National
Engineering
Policy Centre

Royal Academy
of Engineering

July 2024

Rapid decarbonisation of the GB electricity system

Contents

Key messages

A decarbonised electricity system will be the essential backbone of a future, highly electrified Net Zero energy system. Rapid transformation to a decarbonised electricity system will significantly reduce our reliance on fossil fuel imports while providing a range of opportunities to create economic, employment, health, and other benefits. It should be a central part of the country's industrial strategy. Physical delivery of the system we need is fundamentally an engineering challenge that needs the highest levels of political and engineering leadership, alongside significant co-investment from the public and private sectors. The work required in a short time is multifaceted and massive in scale, but also offers an opportunity for the UK to show leadership on Net Zero at a time when other countries are facing the same challenge.

The government's mission to provide clean power by 2030 sharply raises the level of ambition from an already challenging 2035 target. This elevated ambition cannot be met simply by accelerating along the path we are currently on, but will require a radical shift of approach. A plan is needed quickly, prioritising pace over perfection. Six big changes will define that new approach above all.

Building strong support for the vision. Government must clearly set out the objectives of the mission, couched in broad benefits that matter to everyone, not simply narrow targets. This vision will form the basis of an enduring agreement with both the public and industry and help them embrace the coming changes, as well as helping align incentives across the many partners who must play a part in their delivery. Building public support and understanding across the UK will be essential to achieving the mission.

Strong central leadership and governance with engineering at the forefront. Transforming the power system is a major infrastructure programme requiring single-point empowered leadership, accountable to the Prime Minister. The announcement of a dedicated Mission Board is therefore welcome. This function must be capable of understanding and responding to this complex whole system challenge. This requires that it is technically enabled, including a Chief Engineer (or equivalent), for the mission, to oversee how the many elements of the programme combine to achieve the desired outcomes, and supported by sufficient technical and engineering expertise and exceptional use of live data visualisation to manage the process effectively. Leadership will need to be bold and enduring, inspiring belief and empowering new behaviours at all levels of governance including devolved administrations, local authorities, and communities. Placing engineering at the core will drive a whole-systems approach that enables better choices and avoids the high costs and perverse consequences of multiple uncoordinated initiatives.

A more flexible, digitally enabled system. The new system must be different, not just bigger. Transforming the system to be digital-first in a cyber-secure way is essential to supporting and managing a more complex, distributed, renewable-based system, while enabling the public to engage with the system more flexibly, benefiting the grid and saving consumers and government money. Data needs to be shared effectively and developed actively to be a major engine of acceleration.

A front-foot approach to procurement and regulation. In an age of incremental system expansion, government and regulators have sought to protect the consumer and the exchequer by delaying new investment until necessary and relying on competitive market mechanisms to drive down price and shift risk down the supply chain. That approach is no longer fit for purpose as the pace and scale of change increase radically, and as we enter a more competitive world in which developed countries are racing to secure materials and equipment for their own transformation. If the UK is to meet its needs at an affordable price amid fierce global competition it will need to understand that the balance of risks has changed. It must adopt a much more proactive approach to procurement, while regulators must shift posture to act as enablers of the transition, for example encouraging proactive investment to ensure that capacity is available when needed. This amounts to a huge change in how the UK does its business.

Grasping the nettles: planning and consenting, and connection delay. Government will need to look the major constraints to rapid system expansion squarely in the face. Lead times for building new transmission infrastructure are far too long, and there is much to be done to implement the Electricity Networks Commissioner's Report of 2023[1], which showed how this might be reduced by half. The challenge for government if it wishes to go faster than this is not a technical one, but the fact is that doing so would cut into the window in which affected communities can engage with these plans and have their views heard. There are difficult choices to be made and government will need to build and maintain public support. Similarly, the queue for connections stretches out well beyond the period to 2030 and reprioritising it requires hard and urgent choices. If not addressed successfully these two issues will severely limit the extent of acceleration possible.

