larger and stiffer blades, dictates that glass fibre and carbon fibre-reinforced plastics are required.

To meet the 2030 targets set for offshore and onshore wind, we will need over 1 million tonnes of composite material for blade production in the next decade alone. By 2030, composite turbine towers may begin to enter the market[b], further driving up demand for composite materials. As the demand for blades accelerates over the next 10 years so too does the pressure on the materials supply chain, with 80% of the material usage in blades consisting of resin and reinforcing fibre (glass and carbon fibre). Securing a supply of these materials will be crucial in ensuring that blade production does not become a barrier to meeting UK wind generation targets – a challenge for the wind industry in an environment of growing composite demand across many sectors.

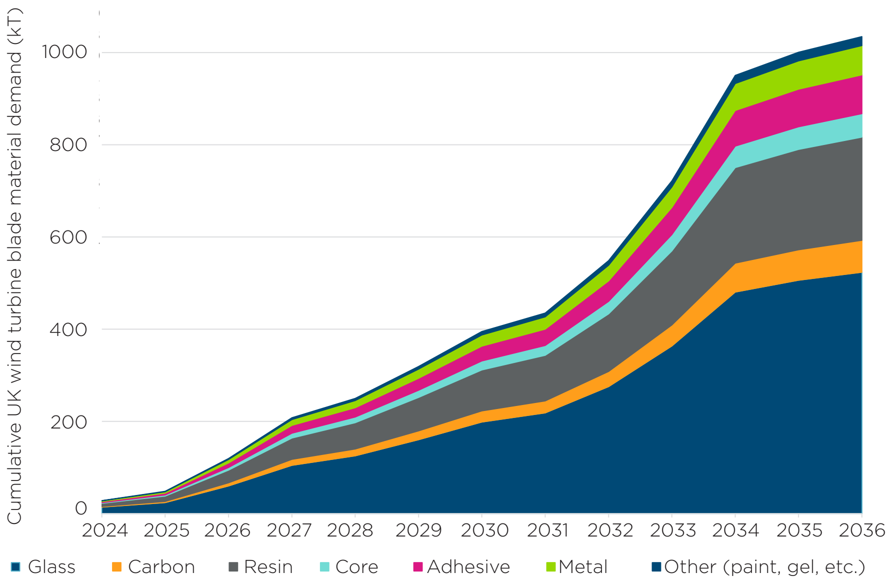


Figure 10: Forecast of the wind turbine blade material requirements for planned UK wind farms.

While composites are critical to the wind sector, in the past little consideration has been given to their end-of-life treatment, and there are currently limited viable options for their recycling. This is changing and initiatives like the SusWIND programme are showing how these challenges can be tackled through industry collaboration.[c] The key to improving the sustainability of wind turbines will be using more sustainable composite materials. These could be composite materials that have less of an environmental impact during production, or ones that enable recycling routes where a greater proportion of the material value is retained. The chemical sciences will be integral in the development and design of these new materials and the solutions to improve recyclability and second-life usage.

Our report, Chemistry-enabled sustainable composites, provides an overview of the opportunities to bring chemistry-based solutions into the UK composites supply chain for the purposes of delivering sustainability within the sector. The report is based on an investigation by the RSC, the National Composites Centre and CPI.

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[a] This spotlight was compiled with the kind support of the SusWIND programme at the National Composites Centre who also provided the forecasting data.
[b] 2024 Offshore Wind Industrial Growth Plan, commissioned by Renewable UK, Offshore Wind Industry Council, The Crown Estate, and Crown Estate Scotland, 2024.
[c] SusWIND Annual Review 2023, National Composites Centre, 2024.

Material supply chains and supply risks

Some of the materials that are used in wind turbines are classed as ‘critical minerals’ in the UK. Mineral criticality is determined on the basis of supply risk and economic vulnerability. The British Geological Survey have classified 34 minerals as highly critical for the UK in their latest assessment.[v] These minerals are vital to the healthcare, security, aerospace and consumer electronics sectors, and find significant use in information and communications technologies. Crucially, critical minerals are also at the heart of most of the technologies, including wind energy, that will enable us to cut our emissions and decarbonise our economies. While rare earth elements (REEs) are essential in the permanent magnets of wind turbines, other critical minerals such as dysprosium and nickel are important in the manufacturing of turbines, for example in steel making. Figure 9 shows the elements used in wind turbines or in the manufacturing of steel, which are also classed as critical in the UK.

