HM Government

UK Net Zero Research and Innovation Framework:

Delivery Plan 2022-2025

Any enquiries regarding this publication should be sent to us at:
NZIBSecretariat@beis.gov.uk

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Note: This Delivery Plan refers to net zero research and innovation (R&I) programmes led by the Department for Business and Trade (DBT); the Department for Energy Security and Net Zero (DESNZ); the Department for Environment, Food and Rural Affairs (Defra); the Department for Transport (DfT); the Department for Science, Innovation and Technology (DSIT) through its funding to UK Research and Innovation (UKRI); and HM Treasury (HMT). More details on all programmes covered in this Delivery Plan, including programme names and any acronyms used, can be found in the Annex section.

Delivery of the UK's net zero research and innovation ambitions

Delivery of the UK's net zero research and innovation ambitions

In October 2021, we published the UK's first Net Zero Research and Innovation Framework, which outlines what scientific and technological challenges need to be answered and over what timescales to reach net zero carbon emissions in the UK by 2050. Strategic, sustained, long-term investment in UK research, innovation, skills and infrastructure will ensure we have the people and solutions we need now, and those we will need in the future, to secure a prosperous and efficient transition to net zero.

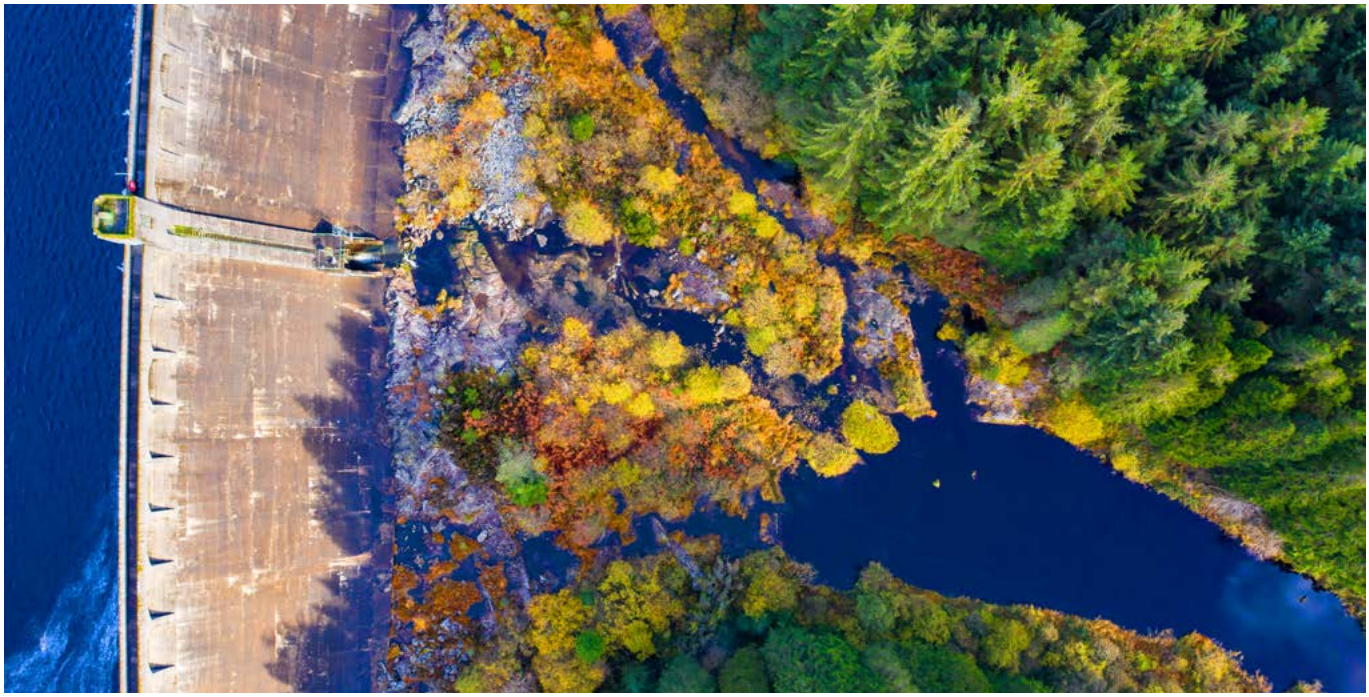
Globally, major initiatives are underway to develop and deploy technology-based solutions to climate change. Delivery of many of these solutions requires government support which will in turn catalyse commitments from the private sector. Future economic growth is likely to be based on low carbon technologies which will, in time, become the lowest cost solution for industry, as well as offering consumers new functionality, for example electric vehicles that can increase the flexibility of our electricity grid and also help to power our homes.

This will need to benefit people across all of the UK and support workers as industries transform. The costs as well as the benefits need to be shared fairly, protecting consumers, workers and businesses. Our net zero target remains a government priority and done right, the net zero transition will provide huge opportunities for jobs, investment and exports, whilst putting consumers at the heart of the transition. In recognition of this, in September 2022, the government commissioned a review into its approach to net zero to better understand the impact of the different pathways to net zero on the UK public and the economy and to maximise economic opportunities from the transition.[1] The Report from this review has now been published.

The UK is well placed to be highly competitive in the future global green economy. Research and innovation is an important part of this. It is essential for securing the UK's strategic advantage in the rapidly growing green economy and it will enable us to lead on and influence the development of the next generation of technologies and solutions needed to deliver net zero globally. The global market opportunity for UK companies from net zero could reach a cumulative £1 trillion to 2030 and the UK's climate technology sector has received over £6.5bn venture capital funding over the last 8 years. Investor interest in clean tech is growing rapidly with $60 billion of venture capital (VC) deployed globally in the first half of 2021 – 14% of all VC funding. Going forward, we want to continue to attract an increasing amount of global investment into the UK.[2]

We will need to gain acceptance for and deploy at scale those technologies that are ready, accelerate the development of those that are not, and begin research into

[1] https://www.gov.uk/government/publications/review-of-net-zero
[2] PwC (2022). PwC Net Zero Future50 report 2022



challenges that do not yet have clear solutions. Government funded research and innovation, appropriate policy and regulatory support, private sector innovation, investor funding and academic research all have key roles to play. Greater clarity on the government's plans and needs will help unlock private sector R&I investment.

This Delivery Plan outlines the Government's current portfolio of research and innovation (R&I) programmes for the Spending Review (SR) period 2022-25, based on the challenges outlined in the Net Zero Research and Innovation Framework.

In total, government expects to invest approximately £4.2 billion in net zero R&I over the period from 2022-25. This includes £1.5 billion specifically allocated to net zero innovation and announced in the Net Zero Strategy, as well as net zero research and innovation delivered through other departmental programmes and through UKRI. Further funding from Ofgem's £450 million Strategic Innovation Fund (£263 million during this SR period) is being invested in innovation relating to the energy networks. This investment reflects the scale of the research and innovation challenges to be tackled.

Government support will concentrate on areas of urgency, or which are difficult for the market to address on its own. It will build on existing UK capability and target areas where strategic leadership is needed to ensure wider societal, economic and environmental benefits. This research and innovation activity will help to facilitate the selection of the most economically efficient pathway to net zero. An increasing focus on applied research and demonstration will support UK businesses to invest, at scale, in solutions which will need widespread deployment.

Achieving net zero in the UK will not keep global temperatures below 1.5˚C if emissions continue to grow globally, and action at home and a joined-up offer abroad are both critical to UK leadership on net zero internationally. The UK will work with partners to bring down the costs of clean technology and support

global climate commitments, delivering on the Glasgow Breakthroughs[3]. This will include multilateral engagement through Mission Innovation, bilateral partnerships, as well as our supporting innovation enabling the energy transition in developing and emerging economies, through the £1bn Ayrton Fund Official Development Assistance (ODA) commitment.

The UK's Ayrton Fund[4] is organised around a series of Ayrton Challenge priorities targeting technology needs in developing countries which are critical but off-track for delivery of Sustainable Development Goals (SDGs), such as the Energy SDG7 and Climate SDG13, and where the UK is particularly well-placed to support. We expect synergies with domestic net zero priorities in terms of knowledge exchange, cost-reductions and accelerated global delivery including in energy storage, hydrogen, smart energy systems, industrial decarbonisation and sustainable cooling.

There is a need for strong coordination in policy and technology development and clear signalling to markets. By taking a systems approach to decision making and spending prioritisation, government aims to navigate this complexity. In practice this means research to help create a shared understanding of interdependencies and risks across different parts of the net zero challenge. This includes considering resilience to changes in climate alongside technology development and the potential role of nature-based solutions. The Net Zero Research and Innovation Framework and this Delivery Plan are intended to help promote transparency across the complex landscape of net zero R&I challenges and the funding opportunities and support available to help researchers tackle them. Progress against the Plan should be monitored by the Net Zero Innovation Board, which will then advise on the relative spend across the areas. Separately it will be necessary to develop a research and innovation roadmap for adaptation to climate change.

Prioritisation of public research and innovation

A key role of government is to catalyse and accelerate private sector investment so that UK companies can benefit from the growing clean tech market. It should aim to deliver a pipeline of investable propositions which increase investor confidence, crowd-in private sector investment, and support a cost-effective net zero transition.

Public R&I programmes focussed on net zero can also have wider benefits for the economy and society, including improving infrastructure such as the UK's buildings stock, and the potential for creating high quality jobs and delivering economic growth across all regions of the UK. By 2030, net zero innovation has the potential to unlock 300,000 jobs in exports and domestic industry through new commercial opportunities across low carbon sectors[5].

We have therefore prioritised government investment based on:

- Maximising UK strategic advantage and developing UK energy security – focussing on the highest potential for UK business opportunities and jobs to enhance economic competitiveness and for securing UK energy supply.

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[3] COP 26 World Leaders Summit - Statement on the Breakthrough Agenda
[4] https://www.gov.uk/guidance/ayrton-fund
[5] Net Zero Strategy, Build Back Greener, October 2021

- Expected contribution to delivering the UK's carbon budgets and major decarbonisation – accelerating the manufacturing and scaling of the solutions that will remove or reduce greenhouse gas emissions, including by considering the current state of technologies and the potential for R&I to make rapid progress.
- Retaining optionality of different net zero pathways – investing in a portfolio of solutions, and tolerating some failure, including novel technologies such as greenhouse gas removals, whilst reviewing and adapting to new knowledge and understanding as it develops.

International co-operation and collaboration will also help to boost the UK's ability to meet its net zero target and support business. Countries have capabilities in different areas of the energy system and technology development. Decisions on which areas of research and innovation to prioritise have considered whether the UK is best placed to lead, collaborate or access certain technologies and solutions. We will also pursue harmonisation of standards and regulations which can help to create a larger market for UK produced net zero related goods and services and speed the global transition.

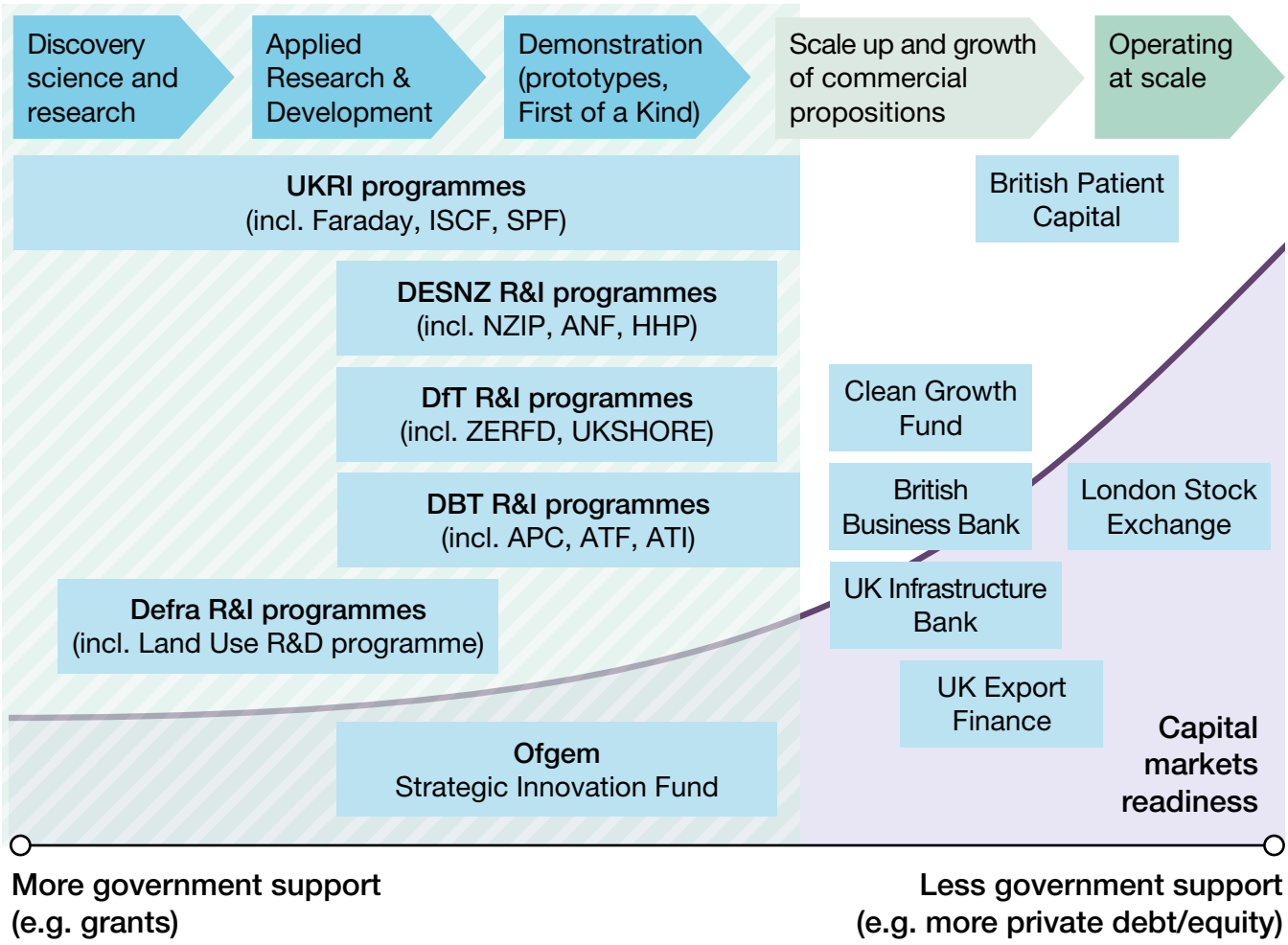
Rationale for intervention

Publicly funded R&I will be needed where market failures or barriers are holding back private sector investment and to create and shape markets which may not otherwise form fast enough to meet net zero targets. High capital costs, long asset life cycles and regulatory barriers associated with the energy sector create significant barriers to innovation and new entrants. Without backing from Government, these combine to lead to under-investment by the private sector in net zero innovation, potentially holding back future economic growth.

Public R&I investment is an important mechanism to reduce or remove these barriers and to help to de-risk private sector investment. Government can go first by investing in earlier stage technologies, as well as leveraging-in private sector finance by co-funding technologies to accelerate their commercialisation. Clear procurement signals can help. These measures can incentivise industry to pursue emerging technologies with greater certainty and act as a signal to industry about future regulatory landscapes and potential further support.

This Delivery Plan focusses on the start-up phase and the development work needed for scale up of innovative technologies where more government support is needed (see Figure 1). This includes fundamental science and research coming out of UK universities and research institutes, as well as applied research, development and demonstration funded through Departmental R&I programmes, UKRI and Ofgem. Wider public and private finance offers, beyond the scope of this Plan, are available for businesses to expand and start to deploy at commercial scale. Private sector confidence to invest will be essential to reach the scale of technological deployment needed to achieve the UK's 2050 net zero target.

Figure 1 - Research and Innovation support covered by this Delivery Plan



Indicates the support covered by this Delivery Plan. See annex for more details on these programmes.

In addition, government continues to invest, through UKRI, in a broad range of centres, institutes and campuses that contribute to the net zero R&I landscape. These work as hubs for business collaboration and can establish a critical mass around UK key capabilities. For example, through UKRI's Catapult Network. This includes the:

- Offshore Renewable Energy Catapult which has the mission to improve existing and develop next generation renewable energy technology in the UK;
- Energy Systems Catapult which supports innovators to commercialise and deliver energy systems innovations;
- High Value Manufacturing and Connected Places catapults which will be critical in delivering the low carbon transition in industry and transport.

UKRI also supports an extensive portfolio of world-leading digital and physical infrastructures. These enable researchers and innovators to collaborate to solve the most pressing net zero challenges and to develop the next generation of research and innovation leaders. The UKRI Energy Programme has supported energy researchers at all career stages with a particular focus on postdoctoral and early career fellowships and broader postgraduate training investments.

Support includes Doctoral Training Partnerships, Industrial Case Studentships, and cohort-based PhD training through Centres for Doctoral Training.

