National Audit Office

REPORT

Support for innovation to deliver net zero

Department for Energy Security & Net Zero

SESSION 2022-23
19 MAY 2023
HC 1321

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National Audit Office

Support for innovation to deliver net zero

Department for Energy Security & Net Zero

Report by the Comptroller and Auditor General

Ordered by the House of Commons
to be printed on 17 May 2023

This report has been prepared under Section 6 of the National Audit Act 1983 for presentation to the House of Commons in accordance with Section 9 of the Act

Gareth Davies
Comptroller and Auditor General
National Audit Office

11 May 2023

HC 1321 | £10.00

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011760 05/23 NAO

Contents

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Key facts

£4.2bn

the government's estimated planned spending in its Delivery Plan for net zero research and innovation provided through the Spending Review from 2022 to 2025

£23bn

Department for Energy Security & Net Zero's (DESNZ) estimate, in its updated Green Finance Strategy, of the new low-carbon investment in 2022 in the UK

£60bn – £170bn

Climate Change Committee's estimate for potential total UK export sales in sectors such as the electrification of transport, green finance, precision agriculture, renewables, sustainable construction and sustainable infrastructure by 2030

Seven	number of categories included in the *Net Zero Research and Innovation Framework*: power; industry and low-carbon hydrogen supply; carbon capture and storage and greenhouse gas removals; heat and buildings; transport; natural resources, waste and fluorinated gases; and 'whole systems approach'
115	number of government programmes providing funds for net zero research and innovation, delivered across eight public bodies
£0.35 million to £685 million	the range in size of funding programmes included in the government's net zero research and innovation Delivery Plan

Summary

Background

1 In June 2019, Parliament passed an amendment to the Climate Change Act 2008, committing the UK to achieving 'net zero' greenhouse gas emissions (emissions) by 2050. This means reducing emissions (also known as 'decarbonisation') substantially from current levels, with residual emissions the UK still emits in 2050 being equal to or less than what is removed from the atmosphere by either the natural environment or carbon capture technologies. Since 2009, in support of the government's decarbonisation commitments, the UK has set legally binding carbon budgets, which restrict the total amount of greenhouse gases the UK can emit over five-year periods. To date the UK has set a series of budgets extending out to 2033–2037.

2 The government expects research and innovation to play a crucial part in the UK achieving net zero. The Department for Business, Energy & Industrial Strategy (BEIS) had responsibility for net zero policy until responsibility was transferred to the new Department for Energy Security & Net Zero (DESNZ) on 7 February 2023. BEIS identified that net zero will require "a step change" in the rate of new technologies and processes being developed and deployed into the market and being adopted by businesses and consumers. The Climate Change Committee, an independent emissions advisory body, has also noted innovation is a fundamental component in the transition to net zero. The International Energy Agency has estimated that nearly half of carbon emission reductions required from the global energy sector for the world to reach net zero will need to come from technologies that are still under development.

3 The government believes that the development of net zero technologies will give UK businesses a competitive edge in world markets. A government review highlighted analysis by consultants in 2020 that estimated that renewable and low-carbon technologies could support 1.38 million low-carbon jobs by 2050, with as many as 804,000 direct jobs in the low-carbon and renewable energy economy by 2030 in the UK. In 2017, research commissioned by the Climate Change Committee estimated a potential for total UK export sales of between £60 billion and £170 billion by 2030 for low-carbon goods and services in areas such as the electrification of transport, green finance, precision agriculture, renewables, sustainable construction, and sustainable infrastructure.

4 The government has defined innovation as the creation and application of new knowledge to improve the world. Successful innovation involves multiple stages that can broadly be understood as:

- research and development: creating and advancing ideas or concepts, typically in science and technology;
- commercial prototype: developing an idea into a material form so it can be validated. This stage typically includes testing the technical aspects of the idea, for example, its performance and safety;
- build and scale: building an idea to full size to allow for more testing;
- proven commercial proposition: once an idea meets the requirements and it can be rolled out profitably, from this point, it can go into large-scale production; and
- capital markets ready: when an innovation is fully developed, and it can establish a new market, or gain a share of an existing market.

In practice, innovation often does not follow a neat stage-by-stage process and will take a less predictable path to market, and many ideas do not succeed.

5 In October 2021, BEIS published the government's *Net Zero Research and Innovation Framework* (the Framework). The Framework is intended to provide the private sector and the academic and research communities an indication of the UK's likely areas of focus over the years ahead. BEIS also outlined in the Framework an intention to follow it up with a detailed Delivery Plan setting out how the government investment will be prioritised. The Delivery Plan was published in March 2023.

6 Prior to February 2023, in addition to overall responsibility for achieving net zero, BEIS had lead responsibility for supporting research and innovation. In February 2023 responsibility for supporting research and innovation was given to the newly created Department for Science, Innovation & Technology (DSIT). A number of departments and other bodies play a key role in supporting the government's net zero research and innovation challenge areas.

7 This report examines whether the government is set up to deliver value for money from its approach to investment in research and innovation to deliver net zero in the UK. In doing so, and in keeping with our statutory remit, the report does not question the merits of the government's policy objectives or challenge areas set out in the Framework. The report examines:

- the effectiveness of mechanisms in place for providing leadership and coordination of net zero research and innovation activities (paragraphs 2.2 to 2.8);
- arrangements for delivering net zero research and innovation support and whether this is aligned with the challenge areas set out in the Framework (paragraphs 2.9 to 2.27); and
- plans for reviewing progress and evaluating impact against the desired outputs and outcomes (paragraphs 2.28 to 2.32).

Key findings

Determining net zero research and innovation challenge areas

8 The Framework set out the UK's net zero research and innovation challenge areas for the first time, providing stakeholders with a clear steer on the main innovation priorities and timescales. The Framework put existing research and innovation work for net zero into a wider context. It identified 31 research and innovation challenge areas across seven categories (**Figure 1** overleaf). It also identified the timeframe within which solutions will be needed in each of the challenge areas. The 31 challenge areas operate over different timescales, ranging from building retrofit and energy efficiency solutions where the government hopes to see significant progress over the next decade, to challenge areas such as decarbonising aviation, which are likely to require a much longer-term focus up to 2050 (paragraphs 1.8, 2.3, 2.7 and Figure 3).

9 The cross-government Net Zero Innovation Board (the Board) oversaw the development of the Framework. The Board is chaired by the government chief scientific adviser and brings together public bodies that fund net zero research and innovation activities together with independent members drawn from industry and academics. Successful support for net zero research and innovation will require the host of departments and public bodies involved to work effectively with their private sector partners, the research community, and investors. Since July 2022, the Board has been supported by an Innovation Delivery Board, comprising of senior officials, which has responsibility for reviewing programme delivery, improving collaboration, and capturing and communicating successful outcomes across the research and innovation process (paragraphs 1.14, 1.15, 2.11 and 2.12).

Figure 1

Categories and challenge areas identified in the government's *Net Zero Research and Innovation Framework*

In October 2021, the Department for Business, Energy & Industrial Strategy (BEIS) published the government's *Net Zero Research and Innovation Framework* which set out 31 challenge areas across seven categories

Categories for research and innovation to 2050	Challenge areas identified in the *Net Zero Research and Innovation Framework*
Power	Improving system integration, flexible demand and energy storage
	Continual development of offshore wind (including floating) and earlier stage renewables
	Developing nuclear Small Modular Reactors (SMR) and Advanced Modular Reactors (AMR)
	Utilising bioenergy and Bioenergy with Carbon Capture and Storage (BECCS)
Industry and low-carbon hydrogen supply	Improving resource and energy efficiency in industrial applications
	Switching to low- and zero-carbon fuels and feedstocks
	Capturing and storing industrial emissions
	Efficient production of low-carbon hydrogen at scale
	Bulk hydrogen transportation and storage
Carbon Capture Utilisation and Storage (CCUS) and Greenhouse Gas Removals (GGR)	Capturing emissions efficiently and at low cost
	Supply chain innovation for CCUS
	Developing and improving transportation and storage of carbon dioxide
	Developing and demonstrating GGR technologies
Heat and buildings	Building retrofit and energy efficiency solutions
	Understanding feasibility and safety of hydrogen for heating
	Further innovation of heat pumps, including installation and use
	Researching and trialling heat networks and non-traditional heat sources
Transport	Transport and mobility as a system
	Decarbonising roads
	Decarbonising railways
	Decarbonising aviation
	Decarbonising maritime sectors
Natural resources, waste and fluorinated gases	Integrated and dynamic approach to land use
	Sustainably managing forests, peatlands and the marine environment
	Sustainable food and biomass production
	Reducing and minimising waste and fluorinated gases
Whole systems approach	Understanding optimal net zero pathways
	Creating an integrated energy system
	Enabling integrated, multi-modal transport systems
	Developing digital solutions and unlocking resource and energy efficiency
	Researching, understanding, and unlocking sustainable behaviours, business and financial models

Source: National Audit Office analysis of the government's *Net Zero Research and Innovation Framework*, October 2021

10 The Board, supported by BEIS, used an evidence-based approach to advise the government on the 31 challenge areas set out in the Framework. BEIS drew on existing evidence sources to inform the 31 challenge areas for the Framework. This included work it undertook in 2019 to identify innovation needs in the UK's future energy system, and a cost optimisation model of the whole UK energy system. This work identified the technologies that will deliver the greatest emissions and cost reductions to the energy system as a whole. BEIS also drew on another model that produced an estimate of all greenhouse gases, including land use emissions, under different technology options. It also provided extensive scenario and sensitivity analysis. The Board engaged with a wide range of expert stakeholders to obtain views on the main challenge areas. This included holding sector workshops with industry stakeholders and academics to brief them on the draft Framework, receive their challenge and validation of the key innovation challenge areas, and discuss priorities. Of the stakeholders we spoke to who were familiar with the Framework, many were broadly supportive of the Framework, with some suggesting it provided a good level of ambition (paragraphs 2.4 to 2.6).

11 BEIS did not consider in its analysis what level of longer-term public sector investment might be required up to 2050 to support delivery of the innovation challenge areas. BEIS did not include any assessment of the expected costs against the 31 challenge areas in the Framework. Some stakeholders we interviewed, while positive about the clarification of the government priorities contained in the Framework were nevertheless concerned at the absence of any financial allocation beyond the current Spending Review period. Some commentators suggest that many of the technologies would require longer-term financial investment from both the public and private sectors (paragraph 2.8).

12 The Board has sought to influence the allocation of resources across departments and UK Research and Innovation programmes. Based on an assessment of the estimated distribution of spend across the stages of innovation, the Board recommended to government departments that there should be a more equal distribution of funding between the research, development and demonstration stages. The Board does not take decisions on how money is used. Individual public bodies continue to decide how to use their resources based on the budgets provided by HM Treasury via the Spending Review process (paragraphs 1.15, 2.11, 2.12 and 2.18).

Overseeing the delivery of support for net zero research and innovation

13 In March 2023, DESNZ published the government's Delivery Plan which sets out for the first time the complex landscape of public sector support for net zero research and innovation. The Delivery Plan maps the government's current portfolio of research and innovation programmes for the Spending Review period 2022 to 2025 against the categories in the Framework. The mapping exercise identified 115 funding programmes supporting net zero research and innovation activities across eight public bodies. Many of these funding programmes pre-dated the development of the Delivery Plan, with some also pre-dating the 2021 Framework. The programmes ranged in size from £0.35 million to £685 million. In total, the programmes in the Delivery Plan amount to approximately £4.5 billion of support for net zero research and innovation from 2022 to 2025. Of this, £4.2 billion was provided through the Spending Review and £0.26 billion was provided by Ofgem.[1] Individual departments and public bodies oversee and manage the cost of delivering the individual programmes they are responsible for as part of their normal business case approval processes. DESNZ has at present no central information on the costs of administering the 115 funding programmes and, therefore, whether support is being delivered in the most efficient way (paragraphs 2.13, 2.16 and 2.19).