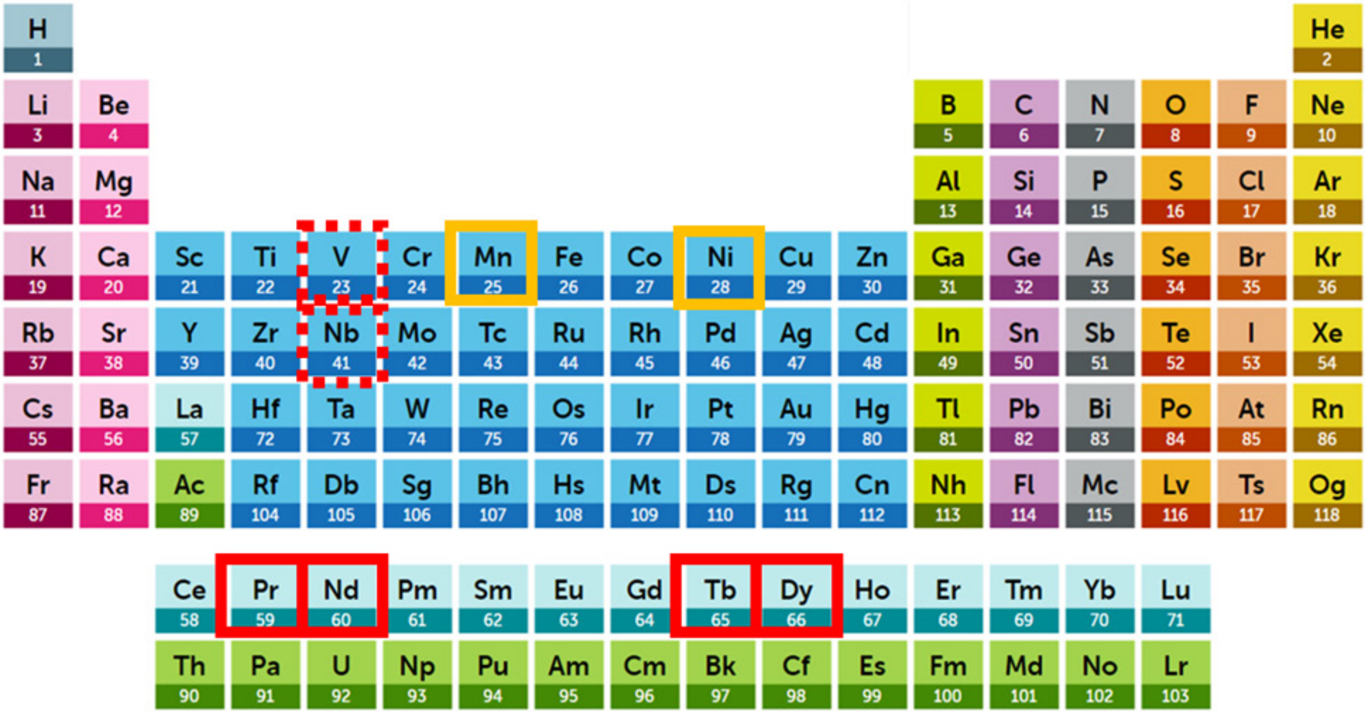

Figure 11: Critical minerals that are essential in wind turbines, or in the manufacturing of steel (dashed red boxes) which is required in large quantities in wind turbines. Those marked in red are already classed as ‘critical’ in the UK. Amber boxes indicate those that are currently on the BGS watchlist.

Supply security issues arise for a number of reasons, including the geographical concentration of supply chains in a small number of countries, supply versus demand imbalances, limited ability to substitute for an alternative material, and low recycling rates.