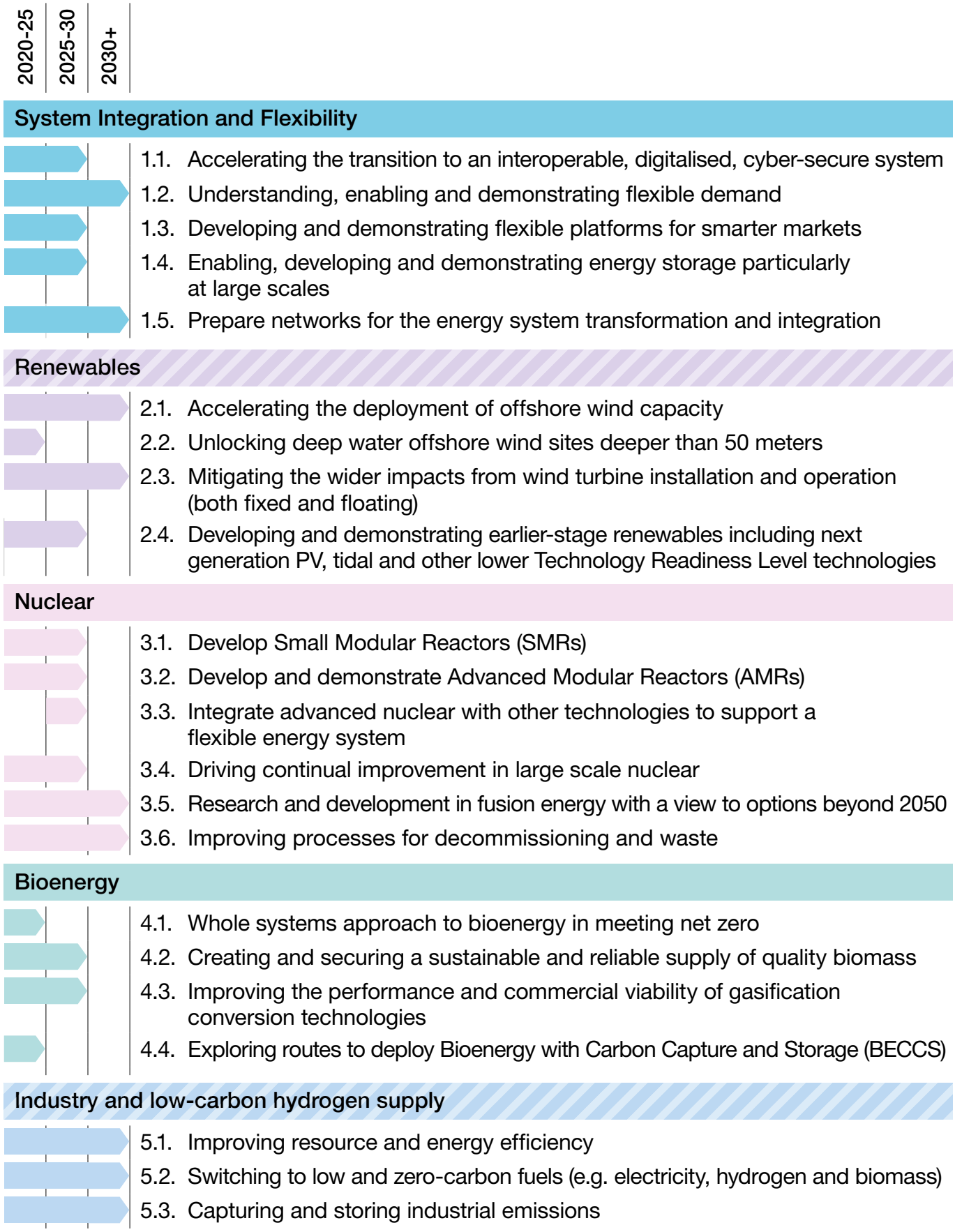
Measuring future progress

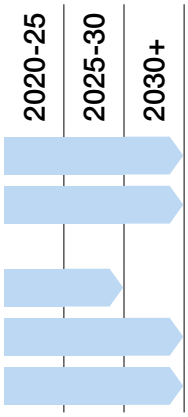
Monitoring and measuring progress against the research and innovation needed to meet net zero is vital. This will inform strategic discussions of the Government's Net Zero Innovation Board, the main government forum advising on net zero research and innovation, to allow policymaking to respond to new information and help guide the direction of the net zero R&I portfolio including the progress made in unlocking private sector investment. The Board advised on the priorities for the current spending review period and will play a key role, in the future, assessing progress against this Delivery Plan and the wider Framework. It will be important to work back from 2050 and identify the clear points by which decisions on technologies will have to be made in order to achieve the necessary scale by 2050.

Assessment of progress will primarily be based on reporting to the Board by departments and public sector spending bodies, on the programmes and initiatives covered by this Delivery Plan and a technology roadmap to 2050. This will be informed by project management information gathered by each department, such as key performance indicators and milestones agreed at programme inception. This will help to ensure that individual programmes have effective governance over delivery, and it will enable the Board to consider and develop recommendations for future prioritisation and spending across the portfolio.

The Delivery Plan is a baseline from which to measure the progress and success of the government's net zero R&I portfolio over the next few years and to help with future prioritisation and spending decisions, including those that can unlock private sector investment. It is intended that an update will be published by the end of the Spending Review period in 2025. This should be the start of a process of tracking the research and innovation needed to support delivery of our net zero target out to 2050. Subsequent plans, covering future Spending Review periods, will continue to improve reporting on the outcomes of programmes and will be based on the most up to date learning and achievements from the current portfolio. This will help develop the technologies and solutions needed to deliver the most cost-effective pathways to net zero.

Figure 2 - Key areas identified in the UK's Net Zero Research and Innovation Framework





5.4. Efficient, cost-effective production of low carbon hydrogen at scale
5.5. Demonstrating effective, low-cost methods of bulk hydrogen transportation and storage
5.6. Power generation
5.7. Effective use of hydrogen at the system level
5.8. Understanding how hydrogen will impact the environment and society

Carbon Capture, Utilisation and Storage (CCUS) & Greenhouse Gas Removal (GGR)

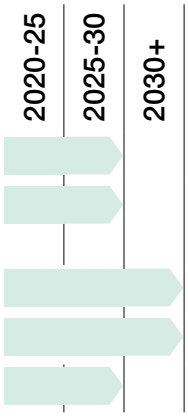
6.1. Capturing CO_2 from point sources, efficiently and at low-cost
6.2. Removing GHGs directly from the air or sea, efficiently and at low-cost
6.3. Reducing energy demand from engineered removal technologies
6.4. Exploring routes to deploy BECCS
6.5. CO_2 transport and storage infrastructure
6.6. Developing economic ways to utilise captured CO_2 in products or processes
6.7. Creating the conditions for future scale-up and deployment/commercialisation
6.8. Monitoring, Reporting, and Verification
6.9. Managing environmental impacts and co-benefits

Heat and Buildings

7.1. Develop an enabling environment for system-wide decarbonisation of building stock
7.2. Removing barriers to widespread energy efficiency retrofits in existing domestic and non-domestic buildings
7.3. Developing, demonstrating, reducing the costs of and de-risking low carbon heating and cooling technologies
7.4. Maximising the potential of heat networks
7.5. Integrating smart, low carbon technologies and solutions
7.6. Understanding end-user behaviour to drive uptake
7.7. Driving down emissions associated with construction

Transport

8.1. Enabling an integrated, multi-modal transport system
8.2. Accelerating the adoption of active travel and public / shared transport
8.3. Complementary approaches to roads decarbonisation
8.4. Addressing regional needs and place-based approaches
8.5. Supporting the development and deployment of zero emission vehicles



8.6. Decarbonising railways
8.7. Developing the UK capabilities to manufacture zero emission powertrain technologies.
8.8. Understanding and enabling hydrogen's role in transport
8.9. Developing net zero emission flight and associated operations
8.10. Decarbonising maritime

Natural resources, Waste and F-gases

9.1. Land use allocation & planning considerations
9.2. Understanding system level greenhouse gas emissions and environmental impacts
9.3. Effecting sustainable and responsible land use change and effects on economic growth / levelling-up agenda
9.4. Sustainably expanding and managing forests and the wider treescape
9.5. Developing increased resilience of forest ecosystems to climate change impacts
9.6. Restoring sustainably and managing peatlands
9.7. Managing soils for improved soil health and resilience
9.8. Sustainably managing the marine environment
9.9. Sustainable Agri-production of food, perennial energy crops and short rotation forestry
9.10. Sustainable consumption
9.11. Developing a sustainable bioeconomy
9.12. Reducing waste and minimising emissions
9.13. Reducing process emissions and energy use in the wastewater treatment sector
9.14. Minimising UK F-gas emissions
9.15. Enhancing the global coverage of atmospheric monitoring of Montreal Protocol controlled substances

A Whole Systems approach

10.1. Navigating pathways to achieving net zero
10.2. Managing socio-economic and behavioural impacts
10.3. Developing an enabling environment for net zero through new business models and finance
10.4. Taking a place-based approach
10.5. Mobilising digital solutions and data and the shift to Industry 4.0
10.6. Developing an integrated energy system

Note: for further details on each of the R&I Challenges and related activity, please see Annex.

Public sector research and innovation investment plan

Public sector research and innovation investment plan

This Delivery Plan outlines combined, UK based net zero related public sector and Ofgem R&I spending of around £4.5 billion for the current spending period (2022-25). The Plan is split into two main sections:

- The R&I investment plan provides a summary of some of the major research and innovation programmes for each net zero sector, their key deliverables and longer-term policy objectives. Together these account for ~85% of the portfolio's spend.
- The Annex offers a more detailed overview of government activity and covers the full portfolio. As well as these major programmes, this includes many smaller projects which are important for tackling the breadth of net zero research and innovation challenges.

Given the size of potential opportunities for UK business and the scale of delivering net zero, the Government is making R&I investments across a broad portfolio of sectors and will create a roadmap for developing and deploying technologies. This will ensure that the most economically efficient pathways to net zero remain open, whilst allowing the market to respond to new opportunities and challenges that arise from the transition to net zero.

Within the current plans, R&I programmes which support technologies with significant business opportunities and energy security benefits to the UK have been prioritised. These are also areas with significant decarbonisation needs. The Government's portfolio is therefore weighted towards Transport and Power, with significant investments in other areas, including Industry & Hydrogen, CCUS and Greenhouse Gas Removals (GGRs), and Heat and Buildings.

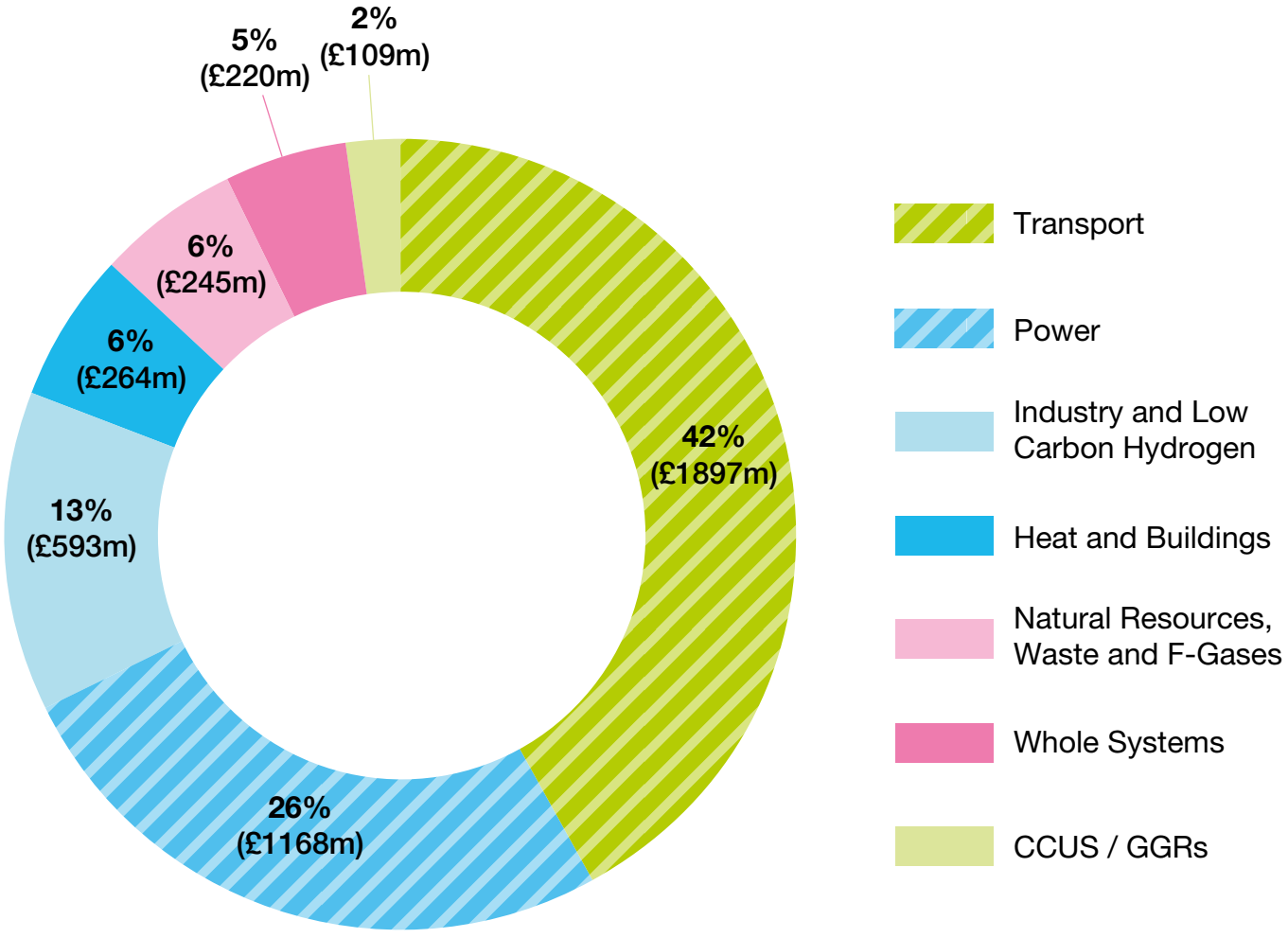
The transport sector currently has the highest carbon emissions in the UK. The Transport Decarbonisation Plan highlighted the huge industrial opportunity from the transition to using electricity, green hydrogen and sustainable low carbon fuels to invest in new jobs across the country. Key programmes will also focus on the strategically important and hard to decarbonise sectors of freight, maritime and aviation.

Significant progress has already been made in decarbonising Power with over half of the UK's electricity coming from low carbon sources.[6] As electrification of other sectors accelerates, continued investment will be required to ensure security of supply and meet ambitious targets for a fully decarbonised electricity system by 2035. Strategic priorities include supporting a UK advanced nuclear industry by demonstrating Advanced Modular and Small Modular reactors. Other major R&I programmes will tackle scaling-up the deployment of offshore wind, developing longer duration energy storage solutions, and preparing the networks for a high degree of variable renewables.

[6] Net Zero Strategy, Build Back Greener, October 2021

The portfolio also supports programmes in earlier stage technologies, such as Greenhouse Gas Removals, Hydrogen production, and harder to decarbonise sectors such as Industry. These require government intervention to help create new markets, or to overcome technological barriers preventing private sector investment. For Buildings, programmes focus on demonstrating the most effective and efficient ways to support large-scale deployment of low carbon heating and retrofitting solutions. Continued support for fundamental research through UKRI to facilitate crucial policy decisions, such as in agriculture and land-use are also important aspects of a balanced portfolio. This helps to ensure the continuing development of ideas across early-stage research, development and demonstration.

Figure 3 - Planned proportion of spending per sector as announced by 31 December 2022



Note: The proportions and spending included in the chart are intended as illustrative as some spending will relate to more than one sector, for example aspects of spend on buildings, power and transport can overlap in certain instances.

Power

The Power sector has led the UK's efforts to reduce greenhouse gas emissions and this rapid decarbonisation will need to accelerate for the UK to reach net zero by 2050. The ambition is to have decarbonised the UK electricity system by 2035. As variable and distributed technologies take up an increasing share of supply, the wider electricity system must undergo a parallel transformation with supporting policy changes and infrastructure improvements. To facilitate this transition:

- ~£182m has been allocated to systems integration and flexibility to demonstrate flexible demand and flexible market platforms, and to develop longer duration energy storage solutions by the end of this decade.
- ~£166m has been allocated to renewables, for example to accelerate the deployment of fixed offshore wind capacity and unlock the potential for floating offshore wind by 2030.

- ~£490m has been allocated for nuclear, this includes development of and working towards deploying Small Modular Reactors; development and demonstration of Advanced Modular Nuclear Reactors by the 2030s; and maintaining the UK's capabilities in decommissioning, clean-up and waste disposal, new build, alternative safer fuels, and continuing to strengthen international collaborations. This is in addition to longer-term fusion research.
- ~£66m has been allocated for bioenergy to improve production and pre-processing, to develop flexible gasification systems, and to explore routes to deploy BECCS by 2030. This aims to identify the most cost-effective and greenhouse gas optimal approaches for the use of biomass.
- Ofgem has allocated £450m (~£263m for this SR period) to its Strategic Innovation Fund, to prepare gas and electricity networks for the net zero transition. This will support innovative projects to help accelerate the transition at lowest cost to consumers.

Government intervention will help to reduce the high capital costs associated with nuclear projects and, by co-funding with industry, share the financial risk around developing the next generation of nuclear power. In renewables, where fixed offshore wind is commercially established and has substantial industry investment, government is acting to remove barriers to developing earlier-stage floating offshore wind. Government is also supporting the future energy system to ensure that critical technologies, such as longer duration energy storage and network infrastructure are available on appropriate timescales.

Opportunities for UK leadership, exports and/or supply chain participation for this sector, include: developing smart technologies and business models for flexible markets, building on UK strengths in Information Technology, Artificial Intelligence and financial settlement; continuing to develop the UK's large offshore wind market, with floating offshore wind being key to deploying in deeper waters; new nuclear; bioenergy for example through development of BECCS technologies; as well as opportunities for businesses to increase efficiencies of solar photovoltaics (PV) and integrate them with other products and services.

System Integration and flexibility

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
DESNZ Net Zero Innovation Portfolio (NZIP), Flexibility Innovation Programme, up to £65m. R&I Challenge: 1.1, 1.2, 1.3 & 7.5	Innovative solutions for electricity system flexibility, including: bidirectional electric vehicle charging; interoperable demand side response systems; data and digital; and other innovative market solutions.	Enable large-scale, widespread electricity system flexibility towards 2035 system decarbonisation.
UKRI Energy Demand Solutions Research Programme including Centre for Energy Demand Solutions, £13.5m. R&I Challenge: 1.1, 1.2, 1.3, 7.2 & 8.1	Research & identify optimal solutions for reducing energy demand at different scales, uses and geographies.	Reducing the amount of decarbonised electricity generation needing to be deployed by 2035.
DESNZ Net Zero Innovation Portfolio (NZIP), Longer Duration Energy Storage Demonstration, up to £68m. R&I Challenge: 1.4	First-of-a-kind full-system prototypes and demonstration of longer duration storage, including electric, thermal and power-to-x.	Develop energy storage technologies to facilitate a decarbonised electricity system with high degree of renewables by 2035.
Ofgem Strategic Innovation Fund, £263m (of total £450m allocation to 2025/26). R&I Challenge: 1.5	Demonstrate whole energy system integration including technologies for data and digitalisation, low carbon heat, and zero emission transport.	Prepare UK networks for a decarbonised electricity system by 2035.

Renewables

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
DESNZ Net Zero Innovation Portfolio (NZIP), Future of Offshore Wind Programme, ~£60m. R&I Challenge: 2.1 & 2.2	Develop lightweight composite components for turbines; floating offshore wind demonstration; supply chains; and mitigation of impact on radar.	Deploy up to 5GW of floating and total of 50GW offshore wind by 2030 towards the UK's 2035 decarbonisation ambition.
UKRI ORE Catapult, including Floating Offshore Wind (FOW) Centre of Excellence, £24m. R&I Challenge: 2.1 & 2.2	Reduce the cost of floating offshore wind farms; developing UK supply chain and innovation opportunities at all stages.	Unlocking offshore wind sites deeper than 50 meters to increase deployment options for offshore wind energy generation.

Nuclear

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
DESNZ Low-Cost Nuclear Challenge, part of the £385m Advanced Nuclear Fund (ANF). R&I Challenge: 3.1	Development of a standardised, Small Modular Reactor design.	Deployment of cost-competitive UK-designed Small Modular Reactors by the early 2030s.
DESNZ Advanced Modular Reactor Programme, part of the £385m Advanced Nuclear Fund (ANF). R&I Challenge: 3.2 & 3.3	Identify and deliver the optimal solution for High Temperature Gas Reactor technology (HTGR).	Demonstration of Advanced Modular Reactor (HTGR technology) and integration with other technologies by the early 2030s.
UKRI Nuclear Fission Research, £105m. R&I Challenge: 3.4 & 3.6	Maintaining capabilities in nuclear decommissioning and safe, cost-effective waste disposal; improvements in new build and alternative, safer fuels.	Continual improvement in large-scale-nuclear to support new deployment and UK areas of strength.