14 The complexity of public sector funding will make it hard for DESNZ and the Innovation Delivery Board to track spending. The next spending round will provide an opportunity to review the overall level of public spend on net zero research and innovation, and the balance of activity across government, including the need for longer-term commitments to key technologies. DESNZ collated the data it set out in the Delivery Plan through submissions from government departments and UKRI. For coordinating portfolio-level information, including the tracking of spending, it will continue to rely on departmental and UKRI data submissions and the underlying programme management of individual government departments and public bodies to ensure programmes are appropriately managed. This will make it difficult to assess how resources are actually being deployed across the innovation process (paragraph 2.17).

1 Ofgem is funded through annual licence fees paid by the licensed companies that Ofgem regulates. Ofgem's Strategic Innovation Fund, which provides innovation funding for the future of gas and electricity networks, is funded through network charges to bill payers that are set by Ofgem.

15 To achieve its net zero objectives the government depends on innovations gaining commercial viability, but the Delivery Plan only covers government support up to the end of the commercial prototype stage. The government intends the Framework to cover the full innovation process. The Delivery Plan details the major programmes for each net zero category, providing support up to the end of the commercial prototype stage and the government's key deliverables. It does not extend, for example, to how the innovation support will work alongside the work of policy teams and industry, and the action that may be needed to de-risk technology deployment and mobilise private sector investment. In March 2023, the government published its updated Green Finance Strategy, providing a high-level overview of how it expects to work with public financing bodies to commercialise and finance green technologies needed for the transition to net zero.[2,3] The government also published in March and April 2023 several net zero investment roadmaps setting out the government support for investing into some sectors including offshore wind, heat pumps, hydrogen, and carbon capture, use and storage; and it committed to publishing a series of further net zero investment roadmaps throughout 2023 (paragraphs 2.14 and 2.15).

16 It is not clear who is responsible for overseeing end-to-end progress on the individual innovation challenge areas. The Board has commissioned from its DESNZ secretariat a series of 'deep dives' looking at the progress made on some of the seven categories identified in the Framework. Individual organisations are responsible for how they spend their own resources, however, no single person or organisation has responsibility for overseeing the performance of the end-to-end innovation system and the delivery of the desired outcomes for the individual innovation challenge areas. Without such oversight, there is a risk that support is not targeted effectively at the right innovation stages, potential blocks to progress are not addressed quickly, and the businesses and the research community lack a clear focal point for providing feedback (paragraph 2.12).

2 HM Government, *Mobilising Green Investment: 2023 Green Finance Strategy,* March 2023. Available at: https://www.gov.uk/government/publications/green-finance-strategy/mobilising-green-investment-2023-green-finance-strategy

3 Public financing bodies include the UK Infrastructure Bank, the British Business Bank, Innovate UK and UK Export Finance.

17 BEIS recognised that organisations were finding it difficult to access support because of the number and complexity of innovation funding schemes. Some stakeholders we interviewed told us that businesses have found it difficult to navigate all the net zero research and innovation sources of public sector funding. The government's 2021 *UK Innovation Strategy* recognised a need to simplify innovation support. Innovate UK is responsible for helping industry navigate public sector funding. It introduced the first version of an online search tool, a key commitment in the *UK Innovation Strategy*, via Innovate UK's online Innovation Hub in December 2022, and it plans a full launch later in 2023. The aim is to help businesses find all innovation funding and support in one place. At the time of our fieldwork, it was too early to assess whether the search tool had made it easier for businesses to find government support for net zero research and innovation (paragraph 2.20).

18 DESNZ estimates that private capital investment in net zero in the UK will need to increase substantially by the late 2020s. DESNZ estimated in its updated Green Finance Strategy that new low-carbon investment in 2022 in the UK was £23 billion.[4] It told us it expects this will need to increase to around two to three times that level per year through the late 2020s and 2030s.[5] It expects most of this increase will need to come from the private sector. The government is currently not able to estimate what the present level of private capital investment in net zero is, but it has commissioned an external project to develop its approach to tracking flows of net zero investment. Since 2021, the government expects the British Business Bank and UK Infrastructure Bank to work with the private sector to support net zero investments and help build the investment market, to support pushing technologies to the market. Both are still in the early stages of building up their expertise on emerging net zero technologies and where to target investment. Our work suggested that they were yet to be integrated into the end-to-end process for supporting net zero research and innovation. Both the UK Infrastructure Bank and the British Business Bank presented their work on green finance to the Board in February 2023. However, neither organisation has representatives on the Board or sector-specific forums, such as the Hydrogen Advisory Council. On 30 March 2023, UK Infrastructure Bank, British Business Bank, UKRI, and UK Export Finance announced they were establishing a joint forum to encourage collaboration (paragraphs 2.21 to 2.25).

4 DESNZ analysis of BloombergNEF data. We have not audited this estimate.
5 DESNZ internal government estimate. DESNZ was unable to provide supporting evidence for this estimate and we have not audited it.

Measuring and evaluating progress

19 DESNZ, with other departments, has started to establish a process for monitoring progress systematically across the Framework but is still to define what outcomes it is seeking to deliver and what level of risk it will tolerate. The uncertain and longer-term nature of innovation makes some level of failure inevitable. At the time of our fieldwork in early 2023, DESNZ was developing an Innovation Delivery Dashboard, including a set of indicators for measuring progress. Many of the proposed programme indicators were output-focused rather than outcome-focused, such as the number of projects and organisations supported, rather than the number of business opportunities created or the potential for reductions in carbon emissions. This reflects the output-focused commitments in the Delivery Plan. The Innovation Delivery Board, with DESNZ, had yet to specify what interim measures of success might look like. It had also yet to define what level of failure it could tolerate across the Framework, instead placing reliance on risk management by departments at the individual programme level. Without clearly defined outcomes, and a clear assessment of its risk tolerance, it will be difficult for DESNZ and the Innovation Delivery Board to assess whether individual innovation challenge areas are making sufficient progress to contribute to the UK achieving net zero within the expected timescales (paragraphs 2.28 and 2.29).

20 The government does not plan to complete a cross-departmental evaluation of activity across the Framework. There are features we regard as good practice in DESNZ's plans for the evaluation of its own Net Zero Innovation Portfolio, a fund directly administered by DESNZ. This includes reviewing progress by theme and an assessment of the feasibility of measuring its impact compared with a scenario without the intervention. DESNZ believes, however, it would be challenging to implement a Framework-wide evaluation approach because of the diverse mix of innovation challenges in the Framework. It would also require collaboration with many funders. However, without a Framework-wide strategy for evaluation, the government may miss opportunities for learning across organisational boundaries (paragraphs 2.29 to 2.32).

Conclusion on value for money

21 BEIS' creation and publication of the *Net Zero Research and Innovation Framework* clarified the government's priorities in pursuit of net zero and helped communicate those priorities to stakeholders outside government. Its development of the Framework brought together departments and funding bodies from across government and has begun to prompt the right questions within government of how to support the innovation that will be needed. There remains, however, a lack of clarity over who is responsible for overseeing end-to-end progress across the innovation system in the priority areas, what success will look like at key milestones, and what government's risk appetite is in supporting the different priorities within the innovation portfolio.

22 The recent Delivery Plan, published by DESNZ, has mapped out the estimated £4.2 billion of net zero research and innovation public sector funding to 2025 for the first time. This is a significant achievement and a vital step, but there is more to do. The complexity of the funding routes, many of them pre-dating the creation of the Delivery Plan, will make it harder for DESNZ and the Innovation Delivery Board to track spend, identify gaps or duplication in funding, and assess whether funding is being delivered through the most efficient mechanisms. The government intends the Framework to cover the full innovation process. Its updated Green Finance Strategy and investment roadmaps provide a high-level overview of how government expects to work with public finance bodies. However, activities aimed at supporting the latter stages of the innovation process, including the take-up of new innovations in the marketplace, have yet to be brought together in the underlying Delivery Plan. DESNZ should take prompt action to further strengthen its governance and delivery mechanisms, building on the good work done to develop the Framework. Without such action there is a risk that the government will not achieve its carbon and economic objectives, or secure value for money from its £4.2 billion investment.

Recommendations

23 We make the following recommendations to the Department for Energy Security & Net Zero and the Department for Science, Innovation & Technology:

a DESNZ should, by October 2023, set out who is responsible for providing stewardship and overseeing cross-government delivery in each of the seven categories within the Framework, and how it will encourage action if progress is not on track against intended outcomes. In doing so, we recognise that it will be important that individual funding bodies continue to have discretion to take decisions based on the merits of individual research and innovation opportunities and the quality of applications for funding.

b DSIT, working with DESNZ, should by October 2023 identify the lessons learned from the development of the cross-government *Net Zero Research and Innovation Framework*. These lessons should be documented and actively considered in future to aid consistent and effective support across government for innovation objectives, while recognising that there cannot be a one-size-fits-all approach. The aim should be to share thinking across government on how best to support innovation systems, comprising public, private and third sector bodies, to deliver against government innovation objectives.

24 We make the following recommendations to the Net Zero Innovation Board:

c The Board with DESNZ should, by March 2024, coordinate a review of net zero research and innovation programme funds to determine their strategic fit with the Framework, the efficiency of delivery (for example whether fewer larger funds would be more efficient to administer), and what consequent changes are needed.

d The Board should build on its work to develop the Framework to estimate, where possible, by March 2024, what level of public investment might be needed to deliver the required net zero research and innovation activity up to 2050.

e The Board should specify desired outcomes and what level of failure is tolerable for each of the challenge areas by December 2023. From then on, it should monitor and publish regular update reports against the output and outcome targets it has set for each of the challenge areas. This could include, for example, the potential for reductions in carbon emissions and creating business opportunities, such as the amount of private investment. Its reporting on outputs should show public spending broken down by stage of the innovation process.

Part One

The government's support for innovation to deliver net zero

1.1 This part covers:

- the government's net zero commitment;
- the net zero research and innovation priorities; and
- the roles and responsibilities for supporting innovation.

The government's net zero commitment

1.2 The Climate Change Act 2008 (the Act) forms the legislative basis of the UK's efforts to reduce its greenhouse gas emissions (emissions) and limit climate change. The Act sets the UK's legally binding targets to reduce emissions. In June 2019, Parliament passed an amendment to the Act, committing the UK to achieving 'net zero' emissions by 2050. This means reducing emissions (also known as 'decarbonisation') substantially from current levels, with residual emissions the UK still emits in 2050 being equal to or less than what is removed from the atmosphere by either the natural environment or carbon capture technologies. Since 2009, in support of the government's decarbonisation commitments, the UK has set legally binding carbon budgets which restrict the total amount of greenhouse gases the UK can emit over five-year periods. To date, the UK has set a series of budgets extending out to 2033–2037.

1.3 The government expects research and innovation to play a crucial part in the UK achieving net zero. The Department for Business, Energy & Industrial Strategy (BEIS) had responsibility for net zero policy until responsibility was transferred to the new Department for Energy Security & Net Zero (DESNZ) on 7 February 2023. BEIS identified that net zero will require "a step change" in the rate of new technologies and processes being developed and deployed into the market and being adopted by businesses and consumers. The Climate Change Committee, an independent advisory body, has also noted innovation is a fundamental component of the transition to net zero. The International Energy Agency has, for example, estimated that nearly half of carbon emission reductions required from the global energy sector for the world to reach net zero will need to come from technologies that are still under development.

1.4 The government believes that the development of net zero technologies will give UK businesses a competitive edge in world markets. A government review highlighted analysis by Ecuity Consulting in 2020 that estimated that renewable and low-carbon technologies could support 1.38 million low-carbon jobs by 2050, with as many as 804,000 direct jobs in the low-carbon and renewable energy economy by 2030 in the UK.[6] In 2017, research commissioned by the Climate Change Committee estimated a potential for total UK export sales of between £60 billion and £170 billion by 2030 for low-carbon goods and services in areas such as the electrification of transport, green finance, renewables such as wind and heat pump technologies, sustainable construction, and sustainable infrastructure, including waste and water.

1.5 In 2021 the government, as part of its *UK Innovation Strategy*, reiterated its commitment to increase public and private sector research and development expenditure to 2.4% of Gross Domestic Product (GDP).[7] Within this, the government committed to increase public research and development expenditure to £22 billion per year, with part of this being net zero-related**.** The *UK Innovation Strategy* builds on the government's work to support clean growth under its 2017 *Industrial Strategy*.