Geographical concentration

Asia currently provides 52% of the raw materials (Figure 12) required for wind turbines, although these figures are not specific to the UK market.[x] China dominates not only the sourcing of many raw materials but also the entire permanent magnet value chain, with estimates suggesting over 90% of production is in China.[xi]

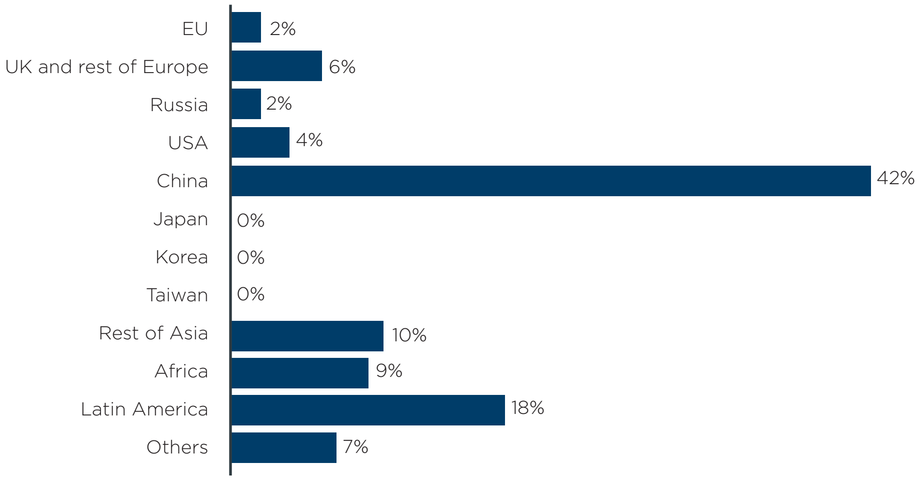

Figure 12: **Percentage** *of raw materials (aggregates, aluminium, boron, chromium, copper, dysprosium, iron ore, lead, manganese, molybdenum, neodymium, nickel, niobium, praseodymium, silica, silicon metal, terbium, zinc) required in wind turbines sourced per region.*

Supply versus demand imbalances

In terms of their infrastructure development, clean energy systems are more material-intensive than current fossil fuel-based systems.[iii] This is leading to significantly increased demand forecasts for certain key minerals and materials in order to meet current climate pledges. For example, copper is essential in all major clean energy technologies – solar PV, wind, EVs and electricity networks – and RSC analysis indicates that a cumulative total of 570,000 tonnes of copper will be required to meet the UK's wind targets by 2050. However, there is growing concern about demand versus supply imbalances of copper – the International Energy Agency suggests there may be global supply shortages of copper as early as 2030.[xii] Copper was added to the critical raw materials list by the EU in 2023, but at present it is not classed as a critical mineral in the UK. Nickel and dysprosium are facing similar near-term supply risks, and they are currently classed as critical minerals in the UK. Although nickel may experience modest shortages (approximately 10% to 20% of demand), dysprosium, which is also used in most electric motors, could see shortages of up to 70% of demand.[xiii] As highlighted in a later section of this analysis, wind turbines have varying lifespans. This means that materials are potentially 'locked away' for several decades. Therefore, these material demands are not going to be met from the recycling of wind turbines in the short- to medium-term.

Materials substitutability

Substituting critical minerals and other materials with appropriate alternatives will be crucial in managing supply chain risks. For example, aluminium is generally viewed as the main substitution for copper. However, it is not an appropriate replacement in every case. It is not as effective as a conductor, and aluminium processing is almost five times as carbon intensive as copper processing.[xvi] The energy demands and environmental impacts of aluminium as a potential substitution need to be considered carefully. New alternatives for copper (e.g. carbon nanotubes) will be important in the future. There may be cases where it is not possible or desirable to substitute for another material. This may arise for several reasons, including functionality that can only be met by a particular material, lack of research and development into alternative materials, and unfavourable economics.

Low recycling rates

Many critical minerals have extremely low recycling rates (e.g. less than 1% of neodymium is recycled at present).[xiv] These low recycling rates may arise for several reasons, including due to technological barriers that mean it is currently not possible to recover materials at scale in the recycling processes that are used. Other materials are recovered preferentially because they have a higher economic value (e.g. gold over lithium).

Understanding the stocks and flows of these materials in the UK economy will be an important enabler for increasing recycling rates. For ‘urban mining’ to be successful and economically viable, these materials must enter the formal recycling system reliably and at sufficient scale. Data needs to be collected at sufficient granularity so that we can map and track critical minerals and other material flows, which can support the recovery and reuse of specific materials. An accurate understanding of the scale and type of material stocks available for mining now and in the future needs to be established.