Bioenergy and Bioenergy with Carbon Capture and Storage (BECCS)

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
DESNZ Net Zero Innovation Portfolio (NZIP), Biomass Feedstocks Innovation Programme, £36m. R&I Challenge: 4.2 & 9.11	Development of innovations to improve yield, efficiency, cost reductions and profitability of biomass feedstocks.	Facilitate a substantial increase in the production of sustainable, domestic biomass to support decarbonisation across a range of sectors.
DESNZ Net Zero Innovation Portfolio (NZIP), Hydrogen BECCS Innovation Programme, £30m. R&I Challenge: 4.3, 4.4 & 6.4	Developing and demonstrating technologies producing hydrogen from biogenic feedstocks combined with carbon capture.	Exploring and identifying the most cost-effective and greenhouse gas optimal approaches for the use of biomass.

Industry and Low Carbon Hydrogen supply

By 2050, emissions from industry need to fall by at least 90% with all remaining emissions offset by GHG removals. The UK's Industrial Decarbonisation Strategy and Net Zero Strategy set out a framework for how government and industry can work together to achieve decarbonisation targets whilst also capitalising on clean growth opportunities. The next decade will be critical for laying the policy and infrastructure foundations for deep decarbonisation whilst ensuring a range of decarbonisation options are available to industry by 2030.

Spending of around £593m is expected across Industry & Hydrogen. This includes:

- Energy and resource efficiency improvements, particularly in industries such as chemicals, cement, steel and glass manufacture.
- Developing and demonstrating industrial process solutions powered by electrification, hydrogen and bioenergy to identify which are best for different industries.
- First of a kind demonstration plants for CCS across several industrial sources.
- Also, work towards longer-term development and demonstration of other low carbon fuels such as process heat from advanced nuclear reactors and the establishment of net zero industrial clusters.

And for hydrogen, working towards:

- Demonstrating efficient CCUS-enabled hydrogen and developing large-scale production capacity in industrial clusters, along with related supply chain development.
- Greater use of zero and negative emission hydrogen production at scale. This will include developing and demonstrating hydrogen production via electrolysis at a range of sites, developing production technologies using BECCS and nuclear energy, and demonstrating low-cost methods of bulk hydrogen storage and transportation, including international transportation, by the 2030s.

Given the range of options for industrial decarbonisation including electrification, hydrogen and bioenergy, government support is helping to identify which solutions are optimal for different industries and to ensure these are ready for industry to roll-out at scale in the 2030s. This is critical to ensure industries can transition without hindering their global competitiveness. For the development of the nascent low-carbon hydrogen sector, government has a key role in reducing high upfront costs of testing new production technologies and infrastructure, delivering key enabling infrastructure such as storage and transportation, and developing the market structures to deliver a UK hydrogen economy.

We see opportunities for UK leadership, exports and/or supply chain participation in: providing circular economy solutions; data analytics and process optimisation using AI and virtual reality; new opportunities to develop knowledge and technologies across the range of UK industry sectors (cement, metals, glass, paper, ceramics, chemicals, plastics and packaging); fuel switching; and opportunities in emerging industries, including low carbon hydrogen and CCUS.

Transitioning to a net zero industrial base

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
UKRI Strategic Priorities Fund National Interdisciplinary Circular Economy Research (NICER) Programme, £22m. R&I Challenge: 5,1, 7.7, 9.10, 9.12, 10.3 & 10.5	Changing the way resources are used, valued, and measured across the UK.	Realise opportunities for businesses and consumers from transitioning to a more circular economy.
UKRI's Industrial Strategy Challenge Fund (ISCF) Made Smarter Innovation Challenge, £92.2m. R&I Challenge: 5.1	Development and integration of new and existing industrial digital technologies, including AI and virtual reality.	Facilitating resource and energy efficiency in industry via support to scale digital technology solutions.
UKRI's Industrial Strategy Challenge Fund (ISCF) Transforming Foundation Industries, £40.6m. R&I Challenge: 5.1	Growing the UK foundation industries (cement, metals, glass, paper, ceramics, chemicals) sector by 2024 in an environmentally sustainable way.	Improving the environmental sustainability of major industrial sectors
UKRI's Industrial Strategy Challenge Fund (ISCF) Smart Sustainable Plastic Packaging Challenge, £42.4m. R&I Challenge: 5.1, 9.10 & 9.12	Develop sustainable plastic packaging materials and designs and enable new recycling processes and infrastructure to be developed at scale.	Establish the UK as a leading innovator in smart and sustainable packaging with a dramatic reduction in plastic waste by 2025.
DESNZ Net Zero Innovation Portfolio (NZIP) Industrial Fuel Switching Programme, £55m. R&I Challenge: 5.2	Develop and demonstrate solutions to switch industry from high carbon to low and zero carbon fuels.	Support increasing amounts of fuel switching to low carbon fuels during the 2020s.

DESNZ Net Zero Innovation Portfolio (NZIP) Industrial Hydrogen Accelerator Programme, £26m. R&I Challenge: 5.2	Demonstrations covering the full technology chain, exploring the potential to produce and use low carbon hydrogen for industrial processes.	Enable switching to low and zero-carbon fuels, in this case hydrogen
DESNZ Net Zero Innovation Portfolio (NZIP) Red Diesel Replacement Programme, £40m. R&I Challenge: 5.2	Develop and demonstrate Red Diesel replacement technologies on construction, mining & quarrying sites.	Accelerating the commercialisation of low carbon alternatives to red diesel and creating spin-off opportunities for other sectors.
UKRI's Industrial Strategy Challenge Fund (ISCF) Industrial Decarbonisation Challenge, £126m. R&I Challenge: 5.2, 5.3, 6.5 & 6.6	Development of low-carbon technologies through investment in deployment projects, clusters and the Industrial Decarbonisation Research and Innovation Centre (IDRIC).	Increasing the competitiveness of industry and reducing the carbon footprint of heavy and energy intensive industries.

Scaling up the supply and demand for low carbon hydrogen

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
UKRI Hydrogen and Alternative Liquid Fuels Research Programme, £7m. R&I Challenge: 5.2 & 5.7	Launch of two Hydrogen Hubs covering technology challenges and integrating hydrogen and alternative liquid fuels into the wider energy system.	Tackling cross-sector challenges relating to hydrogen and hydrogen-based low carbon liquid fuels.
DESNZ Net Zero Innovation Portfolio (NZIP) Low Carbon Hydrogen Supply 2 Programme, £60m. R&I Challenge: 5.4 & 5.5	Develop and demonstrate hydrogen production, storage and transport solutions to supply a UK hydrogen economy.	Support up to 10GW of hydrogen production by 2030, with at least half from electrolytic hydrogen.

Carbon Capture, Utilisation and Storage (CCUS) & Greenhouse Gas Removal (GGR)

CCUS technologies are likely to have applications across many parts of the economy as the UK transitions to net zero. Next-generation CCUS technology aims to have better performance, lower environmental impact and be more widely applicable than current technology. GGR solutions typically fall into two broad categories: engineering and nature based. It's likely a combination of several approaches will be necessary to achieve the level of removals required for net zero.

Around £109m is allocated for research and innovation in this area. Throughout the 2020s this will demonstrate how the technology can be deployed at scale; deliver performance and cost improvements; develop a clear understanding of life cycle emissions; and focus on the development of business models which provide incentives for investors and routes to scaling. In the 2030s, this will shift towards supporting large-scale deployment of CCUS, development of offshore storage and dispersed site technologies, and testing GGR approaches at scale.

Government has an important role to play in overcoming the financial barriers associated with high up-front capital costs of CCUS, as well as the technical challenges relating to capture performance at scale. This also includes support for innovation in the enabling infrastructure for CCUS, such as storage and transportation, as well as the appropriate market frameworks and pro-innovation regulation.

For greenhouse gas removals, the solutions are still at an early stage of development with a lack of strong incentives to develop them at scale. Government therefore has a key role in de-risking the testing and demonstration of these approaches, and in providing clear procurement signals and an appropriate regulatory framework.

Opportunities for UK leadership, exports and/or supply chain participation for this sector include, using UK expertise in offshore engineering and large reservoir space for CO_2 storage to develop the European CCS market, and developing a lead position in GGR technologies. Business opportunities also exist in using CO_2 in the manufacture of synthetic fuels and other chemicals and products.

Carbon Capture, Utilisation and Storage (CCUS) & Greenhouse Gas Removal (GGR)

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
DESNZ Net Zero Innovation Portfolio (NZIP) CCUS Innovation 2.0 Programme, £20m. R&I Challenge: 6.1	Develop novel CCUS technologies and support demonstration of next generation CCUS to reduce deployment costs.	Support the establishment of connections for four of the UK's major industrial clusters to decarbonisation infrastructure by 2030.
DESNZ Net Zero Innovation Portfolio (NZIP) Direct Air Capture and Greenhouse Gas Removals Innovation Programme, £60m. R&I Challenge: 6.2 & 6.3	Demonstration / pilot plants covering Direct Air Capture, bioenergy with carbon capture, seawater solutions and biochar.	Deliver one or more first-of-a-kind demonstrators to enable ambition for 5MtCO_2 of engineered removals annually by 2030.
UKRI Strategic Priorities Fund Greenhouse Gas Removals (GGR) Programme, £22m. R&I Challenge: 6.2, 6.3, 9.4 & 9.6	Support for a series of land-based GGR demonstration projects such as rock weathering, afforestation, perennial crops, peatland and biochar.	Understand the effectiveness, cost and limitations of large-scale land-based GGR methods needed to achieve the level of removals required for net zero.

Buildings and Heat

From 2025, the Future Homes Standard intends to ensure that all new-build homes will have low carbon heating and high levels of efficiency. However, a key challenge is to retrofit the significant proportion of homes and non-residential buildings that require remedial work to achieve high standards of energy efficiency and to use low carbon heating sources.

Around £264m is being allocated to research and innovation which:

- Reduces the costs of heat pumps and the disruption caused by installation and use, as well as driving uptake including via demonstrations at neighbourhood and / or district scale;
- Assesses the feasibility, cost and benefits of using hydrogen for heating. This includes community trials to inform strategic decisions on the role for hydrogen in heat decarbonisation in 2026;
- Supports the development of new supply chain business models and green finance products to enable widespread building retrofit for both domestic and non-domestic properties.

  In addition, other non-R&I support is being provided to improve the operational efficiency of heat networks, improving the evidence base for the performance of existing heat networks, and developing a methodology for identifying heat network zones (see Annex for further details).

Within the heat pump and retrofit sectors, many solutions are technically proven, so government innovation is focussed on supporting increased deployment. For example, through trialling large-scale deployments and encouraging the development of more innovative business and financing models for heating and retrofit installations. Government also has a key role in ensuring strategic decisions on heating, including the role of hydrogen in home heating, are evidence-led and the safety, effectiveness and wider system impacts of technologies are tested and understood.

Major business opportunities exist in the financing, delivery and supply chain associated with retrofitting millions of UK buildings and the potential for the UK to develop expertise in heat network engineering and hydrogen heating for buildings.

Buildings and Heat

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
UKRI's Industrial Strategy Challenge Fund (ISCF) Prospering from the Energy Revolution Challenge, £17m. R&I Challenge: 7.1 & 10.4	Work with local authorities to deliver integrated place-based approaches to deliver cleaner more affordable energy.	Develop smart local energy systems to provide investable, scalable local business models and finance mechanisms to enable greener, profitable investment decisions.
DESNZ Net Zero Innovation Portfolio (NZIP) Green Home Finance Accelerator Programme, £20m. R&I Challenge: 7.2	Develop and pilot novel green lending products, to support domestic energy efficiency and low-carbon heating retrofit amongst non-fuel poor households.	Expansion and diversification of the green lending market, improving access to capital, and reducing barriers to the widespread decarbonisation of the building stock for owner occupiers and private landlords.
DESNZ Net Zero Innovation Portfolio (NZIP) Heat Pump Ready Programme, £60m. R&I Challenge: 7.1, 7.3 & 7.6	Develop and trial technologies and tools to address barriers to heat pump uptake and increased deployment.	Enable heat pump deployment at significantly increased density and scale to support the target of 600k heat pumps installed each year by 2028.

Buildings and Heat

DESNZ Hydrogen Heating Programme (HHP), £100m. R&I Challenge: 7.3	Deliver a neighbourhood trial by 2024, and a village-scale trial by 2025, to assess the feasibility, costs and benefits of 100% hydrogen for heating.	Enable strategic decisions in 2026 on the role of hydrogen for decarbonising heat in buildings.
UKRI Building Information Modelling and National Digital Twins Programme, £20m. R&I Challenge: 7.7	Develop digital technologies for the design and operation of better and safer buildings and infrastructure.	Enable the improved operation of buildings, infrastructure networks and systems, to facilitate energy and resource efficiency.

Transport

The Transport Decarbonisation Plan sets out the "greenprint" for decarbonising the UK's transport system by 2050. Research, demonstration and innovation are needed to accelerate the deployment of technologies that are already close to market as well as to develop and test emerging solutions, particularly across maritime and aviation.

Around £1.9bn has been allocated across government for research and development on transport systems and technologies. Programmes cover a range of technologies and have been designed to consider:

- Technologies, including batteries, charging systems, hydrogen fuel cells and ammonia.
- Infrastructure, vehicle design (including tyre wear), safety and fuel distribution.
- Road vehicles, rail, aviation and maritime.
- Whole systems thinking, understanding the interaction between demand, supply, distribution and storage.

These programmes will inform the combination of approaches for reducing transport's environmental impact, including carbon pollutant emissions, accelerating deployment of zero emission solutions, delivering co-benefits, and removing barriers to implementation.

Government intervention is critical to better understanding transport and mobility as a system, delivering the solutions and evidence required to effectively deliver a cleaner, more efficient transport system. Key areas of intervention and opportunity include supporting the testing and demonstration of technologies in hard to decarbonise sectors where optimal technologies are still unclear, such as freight, maritime and aviation.

Business opportunities include the development of novel or early-stage technology improvements in battery technologies and the development and commercialisation of alternative fuels, which will have a range of applications across sectors, for example, transport and power. Later stage support, particularly in strategically important industries such as aviation and automotive, is important for building internationally competitive supply chains in the UK, and represent areas of UK strength and HGV future growth.

Transport and mobility as a system

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
DfT Live Labs 2 Programme, £30m. R&I Challenge: 8.4	Public-private-academic partnerships to trial innovations decarbonising local road construction, operation, maintenance and decommissioning.	Addressing regional needs and place-based approaches for transport decarbonisation.

Land transport

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
DfT Zero Emission Road Freight HGV Demonstrator (ZERFD) Programme, £200m. R&I Challenge: 8.5	Demonstrating zero emission (exhaust) HGVs and recharging / refuelling infrastructure, enabling multi-year data collection at-scale, in real world operations.	Accelerate the deployment of zero emission HGVs into UK fleets and the associated infrastructure in the UK.
UKRI's Industrial Strategy Challenge Fund (ISCF) Faraday Battery Challenge, £215.2m. R&I Challenge: 8.5	Development of electrochemical energy storage research, early-stage commercialisation, skills and market analysis.	Strengthening EV infrastructure which supports ending the sale of new petrol and diesel vehicles by 2030.
DBT Advanced Propulsion Centre (APC), £225m. R&I Challenge: 8.7	Research, development and commercialisation of the next generation of low carbon and zero emission vehicle technologies.	Accelerating the development and commercialisation of low carbon and zero emission vehicle technologies to maintain UK strengths in the automotive sector.

Land transport

DBT Automotive Transformation Fund (ATF), £75m. R&I Challenge: 8.7	Late-stage collaborative R&D, to accelerate the research, development and commercialisation of strategically important emerging vehicle technologies, strengthening the UK competitive edge internationally.	To ensure a UK led transition to zero emission vehicles, strengthening the UK's attractiveness as an investment location for R&D and advanced manufacturing.

Aviation and Maritime

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
DBT Aerospace Technology Institute (ATI) Programme, £685m. R&I Challenge: 8.9	Co-funding development of zero-carbon aircraft, technologies, ultra-efficient aircraft technologies, enabling technologies and infrastructure.	Supporting the development of zero-carbon and ultra-low-emission aircraft technology, whilst growing UK share of global aerospace manufacturing.
UKRI's Industrial Strategy Challenge Fund (ISCF) Future Flight Challenge, £87.9m. R&I Challenge: 8.9	Develop and demonstrate drones, Advanced Air Mobility and regional passenger aircraft, electrical / hydrogen infrastructure, regulation and standards.	Developing the future aviation ecosystem to allow the safe and effective operation of new forms of net zero aircraft.
DfT UK Shipping Office for Reducing Emissions (UK SHORE), £206m. R&I Challenge: 8.10	Develop and demonstrate pre-commercial clean maritime technologies and support accelerating the deployment of near-commercial solutions.	Supporting the UK maritime sector's transition to low and zero emission technologies.

Natural Resources, Waste and F-Gases

Achieving net zero will require the strategic and sustainable management of land, agriculture, waste and natural resources, with nature-based solutions playing a key role in enabling us to meet this commitment. This should be achieved at the same time as improving biodiversity, air quality, water quality, natural capital, ecosystem services and resilience to climate change.

Around £245m is being allocated to science and socio-economic research on:

- Sustainable farming, including new practices and technologies to reduce emissions such as precision farming, animal and crop breeding, feed additives, sustainable proteins, sustainable fertilisers and pesticides.
- Biomass supply, including forestry, energy crops, agriculture residue, waste, novel feedstocks, GHG lifecycle assessments and crop breeding (see also Bioenergy in the Power section).
- Developing tools to inform land-use decisions, to understand interplay between actors, policy and regulatory frameworks, incentives and technologies.
- Marine and coastal research, including carbon storage in coastal wetlands and shelf sediments, the acceleration of offshore wind in a way that protects and enhances the marine environment, and sustainable salt and fresh-water aquaculture systems.
- Longer-term research on sustainably expanding and managing forests, including improved technology and modelling for carbon storage; woodland types and silviculture; innovative finance models; social and behavioural drivers and barriers.
- Lowland peat management with farming; improved Greenhouse Gas assessment of peatland restoration; reducing methane emissions from landfill; optimal water management for emissions and flood risk.

Given the inherent complexity of this sector, government has a key role in ensuring our understanding and evidence base is sufficiently robust to make effective policy decisions. There are trade-offs and synergies between food production, forestry and biomass production, habitat and peatland restoration, biodiversity and urban expansion. Research will help to determine how best to achieve net zero whilst also delivering against wider government objectives.

Opportunities for UK leadership exist in the agri-tech sector, which serves a growing international market, as well as the biosciences and biotechnologies sector. Carbon professional services, such as selling expertise in low carbon farming practices, also has potential to be a growth area.

An integrated and dynamic approach to land use

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
Defra's Land Use R&D Programme, £6.6m. R&I Challenge: 9.1	Mapping biodiversity, environmental impact of land management actions and delivering a land-use research platform.	Maximising emissions reductions from the farming and land use sector, delivered by Defra's environmental land management schemes under the Future Farming and Countryside Programme.