Innovation and the government's net zero priorities

1.6 The government has defined innovation as the creation and application of new knowledge to improve the world.[8] Successful innovation involves stages that can broadly be understood as: research and development, commercial prototype, build and scale, proven commercial proposition, and capital markets-ready (**Figure 2** overleaf). In practice, innovation often does not follow a neat stage-by-stage process and will take a less predictable path to market, and many ideas do not succeed.

1.7 In its 2021 *Net Zero Strategy*, government committed to enabling the efficient scaling of technologies, systems, and business models to pull them through to commercialisation to allow government to achieve net zero by 2050. The government believes that increased long-term public investment into innovation, skills and infrastructure, alongside appropriate policy support and coordination with industry, will encourage the private sector to invest in long-term net zero technology developments.

6 Ecuity Consulting is now trading as Gemserv, after Gemserv acquired Ecuity in January 2021.

7 On 22 November 2022, the Office for National Statistics (ONS) published new data on research and development expenditure, having updated its methodology. The ONS has not published research and development investment as a percentage of Gross Domestic Product (GDP). This is because the improved estimates of research and development have not yet been incorporated into the calculations of UK GDP and, therefore, an accurate comparison cannot be made as to whether the UK has met its target.

8 Department for Business, Energy & Industrial Strategy, *UK Innovation Strategy*, July 2021. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1009577/uk-innovation-strategy.pdf

Figure 2
Stages of the innovation process

For illustrative purposes, research and innovation can be broken down into stages. In practice, innovation often does not follow a neat stage-by-stage process and will take a less predictable path to market, and many ideas do not succeed

Stage of the innovation process	Types of activities undertaken at this stage
Research and development	Research and development can be understood as creating and advancing ideas or concepts, typically in science and technology.
Commercial prototype	Prototyping is the process of developing an idea into a material form so it can be validated. This stage typically includes testing the technical aspects of the idea, for example, its performance and safety.
Build and scale	Build and scale involves building an idea to full size to allow for more testing.
Proven commercial proposition	Once an idea meets its requirements and it can be rolled out profitably, it is said to be at the proven commercial proposition phase. From this point, it can go into large-scale production.
Capital markets-ready	An innovation is capital markets-ready when it has been fully developed, and it can establish a new market, or gain a share of an existing market.

Note

1 The stages of the innovation process are as presented in the government's *Net Zero Strategy* and *Net Zero Research and Innovation Framework*. The Department for Energy Security & Net Zero has not defined these terms and, therefore, the types of activities undertaken at each stage set out in this Figure are compiled by the National Audit Office.

Source: National Audit Office analysis of the government's *Net Zero Research and Innovation Framework*, October 2021

1.8 In October 2021, BEIS published the government's *Net Zero Research and Innovation Framework* (the Framework), which identified seven categories: comprising six sectors and one category covering cross-cutting systems-wide issues and linkages between sectors; and within those 31 innovation challenge areas (**Figure 3** on pages 20 to 23).[9] In the Framework, BEIS put existing research and innovation work for net zero into a wider context and this is intended to provide the private sector and the academic and research communities with an indication of the UK's likely areas of focus over the years ahead to increase the contribution of innovation towards net zero, and support collaboration. The 31 challenge areas operate over different timescales, ranging from building retrofit and energy efficiency solutions, where government hopes to see significant progress over the next decade, to challenge areas such as decarbonising aviation, which are likely to require a much longer-term focus up to 2050. **Figure 4** on pages 24 and 25 outlines examples of challenge areas identified in the Framework. BEIS also outlined in the Framework an intention to follow it up with a detailed net zero research and innovation Delivery Plan setting out how the government investment will be prioritised.

9 Department for Business, Energy & Industrial Strategy, *Net Zero Research and Innovation Framework*, October 2021. Available at: www.gov.uk/government/publications/net-zero-research-and-innovation-framework

1.9 Government plans to spend approximately £4.2 billion on net zero research and innovation between 2022 and 2025 via the Spending Review, with a further £0.26 billion provided by Ofgem.[10] The funding is distributed across seven government departments and UK Research and Innovation (UKRI) (**Figure 5** on page 26). Of the £4.2 billion, £1 billion went to the Net Zero Innovation Portfolio to support the development of low-carbon technologies and systems and is administered by DESNZ, formerly the Department for Business, Energy & Industrial Strategy. In terms of category, the largest element of the funding is for decarbonising transport, £1.9 billion, followed by power, £1.2 billion (see Figure 7 in Part Two).

Roles and responsibilities

1.10 Prior to February 2023, **BEIS** had overall responsibility across the government for achieving net zero. It also had lead responsibility for supporting research and innovation. In February 2023 responsibility for achieving net zero was transferred to the new **Department for Energy Security & Net Zero**, responsibility for supporting research and innovation and creating the underlying conditions for it to succeed was given to the newly created **Department for Science, Innovation & Technology (DSIT)** and responsibility for supporting business was given to the newly created **Department for Business & Trade (DBT)**.

10 Ofgem is funded through annual licence fees paid by the licensed companies that Ofgem regulates. Ofgem's Strategic Innovation Fund, which provides innovation funding for the future of gas and electricity networks, is funded through network charges to bill payers that are set by Ofgem.

Figure 3

Government's identified key areas for net zero research and innovation to 2050

Government identified the key innovation needs and timescales across seven categories and 31 respective challenge areas that need to be targeted for the UK to reach net zero by 2050 in its 2021 *Net Zero Research and Innovation Framework* (the Framework)

Categories for research and innovation	Decade for delivery			Challenge area identified in the Framework	
	2020s	2030s	2040s	Title	Description
Power	■			Improving system integration, flexible demand and energy storage	Developing an integrated net zero energy system where all connected resources can flexibly respond to all available energy and network capacity, utilising energy storage technologies
	■			Continual development of offshore wind (including floating) and earlier stage renewables	Innovating to improve offshore wind technologies and to develop other renewables such as photovoltaics
	■	■		Developing nuclear Small Modular Reactors (SMR) and Advanced Modular Reactors (AMR)	Developing nuclear fission technologies, that can be categorised as SMRs and AMRs
	■	■		Utilising bioenergy and Bioenergy with Carbon Capture and Storage (BECCS)	Primarily sustainable biomass. Coupling bioenergy with carbon capture can deliver negative emissions (BECCS)
Industry and low-carbon hydrogen supply	■			Improving resource and energy efficiency in industrial applications	Industry is a major source of greenhouse gas emissions. Improving energy efficiency will reduce carbon emissions
	■	■	■	Switching to low- and zero-carbon fuels and feedstocks	Changing the fuel source (eg for heat or power) to low carbon fuels, such as hydrogen and bioenergy
	■	■		Capturing and storing industrial emissions	Applying CCUS to emissions from industrial processes
	■	■		Efficient production of low-carbon hydrogen at scale	Producing hydrogen using low-carbon energy sources at a large scale
	■	■		Bulk hydrogen transportation and storage	Developing the hydrogen network and hydrogen storage to support the security of energy supply
Carbon Capture Utilisation and Storage (CCUS) and Greenhouse Gas Removals (GGR)	■	■		Capturing emissions efficiently and at low-cost	Developing CCUS technologies, and deploying CCUS for industry and hydrogen production
	■			Supply chain innovation for CCUS	Innovation to develop supply chains, including on business models, financing, and risk sharing arrangements
	■	■		Developing and improving transportation and storage of carbon dioxide	Developing lowest-cost transport infrastructure for carbon dioxide, de-risk scale-up of carbon dioxide stores, and development of offshore storage
	■	■	■	Developing and demonstrating GGR technologies	Developing greenhouse gas removal technologies
Heat and buildings	■			Building retrofit and energy efficiency solutions	Retrofitting homes and non-residential buildings to achieve high standards of energy efficiency and to use low-carbon heating sources
	■			Understanding feasibility and safety of hydrogen for heating	Demonstrating the safety and feasability of hydrogen heating, making a decision on hydrogen for heating in 2026
	■			Further innovation of heat pumps, including installation and use	Reducing the cost of heat pump manufacture, reduce disruption from installation and use, and demonstrate use in a range of homes
	■	■		Researching and trialling heat networks and non-traditional heat sources	Developing heat and cooling networks, and innovative solutions to access heat from existing and future fuel sources

Figure 3 *continued*
Government's identified key areas for net zero research and innovation to 2050

Categories for research and innovation	Decade for delivery			Challenge area identified in the Framework	
	2020s	2030s	2040s	Title	Description
Transport				Transport and mobility as a system	Decarbonising the UK transport system through, for example, improving infrastructure for charging and novel battery technology for electric vehicles
				Decarbonising roads	Developing options for hydrogen and electric buses, developing Heavy Goods Vehicles (HGV) technologies such as hydrogen
				Decarbonising railways	Developing hydrogen trains and infrastructure as well as researching hydrogen distribution by rail
				Decarbonising aviation	Developing zero emissions aircraft and airside vehicles
				Decarbonising maritime sectors	Demonstrating zero emission vessels and zero emission ports
Natural resources, waste and fluorinated gases				Integrated and dynamic approach to land-use	Researching tools to inform land-use decisions; understanding the interplay between actors, policy/regulatory frameworks, and technologies
				Sustainably managing forests, peatlands and the marine environment	Developing strategic and sustainable management of treescape and forestry; soil and peatland; and the marine and coastal environment
				Sustainable food and biomass production	Reducing emisisons from agriculture, improving food security, and providing sustainable biomass for energy generation and the wider bioeconomy
				Reducing and minimising waste and fluorinated gases	Developing new practices and technologies to reduce emissions from waste, and reduce the use of fluorinated gases in equipment
Whole systems approach				Understanding optimal net zero pathways	Understanding optimal pathways to reach net zero, interdependencies and trade-offs across physical, natural, social and technological systems
				Creating an integrated energy system	Integrating changes to energy supply, storage, and use with increasing interlinkages between energy sources and different sectors of the economy
				Enabling integrated, multi-modal transport systems	Enabling an integrated, multi-modal transport system and accelerating the adoption of public transport; understanding the role of transport in the energy system
				Developing digital solutions and unlocking resource and energy efficiency	Developing digital solutions to support cross-sector integration, enabling systems-level understanding and unlock resource and energy efficiency
				Researching, understanding, and unlocking sustainable behaviours, business and financial models	Developing new types of business and financial models and to deliver locally and regionally appropriate solutions; incentivising sustainable behaviours

Note
1 The descriptions of the challenge areas are summarised from the Framework and are not an exact quote.

