UK Government

Areas of Research Interest

Clean Energy Superpower Mission (CESM)

Department for Energy Security and Net Zero (2025)

Contents

Foreword

It is a privilege to introduce this document, which charts the path for the UK's leadership in the global clean energy transition. As Chief Scientific Adviser at the Department for Energy Security and Net Zero, I am continually inspired by the ingenuity and determination of researchers, innovators, and practitioners across the country. Their collective commitment is at the heart of our ambition to make Britain a true Clean Energy Superpower.

We find ourselves at a point in history where the need to act on climate change has never been clearer – or more urgent. The scale of technological transformation required is vast, but within that challenge lies extraordinary opportunity. By harnessing the power of research and innovation, we can spur new industries, drive economic growth, create high-quality jobs, and accelerate the net zero transition to secure affordable, clean energy for all.

This document sets out the Mission's Areas of Research Interest, inviting the best minds from academia, industry, and the public sector to work in concert with government. Our mission is twofold: to deliver clean power by 2030 and to accelerate progress towards net zero. Informed by robust evidence and ambitious thinking, the UK is poised to lead the way in the clean energy industries of the future, including in areas such as electric vehicles and battery technologies, CCUS, hydrogen and floating offshore wind.

I invite you to engage with the challenges and opportunities outlined here. By working together, we can develop solutions for a cleaner, more secure and prosperous future.

Professor Paul Monks CB
Department for Energy Security and Net Zero Chief Scientific Adviser

1 Introduction and purpose

The government has five national missions, to:

- Kickstart Economic Growth
- Build an NHS Fit for the Future
- Safer Streets
- Break Down the Barriers to Opportunity
- **Make Britain a Clean Energy Superpower**

The Department for Energy Security and Net Zero (DESNZ) leads on the government's mission to Make Britain a Clean Energy Superpower, working in close collaboration with other departments (see Section 1.1.3).

Research, development, and innovation (hereafter 'R&D')[1] are critical enablers for achieving both pillars of the Clean Energy Superpower Mission (CESM): delivering clean power by 2030 and accelerating to net zero by 2050. They provide the robust scientific evidence base for policy decisions and delivery, enable the successful innovation and scaling up of necessary technologies, and enhance productivity and economic growth. As estimated by the International Energy Agency, approximately 35% of the global emission reductions needed in 2050 to reach net zero rely on technologies that are not yet commercially available.[2]

Areas of Research Interest documents (ARIs) set out research questions and evidence needs of government organisations. They are a key tool for shaping the research landscape – helping to align academic, industry, and public sector efforts with government priorities.

This ARI document sets out the R&D needed to deliver the CESM, based on cross-government consensus. It captures the breadth of challenges and opportunities across both mission pillars and seeks to encourage more structured dialogue and collaboration with external stakeholders.

1.1 The Clean Energy Superpower Mission (CESM)

The CESM seeks to address some of the greatest opportunities and challenges facing this country and the planet. The clean energy transition represents a huge opportunity to ensure energy security (through making Britain energy independent), protect consumers, generate jobs and growth and save our planet.

[1] The term 'R&D' in this document refers broadly to research, development, innovation, and analysis, encompassing activities that support both near-term policy development and delivery as well as and the development of technologies and solutions
[2] International Energy Agency (IEA) (2023), Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach

The CESM has two pillars:

- Deliver Clean Power by 2030
- Accelerate to Net Zero by 2050

These pillars aim to support the following outcomes:

- Enhance energy security
- Protect bill payers
- Create economic growth in the UK and generate and protect jobs
- Reduce the UK's greenhouse gas emissions

1.1.1 Pillar 1: Clean Power by 2030

The Clean Power 2030 Action Plan[3] outlines the government's strategy to establish a clean power system by 2030. This is a sprint to usher in a new era of clean energy independence and tackle three major challenges:

- Ensure a secure and affordable energy supply.
- Create essential new energy industries, supported by thousands of skilled workers.
- Reduce greenhouse gas emissions and limit our contribution to the damaging effects of climate change.

A key milestone is achieving at least 95% low-carbon electricity generation by 2030, in line with advice from the National Energy System Operator (NESO).

Delivering this ambition for a future clean energy system requires deployment at a very significant scale and pace, which can only be delivered by taking rapid action to unblock delivery challenges. This includes deploying between 43-50 GW of offshore wind, 27-29 GW of onshore wind, and 45-47 GW of solar power, as well as significantly reducing our fossil-fuel dependency. These will be complemented by flexible capacity, including 23-27 GW of battery capacity, 4-6 GW of long-duration energy storage, and development of flexibility technologies including gas carbon capture utilisation and storage (CCUS), hydrogen, and substantial opportunity for consumer-led flexibility.

1.1.2 Pillar 2: Accelerate to Net Zero by 2050

Accelerating to Net Zero focuses on achieving Net Zero by 2050, enhancing the UK's energy security, increasing jobs and economic growth and slashing dependence on unstable global fossil fuel markets. The net zero transition is the economic opportunity of the century. This is a chance to support hundreds of thousands of good jobs, to drive investment into all parts of the UK, and to protect the UK economy from future price shocks created by reliance on fossil fuels.

[3] DESNZ (2024), Clean Power 2030 Action Plan

Beyond growth and energy security, the transition to a net zero economy offers wide-ranging benefits for people across the UK, including improved public health, enhanced wellbeing, and greater access to nature. These outcomes are enabled by cleaner energy systems, decarbonised transport, and warmer, more efficient homes, all of which contribute to a healthier and more resilient society. For a more detailed discussion of the health and wellbeing benefits of net zero, see Section 1.4.2 (Health Mission).

We will deliver an updated plan later in October for the accelerating to net zero pillar, setting out the full policy package for all sectors of the economy through to the end of Carbon Budget 6 in 2037. We will also publish a Net Zero Public Participation Strategy later this year which will set out how we will empower individuals and communities to realise the benefits of the transition whilst ensuring that our climate policies are designed in a way that is responsive to people's needs.

1.1.3 Collaborative delivery of the CESM

While DESNZ is the lead department for the CESM, we work collaboratively across several government departments to deliver our mission. This ARI was developed in partnership with the departments listed in Table 1. It covers R&D needs across government and cross-references other relevant ARIs and publications where appropriate.

Table 1 Departmental policy areas relevant to the Clean Energy Superpower Mission

Department	Policy Areas
Department for Energy Security and Net Zero (DESNZ)	Energy systems and infrastructure, energy security, industrial and building decarbonisation, net zero delivery, clean energy industry growth and greenhouse gas removals.
Department for Environment, Food and Rural Affairs (Defra)	Natural resources, land use, biodiversity, waste, circular economy and environmental regulation
Department for Transport (DfT)	Transport decarbonisation, infrastructure, air quality and noise
Department for Business and Trade (DBT)	Industrial strategy, critical minerals strategy
Department for Science, Innovation and Technology (DSIT)	Research, innovation, and digital infrastructure
Ministry of Housing, Communities and Local Government (MHCLG)	Housing, local delivery and planning
Foreign, Commonwealth and Development Office (FCDO)	International development and global energy diplomacy
Department for Health and Social Care (DHSC)	Housing, planning and environments for Health

Department	Policy Areas
Department for Education (DfE)	Skills, education and educational facilities
Ministry of Defence (MoD)	Defence decarbonisation, climate change and resilience, energy and national security, nuclear skills and capabilities.

To advance R&D priorities across both pillars of the mission, the government is also working closely with partners such as UKRI, building on record levels of funding announced in the Spending Review. Effective coordination across the wider research community – including academia, industry, public bodies and other organisations – is essential. This ARI aims to support that effort by providing a shared strategic framework for collaboration.

The CESM also has strong international relevance. The UK's global leadership in clean energy innovation and climate science is supported through initiatives such as the Ayrton Fund, delivered jointly between FCDO, DESNZ and DSIT, which supports international research, development and demonstration across priority areas including energy storage, clean transport, hydrogen, and industrial decarbonisation. These international collaborations help to accelerate progress on shared challenges, build on UK expertise, develop global partnerships and value chains, and ensure that CESM-aligned innovation contributes to global energy transition efforts.