Forests, peatland, and the marine environment

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
HM Treasury's Shared Outcomes Fund: Nature based solutions for climate change at the landscape scale, £12.5m. R&I Challenge: 9.2	Research into how carbon accumulates and is released from different habitats in different circumstances.	Identifying strategies that optimise both biodiversity and climate change at the landscape scale.
Defra's Nature for Climate Fund (NCF) (Trees) R&D Programme, £22m. R&I Challenge: 9.4	Research to support the delivery of the England Trees Action Plan (ETAP) including putting tree planting on a trajectory to meet net zero targets.	Supporting the tree planting target of 30,000 hectares each year by 2025 and developing a sustainable forest economy.
Defra's Peat and Soil R&D Programme, £14.1m. R&I Challenge: 9.6 & 9.7	Develop evidence on lowland peat re-wetting, responsible management, and Greenhouse Gas implications and soil health impacts of alternative farming models.	Developing a pathway for emissions abatement on lowland peat and the sustainable management of soil, supported by a soil health indicator.

Food and biomass

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
Defra's Agricultural Research Programme, £16.4m. R&I Challenge: 9.9	Research into improved crop and livestock genetics & the impacts of novel fertilisers, feeds and management practices.	Enable a more sustainable, productive, resilient and climate smart food system and boost UK food production. 85% of farmers in England engaged in low carbon practices by 2035.
UKRI Strategic Priorities Fund Transforming the UK food systems, £34m. R&I Challenge: 9.9	Research to fundamentally transform the UK food system by placing healthy people and a healthy natural environment at its centre.	Driving efficient, sustainable, resilient food production and contributing to global food security. 85% of farmers in England engaged in low carbon practices by 2035.
UKRI Industrial Strategy Challenge Fund (ISCF) Transforming Food Production Challenge, £28.6m. R&I Challenge: 9.9 & 9.10	Developing and supporting new ways of producing food, reducing emissions and reducing pollution.	Driving efficient, sustainable, resilient food production and contributing to global food security. 85% of farmers in England engaged in low carbon practices by 2035.
UKRI Towards Sustainable, Climate-Neutral Farming Systems (AgZero+), £12.8m. R&I Challenge: 9.9	Developing new UK farming systems to produce sufficient food, whilst reducing emissions and pollution, and protecting biodiversity and soil health.	Driving efficient, sustainable, resilient food production and contributing to global food security. 85% of farmers in England engaged in low carbon practices by 2035.

A Whole Systems approach

A systems approach involves integrating changes to energy supply, storage and use across different sectors of the economy. It focusses on interlinkages between energy vectors, such as understanding the role of transport in the wider energy system and the hydrogen economy, and encourages sustainable consumption across all sectors.

Around £220m has been allocated towards long term research and innovation to understand optimal net zero pathways, interdependencies and trade-offs across physical, natural, social and technological systems. This includes developing new types of business and financial models and a strong local and regional approach to delivering appropriate net zero solutions.

The characteristics of the net zero challenge – requiring action by multiple parties across the public and private sectors within short timeframes and the management of large uncertainties – underline the need for strong government coordination. Government will be the key funder of research which takes a systems approach to policy to navigate this complexity and to provide an important public good to stimulate investment across the whole energy system.

A Whole System approach

Key R&I Programmes 2022-25	Key R&I deliverable(s) 2022-25	Longer term policy objective
UKRI's Changing the Environment Programme, £24m. R&I Challenge: 10.1	Collaborations across energy decarbonisation, circular economy, reversing biodiversity decline, sustainable supply chains and cleaner air.	Identifying and navigating pathways to achieving net zero to enable development of environmental solutions at scale.
UKRI's UK Geoenergy Observatories (UKGEOS) initiative, £12.4m. R&I Challenge: 10.1	Two subsurface observatories in Glasgow and Cheshire will capture new data on the impact of low carbon energy and emission storage solutions on net zero.	Commercialisation of geothermal energy and understanding how geothermal, hydrogen, carbon capture and storage, and storage solutions for renewable energy can reduce carbon emissions.
UKRI's Future Observatory: Design the Green Transition, £25m. R&I Challenge: 10.2	Leading designers and design research teams reimagining the infrastructures and systems needed to address complex challenges.	Harnessing design research and good design policy to achieve the green transition through societal and technological change and green choices.
UKRI Finance for Net Zero Programme, £15m R&I Challenge: 10.3	Supporting the delivery of new financial products and services to ensure a more integrated approach to scaling and levelling-up net-zero solutions.	Unlock financial market solutions to accelerate the low-carbon economy and boost clean growth investment.
UKRI's Industrial Strategy Challenge Fund (ISCF) Driving the Electric Revolution, £33.8m. R&I Challenge: 10.3 & 8.7	Developing products and the supply chain for power electronics, machines and drives.	Developing crucial underpinning technologies needed across all sectors and growing UK manufacturing and supply chains.
UKRI Net Zero Places / Living Labs, £60m. R&I Challenge: 10.4	3-6 pioneer places accelerated towards net zero by 2030 and up to 20 fast follower places and international collaborations.	Unlocking demand and boosting supply of consumer-centric low carbon products and services.

Annex: Government action on net zero research and innovation challenges to 2025

Annex: Government action on net zero research and innovation challenges to 2025

Note: In the following tables, spending figures in bold contribute to the overall totals mentioned in this Delivery Plan. Where figures are not in bold, either they cover multiple challenges and have been counted in another section, or they relate to wider government net zero activities and are not primarily net zero R&I spending, for example support for deployment of low carbon solutions.

Power

Low-carbon power generation will need to be rapidly deployed, with research and innovation driving continual improvements and unlocking new opportunities such as floating offshore wind and small and advanced nuclear technologies. A smart and flexible energy system is essential for integrating high volumes of low carbon power, heat and transport. This includes integrating large-scale and longer-duration energy storage as well as maximising the opportunities for matching flexible supply and demand. Customer-focussed innovation across the supply chain, including industrial energy users as well as domestic consumers, will be key to this transformation. Innovation is also needed in biomass production, which has potential to aid decarbonisation across several sectors and drive negative emissions through carbon capture and storage.

Systems integration and flexibility

Flexibility from technologies such as electricity storage, smart charging of electric vehicles, flexible heating systems and interconnection could save up to £10 billion per year by 2050 and create 24,000 jobs.[7] In July 2021 the government, jointly with Ofgem, published a new Smart Systems and Flexibility Plan and Energy Digitalisation Strategy, outlining how we will deliver the flexibility and innovation needed for a net zero system. These set out actions, through both policy and innovation, to facilitate flexibility from consumers, remove barriers to flexibility on the grid, reform markets to reward flexibility and digitalise the system.

Support for innovation includes developing and demonstrating a range of smart, flexible, secure and accessible technologies and markets through DESNZ's Flexibility Innovation and Longer Duration Energy Storage Demonstration programmes. Together, these deliver the 10-Point Plan commitment to invest in energy storage and flexibility innovation challenges. Ofgem is preparing the networks for this transition, including through its Strategic Innovation Fund. Internationally, the UK is co-leading Mission Innovation's Green Powered Future Mission to demonstrate integration of up to 100% renewables into the energy system.

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[7] BEIS, Ofgem (2021), 'Transitioning to a net zero energy system – Smart Systems and Flexibility Plan.' 2021

Challenge	Current Programme Summary
1.1. Accelerating the transition to an interoperable, digitalised, cyber-secure system **1.2. Understanding, enabling and demonstrating flexible demand** **1.3. Developing and demonstrating flexible platforms for smarter markets**	**DESNZ Net Zero Innovation Portfolio (NZIP) Flexibility Innovation Programme, up to £65m**, is funding industry-led innovation to enable large-scale, widespread electricity system flexibility through smart, flexible, secure and accessible technologies and markets. The programme focuses on supporting innovation under three themes: integrating systems for flexibility; data & digitalisation; and markets for flexibility. The programme will fund innovation across a range of key smart energy applications. See also Challenge 7.5. Current activities launched under the programme include the following: • **Vehicle-to-X (V2X) Innovation Programme,** to address barriers to enabling energy flexibility from bi-directional electric vehicle charging. This will support the development of V2X bi-directional charging prototype hardware, software, business models and anticipates supporting small scale V2X demonstrations. • **Automatic Asset Registration Programme,** to support the development of an automatic, automated secure data exchange process for registering small-scale energy assets and collecting and accessing small-scale energy asset data. • **Interoperable Demand Side Response Programme, t**o develop and demonstrate energy smart appliances to deliver demand side response. • **Smart Meter System based Internet of Things (IoT) Applications Programme,** which aims to support innovation to determine the feasibility of, and trial, smart meter based IoT sensor devices. • **Smart Meter Energy Data Repository Programme,** which aims to determine the technical and commercial feasibility of a smart meter energy data repository, quantify the benefits and costs, and simulate how it could work. • **Energy system 'digital spine' feasibility study**, which aims to support policy development by understanding the opportunities, risks and potential architectures of 'digital spine' for the energy system. • **Alternative Energy Markets Innovation Programme**, which aims to support the design and development of innovative tariffs, products or services (demand side flexibility propositions) under alternative energy market scenarios of a future energy system.

Challenge	Current Programme Summary
	UKRI Energy Demand Solutions Research Programme including Centre for Energy Demand Solutions, £13.5m SR22-25, (£35m overall) – focusses on research into a range of issues on reducing energy demand, including: the capacity to use energy in different locations at different times of day or year (via storage or by changing the timing of activity); fuel switching; smoothing or creating peaks in demand or, in the case of mobility, to re-arrange destinations and journeys in ways that reduce energy demand and/or congestion. See also Challenges 7.2 & 8.1. Internationally, **Mission Innovation's Green Powered Future Mission** is co-led by the UK, with the goal to demonstrate that by 2030, power systems in different geographies and climates can effectively integrate up to 100% variable renewable energies in their generation mix and maintain a cost-efficient, secure and resilient system. Within this, the UK also leads the pillar on data and digitalisation for integration, for data standards and interoperability, secure digitalised systems and integrated data platforms. The UK is also supporting 14 ODA-eligible countries through the ODA-funded **AI and Digitalisation Innovation Fund** under the Clean Energy Innovation Facility (CEIF). This is delivered in partnership with the Asian Development Bank and aims to advance the development of innovative smart energy technologies to support climate mitigation. CEIF also supports the acceleration of innovative energy storage technologies through the Energy Storage Innovation Fund, delivered in partnership with Innovate UK (UKRI) contributing to Challenge 1.4.
1.4. Enabling, developing and demonstrating energy storage particularly at large scales	**DESNZ NZIP Longer Duration Energy Storage Demonstration programme, up to £68m,** is funding industry-led innovation into longer duration energy storage projects (excluding commercial solutions such as pumped hydro / lithium ion) at different technology readiness levels, through first-of-a-kind full-system prototypes or actual demonstrations. Scope includes electric, thermal and power-to-x. **UKRI Grid Scale Storage Programme, £11.3m,** is supporting fundamental research into long-term, technology agnostic solutions to enable development and integration of energy storage technologies at grid level. See also Challenge 8.5 for the Faraday Institute's work which has applicability to energy storage.

Challenge	Current Programme Summary
	Internationally, research is taking place into the technologies available for energy storage in developing countries. Building on the **Faraday Battery Challenge**, the **Ayrton Fund** will investigate replacing the diesel genset in Africa and other regions via the **Transforming Energy Access (TEA) Platform**. The **Ayrton Fund Energy Storage Challenge,** delivered through FCDO and DESNZ, is supporting the development of innovative energy storage technologies in ODA-eligible countries. Support to the Energy Storage Partnership, under the **World Bank Energy Sector Management Assistance Programme**, is funding testbeds in Morocco and South Africa, with a focus on broader market development and acceleration, including for pre-commercial technology.
1.5. Prepare networks for the energy system transformation and integration	Funded through energy bills, the **Strategic Innovation Fund (SIF), £263m to 25/26,** (£450m overall) – is delivered by UKRI on behalf of Ofgem. SIF aims to find and fund ambitious, innovative projects with the potential to accelerate the transition to net zero. These projects should help shape the future of the gas and electricity networks and succeed commercially where possible. The fund will focus on whole system integration, data and digitalisation, low carbon heat and zero emission transport. **UKRI Supergen Programme, £10m SR22-25,** (£55m overall) – supports coordinating research and postgraduate training investments in energy systems integration to help UK distribution and use of solar, bioenergy and offshore wind. **UKRI Powering the Economy Programme, £15m,** enables investment, growth and scaling opportunities for market-ready hydrogen, wind, nuclear, and demand reduction solutions and technologies. Including work on ecosystem standards, regulations, and certification to allow a smarter more integrated power network to flourish. Also supports engagement with international partners to share development costs and open new international markets in the rollout of smarter power systems. See also Challenge 5.2. Internationally, the Ayrton Fund's **Energy Catalyst Challenge Fund (as part of the Transforming Energy Access Platform)** will support green grid innovations in developing countries as well as supporting system level analysis via the **Climate Compatible Growth Programme.**

Renewables

Government is supporting the development of UK manufacturing capabilities for the large components integral to next-generation wind turbines, to accelerate the build-out of fixed and floating offshore wind. This will require engaging closely with industry on how these can be manufactured and delivered, with an emphasis on increasing content of the UK supply chains.

Innovation support is prioritising a Floating Offshore Wind Demonstration Programme and creating a Floating Offshore Wind Centre of Excellence to support the Government target for up to 5GW of floating offshore wind by 2030. In addition, with accelerated deployment to meet the UK's overall up to 50GW deployment of offshore wind target by 2030, research is looking at how to mitigate any wider impacts from offshore wind turbines. For example, the Ecological Consequences of Offshore Wind (ECOwind) research programme aims to understand how marine ecosystems will respond to large-scale expansion of UK offshore wind infrastructure.

Public sector support can also help earlier-stage technologies demonstrate their potential role in delivering renewable energy, for example, space based solar. Whereas advances in UK capabilities in new photovoltaic (PV) technologies offer the potential to drive further improvements in the power output, efficiency, affordability and manufacturability which could support widespread use of solar PV, including in developing countries.

Challenge	Current Programme Summary
2.1. Accelerating the deployment of offshore wind capacity	**DESNZ Net Zero Innovation Portfolio (NZIP), Future of Offshore Wind Programme,** ~£60m, funds innovation programmes to support further deployment of offshore wind, including the Floating Offshore Wind Demonstration, Windfarm Mitigation and Composites Programmes (see below). **DESNZ NZIP, UK Manufacturing Technology for Next Generation Wind Turbines Programme – Composites, £10m.** This industry led innovation project aims to prove that composite materials can deliver significant performance and light-weighting opportunities, essential to addressing the challenge of developing the next generation wind turbine platform beyond 20MW, with an emphasis on increasing content of the UK supply chains. Internationally, ODA directly supports the development of eight offshore wind roadmaps (Vietnam, the Philippines, Colombia, Azerbaijan, India, Sri Lanka, Turkey, Brazil). This work is delivered under the World Bank Energy Sector Management Assistance Programme (ESMAP).

Challenge	Current Programme Summary
2.2. Unlocking deep water offshore wind sites deeper than 50 meters	**DESNZ NZIP Floating Offshore Wind (FOW) Demonstration Programme, £31.6m**, is supporting the development and demonstration of state-of-the-art technologies and products, this will focus on mid-technology readiness level technologies that are ready to be proved such as: mooring/anchoring; dynamic cables; and floaters/foundations. **UKRI Offshore Renewable Energy (ORE) Catapult, £24m, including the Floating Offshore Wind Centre of Excellence.** The ORE was created as an internationally recognised centre of excellence in Offshore Renewable Energy. Its Floating Offshore Wind Centre of Excellence, is working towards reducing the Levelised Cost of Energy from floating wind to a commercially manageable rate. Also, cutting back development time for floating offshore wind farms and developing opportunities for local supply chain and innovation in manufacturing, installation and operations and maintenance.
2.3. Mitigating the wider impacts from wind turbine installation and operation (both fixed and floating)	**The Ecological Consequences of Offshore Wind (ECOWind) Research Programme, £5.1m SR22-25,** (£7m overall) – funded by UKRI and Crown Estates, this research aims to enhance our understanding of ecosystem responses to the cumulative pressures of large-scale deployment of offshore wind. In addition, the British Geological Survey & Plymouth Marine Laboratory's National Oceanography Centre, are undertaking research funded by UKRI to assess the environmental sustainability of different technologies for selected test areas of the UK offshore ('Managing the environmental sustainability of the offshore energy transition: a solutions-based approach'). **DESNZ / Ministry of Defence Windfarm Mitigation for UK Air Defence Programme, £19m,** provides funding to remove barriers to deploying offshore wind, by mitigating the impact of wind turbines on radar. Delivered through the Defence and Security Accelerator, this aims to develop new methods including radar signal processing, Artificial Intelligence (AI) and innovative materials for reducing the impact of wind turbines on radar.

Challenge	Current Programme Summary
2.4. Developing and demonstrating earlier-stage renewables including next generation PV, tidal and other lower Technology Readiness Level technologies	**DESNZ Net Zero Innovation Portfolio (NZIP) and the UK Space Agency's Space Based Solar Power Programme, up to £6m,** will provide grant funding to support projects to develop technologies, energy systems and mission architecture needed for space based solar power. **The Offshore Renewable Energy (ORE) Supergen Hub,** £0.6m SR22-25, (£9m overall) **– part of the UKRI Supergen Programme,** supports and builds-on UK leading academic capacity within the research areas of offshore wind, wave, solar and tidal technology. In addition, UKRI anticipates spending **~£70m** on supporting research and innovation on a range of renewable technologies during this SR period. Specific examples include: • Next generation photovoltaic technologies through the **UKRI Application Targeted and Integrated Photovoltaics – Enhancing UK Capability in Solar Programme,** seeking to advance photovoltaics based upon organic and perovskite semiconductors, that have the potential to reduce both the cost and embodied emissions associated with manufacturing of solar cells. • **Marine Wave Energy,** where UKRI funded eight research projects into: novel designs for niche applications, survivability and reliability of devices in the marine environment; power take off and control systems modelling, forecasting and evaluation of wave energy resource; and new materials for Wave Energy Converters. • **Ocean-Fuel (REFuel) Project,** UKRI research funding to combine offshore wind energy with green hydrogen production and explore storage solutions, such as hydrogen and ammonia, that can help manage the issue of intermittent supply. See Challenge 5.5. Internationally, the **Transforming Energy Access (TEA) Platform under the Ayrton Fund** will be supporting innovations in emerging renewable technologies such as printable, thin film PV technologies. These are areas which UK innovators and partners have leading expertise and the programme will explore their applicability for local manufacture and deployment in developing countries.

Nuclear

There is an important role for large nuclear reactor technologies, Small Modular Rectors (SMRs) and Advanced Modular Reactors (AMRs) in supporting net zero by 2050. The Energy Security Strategy highlighted plans for deployment of civil nuclear of up to 24GW by 2050, representing up to 25% of our projected electricity demand.

Given the scale of new nuclear build, the Government is providing mechanisms to enable and facilitate this, including supporting developers and the supply chain. Innovation funding will target SMRs and AMRs, which have the potential to support decarbonisation across several sectors. SMRs and AMRs are currently being developed by multiple vendors across the world, but there are long timescales associated with designing, licensing, construction and commissioning of new nuclear reactors. To support UK businesses in developing their designs and for SMRs and AMRs to make a meaningful contribution to the energy system, public investment is required to help de-risk the market and incentivise private investors.