Source: National Audit Office analysis of the government's *Net Zero Research and Innovation Framework*, October 2021

Figure 4

Examples of innovation challenge areas in the *Net Zero Research and Innovation Framework*

Four examples of the 31 challenge areas set out in the *Net Zero Research and Innovation Framework*

Example challenge area	Improving system integration, flexible demand and energy storage	Efficient production of low-carbon hydrogen at scale	Decarbonising aviation	Sustainable food and biomass production
Description	Developing an integrated net zero energy system where all connected resources can flexibly respond to available energy and network capacity, utilising energy storage technologies.	Producing hydrogen using low-carbon energy sources at a large scale.	Developing zero emissions flight and airside operations.	Reducing emissions from agriculture, improving food security, and providing sustainable biomass for energy generation and the wider bioeconomy.
Category	Power	Industry and low-carbon hydrogen supply	Transport	Natural resources, waste and fluorinated gases
Decade for delivery	2020s	2030s	2040s	2040s
Lead department	Department for Energy Security & Net Zero (DESNZ)	Department for Energy Security & Net Zero (DESNZ)	Department for Transport (DfT)	Department for Environment, Food & Rural Affairs (Defra)
Relevant and supporting strategies	• *British energy security strategy* (Department for Business Energy & Industrial Strategy (BEIS), 2022). Sets out ambitions for the UK to expand its domestic low-carbon energy supply and become energy independent. • *Transitioning to a net zero energy system: smart systems and flexibility plan 2021* (BEIS and the Office of Gas and Electricity Markets (Ofgem), 2021). Sets out a vision, analysis, and policies to transition to a smart, flexible, decarbonised energy system. • *Digitalising our energy system for net zero: strategy and action plan* (BEIS, Ofgem and Innovate UK, 2021). Sets out policies to digitalise the energy system.	• *UK hydrogen strategy* (BEIS, 2021). Sets out government's vision for the UK's hydrogen sector, including increasing low-carbon hydrogen production to 5 gigawatts (GW) by 2030. It also outlines requirements for the production, distribution, storage, and use of hydrogen and how to secure economic opportunities. • *The British energy security strategy* aimed to double the UK's hydrogen production ambition to produce up to 10 GW of low-carbon hydrogen by 2030.	• *Jet zero strategy* (DfT, 2022). Sets out all aspects of decarbonising aviation including the development and commercialisation of new, low- and zero-emission aviation technologies and market-based investment opportunities. It includes a five-year delivery plan, setting out the actions that will need to be taken in the coming years to support the delivery of net zero aviation by 2050. • *Destination zero* (Aerospace Technology Institute, 2022). Sets out the UK's aerospace technology strategy for UK aerospace to achieve the net zero 2050 target and maintain global competitiveness.	• *Government food strategy* (Defra, 2022). Sets out government's plans for creating a more prosperous agri-food sector. It highlights innovation as a key component to boosting production and profitability in a sustainable way. • *Biomass strategy* (DESNZ, forthcoming). This will review the amount of sustainable biomass available to the UK and how this resource could be best utilised across the economy to help achieve the government's net zero and wider environmental commitments, while also supporting energy security.
Research and innovation challenges	A flexible energy system is required for integrating high volumes of low-carbon power, heat and transport. To date, power system flexibility has largely been provided by fossil fuels. In the future, the UK will need an energy system that matches demand to renewable generation. Government considers new business models and smart technologies will give end-users the opportunity to manage their energy usage, so it better aligns to times of cheap low-carbon electricity. It believes customer-focused innovation across the supply chain, including industrial energy users and domestic consumers, will be key to this transformation.	Government considers low-carbon hydrogen could be a replacement for some high-carbon fuels used today. It, therefore, expects the UK to need significant amounts of low-carbon hydrogen in the energy system. A key innovation priority for government in the next five to 10 years is to demonstrate low-carbon hydrogen production methods as efficient, reliable, and low-cost at increasing scales. Multiple UK projects are planned for both methane reformation with carbon capture use and storage (CCUS), and electrolytic hydrogen routes, but ongoing innovation is required alongside a better understanding of the wider system and environmental impacts.	Government considers aviation to be among the most difficult to decarbonise sectors and, as a global sector, will require international action. Most low-carbon and zero carbon technological solutions are at very early stages of development, with substantial research and innovation required to develop and test a variety of potential solutions over the coming decade. This includes sustainable aviation fuels obtained from low-carbon feedstocks which could be combined with existing conventional jet fuel to reduce emissions.	Government aims to reduce the emissions from agriculture while addressing other land-based challenges such as food security. Government believes research and innovation needs to address the supply and demand of agriculture products, and to develop solutions that support sustainable choices. Increasing the UK's domestic supply of sustainable biomass feedstocks could support decarbonisation efforts through nature-based carbon capture. Multiple challenges need to be overcome to achieve a scale-up in domestic biomass which needs to be carefully managed so that using organic materials for energy does not direct resources away from agriculture and forestry.

Notes

1 The challenge areas are presented and summarised as they are described in the *Net Zero Research and Innovation Framework* (the Framework).

2 The government does not provide a definition for system integration or flexible demand in the Framework, therefore, the description of *'Improving system integration, flexible demand and energy storage'* comes from Ofgem's website www.ofgem.gov.uk/energy-policy-and-regulation/policy-and-regulatory-programmes/full-chain-flexibility

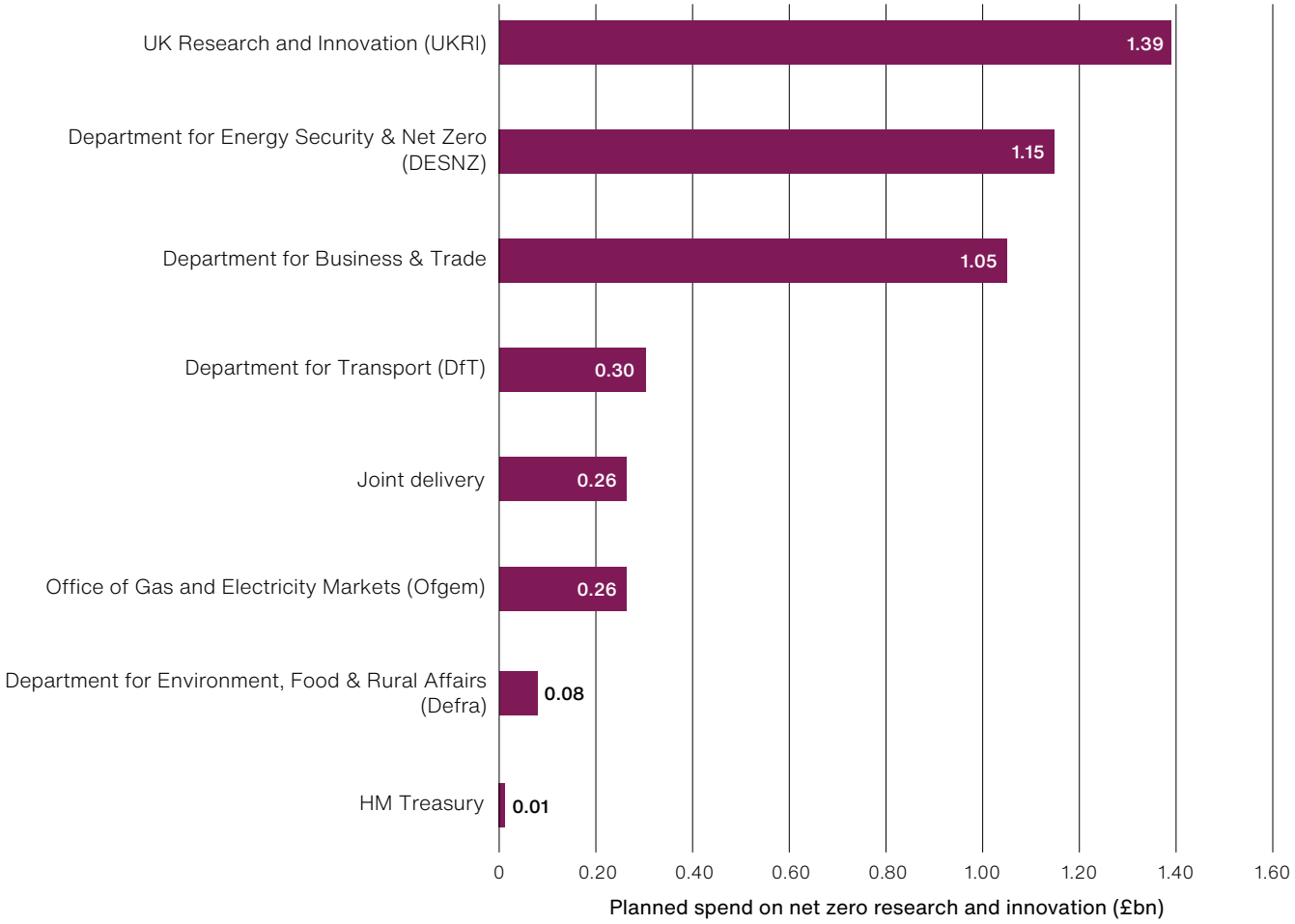
3 The Aerospace Technology Institute (ATI) is an independent organisation funded equally by the government and industrial recipients of grants. Prior to February 2023 the Department for Business, Energy & Industrial Strategy was responsible for ATI funding. In February 2023 responsibility for supporting businesses and ATI funding was given to the newly created Department for Business & Trade.

Source: National Audit Office analysis of the Department for Business, Energy & Industrial Strategy's (BEIS) *Net Zero Research and Innovation Framework*, October 2021; and BEIS data on programmes in the Delivery Plan

Figure 5

Planned spend on net zero research and innovation programmes by public bodies between 2022 to 2025

The net zero research and innovation Delivery Plan outlined approximately £4.2 billion of funding from the Spending Review for net zero research and innovation to 8 public bodies, with a further £0.26 billion provided by the Office of Gas and Electricity Markets (Ofgem)



Notes

1 This Figure includes funding that contributes to net zero research and innovation. The Delivery Plan data contains further relevant research and innovation activities that are not specific to net zero research and innovation, including sector-agnostic support which is not included in the Delivery Plan data.

2 Government provided approximately £4.2 billion through the 2022 Spending Review. A further £0.26 billion was provided by Ofgem, which is funded through annual license fees paid by the licensed companies that Ofgem regulates. Ofgem's Strategic Innovation Fund, which provides innovation funding for the future of gas and electricity networks, is funded through network charges to bill payers that are set by Ofgem.

3 DESNZ compiled these data through departmental returns submitted on relevant programmes. We have not audited the underlying data for the supporting dataset, therefore, we are unable to provide assurance on this estimate.

4 'Joint delivery' refers to programmes that are delivered by more than one department. Programmes are delivered by UKRI and Defra, UKRI and DfT, DESNZ and UKRI, and DESNZ and Ministry of Defence. Some jointly delivered programmes are listed in the government's published Delivery Plan under the lead department instead of both departments responsible for its delivery.

5 Some programmes may be delivered through delivery partners instead of by the department providing the funding.

Source: National Audit Office analysis of the Department for Energy Security & Net Zero's data on programmes in the Delivery Plan

1.11 A number of departments and other bodies play a key role in supporting the government's net zero research and innovation priorities. In addition to the departments already mentioned, the principal bodies include:

- **DfT**, which leads government work on transport and travel-related targets for net zero. DfT is solely responsible for nine programmes in the Delivery Plan, all of which are in the transport sector. The programmes are focused on areas such as decarbonisation of roads, freight, and aviation;
- **Defra**, which leads on programmes on natural resources, waste and fluorinated gases, and is solely responsible for six programmes in the Delivery Plan, targeting agriculture, food, and land use;
- **UK Research and Innovation (UKRI)**, a non-departmental public body now sponsored by DSIT which brings together the seven Research Councils, Research England (which is responsible for supporting research and knowledge exchange at higher education institutions in England), and the UK's innovation agency, Innovate UK. Innovate UK provides research and innovation funding, through grants, contracts, and loans, to businesses from the early stages of idea development to commercialisation. UKRI is solely responsible for 62 programmes across all seven categories in the Delivery Plan, with the highest spend in industry and hydrogen, closely followed by transport; and
- **The Office of Gas and Electricity Markets (Ofgem)**, the regulator of energy markets. It offers funds to support innovation and is responsible for one programme in the power sector in the Delivery Plan. It has developed a set of energy innovation priorities to encourage innovation for energy system needs.

1.12 In some instances, net zero projects that are in further development and beyond early-stage research and innovation may be eligible for support from government investment bodies:

- **The British Business Bank** is a government-owned economic development bank that supports access to finance for smaller businesses. Finance is typically provided to businesses that are starting up, scaling up or expanding. The British Business Bank works with more than 130 partners, rather than financing businesses directly.
- **The UK Infrastructure Bank**, launched in June 2021, provides finance to early-stage technologies commercially deploying for the first time, proven commercial technologies with the intention to accelerate their deployment towards government ambitions and mature technologies transitioning to subsidy-free models.

1.13 In addition to direct funding to support early-stage research and innovation, the government aims to create a policy environment and regulatory framework which incentivises further deployment of new technologies. Private companies may also be encouraged to invest, for example through the tax credits system, although departmental data do not break down how much of this might be ascribed to research and development on net zero activities.