1.2 Structure: Thematic research needs and priority R&D challenges

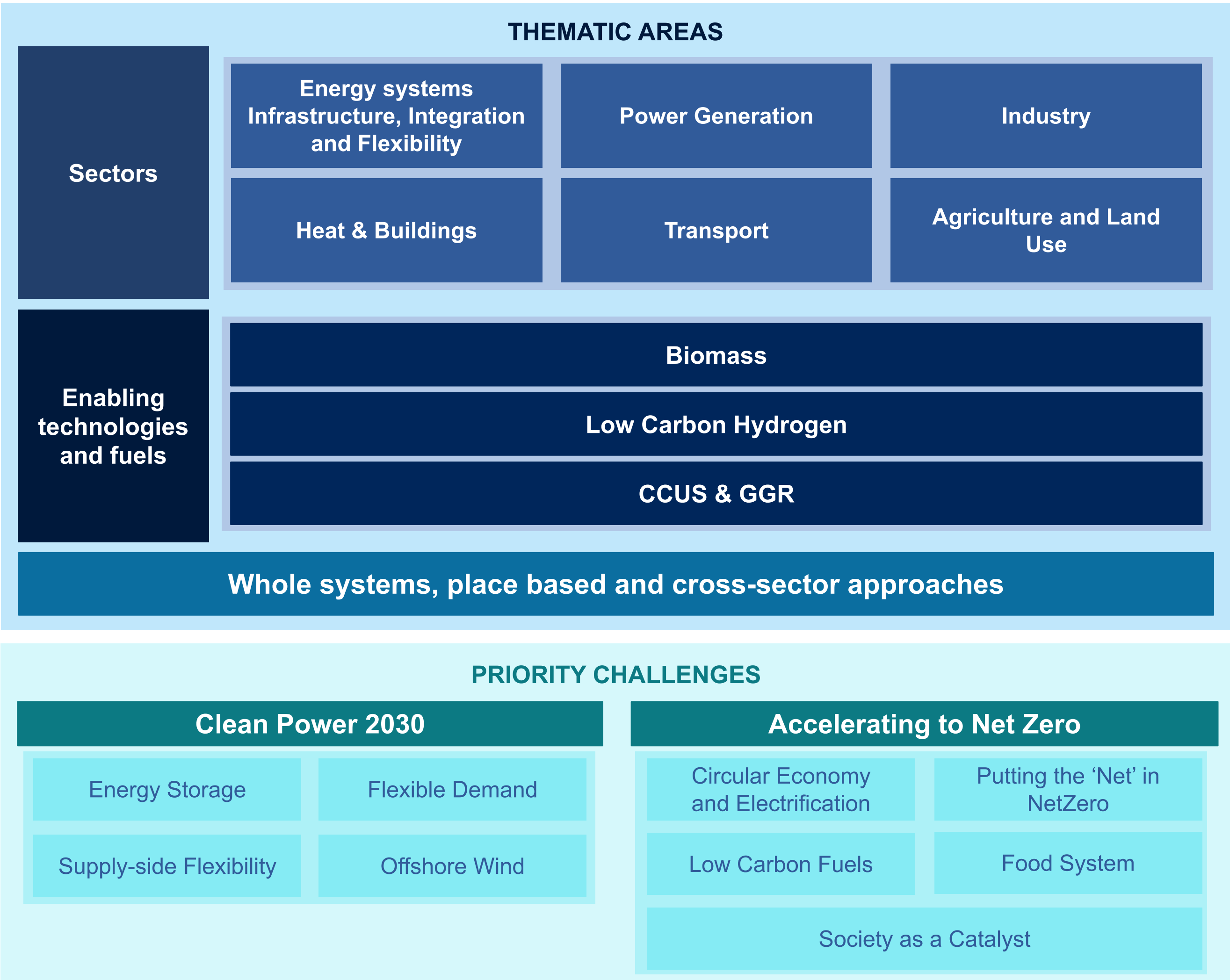
This ARI document begins by outlining the key research needs identified for the CESM, covering the full breadth of relevant research areas. These are outlined in Section 2 and organised into thematic categories:

- **Six key sectors** where outcomes from R&D could have a significant impact in supporting carbon budgets: Energy system infrastructure, integration and flexibility; Power generation; Industry; Heat and buildings; Transport; Agriculture and Land Use.
- **Enabling technologies and fuels** that underpin delivery of decarbonisation across many sectors, as enablers for transition to, and delivery of, a decarbonised economy, including Biomass, Low Carbon Hydrogen and Carbon Capture, Usage and Storage (CCUS) and Greenhouse Gas Removals (GGR).
- **Whole system approach** essential to delivery of net zero, which is a systems challenge.

Building on the thematic longlist, the ARI identifies **nine priority R&D challenges** that represent the most pressing technical, economic, and systemic barriers to deliver our mission – **four for Clean Power** and **five for Net Zero**.

These are outlined in Section 3 and reflect a shared view of where R&D can have the greatest impact, and where coordinated effort across the funding landscape is most urgently needed.

Figure 1 Clean Energy Superpower Mission ARI structure



While this document focuses on mission-driven R&D, targeted research aligned to specific delivery goals, we also recognise the critical role of foundational research in advancing scientific understanding, enabling innovation, and supporting long-term progress towards those missions.

Delivering the CESM will also require action on key enablers that underpin successful innovation and deployment. These include the development of robust standards, effective regulation, and a skilled workforce. Each plays a critical role in scaling technologies, ensuring interoperability, and supporting public confidence. While this ARI focuses on R&D needs, these enablers are recognised as essential to achieving impact and are reflected across the wider research and innovation landscape (see, for example, the Net Zero Research and Innovation Framework).[4]

[4] DESNZ (2021), Net Zero Research and Innovation Framework

1.3 Using this document

This ARI document is intended to support collaboration between government, academia, industry, and other research organisations. It sets out both the full thematic breadth of research areas relevant to the CESM and a focused set of priority R&D challenges where coordinated effort is most urgently required. Together, these provide a strategic framework to guide research investment, shape funding programmes, and inform policy development.

It can be used to:

- **Align research proposals** with government priorities and identify areas of high impact.
- **Support dialogue** between researchers and policymakers on emerging evidence needs.
- **Inform funding decisions** by enabling researchers to clearly link proposals to government priorities.
- **Guide cross-sector collaboration** by highlighting shared challenges and opportunities.

This ARI has been intentionally developed at a strategic level. While it captures the full breadth of research areas relevant to the mission, it does not aim to provide detailed R&D requirements. Instead, it offers directional guidance on the research considered most valuable at the time of assessment, rather than an exhaustive specification. As part of our future plan, we will define what success looks like and develop approaches to measure progress.

1.4 Cross-Mission benefits of CESM R&D

Owing to the interconnected nature of the government's missions, many of the research areas outlined in this ARI also contribute to the delivery of the other four national missions.

1.4.1 Growth Mission

CESM R&D underpins the UK's long-term economic growth by strengthening competitiveness, boosting productivity, and creating high-quality jobs, particularly in regions with historic economic challenges. It supports the development of globally competitive supply chains and accelerates the commercialisation of frontier technologies.

This aligns with the 'UK's Modern Industrial Strategy 2025'[5], a 10-year plan to increase business investment and grow the industries of the future. The Industrial Strategy (IS) structured around eight priority sectors, each supported by a dedicated Sector Plan to guide investment, innovation, and workforce development.

The Strategy frames Net Zero as "the economic opportunity of the century" and includes the 'Clean Energy Industries Sector Plan'[6], which sets out how the UK aims to become a

[5] DBT (2025), The UK's Modern Industrial Strategy 2025
[6] DBT, DESNZ (2025), Clean Energy Industries Sector Plan

global leader in key frontier clean energy industries by 2035. All Secretaries of State were also required to ensure that their respective sector plans supported Net Zero objectives.

Objectives include creating high-quality jobs across the country and positioning the UK as a major exporter of low-carbon products, services, and innovation. A targeted approach focuses efforts on frontier industries where the UK has the greatest potential for growth:

- **Wind** (Onshore, Offshore and Floating Offshore)
- **Nuclear Fission**
- **Fusion Energy**
- **CCUS including GGRs**
- **Hydrogen**
- **Heat pumps**

Additionally, **Electricity Networks** are recognised as a **Foundational Sector**, reflecting their essential enabling role across the economy.

Crucial net zero sub-sectors are also addressed through other Sector Plans, such as:

- **Electric Vehicles** and **Battery Technologies** – within **Advanced Manufacturing**
- **Climate Technologies** – within **Digital Technologies**

1.4.2 Health Mission

CESM R&D contributes to the Health Mission by reducing air pollution through cleaner energy systems and transport, which in turn lowers the incidence of respiratory and cardiovascular diseases. This eases pressure on the NHS and delivers long-term economic savings. Reducing air pollution is a key part of the shift from sickness to prevention in the 10 Year Health Plan. The health impacts of air pollution disproportionately affect disadvantaged groups, and cleaner energy systems and transport will contribute to improving health for the most vulnerable. Cold homes are known to have negative health impacts and improving the energy efficiency of homes (while ensuring adequate ventilation) will improve the health impacts of damp and mould.

The integration of CESM R&D with public health priorities is increasingly recognised in cross-government frameworks such the ‘Climate Adaptation Research and Innovation Framework’[7]. Extreme and prolonged heat, being exacerbated by climate change, also leads to increased pressures on the NHS and social care, and accelerating to net zero is important in helping to mitigate this.

[7] Defra, Government Office for Science (2025), Climate Adaptation Research and Innovation Framework

1.4.3 Opportunity Mission

CESM R&D supports the Opportunity Mission by investing in net zero skills and reducing household energy costs. This enables more equitable access to employment and economic participation, particularly in communities undergoing industrial transition.

Programmes focused on workforce development in clean energy sectors – such as hydrogen, fusion, and offshore wind – are helping to build a pipeline of skilled workers across the UK. Education plays a central role both in preparing the future workforce and in supporting public understanding of climate change and clean energy. This includes developing the knowledge, skills and behaviours needed to thrive in a net zero economy, and supporting behaviour change across society.