Longer-term, fusion could also play a part in the UK's future low carbon energy system. **The Government's Fusion Strategy,** published in 2021, sets out how the UK plans to leverage its global leadership in fusion research to commercialise fusion energy. Advances over the course of last year reinforce the view that this could be an important solution with an impact beyond 2050. Research and innovation will focus on demonstrating the commercial viability of fusion, by building a prototype fusion power plant in the UK that puts energy on the grid. The aim is for the UK to build a world-leading fusion industry which can export fusion technology in subsequent decades.

Challenge	Current Programme Summary
3.1. Develop Small Modular Reactors (SMRs)	**DESNZ Low-Cost Nuclear Challenge, part of the £385m Advanced Nuclear Fund (ANF),** is funding industry led innovation, which aims to develop a compact, standardised nuclear power station product based around a UK-designed small modular reactor (SMR), using modern production methods. SMRs can then be built quickly by the UK supply chain, enabling new deployment in the UK by the early 2030s. These are intended to produce cost-competitive low-carbon electricity and export opportunities for UK businesses.
3.2. Develop and demonstrate Advanced Modular Reactors (AMRs) **3.3. Integrate advanced nuclear with other technologies to support a flexible energy system**	**DESNZ Advanced Modular Reactor (AMR) Research, Development and Demonstration Programme**, part of the £385m Advanced Nuclear Fund (ANF), is aiming to develop and demonstrate High Temperature Gas Reactor (HTGR) technology. The programme is designed to identify and deliver the optimal technology demonstration, to maximise the impact that HTGRs could have on the UK's net zero target, minimising the cost of energy and incentivising private investment. This includes funding for reactor and fuel design, maturity development and supporting complimentary ancillary and cross-cutting R&D. AMRs could also provide an important heat source for industry. **DESNZ Advanced Fuel Cycle Programme (AFCP),** part of the £385m Advanced Nuclear Fund, aims to develop skills, knowledge and capabilities in the areas of advanced fuels, recycling and waste management, through development of new technologies, processes and intellectual property, that can contribute towards a reduction in the whole lifecycle costs of nuclear energy. Other programmes, such as **DESNZ NZIP Low Carbon Hydrogen Supply 2**, will investigate integrating nuclear with other energy vectors. To enhance the UK's engagement in international nuclear research and innovation activities, the **Engage Programme** is intended to help reduce the time, risk and cost of delivering policy objectives on advanced nuclear technologies (ANTs). The international collaboration undertaken as part of the programme helps to de-risk projects by working with partners to overcome challenges associated with ANTs and will provide access to peer review from international experts.

Challenge	Current Programme Summary
3.4. Driving continual improvement in large scale nuclear	UKRI continues to support an extensive **Nuclear Fission Research Programme, £105m,** including maintaining the UK's capabilities in areas of strength, such as decommissioning; facilitating safe, cost-effective clean-up and waste disposal; addressing challenges in new build and alternative, safer fuels; and continuing to strengthen international collaborations to share best practise and accelerate the implementation of technologies. This includes the **Transcend Consortium** £1.4m SR22-25, (£4.5m overall) – which is focussing on the successful delivery of decommissioning, immobilisation and management of nuclear waste solutions.
3.5. Research and development in fusion energy with a view to options beyond 2050[8]	The Government has committed over £700m towards **UK Fusion Programmes and facilities over 2022/23-2024/25**, to design a UK fusion power plant (known as 'STEP' – Spherical Tokamak for Energy Production) and transform the UK's research facilities into a hub for the global fusion industry (which will increasingly include commercial entities and a variety of technologies). **The STEP Programme** aims to develop and build a prototype energy demonstrator in the UK by 2040. By 2024, the programme will complete a concept design, identify key technical solutions and select a site. Five locations have been shortlisted, with the Government committed to announcing the preferred site by the end of 2022. **UKRI Fusion Research Programme 2022-2027,** £46m SR22-25, (£77m overall) – is innovating to make designs easier and cheaper, reducing uncertainties in design, and working with world-leaders from other sectors to exploit digital design methods.
3.6. Improving processes for decommissioning and waste	See above for **DESNZ Advanced Fuel Cycle Programme,** Challenge 3.2 & 3.3, also UKRI's **Nuclear Fission Research Programme** and **Transcend Consortium**, Challenge 3.4.

[8] Investment in fusion is with a view to longer-term energy options beyond 2050. R&D funding for fusion is therefore not included in the totals of net zero R&D outlined in this Delivery Plan.

Bioenergy

The forthcoming Biomass Strategy will set out the Government's position on future biomass use and the policies needed to support this across the economy. Public R&D will focus on priority uses of biomass including how to stimulate the production of sustainable domestic biomass, understanding the availability of sustainable biomass and improving the evidence base around production to support future biomass sustainability criteria. The Net Zero Strategy set an ambition to deploy 5 MT of greenhouse gas removals by 2030 and there is potential for Bioenergy with Carbon Capture and Storage (BECCS) to deliver the majority of this. New approaches to bioenergy, including the use of advanced bioengineering are being supported through UKRI.

Challenge	Current Programme Summary
4.1. Whole systems approach to bioenergy in meeting net zero	**The UKRI Bioenergy Supergen Hub,** £0.6m SR22-25, (£5.2m overall) – brings together UK bioenergy research groups to develop sustainable bioenergy systems. This will synthesise previous research work on land and feedstock availability to assess the potential resource for UK bioenergy and examine new crops that could deliver ecosystem benefits as well as biomass resource. Internationally, the UK is a supporting member of the **Mission Innovation Integrated Biorefineries Mission** co-led by India and the Netherlands. The aim of the Mission is to develop and demonstrate innovative solutions to accelerate the commercialisation of biorefineries, with a target of an additional 10% of fossil carbon replaced by sustainable bio-carbon by 2030 in fuels, chemicals and materials typically produced in domestic biorefineries.
4.2. Creating and securing a sustainable and reliable supply of quality biomass	**The DESNZ Net Zero Innovation Portfolio (NZIP) Biomass Feedstocks Innovation Programme, £36m,** aims to increase the production of sustainable domestic biomass by funding innovative ideas that address barriers to biomass feedstock production. It will support improvements in productivity, through breeding, planting, cultivating and harvesting. 11 innovations will be developed along with a demonstrator operating across multiple UK sites. This project works closely with earlier stage research supported through UKRI, including on new hybrids of biomass crops as well as understanding of the cultivation conditions. See also Challenge 9.11. Government is also funding research projects to enhance its understanding of sustainable biomass feedstock availability. This will update the UK and Global Bioenergy Resource Model to reflect the changing landscape of biomass use, to ensure that it reflects the most up to date evidence base.
4.3. Improving the performance and commercial viability of gasification conversion technologies **4.4. Exploring routes to deploy Bioenergy with Carbon Capture and Storage (BECCS)**	**DESNZ NZIP Hydrogen BECCS Innovation Programme, £30m,** will develop and demonstrate technologies which can produce hydrogen from biogenic feedstocks and be combined with carbon capture. This includes: i) Feedstock pre-processing to optimise biogenic feedstock; ii) Development of advanced gasification technology components focusing on improving syngas quality and upgrading for generation of hydrogen; iii) Development of novel biohydrogen technologies which can be combined with carbon capture. This programme works closely with the Bioenergy Supergen Hub noted above. See also Challenge 6.4.

Industry and low-carbon hydrogen supply

The Industrial Decarbonisation Strategy[9] noted that investment is required to advance the development of low carbon technologies and resource efficiency in the UK. Uncertainties associated with novel technologies are a barrier for the private sector.

Whilst there is a commercial incentive to decarbonise in the long term and many companies have already set ambitious decarbonisation targets, some industries need further direction on how to decarbonise, including the best technical and commercial solutions. Without government intervention, it is highly unlikely that fuel switching development will receive private investment quickly enough to enable large scale deployment from the 2030s. This is a key focus of the HMG net zero R&I portfolio for 2022-25.

Hydrogen is expected to be a key energy carrier with uses in industry, as well as across the wider energy system including in transport, power, low-carbon fuel production and potentially heat. The UK Hydrogen Strategy's 2020s Roadmap sets out our approach to support coordination across different actors in the sector and the British Energy Security Strategy set the ambition to develop up to 10GW of low carbon hydrogen production capacity by 2030, subject to affordability and value for money, with at least half of this coming from electrolytic hydrogen.

Coordination of supply and demand, as well as wider system considerations, will be critical to achieving scale-up of the hydrogen economy. Government funded R&I programmes for 2022-25 will facilitate and de-risk demonstrations for new hydrogen technologies across the value chain, support new opportunities for hydrogen applications, grow UK supply chains and expedite hydrogen's integration into the energy system.

[9] Industrial Decarbonisation Strategy, March 2021

Challenge	Current Programme Summary
5.1. Improving resource and energy efficiency	**DESNZ Net Zero Innovation Portfolio (NZIP) – Industrial Energy Efficiency Accelerator, up to £10m,** supports industry led innovation partnerships between developers of energy and resource efficient technologies and industrial companies willing to trial innovations on-site. It is open to projects from all UK industry sectors that can demonstrate either a novel technology or the use of an established technology in a novel way. **DESNZ NZIP – Energy Entrepreneurs Fund, at least £10m,** particularly supports small and medium sized enterprises, including start-ups, to develop technologies, products and processes in the areas of energy efficiency, power generation, heat generation, energy storage, reducing greenhouse gas emissions and security of supply. Wider government support, outside of R&I funding, is available through the **DESNZ Industrial Energy Transformation Fund (IETF)**, £289m, which will support industrial sites to decarbonise and become more energy efficient. This provides funding for feasibility and engineering studies, as well as supporting first-movers to demonstrate technologies at scale. A further £34m is available through the **Scottish IETF**. **The Industrial Strategy Challenge Fund (ISCF)** addresses the big societal challenges being faced by UK businesses today. It's made up of 23 challenges covering 4 themes including Clean Growth. The following challenges under the ISCF relevant here are: **UKRI's ISCF Made Smarter Innovation Challenge, £92.2m SR22-25**, (£147m overall) matched by a minimum of £147 million from industry – will support manufacturers and technology developers to prove their ideas, quickly develop and scale 'out of the box' digital technology solutions. This will support pioneering the development and integration of new and existing industrial digital technologies, including AI and virtual reality. This programme expects to help raise productivity and accelerate the drive to net zero emissions, create thousands of highly skilled jobs and allow the UK to shape the future of manufacturing. **UKRI's ISCF Transforming Foundation Industries, £40.6m SR22-25** (£66m overall) – aims to transform the UK's foundation industries (cement, metals, glass, paper, ceramics, chemicals) by making them internationally competitive, securing more jobs throughout the UK and growing the sector by 2024 in an environmentally sustainable way.

Challenge	Current Programme Summary
	UKRI's ISCF Smart Sustainable Plastic Packaging (SSPP) Challenge, £42.4m SR22-25, (£60m overall) – aims to establish the UK as a leading innovator in smart and sustainable plastic packaging for consumer products, delivering cleaner growth across the supply chain, with a dramatic reduction in plastic waste entering the environment by 2025. Innovations include prototyping new cleaning product ranges in reusable and refillable packaging, which, when disposed of, will result in significantly lower CO_2 emissions than single-use alternatives. The SSPP challenge is on track to deliver co-investment of over £200m. Working with UKRI international colleagues, this programme is now also delivering results in India, South Africa, Mexico, and Columbia. See also Challenges 9.10 & 9.12. **UKRI Circular Critical Materials Programme, £15m,** aims to capture value from a reliable and resilient UK supply chain from ore, to products for critical magnetic components that underpin net zero technologies, as well as from recycling, and end of life recovery from waste – to reduce embedded carbon while delivering economic growth. This will build and support resilient supply chains driving growth of UK businesses involved in rare earth elements for both primary and secondary materials feedstocks, creating an ecosystem conducive to private investment. We are also establishing a range of research hubs to help foster interdisciplinary research and innovation. Specific initiatives are: UKRI's Strategic Priorities Fund (SPF) **National Interdisciplinary Circular Economy Research (NICER) Programme, £22m SR22-25,** (£30m overall), which aims to change the way resources are used, valued and measured across the UK. See also Challenges 7.7, 9.10, 9.12, 10.3 & 10.5. **UKRI's Sustainable Manufacturing Research Hubs, £15.8m SR22-25,** which supports research in the engineering and physical sciences, related to challenges in commercialising early-stage research and manufacturing for a sustainable future. Their aim is to develop manufacturing processes, systems and networks with greater environmental sustainability.

Challenge	Current Programme Summary
5.2. Switching to low and zero-carbon fuels (e.g. electricity, hydrogen and biomass)	Industry-led innovation programmes, through the **DESNZ Net Zero Innovation Portfolio (NZIP)**, are helping to demonstrate feasibility and reduce costs of technologies, including: **DESNZ NZIP Industrial Fuel Switching Programme, £55m,** aims to support the development of fuel switching and fuel switch enabling technologies for UK industry. This includes fuel switches from high carbon fuels to hydrogen, electricity, biomass and other low carbon fuels. It is open to all industrial sectors and fuel switching technology developers and aims to deliver at least 8 demonstration projects. In addition, targeted innovation funding is focussing on the UK's distilleries industry, see below. **DESNZ NZIP Green Distilleries Programme, £10m,** is funding technologies that can support the decarbonisation of the distilleries sector which can present specific challenges (i.e. remote locations of some distilleries can place them off-grid). The programme is aiming for three demonstration projects. **DESNZ NZIP Industrial Hydrogen Accelerator Programme, £26m,** will support innovation projects exploring the potential to produce and use low carbon hydrogen for industrial processes. It is for single end-to-end projects encompassing the full technology chain, from hydrogen generation and delivery infrastructure through to industrial end-use, including integration of components. **DESNZ NZIP Red Diesel Replacement Programme, £40m,** aims to develop and demonstrate low carbon alternatives to red diesel used in non-road mobile machinery. This will support end-to-end demonstrations on construction, mining and quarrying sites. **DESNZ NZIP Industry of the Future Programme, £1.5m,** aims to increase the range of options available to industry to enable them to decarbonise faster. Funding is available for up to 15 industrial sites to develop industrial decarbonisation roadmaps.

Challenge	Current Programme Summary
	UKRI's ISCF Industrial Decarbonisation Challenge, £126m SR22-25, (£210m overall) – is supporting the development of low-carbon technologies that will increase the competitiveness of industry and reduce the carbon footprint of heavy and energy intensive industries in the UK. It will focus on industries such as iron and steel, cement, refining and chemicals, through investment in deployment projects, cluster plans and **the Industrial Decarbonisation Research and Innovation Centre (IDRIC)**. See also Challenge 5.3, 6.5 & 6.6. **UKRI Hub addressing Research Challenges in Hydrogen and Alternative Liquid Fuels, £3.5m SR22-25**, (up to £10m overall) – will provide a focus for the UK research community, working in close partnership with business and government, to tackle research challenges that underpin production, storage and distribution of hydrogen. This Hub will discover and develop solutions to cross-sector challenges relating to hydrogen and hydrogen-based low carbon liquid fuels. **UKRI Powering the Economy Programme,** £15m, enables investment, growth and scaling opportunities for market-ready hydrogen, wind, nuclear and demand reduction solutions and technologies. This includes work on ecosystem standards, regulations and certification to allow a smarter more integrated power network to flourish. The programme also supports engagement with international partners to share development costs and open new international markets in the rollout of smarter power systems. See also Challenge 1.5. **UKRI Net Zero Make and Use Programme, £15m,** supports feasibility studies in design, materials, supply chains and production in use and re-use of resources, and enabling scale-up support cross industry. Internationally, the ODA-funded **Industrial Decarbonisation Innovation Fund** under the Clean Energy Innovation Facility (delivered in partnership with the World Bank), is supporting the development of innovative clean technologies for facilitating deep decarbonisation in heavy industries in ODA-eligible countries, as well as building technical expertise.

Challenge	Current Programme Summary
5.3. Capturing and storing industrial emissions	**UKRI's ISCF Industrial Decarbonisation Challenge Fund** (see above Challenge 5.2 and Challenges 6.5 & 6.6) provides funding support for the development of cluster delivery plans and unlocking opportunities for CCUS deployment. Further information on CCUS support is included in the CCUS specific section of this Plan.
5.4. Efficient, cost-effective production of low carbon hydrogen at scale	**DESNZ NZIP Low Carbon Hydrogen Supply 2 Programme, £60m**, is supporting the development and demonstration of innovative solutions for the supply of hydrogen. Hydrogen supply solutions include hydrogen production as well as storage, transport technologies, and technologies that could enable hydrogen to supply a wider hydrogen economy. Wider government support, outside of R&I funding, is available through the **Net Zero Hydrogen Fund (NZHF),** announced in the 10 Point Plan, which will invest up to £240m to support the commercial deployment of new low carbon hydrogen production projects. This will advance the government's ambition to have up to 10GW of low-carbon hydrogen production capacity installed by 2030. In addition, the **Hydrogen Business Model,** will support further investment in hydrogen production with £100 million for electrolytic projects to cover the difference between the cost of production (the strike price) and the sale price for hydrogen (reference price). Internationally, the UK co-leads the **Mission Innovation Clean Hydrogen Mission**. The goal of the Mission is to support activities that aim to increase the cost-competitiveness of clean hydrogen through the reduction of end-to-end costs to USD $2 per kilogram by 2030, achieved through both innovation and by delivering at least 100 large-scale integrated hydrogen "valleys" worldwide. **The Climate Compatible Growth Programme** is expected to investigate opportunities for the role of hydrogen in the clean energy transition globally, while the **Transforming Energy Access Platform** is expected to support R&D technology and business model innovations in this area in developing countries.

Challenge	Current Programme Summary
5.5. Demonstrating effective, low-cost methods of bulk hydrogen transportation and storage	**DESNZ NZIP Low Carbon Hydrogen Supply 2 Programme** (see above) will address storage and transport of hydrogen as well as production. Whilst the UKRI funded **Ocean-Fuel (REFuel) Project,** £4.2m SR22-25, (£7m overall) – will explore combining offshore wind energy with green hydrogen production, focussing on storage solutions including hydrogen and ammonia storage.
5.6. Power generation	Low carbon hydrogen can be a key component of our future energy system by providing flexible low carbon electricity generation and creating a pathway for the decarbonisation of unabated gas generation. Government is actively pursuing the potential of hydrogen fired power plants, including exploring the need and case for market intervention.
5.7. Effective use of hydrogen at the system level	**UKRI's Systems Integration for Hydrogen and Alternative Liquid Fuels Hub, £3.5m SR22-25,** (up to £10m overall) – this hub (see Challenge 5.2 for twin) will take a view across all aspects of hydrogen across technologies, sectors and the whole energy system to understand how best to integrate hydrogen and alternative liquid fuels into the wider energy system.
5.8. Understanding how hydrogen will impact the environment and society	UKRI and DESNZ have co-funded the **Environmental response to hydrogen emissions research Programme, £4.1m,** to address gaps in knowledge regarding hydrogen's environmental behaviour, which need to be addressed to understand the implications of a hydrogen economy and to minimise any unintended consequences.