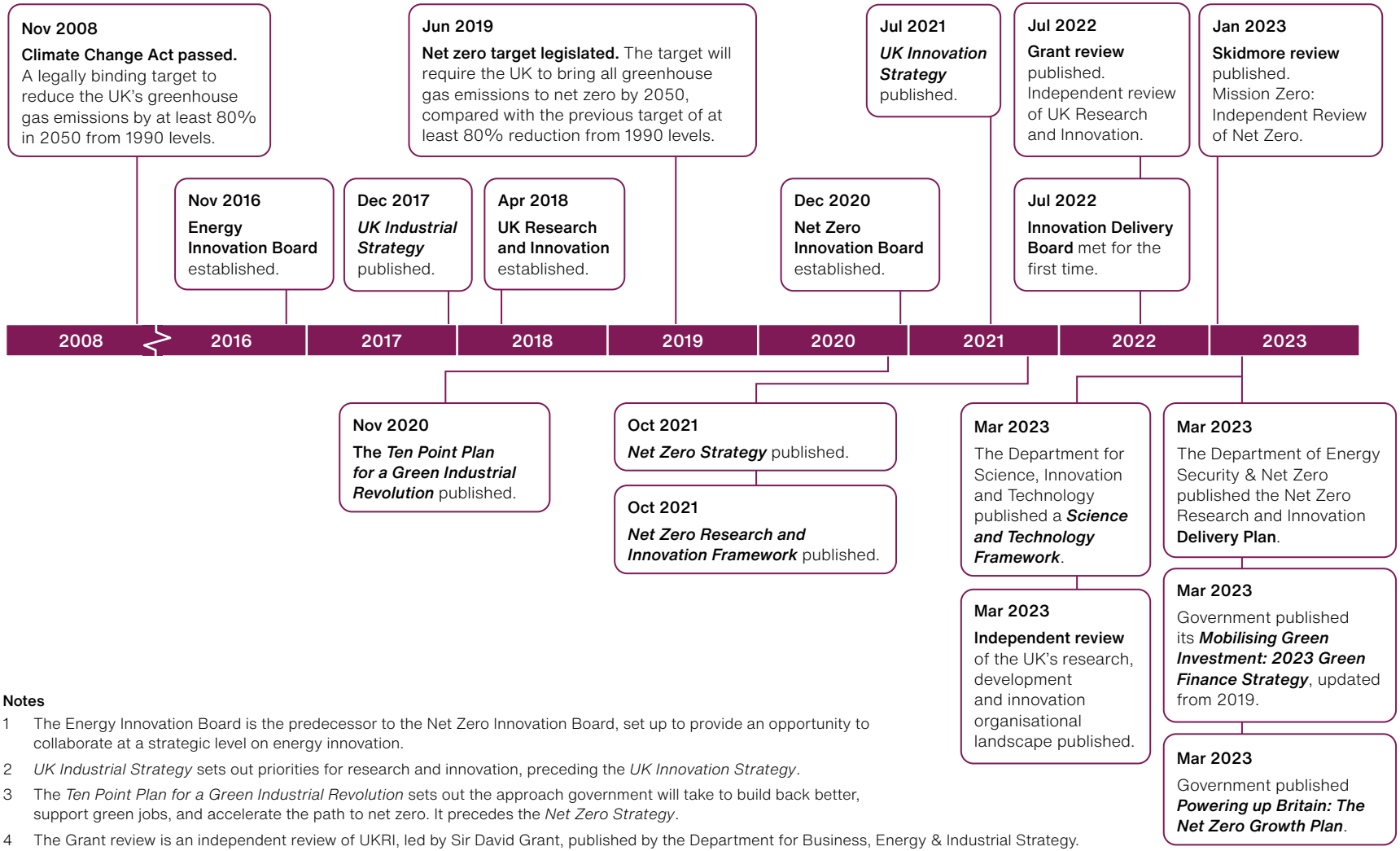
1.14 In December 2020 the government established the **Net Zero Innovation Board (the Board)**, chaired by the government chief scientific adviser, to develop and oversee the net zero research and innovation priorities. It built on a previous Energy Innovation Board, set up in November 2016, which helped organisations work together on energy innovation. Where the Board discusses items of significant interest to ministers, they will be sent short summaries and recommendations from the chair on behalf of the Board, but individual board members decide how the Board's work should feed into their organisations' existing governance structures. Successful support for net zero research and innovation will require the host of departments and public bodies to work effectively with their private sector partners, the research community, and investors. The Board – comprising senior officials drawn from across the major public sector funding bodies, independent members drawn from industry from sectors such as the energy sector and clean growth, alongside some academics – provides strategic oversight of the performance of the net zero research and innovation system. There is a good level of representation from departments across government: a minimum of five members must attend meetings; we found that attendance met this requirement across all meetings held between December 2020 and January 2022.

1.15 The Board was responsible for developing the Framework published in October 2021. While the Board seeks to influence spending decisions across departments and UKRI programmes, it does not have authority to direct decisions on the use of individual funds or policies, as it recognises that public bodies do this through their own decision-making structures. A sub-group of the Board, the **Innovation Delivery Board**, reviews progress and reports to the Board. This sub-group first met in July 2022 and has held three meetings. The recent changes in departmental responsibilities come in the wake of a period of rapid evolution in the policies governing support to net zero research and innovation and in the key institutions used to deliver that support. **Figure 6** charts some of the significant policy documents and other changes since 2008.

Figure 6

Timeline of key events relating to net zero and innovation, between 2008 and 2023

The government's *Net Zero Research and Innovation Framework*, published October 2021, builds on a complex landscape of government strategies, reviews and governance arrangements



Notes

1 The Energy Innovation Board is the predecessor to the Net Zero Innovation Board, set up to provide an opportunity to collaborate at a strategic level on energy innovation.

2 *UK Industrial Strategy* sets out priorities for research and innovation, preceding the *UK Innovation Strategy*.

3 The *Ten Point Plan for a Green Industrial Revolution* sets out the approach government will take to build back better, support green jobs, and accelerate the path to net zero. It precedes the *Net Zero Strategy*.

4 The Grant review is an independent review of UKRI, led by Sir David Grant, published by the Department for Business, Energy & Industrial Strategy.

5 Skidmore review is an independent review of net zero delivery by 2050, led by former Energy Minister Chris Skidmore, to ensure the net zero commitment is met in an economically efficient way.

Source: National Audit Office analysis of published government strategies, reviews, and legislation that has passed in relation to net zero research and innovation

Scope of National Audit Office review

1.16 We examined whether the government is set up to deliver value for money from its approach to investment in research and innovation to deliver net zero in the UK. In doing so, and in keeping with our statutory remit, the report does not question the merits of government's policy objectives or priorities set out in the Framework. We focused on the challenge areas set out in the October 2021 *Net Zero Research and Innovation Framework* and drew upon value-for-money criteria first developed for our 2017 report on *Cross-government funding of research and development*. We examined:

- the effectiveness of mechanisms in place for providing leadership and coordination of net zero research and innovation activities (paragraphs 2.2 to 2.8);
- arrangements for delivering net zero research and innovation support and whether this is aligned with the challenge areas set out in the Framework (paragraphs 2.9 to 2.27); and
- plans for reviewing progress and evaluating impact against the desired outputs and outcomes (paragraphs 2.28 to 2.32).

1.17 In Part Two we set out our main findings on leadership, delivery and measuring the impact of government support for net zero research and innovation. Our study methods are explained further at Appendix One. Our work also included examination of four of the 31 challenge areas in the Framework to provide more detailed examples (see Figure 4). Most of our fieldwork was conducted prior to February 2023 and the creation of the Department for Energy Security & Net Zero and the Department for Science, Innovation & Technology.

Part Two

Leadership, delivery and measuring impact

2.1 This part examines:

- whether a robust process was used to support decisions on innovation priorities (paragraphs 2.2 to 2.8);
- whether there are effective arrangements for overseeing the delivery of net zero research and innovation support (paragraphs 2.9 to 2.27); and
- whether there are mechanisms for measuring progress towards innovation for net zero (paragraphs 2.28 to 2.32).

Determining innovation priorities

2.2 In January 2020, the Council for Science and Technology (CST) called for a clear vision of the system needed to reach net zero, to align public and private investment and individual decisions.[11] It argued that the vision should allow development of clear timescales for decision points, set a framework for working in partnership with industry for delivering the infrastructure changes, and help avoid unnecessary expenditure and delay.

2.3 The *Net Zero Research and Innovation Framework* (the Framework) published by the Department for Business, Energy & Industrial Strategy (BEIS) in October 2021, sets out for the first time the UK's net zero research and innovation priorities (see paragraph 1.8).[12] Prior to the Framework, government had not set out the full extent of the research and innovation effort needed to support the delivery of net zero. We examined the processes used by BEIS to develop the Framework.

11 The Council for Science and Technology advises the Prime Minister on science matters. Its members include senior industrialists, scientists and entrepreneurs.

12 Department for Business, Energy & Industrial Strategy, *Net Zero Research and Innovation Framework*, October 2021. Available at: www.gov.uk/government/publications/net-zero-research-and-innovation-framework

2.4 The Net Zero Innovation Board (the Board) (see paragraph 1.14) used three main criteria to prioritise net zero research and innovation support:

- The opportunity to deliver major decarbonisation gains.
- The potential for major business opportunities for UK companies.
- The number of options to reach net zero, expecting some failure for new technologies.

2.5 Of the stakeholders we spoke to who were familiar with the Framework, many were broadly supportive of the Framework, with some suggesting it provided a good level of ambition. The Board, supported by BEIS, engaged with a wide range of expert stakeholders to obtain views on the main technology innovation needs and business opportunities. This included holding sector workshops with industry stakeholders and academics to brief them on the draft Framework, receive their challenge and validation of the key innovation challenges, and discuss priorities. This consultation had built on previous work undertaken by BEIS in 2019 to identify innovation needs in the UK's future energy system, as well as other existing evidence sources.[13] The BEIS work involved engaging with more than 180 expert stakeholders and carrying out energy system modelling using a database of 600 innovations.

2.6 Decisions on priorities in the Framework were informed by analysis of the impact on carbon emissions and business opportunities of the different technology options. BEIS used the UK TIMES model and the Energy Systems Modelling Environment (ESME), which are both cost optimisation models of the whole UK energy system, to help inform priorities. The UK TIMES model produced an estimate of all greenhouse gases, including land use emissions, under different technology options and carried out extensive scenario and sensitivity analysis. The National Audit Office reviewed the model as part of our January 2022 report on *Financial modelling in government,* and found it an example of good practice for analysing the uncertainty associated with decision-making.[14] The ESME model identified the technologies that, if deployed, will deliver emissions reductions in line with the net zero target as well as cost reductions to the energy system as a whole. It also identified where government intervention would be most beneficial for the different technologies, informing programme funding prioritisation.

13 Department for Business, Energy & Industrial Strategy, *Energy Innovation Needs Assessments*, November 2019. Available at: www.gov.uk/government/publications/energy-innovation-needs-assessments

14 National Audit Office, *Financial modelling in government*, January 2022, paragraph 3.6: "We found instances of good practice when providing users with uncertainty analysis in our case studies. The UK TIMES model, owned by the Department for Business, Energy & Industrial Strategy (BEIS), is a bottom-up, cost optimisation model of the whole UK energy system. It produces an estimate of all greenhouse gases, including land use emissions, under different planning assumptions and uses extensive scenario and sensitivity analysis. It applies scenario assumptions developed by experts across government." Available at: www.nao.org.uk/wp-content/uploads/2022/01/Financial-modelling-in-government.pdf

2.7 BEIS, with the Board, identified guide timeframes within which solutions will be needed in each of the challenge areas in the Framework (Figure 2). To decarbonise heat and buildings, the Framework envisages that solutions will be needed this decade, whereas those for the sustainable food and biomass challenge area, where research is at a much earlier stage, solutions are not expected to be ready until the 2040s. Government recognises that there is uncertainty around the pathways to net zero. There is, therefore, often not a single consensus view from stakeholders on timeframes. Stakeholders we interviewed had differing views on the projected timings with some calling for more urgent action, while some believed that industry might not be able to deliver some solutions, such as long-term energy storage, until later than planned. Government noted in its Framework that breakthrough technologies could change understanding and approaches in some areas, but that time required to develop and deploy new technologies across an economy means that the next decade must not be wasted.

2.8 BEIS did not assess the total funding needed to deliver the challenge areas identified in the Framework and did not consider what level of longer-term public sector investment might be required up to 2050, despite some technologies needing several decades of development. The current funding allocation finishes in 2025. BEIS did not include any assessment of the expected costs against the major categories in the Framework, or of the potential economic challenges and opportunities from these activities. Some stakeholders we interviewed, while positive about the clarification of the government priorities contained in the Framework, were nevertheless concerned at the absence of any financial allocation beyond the current Spending Review period. Some commentators suggest that many of the technologies would require longer-term financial investment from both the public and private sectors.