Behavioural and socioeconomic research is also being used to understand and address barriers to participation, ensuring that the transition to net zero is inclusive and regionally balanced.

1.5 Other relevant ARIs and publications

This ARI also directs readers to further resources for deeper insight. This includes:

- Defra group research and innovation interests 2021 - GOV.UK
- DfT's Areas of research interest 2023 - GOV.UK
- Nuclear Decommissioning Authority Areas of Research Interest 2023 - GOV.UK
- Climate Adaptation Research and Innovation Framework - GOV.UK
- National Energy System Operator (NESO) Innovation Strategy Report
- Net Zero Research and Innovation Framework

For a more detailed assessment of specific R&D needs across key technologies, readers may wish to consult the independent Net Zero Technology Outlook[8] published by the Government Office for Science.

[8] Government Office for Science (2025), Net Zero Technology Outlook

2 Thematic Areas of Research Interest for the CESM

This section sets out R&D needs spanning the full range of research areas relevant to delivering the CESM. These needs are organised, as outlined in Section 1.2, into twelve themes spanning: six key sectors; enabling technologies and fuels; and whole system approaches.

Building on this, Section 3 outlines the nine priority R&D challenges – four for Clean Power and five for Net Zero. These reflect a shared view of where R&D can have the greatest impact, and where coordinated effort across the funding landscape is most urgently needed.

2.1 Sectors

2.1.1 Energy system infrastructure, integration and flexibility

Departments: DESNZ

Electricity demand is predicted to nearly double by 2050 as society transitions to a more resilient and clean energy system. To deliver this increased demand flexibly and efficiently, it is crucial to have the right energy network infrastructure and system arrangements in place. This transition will involve complex interactions between technology, infrastructure, markets, people, data, institutions, policy and the natural environment.

Research is needed to support this transition, including the development of technologies, market arrangements and management systems that enable an integrated and flexible energy system – one capable of efficiently decarbonising the power sector and sustaining it beyond 2030.

Key R&D needs include:[9]

- Improving **energy storage capacity**, performance and cost, particularly at large scale and long duration, and research to support strategies for optimal grid integration and deployment (see also section ‘3.1.2 Energy storage’).
- Developing and demonstrating solutions to accelerate the transition to **smart and flexible electricity systems**, including consumer-led flexibility (see also sections ‘3.1.1 Flexible Demand’ and ‘3.2.5 Society as a catalyst’).
- Developing technologies, investment, and approaches to **enable effective expansion of electricity network infrastructure and grid capacity**, including research to support planning, community engagement (see also ‘3.2.5 Society as a catalyst’), future network

[9] Further information on energy system R&D interests is available in NESO Innovation Strategy Report (2025)

topologies and their environmental implications, and ways to improve the efficiency of existing infrastructure and reduce constraints.

2.1.2 Power generation

Departments: DESNZ

The Power sector has led the UK's efforts to reduce greenhouse gas (GHG) emissions, with emissions having decreased by 6% since 2019 and 73% since 1990.[10] These reductions are mainly due to the shift in fuels mix for electricity generation, inducing the decline of coal and the growth of renewables, alongside increased efficiency.

In 2050, electricity will be the primary form of final energy consumption in the UK and a key method for decarbonising other sectors, such as transport and heat. This transition is expected to drive a significant increase in demand, with annual electricity consumption likely to at least double compared to today.[11] The UK power sector must rapidly decarbonise to achieve Clean Power by 2030 and accelerate towards net zero by 2050, with industries such as wind and nuclear also offering significant potential for long-term economic value to the UK.

Research and innovation are necessary to support delivery of low-cost, low-carbon electricity generation technologies to meet the needs of increasing demand and to understand, and support efforts to mitigate, the negative impact of generation infrastructure on the environment.

Key R&D needs include:

- Developing next generation turbines for both **onshore wind and offshore**, including to unlock deployment in deep water offshore wind sites (50m or deeper), such as through floating offshore wind technology; lower costs and improve sustainability, as well as to reduce environmental impacts during installation, operation and decommissioning (see also section '3.1.4 Offshore wind')
- Further developing **solar technologies** and support solar deployment, including improving installation, systems integration and sustainability, as well as to explore opportunities for next generation solar photovoltaic (PV) with higher load factors.
- Developing and demonstrating **earlier-stage renewables** specifically tidal, geothermal and other lower Technology Readiness Level (TRL) technologies.
- Developing and demonstrating solutions in **new and advanced nuclear technologies**, including Small Modular Reactors (SMRs), Advanced Modular Reactors, nuclear co-generation (heat and power), and advanced nuclear fuels, in addition to improving processes for decommissioning and disposal of waste.[12]
- Developing and demonstrating low carbon solutions for **dispatchable power** (see also section '3.1.3 Supply side flexibility'), including hydrogen-to-power applications (section

[10] DESNZ (2023), Powering Up Britain: Net Zero Growth Plan
[11] DESNZ (2024), Clean Power 2030 Action Plan
[12] Further information on research interests for nuclear decommissioning and waste can be found in NDA's Areas of Research Interest

'2.2.2 Low carbon hydrogen'), Bioenergy with Carbon Capture and Storage (section '2.2.1 Biomass') and Energy Storage (section '3.1.2 Energy storage').

In the near-term, **Fusion** R&D supports jobs and innovation, with the UKAEA campus (part of the Oxford-Cambridge science corridor) also proposed to host the UK's first AI Growth Zone – whilst key areas such as robotics, advanced materials and high temperature superconducting magnets can be leveraged to benefit other energy generation technologies. In the longer-term, Fusion is expected to contribute to the UK's and global low carbon energy system, addressing baseline energy generation needs and helping maintain net zero beyond 2050 as energy demand grows.

Fusion's R&D priorities cover several key areas: the confinement and stabilisation of fusion plasma, including development of simulation and verification of key plasma models; the breeding and recycling of fusion fuel (tritium); the development of advanced materials capable of withstanding extreme fusion environments; remote maintenance and robotics to ensure high availability of power plants; and laser development and target design for inertial fusion.

2.1.3 Industry

Departments: DESNZ, Defra, DBT, DfT, DSIT, MHCLG

The UK manufacturing sectors are crucial to our economy, supplying essential materials and products for daily life, such as household items, concrete for construction, and steel for defence.

A strong industrial sector is vital for the economy and the livelihoods of local communities. However, industries' dependence on fossil fuels and the associated greenhouse gas emissions presents a significant challenge in the context of climate change. Industrial decarbonisation will be critical for achieving carbon budgets, with industrial emissions accounting for 14% of UK annual emissions in 2023.[13] This involves reducing carbon emissions from these sectors through a combination of energy and resource efficiency improvements, fuel switching to low-carbon alternatives (particularly electricity), and the adoption of carbon capture, utilisation, and storage (CCUS) technologies (see also '2.2.3 CCUS and GGRs'). It also involves moving toward a circular, zero waste economy and away from fossil fuel feedstocks.

R&D is required to develop solutions to reduce emissions and waste from UK industries, while also enabling growth by lowering energy costs and helping businesses remain competitive in domestic and global markets. This is expected to require both large scale roll-out of industrial electrification technologies, alongside more specialist solutions for hard-to-abate, high-emitting sectors such as cement, refining and chemicals.

Key R&D needs include:

- Research to understand the **best fuel switching options** for a range of industrial subsectors, including cost-effective and viable solutions that support decarbonisation

[13] DESNZ (2025), Final UK greenhouse gas emissions statistics: 1990 to 2023

through electrification, with a focus on heat technologies, energy storage, and demand-side flexibility (see also '3.2.1 Transitioning to a circular economy and electrification' and '3.1.1 Flexible demand'). This should also include development of hydrogen solutions and other sustainable fuels (see '3.2.3 Low carbon fuels') as well as development of zero-emission off-road machinery.

- Research and innovation in **resource and energy efficiency** to reduce emissions in construction and manufacturing by developing advanced technologies, materials, and manufacturing techniques. This includes support for resource reduction, re-use, repair, remanufacture and recycling processes to enable the transition to a **circular economy** (see also '3.2.1 Transitioning to a circular economy and electrification').
- Developing and demonstrating **CCUS technologies** at scale across industrial applications, especially in sectors such as chemicals and cement, including integration with site operations and exploration of distinct approaches for clusters and dispersed sites as well as industrial heat recovery (see also '2.2.3 CCUS and GGRs' and '3.2.2 'Net' into Net Zero').
- Research to support **defossilisation of the chemical industry**, including quantifying emissions savings, conducting technoeconomic analyses, and developing sustainable feedstocks and processes such as CO_2-to-chemical conversion, bio-engineering and chemical recycling.
- Research to understand and reduce the **Whole Life Carbon (WLC)** of buildings and infrastructure (see also '2.1.4 Heat and buildings'), including developing appropriate embodied carbon benchmarks and improving data and tools for assessing life cycle emissions of key construction materials like cement, steel, glass, and polymers.

While industrial decarbonisation is a central theme, it is essential to recognise that the UK's ability to capture the full value of its clean energy innovation depends not only on inventing new technologies, but also on deploying them at scale through robust manufacturing capabilities. Coordinated R&D efforts are needed on **advanced manufacturing methods, automation, and circular supply chains**. By prioritising research and innovation in these areas, the UK can strengthen its manufacturing base, accelerate the industrialisation of clean energy technologies, and ensure that the economic and societal benefits of R&D are realised domestically.