Carbon Capture, Utilisation and Storage (CCUS) & Greenhouse Gas Removal (GGR)

Even in ambitious decarbonisation scenarios, there are likely to be some residual greenhouse gas (GHG) emissions across the UK by 2050. This means research and innovation is needed to support deployment of industrial-scale CCUS technologies and CO_2 transport and storage infrastructure, as well as to develop other greenhouse gas removal solutions such as Direct Air Capture (DAC).

Public funding for CCUS research and innovation has already been crucial in understanding the fundamental science, developing improved capture processes and equipment, as well as training the next generation of CCUS technical experts. Between 2010 and 2021, the UK has invested more than £318m in CCUS RD&D.[10] The continuing role of public and private funding is to enable a steady stream of de-risked next generation CCUS technology. This will build competitive pressure in the market driving down costs of deploying CCUS and increasing its performance.

The Greenhouse Gas Removals (GGR) sector is in a nascent stage and whilst there is an appetite to develop new technologies, private sector investment is lacking until these technologies can be shown to have commercial promise and there is a clear procurement signal. Government R&I support for GGR technologies will therefore establish demonstration projects, which will aim to increase efficiencies and reduce energy demands and costs. Internationally, the UK is supporting Mission Innovation's Carbon Dioxide Removal Mission which is focussed on the technical development of engineered and hybrid removal processes.

[10] IEA Energy Technology RD&D Budgets Data Explorer; CCUS RD&D figures in nominal GBP values, https://www.iea.org/data-and-statistics/data-tools/energy-technology-rdd-budgets-data-explorer

Challenge	Current Programme Summary
6.1. Capturing CO_2 from point sources, efficiently and at low-cost	**DESNZ Net Zero Innovation Portfolio (NZIP) – CCUS Innovation 2.0 Programme, £20m,** aims to support industry-led innovation projects that either significantly reduce the cost of Carbon Capture Usage and Storage (CCUS) or help UK industry to understand the opportunity for deploying next generation carbon capture technology on industrial, waste or power generation sites for 2030. The programme will co-fund approximately fifteen innovation projects developing next generation CCUS technology that can be commercially deployed between 2025-2030 and up to ten feasibility studies on deploying the next generation CCUS technology at specific UK industrial sites. DESNZ NZIP is also funding the **Accelerating CCS (Carbon Capture and Storage) Technologies (ACT) 3 Programme, up to £5m.** This is an international initiative between 14 countries worldwide aimed at accelerating and maturing CCUS technologies through funding research and innovation projects.
6.2. Removing GHGs directly from the air or sea, efficiently and at low-cost **6.3. Reducing energy demand from engineered removal technologies**	**DESNZ NZIP Direct Air Capture (DAC) and Greenhouse Gas Removals (GGR) Innovation Programme, £60m,** aims to support feasibility and design of early to mid-stage DAC and GGR technologies and provide funding to progress the most promising projects through to demonstration, with the objective of 15 demonstration plants by 2025. **UKRI's Strategic Priorities Fund (SPF) Greenhouse Gas Removal Demonstrators (GGR-D) Programme, £22m SR22–25,** (£31.5m overall) – is supporting a series of 5 land-based GGR demonstrators, including enhanced rock weathering; afforestation; perennial biomass crops; peatland rehabilitation; and biochar. These demonstrators will explore the effectiveness, cost and limitations of large-scale methods of GGR, including environmental impacts and key economic, financial, ethical, legal, social, cultural, behavioural and governance issues. See also Challenge 9.4. Internationally, the UK has joined the **Mission Innovation Carbon Dioxide Removal (CDR) Mission** as a Support Member. The Mission was officially launched at COP26 and is co-led by the United States, Saudi Arabia and Canada. The Mission aims to enable CDR technologies to achieve a net reduction of 100 million metric tonnes of CO_2 per year globally by 2030.

Challenge	Current Programme Summary
6.4. Exploring routes to deploy BECCS **(See also Biomass section)**	**DESNZ NZIP H2BECCS Innovation Programme** will provide £30m support for the commercialisation and deployment of Hydrogen BECCS at scale from feasibility to demonstration projects to achieve negative emission and hydrogen production targets. See also Challenge 4.3 & 4.4.
6.5. CO_2 transport and storage infrastructure	**UKRI's ISCF Industrial Decarbonisation Challenge,** £126m SR22-25, (£210m overall) – is leading the development of industrial clusters across the UK with a focus on CCS infrastructure (offshore storage, onshore transport by pipeline). See also Challenges 5.2, 5.3 & 6.6. **UKRI Infrastructure Fund CO_2 Storage Laboratory: Phase 2 Scoping Project, £2m,** is the second phase of a scoping study to develop plans for a facility to safely store CO_2 deep underground on an industrial sale. The study is looking at developing new technologies and equipment to improve monitoring, reduce costs and further enhance safe storage. See above for ACT3 Programme, Challenge 6.1.
6.6. Developing economic ways to utilise captured CO_2 in products or processes	See above Challenges 5.2, 5.3 & 6.5 for **UKRI's Industrial Decarbonisation Challenge**, including the Industrial Decarbonisation Research and Innovation Centre (IDRIC) where some work is underway on CO_2 utilisation.
6.7. Creating the conditions for future scale-up and deployment/ commercialisation	To develop policies to incentivise the commercial development of engineered GGRs, DESNZ has commissioned research into a range of contract-based and market-led approaches to catalysing investment.
6.8. Monitoring, Reporting, and Verification	In 2021, BEIS established a **GGR Measurement, Reporting and Verification (MRV) Group** comprised of experts across government, industry, academia and regulatory services. This is addressing the challenge of developing an acceptable robust methodology for MRV across various GGR technologies.
6.9. Managing environmental impacts and co-benefits	See above for DESNZ NZIP Direct Air Capture and Greenhouse Gas Removals and UKRI's GGR Demonstrators Programmes, Challenges 6.2 & 6.3.

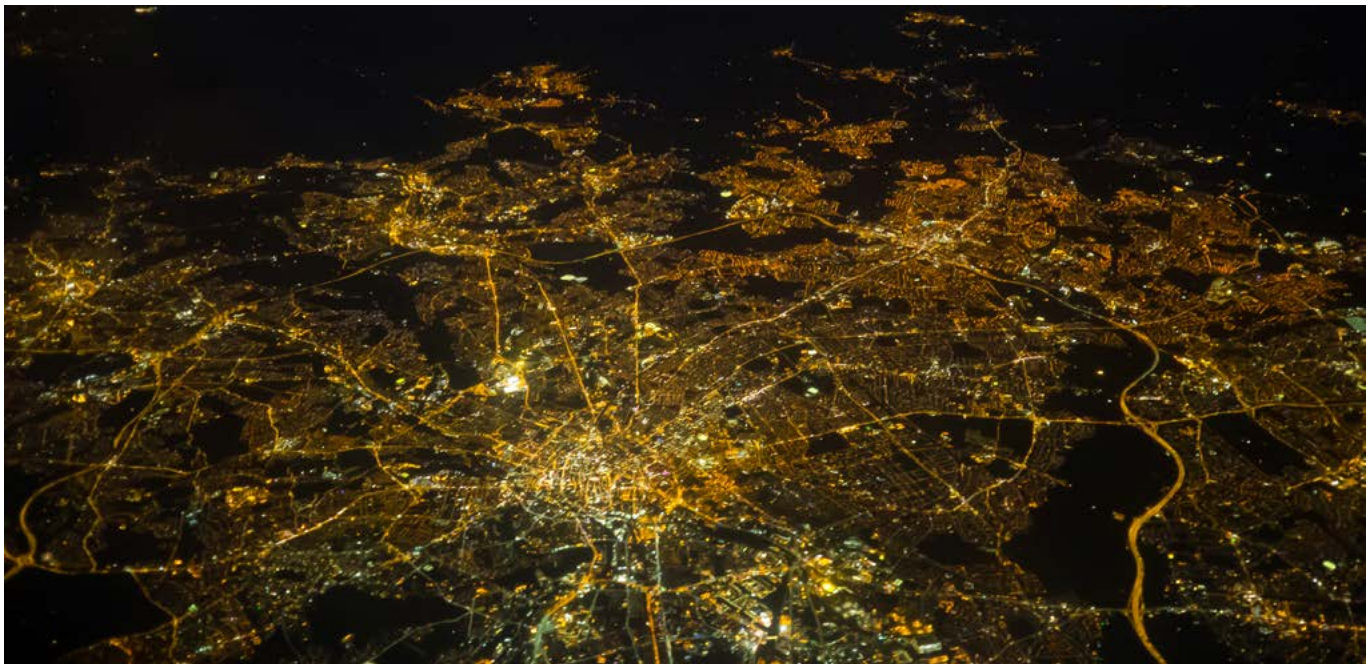
Buildings and Heat

Better energy performance is a core part of the journey to net zero buildings: improving the energy efficiency of the fabric of our buildings and the products we use in a way that will save households and businesses money from their bills, improve the comfort and value of homes and reduce carbon emissions. A key challenge is retrofitting the significant proportion of homes and non-residential buildings that require remedial work. Innovation in technologies, processes and business models, as well as research to understand consumer choices, is essential to support this ambition.

Heat pumps are expected to play a significant role in all heat decarbonisation pathways. Research and innovation is needed to enable the scale-up of heat pump deployment, by reducing their upfront and running costs, improving the consumer journey and preparing the electricity network for widescale deployment.

Low carbon hydrogen could be a key option for decarbonising heat in buildings. The Government is working with industry, regulators and others to deliver a range of projects to assess the feasibility, costs and benefits of using 100% hydrogen for heating. This work includes a programme of community trials, with government supporting industry to deliver a neighbourhood trial by 2024, a village scale trial by 2025 and a plan for a possible pilot hydrogen heated town. This will enable government to take decisions in 2026 on the role of hydrogen in heat decarbonisation.

Wider non R&D support is also being provided to heat networks which, in high density urban areas, are often the lowest cost, low carbon heating option. They are also uniquely able to use local sources of heat that would otherwise go to waste. This support will focus on mechanisms and financing structures that enable the private sector to deliver the infrastructure investment, ways to reduce costs associated with delivery and retrofitting, as well as the whole system benefits of heat networks as a decentralised energy solution using local heat sources.



Challenge	Current Programme Summary
7.1. Develop an enabling environment for system-wide decarbonisation of building stock	Government has funded a range of research into energy performance including **Building for 2050,** an end-to-end study of the design, construction, occupancy, and performance of low carbon newbuild homes; the **Smart Meter Enabled Thermal Efficiency Rating (SMETER) Programme,** supporting technologies that can measure the Heat Transfer Coefficient (HTC) or other in-use metrics of a home using smart meter and other data and for the non-domestic building stock, a **Non-Domestic Building Survey Project** which aims to develop a stock database for all non-domestic buildings in England and Wales. A key priority is developing integrated solutions and **UKRI's ISCF Prospering from the Energy Revolution Challenge (PFER), £17m SR22-25** (£102.5 million overall) – aims to develop smart local energy systems to provide investable, scalable, local business models and finance mechanisms using integrated approaches to deliver cleaner, cheaper energy services. The programme is running until 2023 and to date has co-funded and developed several initiatives including three large-scale smart energy systems demonstrator projects, ten projects to analyse energy assets and consumers in specific local areas, 17 smart local energy system projects and two initiatives to increase knowledge and share best practice. See also Challenge 10.4. Standardisation of installation practices and supply chains are also a key focus. DESNZ's **Heat Pump Ready Programme**, part of the NZIP, is developing and trialling innovative, cost-effective approaches to optimise heat pump deployment at high density. This will include an improved consumer journey, suitable financing options and energy efficiency improvements. It will also engage with Distribution Network Operators to understand network impacts of high-density deployment. **The Heating & Cooling Installer Research Project** will review the existing workforce and the extent to which they may upskill to install heat pumps in future. **UKRI Decarbonising Heating and Cooling Programme, £12.5m SR22-25,** (£14.6m overall) – is developing technologies for heating and cooling buildings and for the food cold-chain.

Challenge	Current Programme Summary
7.2. Removing barriers to widespread energy efficiency retrofits in existing domestic and non-domestic buildings	Government is focussing on finance as a key barrier to retrofitting homes. The £1.8m **Green Home Finance Innovation Fund (GHFIF)**, which completed in March 2022, was a key early step in supporting high-street lenders to design, develop and pilot novel green mortgage products for homeowners to support retrofit. This is being followed by **DESNZ NZIP's Green Home Finance Accelerator Programme, £20m,** this aims to drive innovation in the green lending market and support the establishment of a more diverse range of green finance products, which incentivise domestic energy performance improvements amongst both owner occupiers and private landlords in advancing the Government's ambition, for as many homes as possible to reach EPC band C by 2035. We are also completing work on the **Whole House Retrofit (WHR) Cost Reduction Programme** which started in 2019. This explores cost reduction strategies in the deep retrofitting of buildings, through economies of scale and streamlined installation practices and trialling innovative retrofit technologies, including modular, off-site processes, to reduce the time contractors need to spend in individual homes. In addition, the **Demonstration of Energy Efficiency Potential (DEEP) Research Project** is looking into different combinations of energy efficiency measures to better understand interactions between the building fabric, ventilation and the occupants.

Challenge	Current Programme Summary
	UKRI Net Zero Heat Programme, £15m, aims to enable the UK to be faster than other economies to be completely off gas for heating, space and water in buildings through a combination of reducing demand and a fast, scaled roll out of renewable heating technology. The projects are focussed on: • Market Demand – standardised information on what innovation to do where and when for maximum impact; • Green Finance – to bridge the scaling gap leading to growth in supply chains and localised deployment; • Design Engineering – to reduce capital and installation costs across the system of net zero renovation (fabric and decarbonised heating technologies, incl. installation). **UKRI Energy Demand Solutions Research Programme including the Centre for Energy Demand Solutions**, is exploring different ways for the UK to transition towards using efficient, decarbonised and sustainable technologies for heating and cooling buildings. See also Challenges 1.1, 1.2, 1.3 & 8.1.
7.3. Developing, demonstrating, reducing the costs of and de-risking low carbon heating and cooling technologies	**DESNZ NZIP Heat Pump Ready Programme, £60m,** aims to create an enabling environment for heat pump deployment at a significantly increased density and scale than current deployment levels, and support the development of industry-led innovative solutions across the heat pump sector. This includes: • Developing and trialling solutions and methodologies to deliver high-density heat pump deployment; • Supporting innovators to develop tools and technology solutions which overcome specific barriers to heat pump deployment, such as reducing the lifetime cost and increasing the performance of domestic heat pumps; • Facilitating learning and collaboration within and outside the programme, undertaking research and evaluation activities, and disseminating knowledge, evidence and lessons to key heat pump stakeholders. See also Challenge 7.1 & 7.6.

Challenge	Current Programme Summary
	DESNZ's Hydrogen Heating Programme (HHP), £100m, is working with industry, regulators and others to deliver a range of research, development and testing projects, to assess the feasibility, costs and benefits of using 100% hydrogen for heating. This includes a neighbourhood trial by 2024 and a village scale trial by 2025. The knowledge and experience gained from these projects will enable the Government to take strategic decisions in 2026 on the role of hydrogen in decarbonising heat. This is complemented by an earlier **NZIP Hydrogen Skills and Standards for Heat Programme,** £2.5m. Wider non-R&I support includes DESNZ's £288 million **Green Heat Network Fund (2022-2025)**, which provides grants to enable new and existing heat networks across England to adopt low carbon technologies. This will support the uptake of low-carbon technologies like heat pumps, solar and geothermal energy as a central heating source, and help to unlock opportunities for these technologies to play a greater role in the move to net zero – providing demonstrators and case studies to be used by future projects. The **Green Gas Support Scheme** launched on 30 November 2021 supports biomethane produced via **anaerobic digestion** and injected into the gas grid. Producers receive tariff payments for a 15-year lifetime and the scheme is open to applicants for four years. The government expects to focus on market-based mechanisms for biomethane support once the Green Gas Support Scheme closes in 2025. Internationally, the ODA-funded **Sustainable Cooling Innovation Fund** under the Clean Energy Innovation Facility, is developing sustainable cooling solutions across different sectors in ODA-eligible countries, including projects in Mexico, Colombia, Kenya, Nigeria, India and Vietnam. The **Low Energy Inclusive Appliances (LEIA) Programme** under the Ayrton Fund, also supports the development of sustainable cooling technologies with a focus on agricultural cold chain, domestic and small-industrial including solar-powered cooling.

Challenge	Current Programme Summary
7.4. Maximising the potential of heat networks	DESNZ is investing over £500 million (non-R&I funding) in the **Heat Network Transformation Programme**, bringing together several heat networks initiatives into a single transformation programme. This includes unlocking large scale, low or zero carbon sources of heat such as waste heat from industry and heat from rivers and mines, and facilitating more efficient heat networks, including by providing targeted support for new and existing networks. The following workstreams will generate the evidence base for the performance improvement of existing heat networks: **Heat Network Optimisation Opportunities (HNOO); Greening Existing heat Networks (GEN),** which investigated decarbonisation options for six large existing heat networks; the **Heat Network Efficiency Scheme** will build on a recent demonstrator to deliver improved operational efficiencies and improved outcomes for heat network customers; and **The Heat Network Zoning Pilot** is working with 28 Local Authority partners to understand what a heat network zone could look like in practice and test the methodology to be used for identifying heat network zones.
7.5. Integrating smart, low carbon technologies and solutions	**DESNZ NZIP Flexibility Innovation Programme,** up to £65m – will enable large-scale, widespread electricity system flexibility through smart, flexible, secure and accessible technologies and markets (see main reference in Power section). In addition, work on product standards and energy labelling under the **Energy-Related Products Framework** will look to factor in smart functionality when setting minimum standards and energy labels which could help to further drive innovation in smart technology. See also Challenges 1.1, 1.2 & 1.3. UKRI has funded two calls for **Decarbonising Heating and Cooling**, £12.5m, for research to explore different ways for the UK to transition to using efficient, decarbonised and sustainable technologies for heating and cooling buildings.

Challenge	Current Programme Summary
7.6. Understanding end-user behaviour to drive uptake	**DESNZ NZIP Heat Pump Ready Programme** is developing solutions for high-density heat pump deployment and will look to develop an enhanced 'consumer journey' which provides high levels of consumer satisfaction throughout the heat pump deployment process. Solutions will take a joined-up approach to heat pump roll-out, working across stakeholders, for example, local authorities, energy suppliers, DNOs, manufacturers, consumers groups, installers and finance providers within a given locality. See also Challenge 7.1 & 7.3. The **Energy-Related Products Framework** will consider improvements to existing energy labels and whether to expand the range of products covered by energy labelling to further increase uptake of energy products and drive market transformation. Through new research, we are seeking to understand what messaging helps consumers make better and greener choices, as well as the potential impacts of policy measures on different groups.
7.7. Driving down emissions associated with construction	**UKRI's ISCF Transforming Construction Challenge, £19m SR22-25** (£170m overall 2018-22) – is part of the Construction Sector Deal and aims to accelerate the shift in construction towards manufacturing and digital processes and an approach that delivers best value, including carbon performance, over the life of the asset, to make net zero construction a reality. In addition, the **Interdisciplinary Circular Economy Centre for Mineral-based Construction Materials**, part of the **National Interdisciplinary Circular Economy Research (NICER) Programme**, is focussing on improving the way we use materials such as aggregate, cement, brick, plasterboard, stone and glass. Government is also supporting the development of digital technologies that will improve building design and enable the improved operation of buildings and infrastructure networks and systems through the **UK Building Information Modelling and National Digital Twins Programme (UK BIM/NDT) – £20m**. Internationally, the **Market Accelerator for Green Construction (MAGC) Programme** will fund a £4.5m project to develop a robust evidence base that can be used to further enhance green building standards and motivate the uptake of green construction over conventional approaches. This is part of the £103m ODA-funded capital investment and technical assistance MAGC programme delivered in partnership with the International Finance Corporation.