Overseeing the delivery of support for net zero research and innovation

2.9 Many different organisations involved in supporting innovation, both public and private, will need to work together effectively to accelerate the delivery of viable technologies and other solutions to market. There is no single entity that directs decision-making across the system. The Department for Energy Security & Net Zero (DESNZ) will, therefore, need to have regard to the performance of the system as a whole, as well as the part played by individual entities.

2.10 We examined whether BEIS, and DESNZ as its successor, will be well placed to oversee the delivery of the priorities set out in the Framework. We examined, in particular:

- the responsibilities for overseeing delivery;
- the preparation of a delivery plan;
- the targeting of support; and
- the extent of joint working with the research and business communities.

Responsibilities for overseeing delivery

2.11 The Board, established in 2020, had responsibility for overseeing the development of the Framework. It now has several ongoing functions including providing strategic direction, seeking to influence departmental and UK Research and Innovation (UKRI) spending decisions, and providing advice and challenge on how the impact of net zero research and innovation activity aligns with the delivery of government net zero objectives (see paragraph 1.14). The Board does not have authority to direct decisions on the use of individual funds or policies. Since July 2022, the Board has been supported by a sub-group, the Innovation Delivery Board, comprising senior officials, which has responsibility for reviewing programme delivery, improving collaboration, and capturing and communicating successful outcomes across the research and innovation process.

2.12 It is not clear who is responsible for the delivery of the overall Framework and who is responsible for overseeing end-to-end progress across the innovation process on the individual challenge areas. The Board has commissioned from its DESNZ secretariat a series of 'deep dives' looking at the progress made on some of the seven categories identified in the Framework. Individual organisations remain responsible for how they spend their own resources, for example, preparing business cases to support the creation of new grant schemes. However, no single person or organisation has responsibility for overseeing the performance of the end-to-end innovation system and the delivery of the desired outcomes. Without such oversight, there is a risk that support is not targeted effectively at the right points in the innovation system, potential blocks to progress are not addressed quickly and businesses and the research community lack a clear focal point for providing feedback.

The preparation of the Delivery Plan

2.13 In March 2023, DESNZ published the government's net zero research and innovation Delivery Plan to support the Framework.[15] The Delivery Plan maps out the government's current portfolio of net zero research and innovation programmes for the Spending Review period 2022 to 2025 against the categories outlined in the Framework.

2.14 The Delivery Plan details the major research and innovation programmes for each of the seven net zero categories, their key deliverables and longer-term policy objectives. The Delivery Plan breaks down the funding available within the seven categories set out in the Framework, with the highest levels of funding for aviation, industry and nuclear challenges (**Figure 7** on pages 36 and 37). It also includes an annex which provides a more detailed overview of government activity to describe the breadth of research and innovation activity being delivered by public bodies.

15 HM Government, *UK Net Zero Research and Innovation Framework: Delivery Plan 2022 to 2025*, March 2023. Available at: www.gov.uk/government/publications/uk-net-zero-research-and-innovation-framework-delivery-plan-2022-to-2025

2.15 The government intends the Framework to cover the full innovation process. The Delivery Plan sets out government support up to the end of the commercial prototype stage of the innovation process (see Figure 2). It does not cover the later stages of the innovation process, for example how the innovation support will work alongside the work of policy teams and industry, and the action that may be needed to de-risk technology deployment and mobilise private sector investment. In March 2023, the government published its updated Green Finance Strategy, providing a high-level overview of how it expects to work with public financing bodies to commercialise and finance green technologies needed for the transition to net zero.[16,17] The government also published in March and April 2023 several net zero investment roadmaps setting out the government support for investing into some sectors including offshore wind, heat pumps, hydrogen, and carbon capture, use and storage; and it committed to publishing a series of further net zero investment roadmaps throughout 2023.

The allocation of resources

2.16 To support the development of the Delivery Plan, DESNZ set out the existing distribution of public funding for the Spending Review period 2022 to 2025. Many of the funds pre-date the development of the Delivery Plan with some also pre-dating the 2021 Framework. Through this mapping exercise, DESNZ identified 115 funding programmes across eight public bodies supporting net zero research and innovation activities. Most of the programmes fall within the remit of UKRI and DESNZ (**Figure 8** on page 38). During the Spending Review period, the programmes ranged in size from £0.35 million to £685 million, with nine funds having more than £100 million (**Figure 9** on page 39). The departments and public bodies oversee and manage the cost of delivering the individual programmes they are responsible for as part of their business case approval process. DESNZ has at present no central information on the costs of administering the 115 funding programmes and, therefore, whether support is being delivered in the most efficient way.

2.17 The complexity of public sector funding will make it hard for DESNZ and the Innovation Delivery Board to track spending. The next spending round will provide an opportunity to review the overall level of public spend on net zero research and innovation, and the balance of activity across government, including the need for longer-term commitments to key technologies. DESNZ collated the data it set out in the Delivery Plan through manual submissions from government departments and UKRI. For coordinating portfolio-level information, including the tracking of spending, it will continue to rely on manual collation of data and the underlying programme management of individual government departments and public bodies to ensure programmes are appropriately managed. This will make it difficult to assess how resources are actually being deployed across the innovation process.

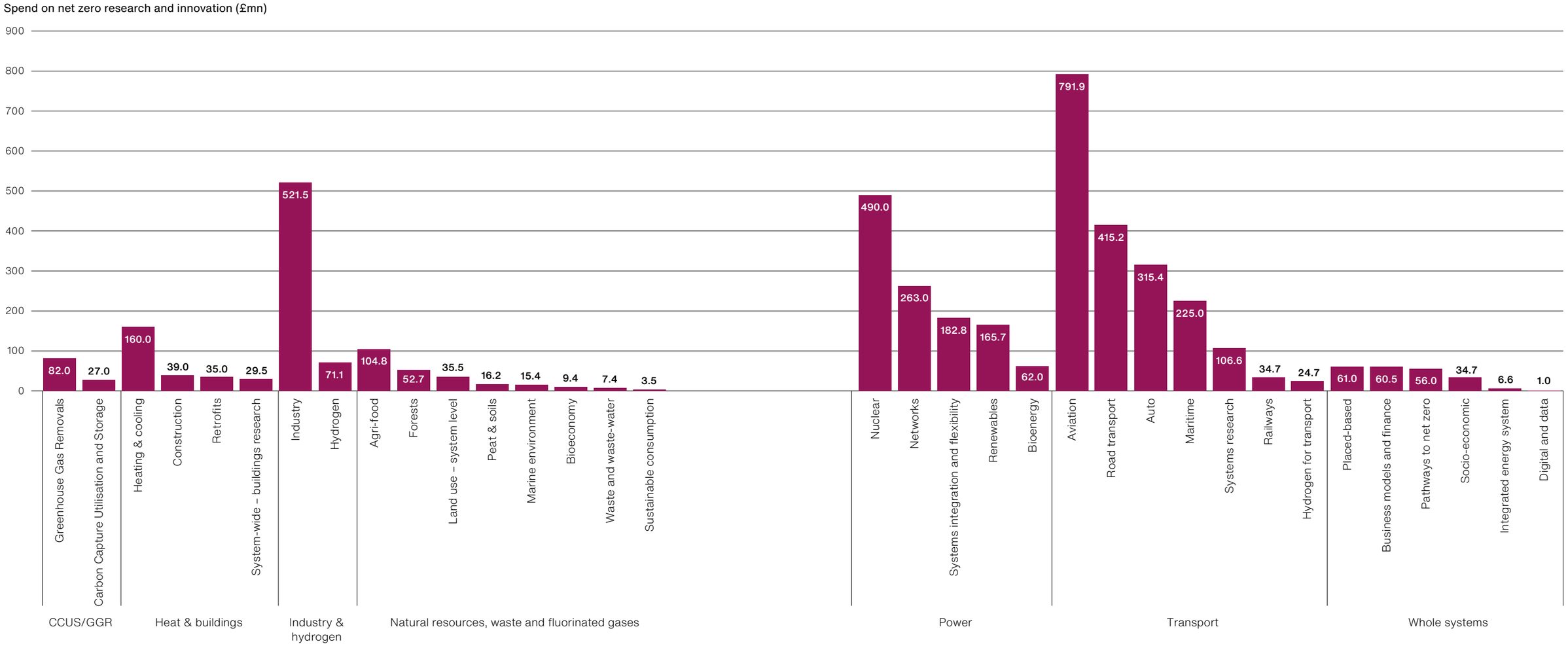
16 HM Government, *Mobilising Green Investment: 2023 Green Finance Strategy,* March 2023. Available at: www.gov.uk/government/publications/green-finance-strategy/mobilising-green-investment-2023-green-finance-strategy

17 Public financing bodies include the UK Infrastructure Bank, the British Business Bank, Innovate UK, and UK Export Finance.

Figure 7

Planned spending for net zero research and innovation programmes across the seven categories identified in the *Net Zero Research and Innovation Framework* between 2022 to 2025

Government's Delivery Plan shows the distribution of approximately £4.5 billion of public sector and Ofgem funding for net zero research and innovation across seven categories and 34 sub-sectors



Notes

1 This Figure includes funding that contributes to net zero research and innovation. The Delivery Plan data contains further relevant research and innovation activities that are not specific to net zero research and innovation, including sector-agnostic support which is not included in the Delivery Plan data.

2 The Department for Energy Security & Net Zero (DESNZ) compiled this data through departmental returns submitted on relevant programmes. We have not audited this self-reported information.

3 There are 20 programmes out of 115 that contribute to more than one challenge area, however, spend is attributed to only one of the challenge areas. Therefore, the division of spend across the categories is an approximation.

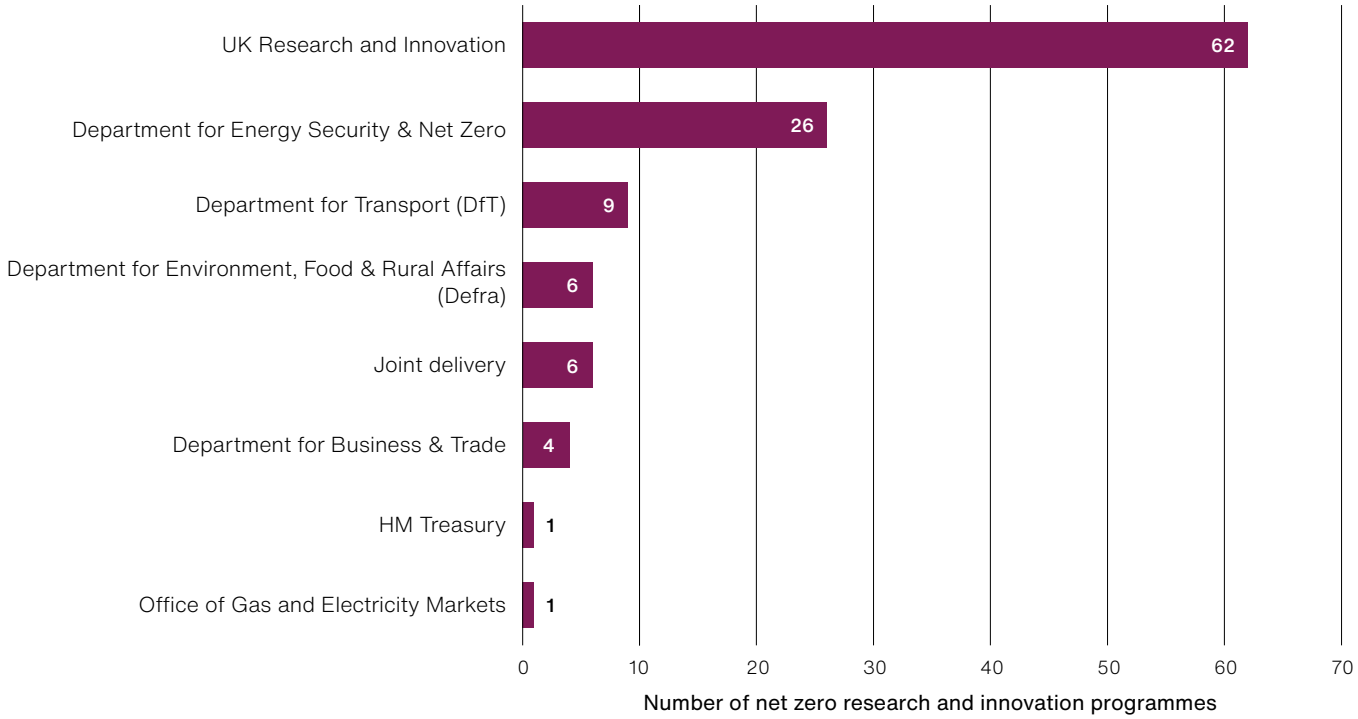
4 Government provided approximately £4.2 billion through the 2022 Spending Review. A further £0.26 billion was provided by Ofgem, which is funded through annual license fees paid by the licensed companies that Ofgem regulates. Ofgem's Strategic Innovation Fund, which provides innovation funding for the future of gas and electricity networks, is funded through network charges to bill payers that are set by Ofgem.