2.1.4 Heat and buildings

Departments: DESNZ, MHCLG, DHSC

The Built Environment makes up approximately 30% of the UK's total emissions,[14] including commercial, public sector and residential buildings, with the majority stemming from heating.[15] By transitioning to low carbon heating technologies and improving energy efficiency, we can

[14] DESNZ (2021), Heat and buildings strategy
[15] Note: This section does not address R&D needs related to industrial heat processes, which are covered separately in Section 2.1.3: Industry.

significantly reduce emissions, lower overall energy use, reduce reliance on imported fossil fuels, and cut energy bills for consumers. The UK's heating and cooling industry also presents a significant growth opportunity, bolstered by an established boiler manufacturing workforce and facilities well-placed for the transition.

R&D is required to enhance deployment, including to increase efficiency and reduce the cost of solutions for decarbonising UK buildings.

Key R&D needs include:

- Research to develop, demonstrate, and de-risk **low-carbon heating and cooling technologies** – such as improved heat pump solutions, combined heating and cooling networks, alternative electric heating, and geothermal systems. This includes efforts to reduce costs, increase consumer engagement, bolster supply chains and to better understand the potential role of alternative low-carbon solutions, particularly where they can provide flexibility to match renewable variability (see also '3.2.5 Society as a Catalyst' and '3.1.1 Flexible demand').
- Research and innovation to better understand, develop and deploy effective **retrofit solutions**. This includes measures such as insulation, solar PV, heat pumps, storage, and passive cooling, how they interact with one another and the existing building fabric and systems, and how consumers understand and use them. Additionally, research should explore ways to expand and diversify the supply chain, including approaches to improving skills and developing models that prioritise high quality installations and advice for consumers.
- Improving the **evidence base on building decarbonisation**, including to further develop a database/digital twin of UK building stock[16], establishing trusted, low-cost, and accurate methods to measure the real-world performance of buildings and identify how these can improve policy and system-level approaches to decarbonisation, deliver co-benefits for missions on health, economic growth and opportunity, and to better understand end-user behaviour to drive uptake of energy efficiency and low carbon measures (see also '3.2.5 Society as a catalyst').
- Research to **future-proof decarbonisation of buildings** to ensure they are designed to improve health of occupants, reduce bills and well adapted to a future climate (reducing risks of overheating, poor air quality, and damp/mould) (see also '2.3.3.3 Climate risks and adaptation').
- Research to improve **building-level emissions accounting**, including integration of material data with operational performance, and implementation of robust methodologies for assessing life cycle emissions across different building types and infrastructure assets (see also '2.1.3 Industry').

[16] The term 'UK building stock' refers to the entire collection of existing buildings in the UK, encompassing both domestic (residential) and non-domestic (commercial and public) structures such as hospitals, supermarkets, data centres, schools, care homes.

2.1.5 Transport

Departments: DfT, DBT, DESNZ

Transport is currently the UK's largest emitting sector.[17] The government is acting to accelerate the development and deployment of the clean technologies we will rely on to decarbonise the sector, with a vision for decarbonised transport that maximises the opportunities they offer for our climate and growing the economy. This includes supporting transforming existing industries, such as our world-leading automotive sector, and growing nascent industries, such as clean maritime, aviation and low carbon fuels.

Research, development and demonstration will play an important role in delivering on this technology-led transition.

Key R&D needs include:[18]

- Research and innovation to support the development and rollout of solutions for **hard to decarbonise surface transport** such as heavy goods vehicles, alongside research into embedded carbon metrics for vehicle manufacturing, advanced battery and driveline technologies, resource efficiency and circularity approaches, software architecture and AI platforms, and scaling UK-based Zero Emission Vehicle (ZEV) production.
- Research and innovation to support the development and rollout of **clean maritime technologies**.
- Research and innovation to support **decarbonising aviation** including scaling of zero/low carbon fuel technology, such as hydrogen, synthetic, and biomass-derived fuels (see also '3.2.3 Low carbon fuels'), as well as **addressing non-CO_2 climate effects** including particulate emissions at high altitudes, which also contribute to warming.
- Research to understand the **role of hydrogen and other low carbon fuels** in decarbonising **non-aviation transport**, including enabling factors such as safe transport. Aviation is covered in the point above (see also '3.2.3 Low carbon fuels').
- Research to support a **cross-system approach** to decarbonising transport, including impact of regulation and other levers, and on behaviour change (See also '3.2.5 Society as a catalyst), as well as wider impacts on health such as air quality.

2.1.6 Agriculture and Land Use

Departments: Defra, DESNZ

Agriculture is an essential industry to the UK, with farmers making a critical contribution to food security, our economy, health and environment. Agriculture contributes approximately 12% to total annual emissions.[19] Ruminant livestock (e.g. cattle and sheep) are the primary source of

[17] DfT (2023), [Transport and environment statistics: 2023 (2021 data)]
[18] Further information on transport R&D interests is available in DfT's ARI: [Areas of research interest 2023]
[19] DESNZ (2025), [Final UK greenhouse gas emissions statistics: 1990 to 2023]

these emissions, contributing around two-thirds. Other sources include agricultural soils (from fertiliser use and slurry application), stationary combustion sources and off-road machinery.

Decarbonising the sector is challenging owing to biological processes in livestock and soils which produce emissions. Despite being a hard-to-abate emitter, the sector is uniquely placed to sequester and reduce emissions through land management practices such as hedgerow creation, forestry and agroforestry. The transition to more climate friendly agricultural practices goes hand in hand with food security, farm productivity, and enhanced biodiversity. That is why Defra will be publishing the Land Use Framework, Farming Roadmap, and Environment Improvement Plan later this year. Together, these documents will outline how our land must evolve to meet environmental and land use challenges, drive sustainable growth, and set a clear vision for the farming sector through 2030 and 2050. This work will underpin the "Good Food Cycle", which identifies ten priority outcomes essential for building a thriving, resilient food sector.[20]

Research and innovation are needed to improve the efficiency of food and energy crop production, including for sustainable fuels, and to develop and deploy low-carbon agricultural technologies and practices. These efforts aim to reduce emissions from agriculture, optimise land use, protect biodiversity, and support UK food security and productivity under realistic climate change scenarios.

Key R&D needs include:[21]

- Developing the tools and capabilities to inform **land-use decisions** and policy interventions at national and local scales, enabling sustainable land use change. This includes improving understanding of multifunctional land use (e.g. agrivoltaics), climate resilient land use options and balancing competing needs for land across the different sectors of the economy.
- Research to better understand system level **greenhouse gas emissions and environmental impacts** in agricultural (including aquaculture) practices as well as the wider land use system, including the transformation required to deliver climate and nature goals.
- Research and innovation to support the **sustainable production** of food, perennial energy crops, and short rotation forestry. This includes developing novel crop and livestock breeding techniques and trialling land management interventions to create more economically valuable, climate-resilient, and lower-emission food systems. Efforts should also focus on promoting **sustainable consumption** (see also '3.2.4 Food system' and '3.2.3 Low carbon fuels').

[20] Defra (2025), A UK government food strategy for England
[21] Further information on Agriculture and Land Use R&D interests is available in Defra's ARI: Defra group research and innovation interests 2021

2.2 Enabling technologies and fuels

2.2.1 Biomass

Departments: DESNZ, Defra

Biomass is defined as any material of biological origin, including the biodegradable fraction of products, crops, wastes and residues from biological origin. When sourced sustainably, it is a versatile, low-carbon resource that can be used in multiple ways (such as delivering negative emissions or low carbon electricity and hydrogen production) meaning that it will be an important component in our pathway towards net zero, in particular in harder to decarbonise sectors. However, sustainable biomass is a globally limited resource, and its use must be prioritised in the most socially valuable end uses so that we can maximise its potential for decarbonisation (via energy and non-energy use), while avoiding any unintended negative impacts on the wider environment and communities.

Research is required to support delivery of a sustainable and reliable supply of quality biomass for bioenergy, carbon capture and biomass conversion into fuels and products, and to understand demand on land use and routes to minimise negative impacts on the environment.

Key R&D needs include:

- Identifying the most cost-effective and GHG-optimal methods of **utilising sustainable biomass** to meet net zero, including improving understanding of the demand for different types and grades of sustainable biomass in key industries.
- R&D to **enable delivery of a sustainable and reliable supply of quality biomass** by understanding the potential sustainable biomass resource available to the UK, mapping their geographic distribution and types, exploring ways to increase sustainable supplies, improving UK biomass productivity, and minimising environmental impacts through comparative life cycle analysis of emissions.
- Optimising **Bioenergy with Carbon Capture and Storage (BECCS)** deployment by assessing potential and environmental consequences of combining BECCS with other technologies.
- Analysing the **life cycle emissions of biomass**, both domestic and imported – including woody biomass, sustainable liquid biofuels, and emerging feedstocks.
- Increasing understanding of **non-energy uses of biomass**, such as in chemicals and steel, and identifying opportunities, tensions, and impacted biomass types.
- Exploring **biomass sustainability issues**, including forest carbon, soil carbon, indirect land use change, cascading use, and monitoring, reporting and verification in supply chains.
- Improving the **performance and viability of conversion technologies**, such as gasification and other thermochemical, physical or biological technologies, and strengthening evidence on GHG and air quality impacts.