Transport

The Transport Decarbonisation Plan[11] stressed the importance of R&D, technology and innovation in enabling the UK to meet our net zero ambitions. Such investment will also drive long-term growth by helping the UK to lead this global transition. The aviation and maritime sectors, where low and zero emission technologies remain at early technology readiness levels are particularly exciting opportunities to capture this future growth.

The Department for Transport's (DfT's) current areas of research interest are focussed on the following:

- Technological requirements to deliver transport decarbonisation;
- Decarbonisation of road vehicles and freight;
- Accelerating the transition to zero emission maritime and aviation;
- Place based solutions and environmental impacts;
- UK as a hub for green transport, technology and innovation;
- Exploring how hydrogen technologies and innovations could be applied to the transport system;
- Role of green choices in meeting environmental commitments;
- Accelerating modal shift to public and active transport;
- Impact of transport on the energy system;
- Reducing carbon in a global economy.

Battery electrification is expected to remain the dominant zero emission technology in the lighter duty sector, including drones and light aircraft. Hydrogen is expected to have a significant role in decarbonising areas that batteries cannot reach.

[11] Decarbonising Transport: A Better, Greener Britain, July 2021

For example, heavier transport applications, or where energy density requirements, longer ranges or refuelling times make it the best choice. Research and innovation is also underway on integrating electric vehicles with the wider electricity system to balance energy supply and demand.

Trialling and evaluating new approaches to supporting people to choose less carbon-intensive travel options will help improve transport for the user, while supporting the development of a net zero transport system. Social and behavioural research will explore how people's motivations, opportunities and capabilities to travel differently are shaped by social and technological factors. Working with local government and communities will build societal readiness and drive progress in a collaborative and inclusive way.

Challenge[12]	Current Programme Summary
8.1. Enabling an integrated, multi-modal transport system	DfT will coordinate a portfolio of transport decarbonisation research programmes to ensure cross-modal learning and systems thinking. Specific research projects include: **The DfT Freight Innovation Fund, £7m,** will support the commercialisation of proven capital projects that improve inter-modal links as part of supply chains or further enabling modal shift. **DfT's Behavioural Science Research Programme** – will collate evidence, diagnose behaviour, develop options to inform policy and communications and support tests and trials to encourage sustainable travel choices. This will include research on improved consumer information on the environmental impact of travel and car-purchasing choices ('eco-labelling') and behavioural research on topics such as shared mobility. **DfT's Zero Emission Vehicle Repower Accreditation Scheme** – is funding the development of an accreditation scheme for buses retrofitted with zero emission powertrains, with potential to be expanded to other modes. **UKRI Digital Twins Transport Use Case, £2.6m SR22-25**, (£20m overall) – in partnership with DfT, aims to carry out research into digital twinning for decarbonising and improving the connectivity of UK transport systems.

[12] The following Challenges cover the same content as outlined in the Framework, but revised groupings reflect latest thinking.

Challenge	Current Programme Summary
	UKRI also has a range of networks and research focussing on this challenge, including: **DecarboN8, £0.4m SR22-25** (£1.3m overall) – an industry/government network to design solutions to decarbonise the transport industry; **the Place-based Climate Action Network (PCAN),** £1m SR22-25, (£3.5m overall) – which focusses on local decision making; **the Centre for Research into Energy Demand Solutions (CREDS)** – which has a transport theme looking at where transport energy demands are highest, constraints and opportunities for transport flexibility and how to accelerate the take-up of carbon and energy reduction policies; and the **Centre for Climate Change and Social Transformation (CAST)**, £2m SR22-25**,** (£5m overall) – which includes mobility as one of its four challenge areas. Internationally, the **Ayrton / ODA Climate Compatible Growth Programme,** is exploring integrated transport and energy scenarios and planning and the **Transforming Energy Access Platform,** is supporting zero emission vehicle energy storage technology and business model innovations in developing markets.
8.2. Accelerating the adoption of active travel and public / shared transport **8.3. Complementary approaches to roads decarbonisation**	**The DfT Moments of Change – Public Transport Adoption Project,** will identify which 'moments of change' in people's lives (e.g. moving home, changing jobs, having children or retiring) are most influential on public transport usage and how these moments can be leveraged to facilitate mode shift. This will add to previous work that produced guidance on using 'moments of change' to encourage active travel. **The DfT Future of Transport Programme, £0.6m,** aims to stimulate innovation in the transport sector, create new transport markets, secure a 21st-century transport system and secure the UK's position as a world-leading innovator, decarbonising the transport system for the benefit of all society. It will explore how changes in travel choices, including modal shift, can contribute towards delivering emission targets. **The Centre for Connected and Autonomous Vehicles' Commercialising Connected and Autonomous Mobility (CAM) Programme, £66m,** funded by DBT, supports the deployment and commercialisation of CAM services and the development of CAM supporting technologies to ensure clean, safe and secure self-driving vehicles and services in the UK, that can contribute towards reaching net zero targets.

Challenge	Current Programme Summary
8.4. Addressing regional needs and place-based approaches	**The Live Labs 2 Programme, £30m** – is funded by DfT and run by the Association of Directors of Environment, Economy, Planning and Transport (ADEPT). These are Local Authority (LA) led public-private-academic partnerships to trial innovations which decarbonise emissions from local roads construction, operation, maintenance and decommissioning. **DfT's Transport Research Innovation Grants (TRIG),** in partnership with Connected Places Catapult, has run a **Local Transport Decarbonisation Funding Call in 2022, £0.65m** – this will support innovative proof of concept projects aimed at finding innovative solutions to accelerate decarbonisation of transport in local areas.
8.5. Supporting the development and deployment of zero emission vehicles	**DfT Zero Emission Road Freight Demonstrator (ZERFD) Programme, £200m,** will support industry to demonstrate multiple zero emission HGV technologies. This will kick-start at-scale deployment of long haul zero emission HGVs and their supporting infrastructure across the UK. Consortia of fleet operators, vehicle manufacturers, energy, charge point and refuelling providers will operate large scale demonstrations of the zero emission technologies in real world UK operations to gather evidence on their benefits and disbenefits. It will also develop the UK's supply chains in each technology. The programme will break down the barriers to technology adoption, spotlighting the best technology, or combination of technologies, to replace diesel HGVs. **UKRI's ISCF Faraday Battery Challenge (FBC), £215.2m,** (£541m overall) – is investing in research and innovation projects and facilities to drive the growth of a leading battery industry in the UK. Phase 1 aims to develop battery technologies that are cost-effective, high performing, longer range, faster charging, long-lasting, safe & recyclable. Phase 2 has two overarching aims: • To ensure the UK meets its climate commitments in the required timescale, through supporting the decarbonisation of transport and the energy industry • Taking action to develop a world-class intellectual and physical supply chain for batteries in the UK and secure the future of the UK automotive industry. See also Challenge 1.4.

Challenge	Current Programme Summary
8.6. Decarbonising railways	Government R&D on rail decarbonisation will focus on reducing the cost of rail electrification, developing solutions for discontinuous electrification and improving capability of battery and hydrogen trains and associated infrastructure. It will be delivered as an element of **Network Rail's and the Rail Safety and Standards Board's** on-going **R&D Programmes, £24m**. **The DfT-funded Rail Innovation Programme First of a Kind, £10.7m,** currently includes a focus on decarbonisation.
8.7. Developing the UK capabilities to manufacture zero emission powertrain technologies.	**The DBT funded Advanced Propulsion Centre (APC), £225m,** runs targeted, late stage, collaborative R&D competitions to accelerate the UK's development and commercialisation of low carbon and zero emission vehicle technologies. This will be delivered in partnership with UKRI. Delivered in partnership with the APC and funded by DBT, **the Automotive Transformation Fund (ATF), £75m (R&D element)** – supports capital investment and late-stage R&D to build an internationally competitive electric vehicle supply chain in the UK. This includes unlocking private investment in giga factories, battery material supply chains, motors, power electronics and fuel cell systems. The ATF will create and safeguard UK jobs, building an end-to-end supply chain for batteries and components, and anchoring investment in UK manufacturing. **DfT's Zero emission Powered Light Vehicles (PLV) Feasibility Study, £0.35m**, will be delivered by the Niche Vehicle Network and provide grant funding to projects to undertake R&I aimed at supporting the accelerated development of innovative zero emission vehicle technologies applicable to road going PLV. This delivers on the Motorcycle Industry Association and Zemo Partnership's **Action Plan for Zero Emission Powered Light Vehicles,** which recommends activity on delivering the product (creating supply) and stimulating the market (driving demand).

Challenge	Current Programme Summary
	UKRI's ISCF Driving the Electric Revolution Challenge, £33.8m, (£80m overall) – supports R&I developing products and supply chain for the drivetrain for almost all zero carbon land transport options. Including electric and hydrogen, this aims to deliver a resilient supply chain for Power Electronics, Machines and Drives. See main reference in Whole Systems section (Challenge 10.3). **UKRI Mobility: Net Zero Powertrains and Digital Transport Programme, £15m,** aims to accelerate the move to electrification including batteries, power electronics, machines and drives, hydrogen fuel cells and other alternatives like liquid hydrogen and ammonia. As well as digital transport through the exploration and pilot investments in applications of vehicle connectivity and data for net zero.
8.8. Understanding and enabling hydrogen's role in transport	DfT support for **the Tees Valley Multi-modal Hydrogen Transport Hub, £24m,** is deploying refuelling infrastructure and vehicles in Tees Valley to explore how hydrogen works across transport modes. This will be complemented with support for relevant skills (e.g. hydrogen-specific college courses) in the area. Core funding has been allocated to the Hydrogen Hub with opportunities to align with other modal-specific programmes of work. UKRI supports a network on hydrogen-fuelled transportation **(Network-H2), £0.4m SR22-25,** (£1m overall). This multi-disciplinary network cuts across technology, socioeconomics, behavioural science and policy, and covers all modes of transport and hydrogen energy.

Challenge	Current Programme Summary
8.9. Developing net zero emission flight and associated operations	**The Government's Jet Zero Strategy**, published in July 2022, sets out our approach to decarbonising the aviation sector by 2050. The Jet Zero Council, established in July 2020, plays a key role in ensuring the strategy is delivered in partnership with industry, with the aim of delivering at least 10% sustainable aviation fuel (SAF) in the UK fuel mix by 2030, and zero emission transatlantic flight within a generation. DBT is supporting innovation into low, zero carbon emission and cross cutting aircraft technology through **the Aerospace Technology Institute (ATI) Programme, £685m**. Funds will be used to support the development of zero-carbon and ultra-low-emission aircraft technology, cementing the UK's place at the forefront of advancing new green technology whilst supporting tens of thousands of jobs. The ATI has also published the reports from the £15m Government funded FlyZero project which highlights the opportunities of hydrogen in aviation. Zero Emission Flight Infrastructure. In 2022/23 the Government is providing a second year of funding to the **Zero Emission Flight Infrastructure project, £1.2m,** providing funding for research into the ground handling of future hydrogen aircraft. Wider non-R&I funding is being provided by DfT to support the development of a **UK Sustainable Aviation Fuel** industry, to build on progress made through previous advanced fuels competitions. Current support includes: **DfT's Advanced Fuels Fund,** £165m, supports the commercial deployment of innovative fuel production technologies and the advancement of a diverse range of technology routes to SAF and other advanced fuels. In December 2022, five winning projects were announced from the first application window and awarded a total of £82.5m across three financial years (2022-25). **UK SAF Clearing House,** £12m, established in 2022, supports the testing and certification of new SAF production pathways to accelerate their use in commercial and military aircraft. **Net Zero Transatlantic Flight Fund, £1m**, funded by DfT in partnership with Innovate UK, is a competition to support industry to meet the government's ambition to achieve the first ever net zero transatlantic flight on a passenger aircraft, using 100% sustainable aviation fuels (SAF) by the end of 2023. In December 2022, Virgin Atlantic was announced as the winner and will operate the flight.

Challenge	Current Programme Summary
	UKRI's ISCF Future Flight Challenge, £87.9m SR22-25, (£125m overall) – is working across aviation, energy and infrastructure sectors to demonstrate operations of drones, air mobility and regional passenger aircraft using electric and hydrogen propulsion systems.
8.10. Decarbonising maritime	**DfT's UK Shipping Office for Reducing Emissions (UK SHORE), £206m**, aims to transform the UK into a global leader in the design and manufacturing of clean maritime technology. UK SHORE interventions include the **Clean Maritime Demonstration Competition,** currently in its third round of funding. This round is aimed at funding large technology and system demonstrations. Future interventions will be aimed at accelerating the roll out of zero emission solutions for vessels and port-side infrastructure that are nearing commercialisation, developing international green shipping corridors, exploring green skills initiatives, and undertaking grant schemes for early research projects delivered by universities. UKRI has supported **Decarbonising the UK's Freight Transport,** which focussed on shipping freight, considering supply chain innovations required to meet net zero. UKRI are also funding the **Maritime Consortium, £19m SR22-25,** (£33m overall) – led by Artemis Technologies to develop a zero emissions electric hydrofoil. There is also work on fuel cells and associated hydrogen storage and bunkering arrangements, through the **Hyseas 3 Project** funded through Horizon 2020. Internationally, the UK is collaborating through the **Mission Innovation, Zero-Emission Shipping Mission** co-led by the governments of Denmark, Norway and the United States, along with the Global Maritime Forum and Mærsk McKinney Møller Center for Zero Carbon Shipping. The UK participates in the ports and fuel infrastructure pillar of the Mission.

Natural resources, Waste and F-gases

There are multiple demands on land that influence how it is used. There are trade-offs and synergies between food production, forestry and biomass production, habitat and peatland restoration, biodiversity and urban expansion. Innovation is needed in methods of sustainably managing forests, peatland and the marine environment, to promote carbon sequestration alongside wider environmental benefits. As well as innovation on the resilient supply and demand of agricultural products and promoting sustainable choices. Enhancing waste management techniques to reduce emissions from landfill and the wastewater treatment sector are also priorities.

The Government's net zero and environment targets will drive land use change across the UK. Delivering this change will require policy to take account of land use as a complex system that must also accommodate new homes and new infrastructure, whilst maintaining food security. The scale of change and the need for a coordinated and strategic approach calls for government intervention. For example, the Defra systems research programme has various workstreams within its land-use research project, such as a review of global, national and regional drivers of land-use change. This will help to contextualise land-use challenge and refine future scenarios with a holistic view of potential interactions between land-use change trajectories and environmental outcomes.

Challenge	Current Programme Summary
9.1. Land use allocation & planning considerations	**Defra's Land Use R&D Programme, £6.6m,** aims to provide the capability and evidence to deliver an approach to land-use change for net zero and environmental recovery, whilst maintaining food security. It will focus on spatial land allocation, impacts of land-use change on ecosystem services and biodiversity, and attitudes and choices towards land-use change. This research, alongside in house analysis, will underpin corresponding policy development on Defra's Land Use Framework. **UKRI's Sustainable Agri-food for Net Zero Network+, £5m,** will consider the UK agri-food systems' sustainability and increased resilience to climate change and the resulting environmental impacts, whilst maintaining increased productivity. It will also help the UK's agri-food sector enhance biodiversity, maintain healthy ecosystems, nurture livelihoods, support healthy consumer habits and minimise overseas trade-related environmental impacts. **UKRI's Molecules to Landscapes Programme, £6.7m**, fosters collaborations and builds capability through interdisciplinary projects including environmental engineering, ecology, agri-systems, molecular biology and data science. An important outcome will be the identification of innovative solutions to inform and develop future agroecological practices that reduce the impact of agriculture on the terrestrial, freshwater, atmospheric or marine environments and their diverse flora and fauna. UKRI has supported **Strategic Priority Fund Landscape Decisions: towards a new framework for using land assets, £1.2m SR22-25**, (£10.5m overall) – which focussed on finding ways to deliver a better, evidence-based and interdisciplinary decision-making framework to inform how land is used in the UK, through research collaboration with policy, business and land management partners.

Challenge	Current Programme Summary
9.2. Understanding system level greenhouse gas emissions and environmental impacts	In addition to the above, Defra has an ongoing **programme of work on systems research**, innovation, futures and earth observation, including projects on Artificial Intelligence for horizon scanning and a systems research academic fellowship. The Environment Agency will also deliver a project to ensure a sustainable transition to net zero, where the wider environmental and social risks are considered alongside carbon savings. **HM Treasury's Shared Outcomes Fund: Nature based solutions for climate change at the landscape scale, £12.5m**, is supporting research into how carbon accumulates and is released from different habitats in different circumstances, identifying strategies that optimise both biodiversity and climate change at the landscape scale. **UKRI supports Detection and Attribution of Regional greenhouse gas Emissions in the UK (DARE-UK), £3.5m**, which is developing systems to estimate greenhouse gas emissions to improve the accuracy of the UK's inventory reports, focussing on three major greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).
9.3. Effecting sustainable and responsible land use change and effects on economic growth / levelling-up agenda	**Defra's Natural Environment Readiness Fund (NEIRF)** will provide technical assistance and capacity-building to stimulate a pipeline of nature projects for the private sector to invest in. Projects will provide a return on investment by capturing the value of the carbon, water quality, biodiversity, and other benefits provided by natural assets such as woodlands, peatlands, catchments and landscapes.
9.4. Sustainably expanding and managing forests and the wider treescape	**Defra's Nature for Climate Fund (Trees) R&D Programme, £22m,** supports projects that increase biodiversity through habitat creation and restoration as well as environmental, social and economic benefits, including climate change mitigation. Also, knowledge gaps that need R&D to help further inform our future tree planting programmes and management of woodland.

Challenge	Current Programme Summary
	Nature based solutions for climate change at the landscape scale pilot, under HM Treasury's Shared Outcomes Fund, will investigate how carbon accumulates or is released from different habitats in different circumstances. It will also develop new governance and blended funding models for landscape scale action. The evidence produced will help deliver both the 25 Year Environment Plan goals and net zero goals. **Defra's Plant Health Research Programme, £18.75m,** works to understand, prevent and manage plant health outbreaks to protect natural capital assets from pests and diseases. The programme also seeks to support the planting of landscapes and agriculture more resilient to pests and diseases and other stresses. Initiatives include the **Future Proofing Plant Health Programme** involving Defra, RBG Kew, Forest Research, Natural England, JNCC and Fera Ltd and the new Centre for Forest Protection. **UKRI's The Future of UK Treescapes Programme, £11.9m SR22-25**, (£315m overall) – aims to inform future decisions on treescape expansion, management and resilience for the benefit of the environment and society. See also the UKRI SPF GGR Programme reference in the CCUS & GGR section, Challenge 6.2 & 6.3. There is also research being conducted **through International Climate Finance (ICF)** on sustainable forestry. While the beneficiaries are overseas, it will also have relevance in the UK. This is also relevant for Challenge 9.5.