Production bottlenecks

There are growing concerns about production capacities of the wind supply chain, as well as material supply concerns. The manufacture of wind turbines is complex as component parts are produced in several different locations and countries. For example, the construction of the Beatrice offshore wind farm involved 10 suppliers across six countries for the main components.[vii] The UK has the capability to manufacture blades, cables and foundations but not towers or nacelles, which are predominantly produced in Spain and Germany (see map below). Despite the presence of plants in the UK to manufacture wind turbine blades, more than 60% of composite parts are still imported, although there is variation in this figure depending on which contracts have been awarded.

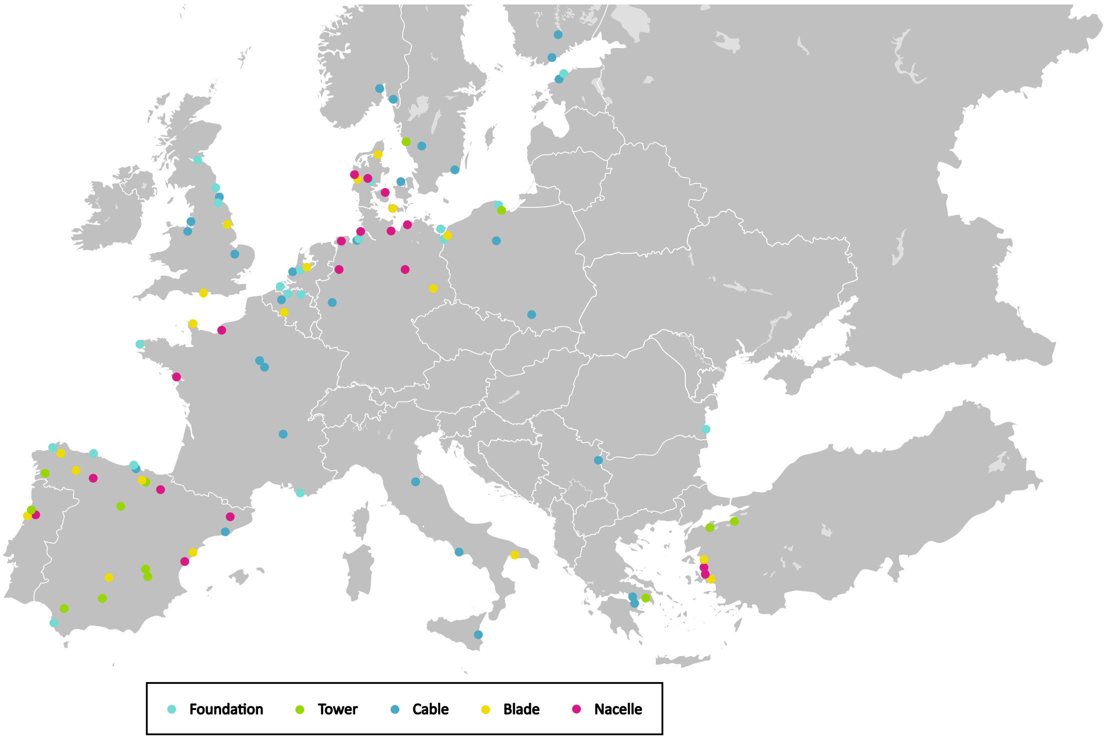

Figure 12: Distribution of manufacturing facilities for main wind power components in Europe. This illustration is modified from [The State of the European Wind Energy Supply Chain](#) and reproduced with permission from Rystad Energy.[vii]

To avoid production bottlenecks limiting the pace of deployment of wind energy infrastructure, there is a need to rapidly expand supply chain capacities across Europe and the UK. This has been assessed as urgent for a number of key components in the construction of wind farms.[vii]

Turbines

Turbine blade manufacturing is currently causing a bottleneck in European turbine supply. The trend towards larger turbine sizes in offshore wind means there is a big gap between current manufacturing capabilities and the projected demand for these bigger models. While onshore wind is not seeing such a trend towards larger turbine size, the growth in onshore wind still requires an increase in manufacturing capacity.

Foundations

Monopiles are likely to remain the dominant foundation type. Manufacturing capacity needs to be scaled up to meet the growing demand, particularly to produce monopiles that support the largest turbine blades. The manufacture of floating foundations is currently at pilot or pre-commercial stage and must be industrialised rapidly to meet demand by the end of the decade.