2.2.2 Low carbon hydrogen

Departments: DESNZ

Low carbon hydrogen[22] is essential to achieving the Clean Energy Superpower and Growth Missions and plays a critical role in the UK's clean energy transition. It offers flexible deployment for power and is vital for decarbonising hard-to-electrify sectors such as high-temperature industrial processes and heavy transport uses like aviation and maritime. Hydrogen-fired power stations can provide flexible low-carbon generation as renewables scale, while surplus renewable electricity can be used to produce hydrogen, which also enables large-scale, long-duration energy storage to support energy security.

The UK is well-positioned to lead in this sector, with strong domestic expertise, favourable infrastructure, and a supportive policy environment. The global market for hydrogen technologies presents a significant economic opportunity, with UK exports in hydrogen production equipment and fuel cells potentially reaching up to £2.2 billion by 2030 and £9.8 billion by 2050.[23] To realise this potential, R&D will be critical – not only to develop and demonstrate early-stage and first-of-a-kind technologies – but also to bridge the "valley of death" and support commercialisation.

Further R&D is needed to support scaling-up the supply and demand for low carbon hydrogen including developing and demonstrating cost effective production, distribution and storage of low carbon hydrogen at scale.

Key R&D needs include:

- Develop and demonstrate efficient, cost-effective **production** of low carbon hydrogen at scale, including integration of large-scale electrolysis technology with variable renewable sources, as well as development of negative emissions hydrogen production technologies and more efficient disruptive technologies.
- R&D to demonstrate effective, safe, low-cost methods of bulk hydrogen **transportation and storage**, as well as developing the evidence base on these solutions (see also '3.1.2 Energy storage').
- Develop and demonstrate large, centralised hydrogen fuelled **power generation** options (see also '2.1.2 Power generation' and '3.1.3 Supply-side flexibility') and explore the role of fuel cells in applications such as decentralised power, industrial combined heat and power (CHP) and heat networks.
- Understanding **whole systems approach** to determine the most effective uses of hydrogen, including modelling the interrelated nature of future hydrogen production, storage, demand and use by different sectors, and impacts on wider environmental goals.

[22] Defined in the UK Low Carbon Hydrogen Standard - GOV.UK
[23] DESNZ (2025), Hydrogen Update to the Market – July 2025, p. 24.

- Assessing the **environmental and social impacts** of hydrogen use, including sources and levels of fugitive hydrogen, atmospheric impacts, co-benefits, and trade-offs.

2.2.3 CCUS and GGRs

Departments: DESNZ, Defra (for nature-based GGRs)

CCUS (Carbon Capture, Usage and Storage) and GGRs (Greenhouse Gas Removals) are complementary solutions in the UK's path to net zero. CCUS primarily targets emissions at their source – such as from industry, power generation or hydrogen production – by capturing and storing them before they enter the atmosphere, while GGR technologies remove greenhouse gases, predominantly CO_2, directly from the atmosphere.

Both approaches are critical to meeting our climate commitments and delivering energy security. They will play an important role in accelerating progress towards net zero by 2050, supporting the growth of key industries, and helping to decarbonise the UK's economy. With world-class research, engineering expertise, access to geological storage and a supportive policy environment, the UK is well-placed to be a global leader in CCUS and GGR technologies – sectors poised to drive growth and create thousands of jobs over the next decade. [24] [25]

CCUS is expected to underpin a considerable proportion of the CO_2 reductions required to meet the UK's legally binding ambitions and international obligations. It is essential to decarbonising our energy intensive industries, such as cement and refining, and enabling the decarbonisation of sectors such as aviation, through the production of blue hydrogen and the scaling-up of Sustainable Aviation Fuel (SAF), both of which rely on CCUS to reduce lifecycle emissions. The UK has a unique opportunity to be a world leader in CO_2 storage services, with an estimated potential to store more than 78 billion tonnes of CO2.[26] This is around 200 times the UK's total GHG emissions in 2023.

GGR technologies will also be important for reaching net zero – balancing residual emissions from hard-to-decarbonise sectors while providing new economic opportunities. GGR solutions typically fall into two broad categories: engineered approaches, such as Direct Air Carbon Capture and Storage (DACCS), Bioenergy with Carbon Capture and Storage (BECCS), biochar and enhanced rock weathering; and nature-based approaches which leverage ecological processes like peatland restoration, afforestation, and enhanced soil management to sequester carbon. Both engineered and nature-based approaches will be needed to remove CO2 at the speed and scale required to meet our climate targets. Some engineered technologies (e.g. DACCS and BECCS) require CO_2 transport and permanent storage infrastructure, while others (e.g. biochar, enhanced rock weathering, carbon-negative building materials, marine carbon dioxide removals) do not.

[24] DESNZ (2025), UK carbon capture, usage and storage (CCUS)
[25] DBT, DESNZ (2025), Clean Energy Industries Sector Plan
[26] DESNZ (2023) Carbon capture, usage and storage: a vision to establish a competitive market

R&D in greenhouse gas removal and carbon capture technologies is required to support the development of methods for achieving net reductions in GHG emissions and enable their effective and responsible deployment (see also ‘3.2.2 The ‘Net’ in Net Zero’).

Key R&D needs include:

- Developing and demonstrating next generation technologies and improving existing technologies to **capture CO2 from point sources** – efficiently, safely and at low-cost – including scaling up across the ‘valley of death’, deploying these technologies, and sharing knowledge to improve future projects.
- Develop, demonstrate and commercialise tec**hnologies to remove GHGs directly from the air or sea** – at scale, efficiently, responsibly and at low cost – including both engineering and nature-based solutions. This should be carried out alongside developing the evidence base: assessing the technical potential, costs, and environmental impacts of different solutions; optimising removal strategies through co-location, flexible operation and stacking technology combinations to maximise benefits and efficiency; and improving understanding of long-term effectiveness and resilience of non-CCS approaches.
- R&D to identify optimal methods and technologies for the **safe transport and storage** of CO_2, including options for dispersed sites and CO2 network purity monitoring.
- R&D to **support development and growth of the GGR/CCUS sectors and supply chains** including improving measurement, monitoring and verification techniques (including across time horizons), understanding environmental and social impacts and barriers to deployment, optimising system-wide integration of CCUS and GGR, improving understanding of impacts on the UK economy, and developing and improving uses for captured CO2 (e.g. sustainable fuels, building materials or chemicals defossilisation).

2.3 Whole System and cross-cutting

Departments: DESNZ, Defra, DfT, DBT, DSIT, MHCLG, FCDO, DfE

The section starts by describing system-wide and cross-cutting R&D themes needed to support delivery of the CESM. It then offers a more detailed examination of several key, cross-cutting research areas, including climate science, energy security, and resilience and adaptation.

2.3.1 Whole systems, place based and cross sector approaches

A whole systems approach allows better understanding of the interrelated nature of different sectors and between new technologies, consumer behaviour and business models, and allows assessment of interactions between different aspects of the system required to reach net zero. A systems approach can help to identify potential co-benefits or tensions, manage uncertainty, target points of greatest leverage, mitigate unintended consequences and identify highest value and lower cost pathways that maximise benefits.

R&D can enhance our understanding of the impacts of different pathways to delivering net zero by 2050 – including their implications on physical, natural, social and digital systems. Research is needed to understand and measure whole system policy impacts and technology changes to support an environmentally positive and climate resilient path to net zero, recognising the transition to net zero is a systems challenge.

Key R&D needs include:

- Whole systems research and analysis to **guide sustainable and resilient pathways** to achieving net zero, including biodiversity considerations, cross-sector approaches and modelling capabilities, as well as to maximise co-benefits for the other government missions.
- R&D to better **integrate net zero energy systems** across different energy vectors and sectors of the economy to enhance efficiency, including to optimise infrastructure, enable flexibility and demonstrate integrated energy systems.
- Research to better understand and address the **socio-economic and behavioural** impacts of clean energy and net zero solutions, including impacts on energy prices and affordability for consumers, and to enable behavioural change that supports access to the benefits of these technologies and can accelerate uptake (see also '3.2.5 Society as a catalyst').
- Research to support an **enabling environment for net zero** through new business models, green and transition finance instruments, alongside clear standards to unlock the value of innovation, manage risk and enable faster uptake of low carbon solutions.
- Research and innovation to support a **place-based approach** to clean energy and net zero policies, helping tailor them to the specific needs and circumstances of different regions, and improve understanding of the distributional consequences of decarbonisation, including how its various impacts and opportunities are distributed across communities, particularly disadvantaged groups.
- R&D to help mobilise **digital solutions and data**, such as through AI, to achieve net zero goals. This includes enabling cross-sector integration and systems-level understanding, enhancing resource and energy efficiency, and to understand where digital technologies, such as AI, may increase energy demand.
- Research to identify and address **net zero skills** gaps across sectors and supply chains, including development of regional training pathways and workforce transition strategies to support deployment of clean energy technologies.
- Research to integrate **monitoring, reporting and verification** to measure and track GHG emissions across different technology areas and fields to ensure emissions accounting is comparable and robust. This includes improving observational capabilities for monitoring GHG concentrations and their attribution to different emitting sectors, especially for sources with high uncertainty.