Challenge	Current Programme Summary
9.5. Developing increased resilience of forest ecosystems to climate change impacts	**The Centre for Forest Protection (CFP)** is a partnership between Defra, RBG Kew and Forest Research which is particularly focused on understanding and managing the biotic stresses facing woodlands and trees.
9.6. Restoring sustainably and managing peatlands	**Defra's Peat and Soil R&D Programme, £14.1m** (including £3m from the Nature for Climate Fund, also covering Challenge 9.7) – will provide evidence to support peatland policy development. This will support the **England Peat Action Plan** commitments for restoration and responsible management, as well as our carbon budget and net zero goals. The results will identify where raising water tables is viable, what practices will deliver what level of abatement and what the trade-offs will be. See also the UKRI **SPF GGR Programme** reference in the CCUS & GGR section, Challenges 6.2, 6.3 & 9.4.
9.7. Managing soils for improved soil health and resilience	Several measures are being developed to help improve and protect soil and make it more resilient to the impacts of climate change in England. These include how land management practices, for example through the **Sustainable Farming Incentive soil standards**, and planning can help protect soil and make it more resilient to the impacts of climate change. Agroecology is a primary management model being investigated. In addition, a **Soil Health Indicator** will be developed that tracks progress towards improved soil management for both soil health and resilience. R&D will develop the chemical, biological and structural metrics that will constitute the indicator. UKRI supported the European Joint Programme **Collaborating for healthy, resilient and sustainable agricultural soils, £2.1m SR22-25,** along with 17 other countries and the Global Research Alliance on Agricultural Greenhouse Gases. The programme aims to foster holistic agricultural soil management practices which will assist in making a shift to diversify farming practices to include a variety of sustainable and environmental practices. Areas covered include soil organic carbon sequestration, biodiversity and sustainable production, and a healthy environment.

Challenge	Current Programme Summary
9.8. Sustainably managing the marine environment	**The UK Blue Carbon Evidence Partnership (UKBCEP)** – launched at COP26, aims to identify a pathway for blue carbon evidence which supports policy needs across the UK. The partnership will initially develop and publish an Evidence Needs Statement, outlining the key evidence gaps required to support UK government and devolved administration policy. **UKRI Strategic Priority Fund Sustainable Management of UK Marine Resources, £9.2m SR22-25,** (£12m overall) – aims to improve understanding of societal perspectives and behaviours concerning the marine environment. It will integrate this into systems-based approaches that support the development and analysis of interventions to inform effective decision-making for marine management and policy development which support societal goals such as achieving net zero. **Defra's Blue Carbon Programme, £1.2m,** is undertaking research to determine an accurate representation of GHG fluxes from coastal habitats and seascapes-scale consideration of the role of subtidal ecosystems in carbon storage and emissions, and how this may determine future policy decisions. **UKRI Biological influence on future ocean storage of carbon (BIO-Carbon), £5m SR22-25,** (£10.3m overall) – is a recently announced initiative to understand the role of marine life in ocean carbon storage, how this carbon store functions and enable robust predictions of future ocean carbon storage in a changing climate. **Defra / DESNZ partnership with The Crown Estate's Offshore Wind Evidence and Change Programme (OWEC)** is a research and data-led programme to facilitate the sustainable and coordinated expansion of offshore wind in the UK.

Challenge	Current Programme Summary
9.9. Sustainable Agri-production of food, perennial energy crops and short rotation forestry	**Defra's Agri-food Research Programme, £16.4m,** will support continued strategic agri-food research to deliver emissions reductions, develop longer term decarbonisation options and address climate resilience in the agri-food sector. The programme has fed into the development and delivery of the **UK Food Strategy** and shaped the content of our Environmental Land Management Schemes, particularly the **Sustainable Farming Incentive**. It has also influenced the technologies included in the **Farming Innovation Fund** grants and investments in translational research and innovation via the **Farming Innovation Programme.** Defra will continue to research options to deliver near term emissions reductions via successful implementation of no-regrets mitigation options. Medium term research will focus on enhancing livestock sustainability through investigating changes to production to reduce GHG emissions, improve welfare and boost productivity. It will also gather evidence to support policy options on preserving genetic resources. The programme will explore the potential of agro-ecology and regenerative agriculture through a UK living labs network, working with appropriate partners, and undertaking user-centred research. It will also explore the opportunities for novel fertiliser media and improved agronomy to contribute towards food security and improved environmental outcomes. Agri-food resilience research includes research into crop genetics in partnership with UKRI and industry via the **Crop Genetic Improvement Platform**, with a renewed focus on targeted breeding insights developed under our Agri-food Climate Service in partnership with the Met Office Hadley Centre. The programme will also explore novel and diversified crops for food production and the bioeconomy in the context of a changing climate.

Challenge	Current Programme Summary
	UKRI Strategic Priorities Fund Transforming the UK Food Systems, £34m SR22-25, (£47.5 overall) – is supporting research to fundamentally transform the UK food system by placing healthy people and a healthy natural environment at its centre. It is addressing questions around what we eat, produce and manufacture and what we should import, taking into account the complex interactions between health, environment and socioeconomic factors. See also Challenge 9.10. In collaboration with Defra, UKRI supports the **ISCF Transforming Food Production Challenge, £28.6m SR22-25,** (up to £90 million overall) – which is supporting the development of new ways of producing food, reducing emissions (net zero by 2040) and pollution whilst contributing towards feeding a growing world population. See Challenge 9.1 for **UKRI Sustainable Agri-food for Net Zero Network+**. UKRI is developing an Institute programme, **Towards Sustainable, Climate-Neutral Farming Systems (AgZero+), £12.8m,** to address the urgent need for long-term research to help design new UK farming systems which produce sufficient food, whilst reducing emissions and pollution, protecting biodiversity and enhancing soil health. **UKRI Novel Low Emissions Agricultural Production Systems, £13m,** will deliver feasibility studies and industrial research focussed on controlled environment agriculture such as vertical farming, alternative proteins and, through investor partnerships, support the establishment of new industry segments in the UK and globally.

Challenge	Current Programme Summary
9.10. Sustainable consumption	**The Resources and Waste Strategy** covers policies, particularly collection and packaging reforms, which are designed to reduce residual waste and therefore should help reduce consumption of raw materials and increase resource productivity. The UKRI Strategic Priorities Fund **National Interdisciplinary Circular Economy Research (NICER) Programme** of circular economy centres will be key contributors to building up this knowledge base. Within the Agri-food sector, the strategy for R&D and innovation is driven by the government's **Food Strategy**, which sets out the approach on research and innovation to support a more sustainable food system farm to fork. See also the **Strategic Priorities Fund Programme for transforming the food system – Transforming UK Food Systems – Global Food Security,** Challenge 9.9. **UKRI Plastics Circular Economy Research Programme, £3.5m SR22-25,** (£7m overall) – will research into delivering a circular economy for plastics and harness the significant positive economic and environmental impacts this will enable. **UKRI's ISCF Smart Sustainable Plastic Packaging Challenge,** £42.4m SR22-25, (£60m overall) – is designed to ensure the required innovation to meet the UK Plastics Pact targets will be developed by industry and academia. This programme is developing new approaches to refill/reuse by retailers as well as new materials and new collection, sorting and recycling technologies for plastic packaging, which has the potential to significantly lower emissions associated with plastic packaging. This includes options for future plastic packaging, including bio-based polymers. See also Challenge 5.1 & 9.12.
9.11. Developing a sustainable bioeconomy	**DESNZ's Net Zero Innovation Portfolio (NZIP) Biomass Feedstocks Innovation Programme** will support increasing the production of sustainable domestic biomass by funding innovative ideas that address barriers to biomass feedstock production. It will support improvements in productivity, through breeding, planting, cultivating and harvesting. See also Challenge 4.2.

Challenge	Current Programme Summary
	Defra is supporting several projects, including **Enhancing Biomass for Biodiversity** which will investigate the potential for biomass plantations to enhance biodiversity in the UK, as well as development of evidence on economic and environmental impacts of land-use change (Biodiversity and Ecosystem services modelling) resulting from biomass production. **Earth Observation and geospatial mapping** will also be used to identify, quantify and locate crops across the UK and the potential for new areas of planting. UKRI has supported several **Networks in Industrial Biotechnology and Bioenergy, £4.4m SR22-25,** to pump-prime support for bio-based manufacturing and remediating the environment. The first six networks will contribute expertise to underpin biobased manufacturing for sectors such as materials, chemicals, energy carriers, pharmaceuticals and construction. The focus is to drive new ideas to harness the potential of biological resources for producing and processing materials, biopharmaceuticals, chemicals and energy. UKRI is also **funding bio-based approaches in textile manufacture and precious metal recovery, £5m SR22-25,** to develop bio-based tools to improve sustainability and reduce emissions in these two industries.
9.12. Reducing waste and minimising emissions	Government commissioned research will provide robust and up-to-date waste composition analysis projects, as well as targeting future landfill emissions and increasing the capture of emissions from existing waste. **The Waste Composition Programme** will be vital in providing a baseline to monitor and evaluate the impact of policies and progress towards key targets. Additional net zero research will be undertaken to support minimisation of methane emissions from landfills and the UKRI Strategic Priorities Fund **National Interdisciplinary Circular Economy Research (NICER) Programme** of circular economy centres aims to reduce waste. See also **UKRI's ISCF Smart Sustainable Plastic Packaging Challenge,** Challenges 5.1 & 9.10.

Challenge	Current Programme Summary
	Food Loss and waste makes a significant contribution to GHG emissions, with food waste accounting for about 10% of global emissions. UKRI is developing a research programme to address this challenge, building on the **Horticulture Crop Quality and Food Loss Prevention Network, £0.5m SR22-25**. Internationally, the **Ayrton Fund / ODA-funded Transforming Energy Access Programme (TEA)** is supporting innovations in reducing and managing electronic waste in Africa.
9.13. Reducing process emissions and energy use in the wastewater treatment sector	The water industry has launched their route map to net zero by 2030. Water companies will be making investments in reaching net zero, regulated by Ofwat, with funding raised through water bills. Evidence assessments of measures to reduce Greenhouse Gas Emissions from the wastewater treatment sector will be commissioned by Defra. UKRI alongside Defra are investing **£6.9m SR22-25** (£8.4m overall) into **understanding changes in the quality of UK freshwaters** that will support reduced water treatment costs including reduced emissions through better planning for improving water quality.
9.14. Minimising UK F-gas emissions	Work on this is being undertaken as part of policy appraisal in the review of the F-gas Regulation. This includes exploring alternative technology options through engagement with industry.
9.15. Enhancing the global coverage of atmospheric monitoring of Montreal Protocol controlled substances	Internationally, work is mainly aimed at the identification and filling of gaps in, and enhancement of current global monitoring of ozone depleting substances.

A Whole Systems approach

Taking a systems approach requires research to understand the interrelated nature of different sectors, the interaction of new technologies and how these impact consumers' green choices and business models, as well as their potential impacts on health. Cross-cutting themes and systems research questions include understanding the optimum use of scarce resources; integration of digital solutions; the need for broad public support of new technologies; as well as the development of viable markets, regulatory arrangements and supply chains. The characteristics of the net zero challenge requires action by multiple parties across the public and private sectors, delivery at pace and management of uncertainty.

Taking a systems approach to policy will help to navigate this complexity. We must consider the environment, society and economy as parts of an interconnected system, where changes to one area can directly or indirectly impact others. This will help to ensure we design policy to maximise benefits, account for dependencies, mitigate conflicting interests and take account of learning as we go. It reduces the risk of unintended consequences, ensuring individual decisions designed to help achieve net zero do not end up hindering it or other important objectives.

Challenge	Current Programme Summary
10.1. Navigating pathways to achieving net zero	**The UKRI Changing the Environment Programme, £24m SR22-25,** (£40m overall) – aims to stimulate new collaborations across disciplines, to help realise the full potential of the UK's contribution to environmental challenges such as energy decarbonisation, creating a circular economy, reversing biodiversity decline, sustainable supply chains and cleaner air. In addition, the **UK FIRES Research Programme, £2m SR22-25,** (£5.2m overall) – aims to reveal and stimulate industrial growth in the UK compatible with a rapid transition to zero emissions. **The Strategic Priority Fund UK Climate Resilience Programme, £2.1m SR22-25,** (£18.7m overall) – funded by UKRI and the Met Office, focusses on drawing together climate research and expertise to provide robust, multi and interdisciplinary climate risk and adaptation solutions research, required to ensure the UK is resilient to climate variability and able to exploit adaptation and green growth opportunities. **UKRI's Geoenergy Observatories (UKGEOS), £12.4m SR22-25,** (£31m overall) – is developing two subsurface observatories in Glasgow and Cheshire. This network of UK observatories will deliver essential new data to understand how geothermal energy, hydrogen, carbon capture and storage, and storage solutions for wind, solar and tidal energy can reduce our carbon emissions. Air pollution and climate are interlinked, with many air pollutants being 'climatically active', such that improving air quality also contributes to mitigation against climate change. **The UKRI Strategic Priority Fund Clean Air Programme, £15.5m SR22-25,** (£42.5m for wave 1 and wave 2 overall) – adopts an integrated approach to develop innovative solutions which could have co-benefits for both air quality and climate change. Internationally, **the Climate Compatible Growth (CCG) Programme**, £38m, part of the Ayrton Fund, is helping developing countries with economic strategies, plans and policies to attract investment into low-carbon growth opportunities.

Challenge	Current Programme Summary
10.2. Managing socio-economic and behavioural impacts	**UKRI's the Future Observatory: Design the Green Transition Net Zero Programme, £25m,** supports design, research, innovation and public engagement on societal change and green choices. This includes a national engagement centre, up to 50 hyperlocal, place-based engagement projects and 4 large-scale regional clusters, as well as embedding highly qualified design researchers in public, private and third sector organisations. **UKRI's Centre for Climate Change and Social Transformations (CAST), £2m SR22-25,** (£5m overall) – supports research on green choices in four areas of everyday life with potential climate change impacts: consumption of goods and physical products, food and diet, travel, and heating / cooling. **UKRI's Advancing Capacity for Climate and Environment Social Science (ACCESS), £2m SR22-25,** (£5m overall) – aims to provide leadership to the social science contribution to tackling and solving environmental problems, by providing insights and new solutions to support the transition to a sustainable and biodiverse environment and a net zero society. UKRI supported research programme, the **Economics of Biodiversity, £5.7m SR22-25,** (£6.4m overall) – will address how biodiversity and ecosystems connect to wider societal factors, such as achieving net zero, by advancing our understanding of the economic value, benefits and costs that society associates with, and derives from, biodiversity. Internationally, the Ayrton Fund supports the **Modern Energy Cooking Services (MECS) Programme –** £27.4m, which aims to transition from biomass to clean cooking in developing countries, delivering major health and environmental benefits.

Challenge	Current Programme Summary
10.3. Developing an enabling environment for net zero through new business models and finance	**The UKRI Strategic Priorities Fund National Interdisciplinary Circular Economy Research (NICER) Programme**, see Challenge 5.1 and other references. Over the next four years, the programme aims to deliver systemic change in the way resources are used, valued and measured across the UK. The UKRI **Climate and Environmental Risk Analytics for Resilient Finance (CERAF) Programme, £8.3m SR22-25**, (£10m overall) – aims to establish climate and environmental risk analytics capabilities and capacity in the UK. This aims to meet the needs of the financial services sector and enhance the resilience of the financial system to the increasing impact of climate change. In addition, UKRI is also supporting the **Nature Positive Finance Programme, £3.4m SR22-25,** (£5m overall) – which complements and draws on the **Economics of Biodiversity Programme** (see Challenge 10.2 for further details) to further our understanding of the complex interlinkages between biodiversity, finance and society, which can be integrated into financial decision making. These programmes jointly will help to deliver robust models and scenarios leading to a more sustainable financial services industry for net zero, aligning global financial systems with climate and biodiversity goals. **UKRI Finance for Net Zero Programme, £15m,** aims to unlock the complex solutions required to accelerate the low-carbon economy and boost clean growth investment. This will include partnering with leading experts, developing new financial models, connecting investors with businesses and focusing on access to finance. It will support the delivery of new financial products and services to ensure a more integrated approach to scaling and levelling-up net zero solutions.

Challenge	Current Programme Summary
	UKRI's ISCF Driving the Electric Revolution Challenge (DER), £33.8m SR22-25, (£80m overall) – is investing in innovation projects and open access facilities to drive the growth of Power Electronics, Machines and Drives (PEMD) in the UK. This is an underpinning technology across all sectors and interventions in renewable energy, transport and recycling of critical minerals and other materials are intended to grow UK manufacturing and supply chains. **UKRI Circular Critical Materials Programme** – see Challenge 5.1. Internationally, the ODA-funded **Transforming Energy Access (TEA) Platform** supports early-stage testing and scale-up of innovative technologies and business models that accelerate access to affordable, clean energy in developing countries in Sub-Saharan Africa, South Asia, and the Indo-Pacific region.
10.4. Taking a place-based approach	**UKRI's ISCF Prospering from the Energy Revolution Challenge (PFER),** £17m SR22-25, (£102.5m overall) – is investing in industry and research to accelerate innovation in smart local energy systems. See also Challenge 7.1. **The Place-Based Climate Action Network (PCAN), £1m SR22-25,** (£3.6m overall) – is a UKRI supported network that is developing city-level Climate Commissions in Leeds, Belfast and Edinburgh and replicating the model at different scales across the UK. These Climate Commissions enlist business and civic leaders to work with local authorities on climate action. **UKRI Net Zero Places / Living Labs, £60m,** is tapping into the opportunities and markets for transforming places across the UK in a just transition to net zero, by unlocking demand and boosting supply of consumer-centric low carbon products and services. This will include solutions creating levelling-up and societal advantages, such as reduced pollution and other health benefits. The programme will match the ambition of towns, cities and communities, with the know-how for overcoming systemic challenges, unlocking finance and integrating consumer-centric products and services.

Challenge	Current Programme Summary
10.5. Mobilising digital solutions and data and the shift to Industry 4.0	**The National Interdisciplinary Circular Economy Research (NICER) Programme** – See Challenge 5.1 and other references. **Constructing a Digital Environment Programme, £1.06m SR22-25,** (£10.04 overall) – funded by UKRI and Defra, is developing a digitally enabled environment by creating an integrated network of sensors, methodologies and tools for assessing, analysing, monitoring, and forecasting the state of the natural environment at higher spatial resolutions and frequency than previously possible. This will inform our understanding of long-term environmental change and prediction of events.
10.6. Developing an integrated energy system	UKRI is supporting a network of research centres focussed on whole systems analysis of the energy system. This includes: the **UK Energy Research Centre (UKERC), £6.6m,** which conducts a whole systems research programme addressing the transition to a net zero energy system and economy.

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