Source: National Audit Office analysis of the Department for Energy Security & Net Zero's data on programmes in the Delivery Plan

Figure 8

Number of net zero research and innovation programmes by public body between 2022 to 2025

UK Research and Innovation (UKRI) and the Department for Energy Security & Net Zero (DESNZ) are responsible for almost three quarters of the 115 net zero research and innovation programmes set out in the government's Delivery Plan for the *Net Zero Research and Innovation Framework*



Notes

1 This Figure includes funding that contributes to net zero research and innovation. The Delivery Plan data contains further relevant research and innovation activities that are not specific to net zero research and innovation, including sector-agnostic support which is not included in the Delivery Plan data.

2 The Department for Energy Security & Net Zero (DESNZ) compiled this data through departmental returns submitted on relevant programmes. We have not audited this self-reported information for the supporting dataset, therefore, we are unable to provide assurance on this estimate.

3 'Joint delivery' refers to programmes that are being delivered by more than one department. Programmes are delivered by UKRI and Defra, UKRI and DfT, DESNZ and UKRI, and DESNZ and Ministry of Defence. Some jointly delivered programmes are listed in the government's published Delivery Plan under the lead department instead of both departments responsible for its delivery.

4 Some programmes may be delivered through delivery partners instead of by the department providing the funding.

Source: National Audit Office analysis of the Department for Energy Security & Net Zero's data on programmes in the Delivery Plan

Figure 9

Distribution of planned spending for net zero research and innovation, as set out in the government's Delivery Plan for the *Net Zero Research and Innovation Framework*

Of programmes in the Delivery Plan, 92% have £100 million or less of funding (£0.1 billion), with only nine programmes having more than £100 million

Amount of spend	Number of net zero research and innovation programmes	Percentage of total programmes
(£mn)		(%)
0–10	46	40
11–50	47	41
51–100	13	11
>100	9	8
Total	**115**	**100**

Notes

1 Programmes range in size from £0.35 million to £685 million for the Spending Review period 2022 to 2025.

2 This Figure includes funding that contributes to net zero research and innovation. The Delivery Plan data contains further relevant research and innovation activities that are not specific to net zero research and innovation, including sector-agnostic support which is not included in the Delivery Plan data.

3 The Department for Energy Security & Net Zero compiled this data through departmental returns submitted on relevant programmes. We have not audited the self-reported information for the supporting dataset, therefore we are unable to provide assurance on this estimate.

Source: National Audit Office analysis of the Department for Energy Security & Net Zero's data on programmes in the Delivery Plan

2.18 In September 2021, the Board assessed the estimated distribution of spend across the different stages of innovation and recommended the government should provide a greater proportion of spending on the later demonstration stages. The assessment showed that the ratio of funding for the research, development and the demonstration stages of innovation was 40:45:15 in 2019-20. The Board recommended to government departments that there should be a more equal distribution of funding between the research, development and demonstration stages between 2022 and 2025, thereby providing a greater proportion of funding for trials and commercialising technologies.

2.19 The Delivery Plan aims to provide greater transparency on how funding between 2022 to 2025 is to be allocated. However, the complexity of the sources of public sector funding will make it difficult to track spending and identify gaps or duplication in funding. The Delivery Plan sets out a total spend of approximately £4.5 billion for supporting net zero research and innovation from 2022 to 2025, of which £4.2 billion was provided through the Spending Review and £0.26 billion was provided by Ofgem.[18] The Delivery Plan sets out funding from 2022 to 2025 by public body, category and challenge area for the first time (Figure 7). The largest planned spend is for activities falling within the transport and power categories, areas where the government believes there are significant decarbonisation needs. Data have started to be tracked across some of the seven categories set out in the Framework to review how the planned spend compares with the Board's previous advice to deliver a more equal distribution of support across the research, development and demonstration activities (paragraph 2.18), but data are not yet available across the Framework as a whole. The lack of data on the profile of spending across the innovation process may make it more difficult for government to track the shift in support as technologies move towards the prototype phase (see paragraph 2.18).

2.20 BEIS recognised that businesses can find accessing support difficult because of the number and complexity of different innovation funding schemes. Some stakeholders we interviewed told us that businesses have found it difficult to navigate the public sector net zero research and innovation funding sources. The government's 2021 *UK Innovation Strategy* recognised a need to simplify innovation support. It committed to developing an online finance and innovation hub between Innovate UK and the British Business Bank, to reduce complexity faced by companies in accessing funding. In December 2022, Innovate UK, which has responsibility for helping industry navigate public sector funding, introduced the first version of an online Innovation Hub, which aims to help businesses find all innovation funding and support in one place. It plans a full launch later in 2023 following further user-testing. At the time of our fieldwork, it was too early to assess whether the search tool had made it easier for businesses to find government support for net zero research and innovation.

18 Ofgem is funded through annual licence fees paid by the licensed companies that Ofgem regulates. Ofgem's Strategic Innovation Fund, which provides innovation funding for the future of gas and electricity networks, is funded through network charges to bill payers that are set by Ofgem.

Stimulating private sector investment

2.21 Private sector investment will be critical to enabling new technologies to scale up and enter the market. DESNZ estimated in its updated Green Finance Strategy that new low-carbon investment in 2022 in the UK was £23 billion.[19] It told us it expects this will need to increase to around two to three times that level per year through the late 2020s and 2030s.[20] It expects most of this increase will need to come from the private sector. The government is currently not able to estimate what the present level of private capital investment is in net zero. We recommended in 2020 that BEIS and HM Treasury should establish monitoring arrangements that enable them to track whether they are achieving the required investment from the private sector. In response, in March 2023, DESNZ outlined in its Green Finance Strategy that it had commissioned an external project to develop its approach to tracking flows of net zero investment systematically from public and private sources of finance. The first stage of the project aims to identify key data gaps to help develop the approach and is planned to conclude in summer 2023.

2.22 The Framework sets out roughly where in the innovation process it believes the net zero research and innovation challenge areas are and an expectation that the innovation stage would influence the type of public sector support required. This showed that challenge areas such as low-carbon hydrogen and advanced nuclear solutions which are in the earlier stages of development will require more government finance, while other more mature challenge areas such as electrification of transport and offshore wind will need less government finance and more private investment. BEIS also carried out a more detailed analysis of the potential investment needs for hydrogen production. In April 2022, BEIS published the government response to its consultation on design of a business model for low-carbon hydrogen alongside a hydrogen investor roadmap. This followed the August 2021 publication of the *UK Hydrogen Strategy*. The government set out in its roadmap, which it updated in April 2023, an ambition for increased hydrogen production of 10 GW (gigawatts) by 2030, needing up to £9 billion of investment, but it has not set out the level of investment beyond this date.

2.23 UKRI and other funding bodies have made private sector investment a condition of allocating public funds to support scaling up by using match funding on some of their net zero research and innovation programmes. UKRI also provides funding that is specifically targeted at the commercialisation stages of innovation, although it is not specific to net zero. It provides this support through several schemes and centres, including innovation loans of between £100,000 and £2 million in value to help small businesses to scale up innovations. The UK's nine 'Catapults' are designed to support innovation and de-risk the transition from research to commercial delivery. As an example from our deep-dive on flexible energy storage, the Energy Systems Catapult aims to help businesses develop new clean technology products and services in the UK.

19 DESNZ analysis of BloombergNEF data. We have not audited this estimate.
20 DESNZ internal government estimate. DESNZ was unable to provide supporting evidence for this estimate and we have not audited it.

2.24 Since 2021, government has expected the British Business Bank and UK Infrastructure Bank, to support net zero investments and help build the investment market, to support pushing technologies to the market. Both organisations are still in the early stages of building up their expertise on emerging net zero technologies and where to target investment:

- British Business Bank – the British Business Bank was given a specific net zero remit in 2021.
- UK Infrastructure Bank – the government launched the UK Infrastructure Bank in June 2021 to increase infrastructure investment supporting regional and local economic growth and tackling climate change. It has an indicative minimum investment size of £25 million for finance to private sector projects and five priority sectors including clean energy.

2.25 Our work suggested that these organisations were yet to be integrated into the end-to-end process for supporting net zero research and innovation. Officials from the UK Infrastructure Bank informed us they had begun to establish contact with some officials supporting the earlier stages of the innovation process. Both the UK Infrastructure Bank and the British Business Bank presented their work on green finance to the Board in February 2023. However, neither organisation has representatives on the Board nor sector-specific forums, such as the Hydrogen Advisory Council. On 30 March 2023, the UK Infrastructure Bank, British Business Bank, UKRI, and UK Export Finance announced they were establishing a joint forum to encourage collaboration.

Joint working between public and private sectors across the innovation process

2.26 Effective support for innovation will require strong joint working between the public and private sectors and between the various public bodies that may become involved in providing support along the way.

2.27 We found evidence of collaboration between the public and private sectors across all four challenge areas we looked at (paragraph 1.17), examples included:

- Production of hydrogen: The *UK Hydrogen Strategy* recognised that the efficient production of low-carbon hydrogen will require support from industry and the research and innovation community. BEIS established a Hydrogen Advisory Council comprising representatives from public bodies, industry and academia. Its role is to inform the development of hydrogen as a decarbonised energy carrier for the UK, including identifying actions for supplying low-carbon hydrogen at scale for use across the energy system. Priorities for the efficient production of low-carbon hydrogen set out in the *UK Hydrogen Strategy*, including ensuring partnerships with key organisations to secure private investment are in place, were developed in partnership with industry through the Hydrogen Advisory Council. In line with advice from industry, BEIS has also published a Hydrogen Business Model which was developed through consultations with key stakeholders;

- Decarbonising aviation: The *Jet Zero* strategy recognises that its decarbonisation goals can only be achieved by collaborating across the aviation ecosystem. The aviation sector has three main joint government and industry forums: the *Aerospace Technology Institute* set up in 2013, which brings together academics and industry experts to develop the strategic direction for aerospace technology and help fund research and development; the *Jet Zero Council*, which BEIS and Department for Transport set up in July 2020 to bring together government, industry, and academia to help deliver new technologies and fuels to reduce aviation emissions; and the *Aerospace Growth Partnership*, which is a strategic partnership of the aerospace industry and government; and

- Sustainable food and biomass: In the sustainable food and biomass production challenge area, innovation opportunities are less well understood and, therefore, the input from and collaboration with stakeholders is important. Consequently in 2019, BEIS commissioned a project to assess the potential for innovation to increase the supply of, and reduce the cost and emissions from, domestic feedstocks that included conducting interviews with industry stakeholders to understand the barriers that were preventing substantive levels of production in the UK.

Measuring and evaluating progress

2.28 At the time of our fieldwork in early 2023, DESNZ was developing a process for monitoring progress systematically across all the 31 challenge areas in the Framework. It has not yet defined what outcomes it is seeking to deliver for each of the 31 challenge areas and what level of risk it will tolerate. This work included the development of an Innovation Delivery Dashboard, including a set of indicators for measuring progress. DESNZ intends the performance data to be reported to the Innovation Delivery Board.