- Research to improve **data acquisition and methodologies**, to reinforce our ability to track with integrity and completeness emitting processes and activities though our GHG emissions inventory so that success of technologies, policies and measures can be better tracked and represent the latest science and strongest datasets (see also '2.3.2 Climate science').
- Research to support the **transition to net zero globally**, such as integrated approaches to mitigation and adaptation, understanding of cross sectoral synergies and trade-offs and resilient development pathways to enable transformational change.

2.3.2 Climate science

Departments: DESNZ, DSIT, FCDO, Defra

Climate science investigates the structure and dynamics of Earth's climate system. It seeks to understand how global, regional and local climates are maintained as well as the processes by which they change over time. Climate science underpins the CESM's strategic objectives, shaping domestic emission reduction efforts, bolstering the security and resilience of energy supplies, and guiding progress toward net zero. It also provides the foundation for advancing international climate leadership.

Meeting the mission's evolving climate-information needs depends on continually developing scientific knowledge, robust expertise, and sophisticated technical capabilities – including models, data, and infrastructure. The UK's internationally recognised strengths in climate science reinforce its status as a leader in global clean energy innovation and amplify its role within international climate collaborations.

R&D is needed to further develop climate-modelling capabilities to improve our understanding of climate risks and impacts, including compounding and cascading hazards, tipping points and interventions. It will also improve observational capabilities such as in Earth observations from space and other platforms for monitoring key changes to our climate (such as temperature, sea-level rise and extremes) and GHG emissions, and support development of robust mitigation and adaptation strategies.

Key R&D needs include:

- Develop advanced **climate-modelling and monitoring capabilities** to better capture present-day and future changes in mean climate and climate hazards.
- Improved quantification and **understanding of climate risks**, including changes in extremes, cascading and compounding risks, climate interventions, localised impacts as well as tipping points and other high-impact low-likelihood events.
- Improve our understanding of **climate attribution, probabilities and uncertainties**.
- **Understanding overshoot**, including comparing the costs, risks, benefits, and feasibility of global mitigation pathways that temporarily exceed 1.5°C before returning to it within this century, versus those that stabilise at different temperature levels between 1.5°C and 2°C.

- Improved **quantification of avoided impacts and the costs of inaction**, including better estimates of future damage costs of climate impacts at different levels of warming.
- **Provision of accessible climate information** to help identify risks and support resilience and adaptation decisions for the CESM.
- Adopt a systems approach to develop credible **climate mitigation and adaptation strategies** and pathways to support and future-proof UK carbon budget and net zero delivery, and global net zero, whilst identifying co-benefits and trade-offs for the UK and internationally.
- Explore the **potential of AI to improve the generation, delivery and use of climate information**, including from climate models and observational systems.

2.3.3 Energy security, resilience and climate adaptation

Departments: DESNZ, DSIT, MHCLG, Defra, DfT, MoD, DHSC, DfE

Energy security is a cornerstone of national resilience and economic stability, and a key objective of the CESM. As global energy demands shift in response to environmental and geopolitical pressures, reliable access to energy remains essential for powering homes, industries, and vital services. This means addressing vulnerabilities while transitioning to cleaner, more sustainable systems, and also recognising that, while demand for oil and gas is expected to decline, these resources still play a vital role in the transition, providing system flexibility, economic stability, and continuity of supply during a period of change.

Alongside mitigation efforts, there is growing recognition of the need to adapt to unavoidable climate change impacts. Ensuring climate resilience is built into our energy networks, now and in the future, is essential for maintaining energy security and resilience. This includes adapting existing infrastructure and ensuring new technologies are robust to future climate scenarios.

2.3.3.1 Energy security and resilience

To ensure long-term energy security and system resilience, research is needed to understand how the UK's energy infrastructure and supply chains can evolve in response to emerging risks and changing market conditions. This includes preparing for both high-impact, low-likelihood events and higher likelihood, lower impact disruptions, while enabling a managed transition away from fossil fuels.

Key R&D areas include:

- Understand the **future of the UK gas and fuel systems**, including market dynamics, supply security, carbon emissions, and infrastructure viability.
- Assess the feasibility and cost of **gas network repurposing and decommissioning** approaches.
- Evaluate **risks to energy security and resilience**, including high-impact low-likelihood and higher likelihood, lower impact events.

- Investigate **exposure and vulnerability of the energy system to threats and hazards** such as cyber-attacks, severe space weather and damage to sub-sea infrastructure.
- Explore socio-economic challenges and preparedness of industry and society against **energy disruption**.
- Assess the role of **interconnectors** in mitigating supply risks and enhancing system resilience.

2.3.3.2 Offshore energy transition

The offshore energy sector is central to the UK's energy landscape and will play a key role in the transition to net zero. Research is needed to reduce emissions from offshore oil and gas operations, repurpose infrastructure for low carbon uses, and ensure the transition is both economically viable and socially just.

Key R&D areas include:

- Develop cost-effective solutions to reduce emissions from **offshore oil and gas infrastructure**, including enhancing monitoring, reporting and verification approaches.
- **Repurpose offshore infrastructure** for CO_2 and hydrogen storage.
- Advance **digitalisation** for offshore asset management and decommissioning.
- Understand **socio-economic impacts** of the offshore energy transition to support a just and secure shift.

2.3.3.3 Climate risks and adaptation

The UK faces multiple risks from climate change, including from more frequent extreme weather. There is a pressing need to future proof policies and investment in clean power and net zero against current weather extremes and future changes in climate.

Ensuring that climate resilience is built into our energy networks, both now and in the future, is essential for maintaining energy security and resilience. This means both adapting existing electricity and gas infrastructure to future climate scenarios and ensuring that new technologies, such as CCUS and hydrogen, are built in a way that is resilient to those future scenarios. Similarly, consideration of future climate scenarios is critical to ensuring the continued resilience of UK building stock including hospitals, supermarkets, data centres, schools and care homes.

Research and innovation are required to support climate adaptation measures by identifying, quantifying, and mitigating risks that could affect energy demand, supply, and infrastructure, as well as the present and future built environment. A transdisciplinary approach will be essential to effectively identify and mitigate these risks, drawing not only on foundational climate science, but also engaging engineering, economics, social sciences, and data science communities to deepen our understanding of potential impacts and the critical thresholds that underpin system resilience.

Key R&D areas include:

- Research to improve understanding of **the risks to existing and future energy infrastructure from climate impacts**, and the geographical distribution of these risks
- Developing **consistent metrics** for defining, measuring and monitoring climate resilience of the net zero system,
- Research to understand **compounding and cascading effects of climate hazards** on the energy system and impacts on other systems such as water supply and health through system interdependencies, to inform more resilient policies and investments that account for the effects of climate change.
- Research to assess the **sensitivity of pathways to deliver clean power** to future climate change risks.
- Transdisciplinary research to identify levers and barriers to increase **climate resilience solutions**.
- Research to **identify building occupants, types and settings most susceptible to climate hazards** (such as overheating).
- Development of **evidence to support retrofitting and adaptation strategies** to increase the resilience of the UK's built environment to future climate conditions (e.g. use of shutters, natural shading, or cooling systems) (see also '2.1.4 Heat and buildings).

The Climate Adaptation Research and Innovation Framework (CARIF) further sets out key climate adaptation research and innovation challenges for the UK across government.

3 Priority R&D challenges for the CESM

Building on the thematic list of R&D needs above, this section outlines the nine priority R&D challenges – four for Clean Power and five for Net Zero. These priority R&D challenges reflect a shared view of where R&D can have the greatest impact in delivering the CESM and were agreed through cross-government consensus.

3.1 Clean Power 2030

We are committed to achieving Clean Power by 2030, defined as delivering at least 95% of electricity generated from low-carbon sources.[27] This transition aims to ensure secure and affordable energy, support the growth of new industries, and protect the environment from the harmful impacts of climate change.

As outlined in the Clean Power Action Plan,[28] to achieve Clean Power by 2030 and accelerate to net zero, we need rapid deployment of renewable energy projects, flexible capacity, and a reduction in fossil fuel dependence. Traditionally, we have been dependent on fossil fuels to meet peak power demands due to their flexibility, which has made the UK vulnerable to unstable energy prices.

The following R&D challenges will deliver near-term solutions for key barriers to delivering Clean Power by 2030. While these R&D priorities are focused on meeting the 2030 goal, continued research and innovation in these areas will be essential to sustain a secure, affordable, and low-carbon electricity system beyond 2030 as demand grows, and technologies evolve.

3.1.1 Flexible demand

Challenge: How can system AI / Digital tools be used to provide peak-time demand and consumer flexibility – and (in effect) reduce the need for peak time gas generation?