Wind turbine installation vessels

While there has been recent growth in the fleet of wind turbine installation vessels (WTIVs), this is unlikely to match the demand for these vessels later in the decade. As in other parts of the supply chain, the trend towards larger turbines will put pressure on the supply of WTIVs that are of an appropriate size. Growth in demand outside of Europe will likely pull away vessel capacity from Europe, potentially worsening supply-demand imbalances.

Given the projected growth in the wind sector in the UK, and the challenges surrounding supply chains of many of the critical minerals and materials that are used within wind turbines, it is crucial that the material requirements to meet the UK's capacity targets are understood and accounted for.

Producing this report has been challenging for a few reasons:
- The lack of easily accessible data on the share of turbine technologies in the UK market
- The need for estimations around material intensity, and the need to use EU data to do this
- The lack of future targets for capacity, particularly for onshore wind

While this means some of the data in this report comes with important caveats, two things are clear:
- The material demand to meet projected UK capacity is undoubtedly significant
- UK-specific data is lacking. This should be addressed by improving data collection, including the mapping and tracking of critical mineral and other material streams

With competing demands for many of the materials crucial in wind energy by other technologies and processes, a comprehensive cross-industry or sector mapping of material flows needs to be undertaken to gain a complete understanding of the UK's material requirements.

Waste and circularity

Decommissioning

RSC analysis suggests that 44 GW of wind turbines will have to be decommissioned before 2050, generating an estimated 20 million tonnes of waste. To manage these significant waste projections, infrastructure needs to be in place to manage this waste stream and to recycle and recover the materials that wind turbines are composed of. This infrastructure will need to be able to manage the pace of wind turbine decommissioning without making trade-offs on material recovery. As mentioned in the section on composites, the design for end-of-life recovery will also be crucial.

Significant quantities of waste are also generated at the production stage. For example, in the manufacture of the turbine blades, estimates suggest that material wastage is between 12–30% of the finished blade mass, and there are also losses during the service phase. Minimising waste is crucial in a circular economy, and this illustrates how important it is to be taking steps to address waste generation at all stages of a product lifecycle.

Establishing figures for the decommissioning of wind turbines in the UK proved complicated and required a number of assumptions to be made as outlined in Table 1 below. This highlights the need for additional data around UK market share, turbine lifespan and material demand of different turbine technologies.

Assumption	Limitations
Wind turbines have an average lifetime of 25 years.	The lifetime can be much shorter. For example, some turbines have a lifetime of less than 10 years, or much longer (especially for onshore).
Wind turbine installed capacity is based on actual data until 2022. Installed capacity in 2023, 2024 and 2025 assumes that each year a capacity of 4.5 GW (for offshore wind turbine) and 1.1 GW (for onshore wind turbines) is installed.	The tonnes per GW of installed capacity was used as an approximation to calculate material demand. This is an important limitation because figures can vary greatly between different turbine types. The market shares of different turbine technologies were also taken into account in the calculations, and again this may vary in the future. Attempting these calculations highlighted the absence of quality data in the UK on material stocks and flows.
The assessment of waste generated by decommissioned turbines uses the same methodology as the one used to assess the material consumed by wind turbine construction.	
The assessment of the waste generated is based on the 2050 turbine technologies market share.	Since market shares will evolve over time, this assumption potentially skews the model significantly. However, at the time of the analysis no other data sources were readily accessible.

Table 1: Assumptions made in this report to calculate projected waste volumes for wind turbines.

Establishing circularity in the wind energy sector

One of the key principles of a circular economy is to keep materials circulating for as long as possible at their highest value. While recycling is important, this is the bottom of the waste hierarchy. Longer turbine use combined with re-manufacturing, reuse and repair of turbines should be happening at scale in a circular wind sector. However, little information is available about the wind turbine re-manufacturing and reuse markets. Although, some manufacturers offer a programme to refurbish turbines to extend their life. The length of lease contracts is potentially one area that is limiting the design of turbines that have longer life spans. Turbines have been designed to match the current length of these contracts, often around 25 years. However, more recently, there have been shifts in the length of leases around the UK, which will enable wind farms and components to be designed for greater longevity. Designing for modularity of components will likely be crucial in supporting repair and upgrade of turbines.