2.29 Many of the proposed programme indicators are output-focused rather than outcome-focused, such as the number of projects and organisations each programme has supported, rather than the number of business opportunities created or the potential for reductions in carbon emissions. This reflects the output-focused commitments in the Delivery Plan. The Innovation Delivery Board, chaired by DESNZ, had yet to specify what interim measures of success might look like at key milestones. Although the uncertain and longer-term nature of innovation makes some level of failure inevitable, the Board, with DESNZ, had also not yet defined what level of failure it could tolerate across the Framework, instead placing reliance on risk management by departments at the individual programme level. Without clearly defined outcomes, and a clear assessment of its risk tolerance, it will be difficult for DESNZ and the Innovation Delivery Board to assess whether individual innovation challenge areas are on track to contribute to the UK achieving net zero.

2.30 Government does not plan to complete a cross-departmental evaluation covering activity across the Framework, which would extend across departmental boundaries. DESNZ believes it would be challenging to implement a Framework-wide evaluation approach because of the diverse mix of innovation challenge areas in the Framework. It would also require collaboration with many funders. However, without a Framework-wide strategy for evaluation, government may miss opportunities for learning across organisational boundaries. Having a single evaluation strategy to encompass the whole Framework could also help ensure that the most pressing evaluation gaps are prioritised, planned for and resourced.

2.31 Progress monitoring is well developed within DESNZ. We reviewed the approach to monitoring and data collection for individual programmes in our deep dive areas. DESNZ's Net Zero Innovation Portfolio and its predecessor, the Energy Innovation Portfolio, for example, have areas of good practice that could inform the monitoring approach for the innovation process as a whole. Projects in the portfolios' programmes collect and submit key inputs, outputs and outcomes data from a cross-portfolio set of key performance indicators. This means that progress can be reviewed at project, theme and portfolio level. These data are collated and used by the DESNZ Energy Innovation Evaluation team and enable portfolio-wide reporting of progress to the portfolio board. They also feed into evaluation activities. DESNZ plans to measure the following key outcomes for the Net Zero Innovation Portfolio programmes: follow-on funding secured, reduction in energy costs, increased energy efficiency/reduced energy demand, increased energy system flexibility, commercialisation advancement, carbon dioxide emissions reductions, and policy influence.

2.32 DESNZ has planned an overarching evaluation of the Net Zero Innovation Portfolio, and its predecessor, the Energy Innovation Portfolio, alongside other evaluations at theme and programme level. The evaluation is being delivered by an externally contracted consortium. A progress report, which brings together updates from the programmes within the Net Zero Innovation Portfolio to the end of 2022, is expected to be published in May 2023. This will set out data against key performance indicators, such as the number of programmes completed, and the number of jobs created. The overarching evaluation that DESNZ has planned includes a number of features we regard as good practice, including:

- an assessment of how the emerging results from the portfolio could be used to shape the priority given to the various net zero research and innovation challenges;
- an assessment of the feasibility of measuring the impact of the Net Zero Innovation Portfolio compared with a scenario without the intervention;
- a focus on developing findings across themes, rather than confined to specific programme or projects;
- mid-term evaluation analysis and reporting to ensure early learning on processes and progress against outcomes is fed back into the programme; and
- the contracted evaluation team has identified causes of a high rate of missing outcomes data from the Energy Innovation Portfolio programmes and the team is seeking to address this.

Appendix One

Our evidence base

1 We reached our independent conclusions on whether the government is set to deliver value for money from its approach to investment in research and innovation to deliver net zero in the UK following our analysis of evidence collected between September 2022 and February 2023. We used both qualitative (interviews, document review and deep dives) and quantitative methods to collect and analyse evidence. Details of the methods used are below.

2 We focused on the challenge areas set out in the government's *Net Zero Research and Innovation Framework* (the Framework), published by the Department for Business, Energy & Industrial Strategy (BEIS) in October 2021. For the period we were collecting evidence, BEIS had overall responsibility across the government for achieving net zero. It also had lead responsibility for supporting research and innovation. In February 2023, following the conclusion of our fieldwork, responsibility for achieving net zero was transferred to the new Department for Energy Security & Net Zero (DESNZ), responsibility for supporting research and innovation and creating the underlying conditions for it to succeed was given to the newly created Department for Science, Innovation & Technology (DSIT) and responsibility for supporting business was given to the newly created Department for Business & Trade (DBT).

Our evaluative criteria

3 We examined the effectiveness of government support for net zero research and innovation based on criteria first developed for our 2017 report on *Cross-government funding of research and development*. We reviewed:

- the effectiveness of mechanisms in place for providing leadership and coordination of net zero research and innovation activities;
- arrangements for delivering net zero research and innovation support, and whether this is aligned with the challenge areas set out in the Framework; and
- plans for reviewing progress and evaluating impact against the desired outputs and outcomes.

Interviews

4 We undertook interviews with BEIS, public bodies, and other stakeholders. We covered topics based on the evaluative criteria. We carried out all interviews online, with each one typically lasting one hour. Interviews took place between September 2022 and February 2023. We took detailed notes and subsequently agreed them with the relevant organisation. We analysed the notes of these interviews and identified common themes to inform our findings.

Departmental interviews

5 To understand the steps taken by BEIS to support net zero research and innovation, we conducted interviews with relevant teams within the Department. This included officials responsible for:

- the overarching *UK Innovation Strategy*;
- policy surrounding net zero research and innovation;
- delivering the challenge areas outlined in the Framework;
- managing the portfolio of net zero research and innovation programmes; and
- green finance and managing private sector investment in net zero research and innovation.

6 We covered topics based on our evaluative criteria and tailored the questions to the responsibilities of each team. For example, we asked the green finance team questions about how it manages, incentivises and monitors private sector investment for net zero research and innovation.

7 For our four deep dives, we also interviewed officials from the Department for Transport (DfT), and the Department for Environment, Food & Rural Affairs (Defra). See the section on deep dives for further information.

Public body and stakeholder interviews

8 We also met with and received written submissions from officials from public sector bodies and stakeholder bodies to understand their perspectives on the effectiveness of government support for, and/or how they support, net zero research and innovation. For the stakeholders, we interviewed industry bodies, academics, research institutes and trade associations to ensure we captured a range of views and perceptions. Additionally, we interviewed some of these bodies specifically for our deep dives. Further information can be found in the deep dive section. The bodies we spoke to or received written submissions from were:

- ADS Group;
- Aerospace Technology Institute;
- Association for Renewable Energy and Clean Technology;
- British Business Bank;
- Centre for Innovation Excellence in Livestock;
- Climate Change Committee;
- Confederation of British Industry;
- Crop Health and Protection (AgriTech centre);
- Energy Networks Association;
- Energy Systems Catapult;
- Federation of Small Businesses;
- Government Office for Science;
- Green Alliance;
- representatives from the Hydrogen Innovation Initiative;
- Industrial Decarbonisation Research and Innovation Centre;
- Office for Science and Technology Strategy;
- Office of Gas and Electricity Markets (Ofgem);
- Rolls-Royce;
- Royal Society;
- UK Energy Research Centre;
- UK Hydrogen and Fuel Cell Association;
- UK Infrastructure Bank;
- UK Research and Innovation (UKRI); and
- Vertical Aerospace.

9 We based the interview topics on our evaluative criteria, again tailoring our questions depending on the stakeholder being interviewed. We asked academics and research institutes, for example, questions about the earlier stages of research and innovation, while we asked industry bodies more questions about scaling up and commercialising an innovation.

Document review

10 We reviewed more than 140 published and unpublished documents, of which around 130 were provided by BEIS and UKRI. We reviewed these to understand how the government is supporting research and innovation to deliver net zero. This included a review of:

- board meeting minutes and papers;
- published government strategies;
- business cases;
- policy papers; and
- ministerial submissions.

11 We carried out our review between October 2022 and February 2023. Documents reviewed covered the period between May 2018 and March 2023.

12 We reviewed the documents against a framework we developed that reflected the evaluative criteria outlined in paragraph 3. We then summarised the findings and identified key themes against our evaluative criteria to inform our conclusions.

Deep dives

13 To support our examination of the overall study questions, we included a more detailed look at four of the 31 net zero research and innovation challenge areas from the Framework (deep dives). We looked at how the government supports net zero research and innovation for the four challenge areas, including how it helps to address barriers; and how it monitors and evaluates performance against intended outcomes. We selected challenge areas based on the following criteria:

- Maturity, to understand the issues faced by challenge areas at different stages of innovation. We based this on the decade for delivery given to each category for research and innovation in the Framework.
- Department responsible, to compare approaches taken by different departments and highlight the effectiveness of cross-government working.
- Opportunity for decarbonisation, as reducing the level of emissions across different sectors is important in reaching net zero by 2050.

14 We created a sampling matrix to assess which of the 31 challenge areas of the Framework fulfilled our sampling criteria. We chose the following four challenge areas as the focus of our deep dives as they all were identified as an opportunity for major decarbonisation, had differing levels of maturity, and different departments leading on delivery:

- Improving system integration, flexible demand, and energy storage:
    - Maturity is in 2020s, lead department is BEIS.
- Efficient production of low-carbon hydrogen:
    - Maturity is in the 2030s, lead department is BEIS
- Decarbonising aviation:
    - Maturity is in the 2040s, responsibility falls to DfT
- Sustainable food and biomass production:
    - Maturity is the 2040s, responsibility falls to Defra.

15 To obtain evidence on our deep dives, we conducted interviews and document review, and attended two conferences.

16 We conducted interviews with key stakeholders across the four deep dives. For each deep dive, we aimed to seek a mix of views from at least three stakeholders across industry, academia and the public sector. Interviewees are listed within the Interviews section (paragraph 8). We also conducted interviews with officials from BEIS, DfT and Defra. Our interview topics covered areas of the evaluative criteria for the study. We adjusted our interview questions to ensure they were relevant to the interviewees.

17 We reviewed over 200 published and unpublished documents in total that were available online or sent to us by BEIS, DfT and Defra. We reviewed these documents against our evaluative criteria, tailoring the criteria to ensure relevance to the selected deep dive.

18 We attended two industry conferences relevant to our deep dives to aid our understanding of the net zero research and innovation issues for the sector. These included a conference for the hydrogen sector for our deep dive on hydrogen production, and a conference for the aviation sector.

19 We synthesised our deep dive evidence by drawing out key themes in line with our evaluative criteria. We used these to provide illustrative examples of how government support for net zero research and innovation is working, and to triangulate our other interviews and our data analysis. We did not seek to comment on the scale or prevalence of these issues across the challenge areas or make comparisons between challenges of the Framework.

Quantitative analysis

20 We used the Delivery Plan data from DESNZ, which sets out net zero research and innovation spending from 2022 to 2025, to understand public funding for net zero research and innovation. We analysed these data to assess the number of different programmes contributing towards net zero research and innovation; the amount of spend as outlined in the Framework; and the funding contribution from different departments.

21 Prior to our analysis, we filtered the programmes to include only those contributing to net zero research and innovation spend (as the data also included other broader activities related to the innovation challenges), meaning that each programme only appeared once. We did this to determine the total number of programmes while avoiding double-counting. We agreed the findings of our initial analysis with DESNZ to provide assurance on our analysis and our interpretation of these data. The Delivery Plan data uses self-reported information from government departments responsible for delivering net zero research and innovation programmes. We cannot provide assurance on this estimate as we were unable to audit the underlying information sent by departments.

CORRECTION SLIP

Title: Support for innovation to deliver net zero

SESSION 2022-23

HC 1321
ISBN: 978-1-78604-489-1

Ordered by the House of Commons to be printed on 17 May 2023

Correction One:

On page 15 of the Summary, paragraph 24, bullet d, an error needs to be corrected. The deadline date is wrong it should say March 2024

The text currently reads:

d The Board should build on its work to develop the Framework to estimate, where possible, by March 2023, what level of public investment might be needed to deliver the required net zero research and innovation activity up to 2050.

The text should read:

d The Board should build on its work to develop the Framework to estimate, where possible, by March 2024, what level of public investment might be needed to deliver the required net zero research and innovation activity up to 2050.

BACK

Date of correction: 18 May 2023

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National Audit Office

Design and Production by NAO Communications Team
DP Ref: 011760-001

£10.00

ISBN 978-1-78604-489-1