Departments: DESNZ, DSIT

Currently, power system flexibility to meet peak demand is mainly delivered through use of fossil fuels. Building a smart and flexible electricity system that actively manages the scale and nature of demand will enable a more efficient, secure and lower-cost system. AI and digital tools can utilise growing data to help shift power demand from scarce to abundant periods, providing cheaper, cleaner energy for consumers. AI tools can also enhance the identification of low-carbon technologies, such as solar power, batteries, heat pumps, and electric vehicles

[27] DESNZ (2024), Clean Power 2030 Action Plan
[28] DESNZ (2024), Clean Power 2030 Action Plan

(EVs) within networks where visibility is currently limited. This would increase the accuracy of forecasting peak demand and the potential to shift demand, as well as network capacity needs.

More broadly, R&D is required to support the Clean Flexibility Roadmap[29] by developing and testing grid-, commercial-, and consumer-level technologies, standards and tools that enable peak-time flexibility as an alternative to carbon-intensive gas generation or costly over-building of other generation or associated network and electricity storage infrastructure. While reducing peak demand is the priority, solutions are also needed to shift electricity use between days, better aligning demand with periods of high renewable energy availability.

Beyond AI and digital innovation, the Clean Flexibility Roadmap highlights several areas where innovation is needed to resolve system-level barriers to unlocking peak-time flexibility. These are not necessarily directly digital in nature but are critical to enabling a smart, flexible electricity system:

Innovation to unlock flexible asset access to energy markets, enabling a wider range of consumer and commercial technologies to participate in flexibility services and meet energy security requirements at lower cost. This includes domestic (including low-income and vulnerable) and non-domestic users.

Innovation to develop and test interoperability standards for key domestic-scale energy smart appliances including smart EV chargers, heat pumps and batteries, ensuring they can work together seamlessly across platforms and systems and that consumers can switch flexibility service provider without needing a home visit.

Large-scale EV V2X (‘electric vehicle to everything’) demonstrators to resolve deployment challenges – including cost, interoperability, and integration of EV battery storage with energy networks – and to test the role of electric vehicles in providing system flexibility.

3.1.2 Energy storage (Long Duration Energy Storage)

Challenge: Storing low carbon energy for when it is needed: How can we deliver large-scale, long-duration energy storage – including but not limited to multi-week timescales – through newer or innovative technologies?

Departments: DESNZ, DSIT

As the share of variable renewable generation increases, the UK power system will need long-duration flexible capacity to maintain reliability during periods of low renewable output and reduce reliance on unabated gas backup. Long Duration Energy Storage (LDES) is therefore essential to providing clean power by 2030 and sustaining it as electricity demand grows.

Several technologies already exist and can be deployed commercially where supportive market arrangements are in place, including lithium-ion battery systems and pumped storage hydropower facilities. However, future power systems will require a broader suite of cost-

[29] DESNZ (2025), Clean flexibility roadmap

effective, long-duration storage solutions capable of discharging continuously over various timescales – such as 8 hours, 24 hours, and multi-week durations – tailored to different locational, system, and market needs, and with appropriate energy density.

Policy support is available through Ofgem's Cap and Floor scheme which provides valuable support for mature or near-mature LDES technologies. However, it is not intended to replace early-stage R&D, which remains essential for the continued expansion of the sector and key to developing and testing a diverse range of options and approaches.

R&D should focus on reducing cost and improving the performance of LDES systems, including those capable of discharging continuously at full power for extended periods, and those offering location flexibility, high round-trip efficiency, relatively short build times, and minimal safety and environmental risks.

Hydrogen is a promising energy vector for long-duration energy storage, dispatchable power generation, and industrial decarbonisation. With regards to hydrogen, within this challenge, the focus is on **hydrogen production and storage** – the upstream enablers of long-duration energy buffering.

Hydrogen storage, particularly for multi-week applications, offers significant potential. R&D is needed to ensure the structural integrity and reliability of both geological and above-ground storage infrastructure capable of fast cycling, rapid response and high flow-rate to meet variable power demand.

This must be complemented by R&D to reduce the costs of **hydrogen production** through the development of negative emissions pathways, more efficient disruptive technologies, and integration of large-scale electrolysis with intermittent renewables.

3.1.3 Supply-side flexibility

Challenge: Low carbon sources of capacity that can provide electricity at short notice: How can innovative technologies help deliver the low carbon dispatchable 'power capacity' needed by 2030?

Departments: DESNZ, DSIT

As the UK transitions to a power system dominated by variable renewables, it will require low-carbon sources of dispatchable capacity that can be rapidly deployed and sustained over extended periods. These technologies must replicate the role currently played by unabated gas, ensuring system resilience during periods of low wind or solar output. It's estimated that 40–50 GW of such dispatchable and long-duration capacity will be needed by 2030.[30]

[30] DESNZ (2024), Clean Power 2030 Action Plan

Key technology pathways include:

- **Carbon capture for power generation**: R&D should focus on improving capture rates, reducing energy intensity, and integrating carbon capture into flexible generation assets. Although point source carbon capture is covered under the Putting the Net in Net Zero challenge, its inclusion here highlights its specific role in enabling low-carbon dispatchable power, rather than broader sector-wide decarbonisation.
- **Hydrogen-to-power (H2P):** R&D to enable cost reductions for scalable H2P technologies capable of delivering long-duration flexibility at competitive cost to unabated gas. While hydrogen production and storage are addressed under the 'Energy Storage challenge', its inclusion here focuses on hydrogen conversion technologies and supporting infrastructure to deliver long duration dispatchable electricity from stored hydrogen on demand.
- **Long-duration electricity storage (LDES):** An important enabler of low-carbon grid flexibility, R&D needs for LDES are covered under the dedicated 'Energy Storage' challenge above.

While some of these technologies are already being developed, further innovation is needed to improve performance, reduce costs, and accelerate deployment. This includes exploring new approaches and scaling up promising solutions to ensure the system remains secure, resilient, and low carbon – even during prolonged periods of low renewable generation.

3.1.4 Offshore wind

Challenge: How can R&D further develop the UK's world-leading capabilities in offshore wind?

Departments: DESNZ, DSIT, MoD, DBT

The UK is a global leader in offshore wind, with a mature fixed-bottom sector and emerging strengths in floating offshore wind (FLOW), including the world's largest pipeline of FLOW projects based on confirmed seabed exclusivity.[31]

Early R&D action is critical to ensure the UK is ready to scale FLOW rapidly, securing industrial benefits and meeting longer-term decarbonisation objectives – particularly as seabed availability becomes increasingly constrained.

As a frontier industry within the Industrial Strategy's Clean Energy Sector plan, FLOW represents a transformative opportunity for UK energy security, industrial growth, and global leadership in clean energy. The offshore wind sector is projected to deliver over 100,000 direct manufacturing jobs and £25 billion in gross value added (GVA) by 2035 – contingent on the UK

[31] DESNZ (2024), Clean Power 2030 Action Plan

developing a market-making, multi-generational wind manufacturing ecosystem capable of supporting both fixed and floating offshore wind technologies.[32]

Building on this competitive advantage offers an opportunity to increase energy security, lower system costs, and unlock wider economic benefits, such as positioning the UK for export opportunities in global clean energy markets.

Despite strong policy support, the pace of innovation has been constrained by limited market coordination and integration of novel components. R&D is needed to unlock the full potential of offshore wind, both by improving existing technologies and enabling large-scale deployment of next-generation floating systems.

R&D priorities include:

- **Reducing the levelised cost of energy** for floating offshore wind by advancing design and modelling techniques to integrate novel components into existing technologies and designs, and development of autonomous operations and maintenance systems.
- **Strengthening UK manufacturing capabilities** for floating offshore wind by addressing key innovation challenges in high-voltage dynamic cable production, mooring and anchoring systems, and foundation design.
- **Accelerating industrialisation of advanced turbine manufacturing** in the UK, including innovations in blade design, materials, and modular construction techniques to support both fixed and floating offshore wind deployment.
- **Developing radar mitigation solutions** to address interference caused by offshore wind farms.

3.2 Accelerating to Net Zero

The transition to a low-carbon economy requires urgent action to decarbonise all sectors to meet our carbon budgets and ensure the sustainability of our energy systems. Clean Power 2030 provides a foundation, but we must go further to meet our net zero ambitions by 2050 particularly in sectors that are harder to decarbonise. The priority research areas below focus on cross-cutting net zero challenges and hard-to-decarbonise sectors: transport, agriculture and industry.

3.2.1 Transitioning to a circular economy and electrification

Challenge: How can R&D help reduce emissions and waste through transitioning to a circular economy and enabling electrification of key sectors: industry, buildings and transport?

[32] RenewableUK, Offshore Wind Industry Council, The Crown Estate, and Crown Estate Scotland (2024), Offshore wind Industrial Growth Plan

Departments: DESNZ, Defra, DBT, DfT

Transitioning to a circular economy and electrification are complementary strategies that underpin a resilient and sustainable economy. Accelerating their adoption will reduce emissions across key sectors and supply chains, secure access to resources, and maintain the UK's productivity and industrial competitiveness.