There are some examples in Europe of companies selling used wind turbine parts for reuse in other turbines. However, EU policy prevents subsidised wind farms from being built with used parts from dismantled farms. Another challenge is the lack of availability or sharing of monitoring data that analyses operating conditions and assesses the fatigue of turbine components. In addition, when a part is reused, all the historical data may be lost unless the companies in question take measures to collect and pass on such information as part of their service.

Repowering existing wind farm infrastructure is potentially more cost-effective than commissioning new farms, and is likely to be important in achieving the policy target of doubling onshore wind. Full (existing turbines and structures are completely replaced on the same site) or partial repowering or refurbishment can be carried out. Partial repowering can include replacing turbines while maintaining existing towers or foundations, replacing towers while maintaining foundations, or replacing generation equipment, among other things. Ideally, the replaced components can be sold as spare parts or reused in other applications. Changes to, for example, blade lengths as part of a repowering process may have planning implications.

According to the Momentum Group[xv] – which recommissioned five refurbished turbines at the Bockstigen wind farm in Sweden – replacing the nacelles, blades and control systems with components sourced from refurbished turbines, while reusing the original turbine towers, foundations and transmission cables, has extended the life of the turbines by at least another 15 years. This also more than doubled the expected annual electricity generation, from 5,000 megawatt-hours to 11,000 megawatt-hours.

In the UK, the recent changes to the Contracts for Difference auction scheme will help support repowering projects for onshore wind.[xvi] From Allocation Round 7 (AR7), applications for finance will be able to be made to repower onshore wind farms once they have reached the end of their operating life (25 years). In addition, infrastructure may begin to be replaced while the wind farm is still operational, minimising the time sites are inactive for.

Chemistry in a circular wind sector

The chemical sciences have an important role to play in establishing a circular wind sector. As discussed previously in this report, the development of new materials, such as sustainable composites, will be important to improve the end-of-life management of turbine waste. Similarly, finding substitutions for some of the materials facing the greatest supply side shortages (e.g. REEs) coupled with new recycling technologies will not only help to reduce primary extraction and waste, but also diversify supply chains. Table 2 below gives further examples of the ways that the chemical sciences can contribute to solving many of the technical challenges in a circular wind sector.

Material choices			Circulate equipment and materials		
	Use fewer materials	**Substitute for low-carbon, circular materials**	**Maintain and repair**	**Reuse and refurbish**	**Recycling**
Blade (high level)	Reduction in material use through carbon fibre with a higher compressive strength Reduction in waste during blade production	Sustainably derived base chemicals Resins, adhesives and polymers designed for end-of-life Regenerative resins, adhesives and polymers which positively impact the biosphere during their lifetime	Systems designed for ease of repair Non-toxic, durable coating materials	Higher fatigue resistant material for an increased blade lifespan to enable blade reuse	Chemical recycling systems designed to generate valuable output materials Development of lower energy chemical recycling methods to minimise environmental and economic cost
Nacelle	High voltage direct-current generators Replacing steel with cast iron in the rotor shaft and main bearing	Superconducting direct-drive generators Other generators that use fewer rare earth elements		Permanent magnets reuse	Rare earth elements recycling
Tower	Higher strength steel Increased tower diameter Lattice tower	Alternative materials (e.g. wood, aluminium, concrete, composites), including hybrid designs with steel			Increased recycling
Foundation	High alloy steel Lattice structures such as jacket designs	Hybrid materials (e.g. steel and concrete) Sustainable geopolymers to replace Portland cement			
Cables and other electrical equipment		High deployment conductor materials (e.g. graphene) Alternatives to sulfur hexafluoride gas in electrical equipment			

Table 2: Contributions that the chemical sciences can make in a circular wind sector.

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About us

With over 60,000 members in more than 100 countries and a knowledge business that spans the globe, the Royal Society of Chemistry (RSC) is the UK's professional body for chemical scientists, supporting and representing our members and bringing together chemical scientists from all over the world. Our members include those working in large multinational companies and small to medium enterprises, researchers and students in universities, teachers and regulators. There are numerous ways in which chemical scientists are working towards a sustainable, clean and healthy planet, and this report is part of the Royal Society of Chemistry's contribution to do so.

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