3.2.1.1 Circular economy

Transitioning away from inefficient, high-carbon production methods is essential for achieving net zero. By reducing waste and shifting to a circular economy, we can achieve significant carbon savings across the economy. This requires moving away from the traditional 'take, make, dispose' model towards systems that eliminate waste and maximise resource efficiency. By designing products and processes for durability, reuse and recycling, the circular economy closes material loops, reduces environmental impacts, and supports economic growth.

The UK is well positioned to lead in resource efficiency and materials innovation, but adoption is constrained by barriers such as commercialisation challenges, supply chain inertia, and business model adaptation.

R&D should generate practical strategies and advance knowledge to accelerate the shift from a linear to a circular economy. This includes scalable solutions for resource efficiency, waste reduction, and sustainable value creation across key sectors: construction (including concrete, steel, glass, ceramics), automotive, chemicals, plastics, and critical minerals.

3.2.1.2 Electrification

Electrification will also play a vital role in achieving net zero goals by replacing fossil fuel-based systems with low carbon solutions in key sectors such as transport, industry, and buildings. Shifting to electric technologies enables the use of clean power, lowers emissions, and improves efficiency. Electrification also enables participation in consumer-led flexibility, allowing industry and consumers to benefit from periods of low-cost electricity (see '3.1.1 Flexible demand').

Key areas where R&D is needed to support electrification across industry, buildings, and transport include:

- **Industrial processes**: R&D to enable electrification of industrial operations, especially those requiring high-temperature heat. Research is needed to develop cost-effective solutions that are comparable to fossil fuel systems in production rate and quality, minimise site modifications and downtime, and ensure seamless grid integration.
- **Heat pumps**: R&D to reduce both capital and operational costs and to enhance heat pump efficiency, to ensure their competitiveness with fossil fuel systems. Research is also needed to optimise performance and integration with technologies such as photovoltaic systems and batteries (see also '3.2.5 Society as a catalyst').

- **Heavy Goods Vehicles (HGVs):** R&D to demonstrate the performance of zero emission HGVs under real life conditions and to understand their charging and fuelling requirements.

The shift to greater electrification and hydrogen production will place new demands on the energy system, especially for grid expansion and peak capacity. Addressing these challenges will require targeted R&D in grid infrastructure, flexibility, and system efficiency (see Section 2.1.1 for detailed research needs).

3.2.2 Putting the 'Net' in Net Zero

Challenge: How can R&D accelerate the transition to net zero by supporting delivery of negative GHG emissions and preventing their release, including developing and deploying engineered and nature-based solutions, while minimising environmental and societal impacts?

Departments: DESNZ, Defra (for nature-based GGRs)

Achieving net zero will require both the removal of greenhouse gases and the mitigation of residual emissions from sectors where full decarbonisation is challenging. Many decarbonisation strategies depend on next generation point source carbon capture, which is essential for large-scale industrial decarbonisation and low-carbon power. Without major growth and development in point source and wider CCUS, meeting carbon budgets is unlikely.

Greenhouse gas removal (GGR) is equally critical, particularly for offsetting residual emissions from hard-to-abate sectors such as agriculture and aviation. These sectors face unique challenges that make full decarbonisation by 2050 difficult without affecting productivity or growth. A mix of engineered solutions – such as Direct Air Carbon Capture and Storage (DACCS) and Bioenergy with Carbon Capture and Storage (BECCS) – alongside nature-based approaches like afforestation and soil carbon sequestration, will be necessary to remove and prevent the release of carbon dioxide at the pace and scale required.

The UK is a leader in CCUS and GGR technologies, with strong research capability, geological storage potential, and supportive policy frameworks. As global activity accelerates, there are substantial opportunities for growth. While some CCUS technologies are approaching commercial deployment, continued innovation is needed across both CCUS and engineered GGR technologies to lower operational costs, reduce energy demand, and improve capture efficiency and reliability, helping to enable widespread deployment. This must be complemented by efforts to enhance monitoring and verification methods, integrate carbon capture and storage into energy systems, understand and mitigate safety and environmental impacts, and evaluate the feasibility and long-term effectiveness of non-CCS greenhouse gas removal solutions.

Note: While carbon capture (for power production) is addressed under the 'Supply-side Flexibility' challenge, its inclusion here reflects its role in enabling net zero delivery by mitigating residual emissions across hard to abate sectors, particularly through advancing next generation point source carbon capture technologies for industrial applications.

3.2.3 Low carbon fuels

Challenge: Can low carbon fuels be developed (including hydrogen, synthetic fuels, and biomass-derived fuels), that can be scaled and used across multiple sectors, such as power generation, marine transport, aviation and hard-to-decarbonise industrial sectors, while minimising environmental impacts?

Departments: DESNZ, DfT, DBT, Defra

Developing solutions to deliver low carbon fuels is essential for supporting decarbonisation of multiple key sectors, especially power, transport and industrial sectors. Fuels such as hydrogen (see '3.1.2 Energy storage'), alongside synthetic fuels and biomass-derived fuels, offer promising low carbon alternatives to traditional fossil fuels. However, the development and deployment of low carbon fuels must be carefully managed to ensure that they do not compromise food security, health or productivity within the UK.

Research and development in this area must focus on creating efficient, scalable, and economically viable fuel options that can integrate seamlessly into existing infrastructures and enable other decarbonising technologies such as Hydrogen to Power (see '3.1.3 Supply-side flexibility'). A comprehensive approach that includes advancements in fuel production technologies, distribution systems, and end-use applications is necessary to achieve these goals and support a nationwide decarbonisation effort.

Note: R&D needs for hydrogen production and storage are addressed under the 'Energy Storage' challenge, while hydrogen for power generation (H2P) falls under the 'Supply-side Flexibility' challenge. This reflects hydrogen's important role in supporting the Clean Power by 2030 goals. However, further R&D is still needed to develop hydrogen as a low carbon fuel beyond 2030, particularly in terms of scalability, performance, and cost-effectiveness. These aspects remain within the scope of this challenge.

3.2.4 Food system

Challenge: How will climate change impact the food system, and how can decarbonisation efforts be directed to address these impacts? Additionally, how can the environmental impact of the food system be quantified to guide mitigation and adaptation efforts and empower producers, businesses, and consumers to decarbonise?

Departments: Defra

The food system is a major driver of environmental degradation and a significant source of GHG emissions, making it highly relevant to the CESM. Activities such as deforestation for agriculture, excessive fertiliser use, and inefficient distribution networks contribute substantially to emissions and ecological harm. At the same time, climate change poses growing risks to food systems – including altered precipitation patterns, more frequent extreme weather events, and shifting temperature regimes – which threaten crop yields, livestock productivity, and food security.

Research should focus on developing comprehensive strategies to mitigate the environmental impact of food systems while ensuring their sustainability and resilience. Key areas of investigation include sustainable agricultural practices, efficient resource utilisation, integrated value chains rooted in circular practices, and innovative technologies for reducing emissions throughout the food supply chain. By quantifying the environmental impact of the food system, researchers can guide mitigation and adaptation efforts and empower producers, businesses, and consumers to adopt more sustainable practices. Collaboration between policymakers, scientists, industry stakeholders, and the public will be essential to devise and implement solutions that support decarbonisation while maintaining food security and productivity.

3.2.5 Society as a catalyst

Challenge: How can social and behavioural science be leveraged to support the clean energy and net zero transition, including understanding the impact of policies on the public and organisations and exploring options to incentivise and drive sustainable choices?

Departments: DESNZ, DfT, DBT, DSIT, Defra, MHCLG, FCDO, DfE

The net zero transition will require an economy-wide transformation, in which people will play a central role. R&D in this area could develop our understanding of opportunities and barriers to uptake, including the potential role for incentives, optimising customer journeys, effective education strategies, government-led messaging, and other levers.

By leveraging social and behavioural science, we can better understand the impact of policies on the public and ensure that everyone who wants to access the benefits of the clean energy transition can. This includes identifying the most effective methods to promote and support widespread adoption of clean energy practices, alongside examining how different interventions and messages are understood and acted on amongst various demographics.

Behavioural research can support multiple CESM research areas, including:

- Helping identify effective interventions, advice and support that boost awareness, confidence, and encourage **adoption of low-carbon technologies**, such as heat pumps, EVs, energy-efficient products, flexibility services, and other low carbon solutions that reduce bills and save emissions, including by low-income and vulnerable consumers, and by exploring the most effective triggers and incentives, from financial incentives and innovative business models through to social norms.
- Supporting the development of **simplified, intuitive controls and innovative solutions** that help consumers understand how to run their **heat pump systems** effectively, as well as **informing customer journey improvements** to make installation

as simple and familiar as purchasing a conventional heating system, or in the uptake of green finance (see also '3.2.1 Transitioning to a circular economy and electrification).

- Supporting **adoption of more resource efficient products and encourage participation in the circular economy**, through behaviourally informed strategies to reduce material consumption, repair, reuse and recycle (see also '3.2.1 Transitioning to a circular economy and electrification).

Effective solutions must address user needs, build trust, and consider what drives consumers to shift behaviours and purchasing decisions, making low carbon choices straight forward and relevant to daily lives.

This publication is available from: www.gov.uk/desnz

If you need a version of this document in a more accessible format, please email alt.formats@energysecurity.gov.uk. Please tell us what format you need. It will help us if you say what assistive technology you use.