Retain a long-term view. The 2030 pledge is an important stimulus for speed and a major milestone on the road to Net Zero by 2050. The intense focus on delivery towards 2030 must not delay the short-term actions needed to unlock the best options for the subsequent period, or worse do things which compromise that longer-term objective.

This report sets out advice for the incoming government, with a focus on near-term actions and those which would most define a shift to a more radical, accelerated approach in keeping with the Government's ambition. Government needs to set the landscape and build public support, but delivery is an engineering challenge, and the engineering community is ready to participate in the creation of the new system the UK needs.

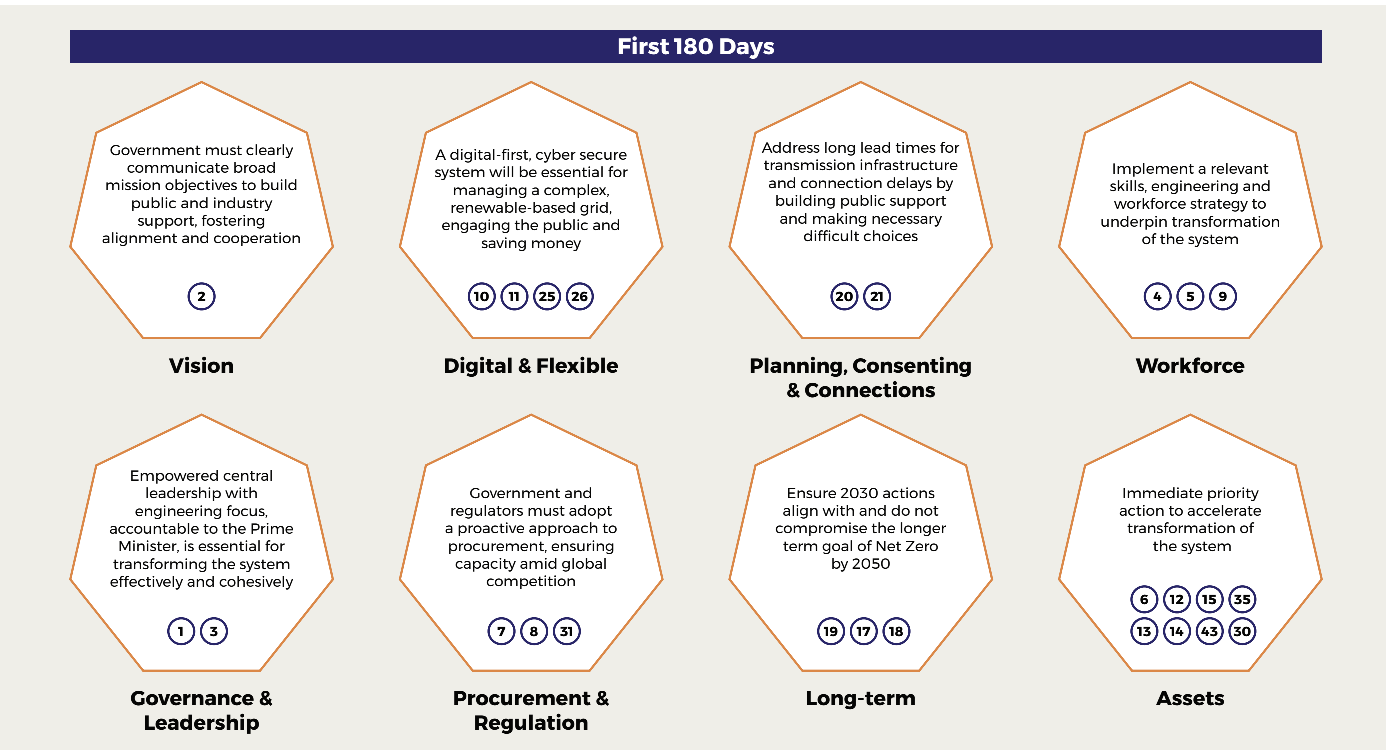

Figure 1 | Key messages together with related priority actions raised in this report for the first 180 days of Government

Introduction: **A radical approach to rapid electricity system decarbonisation**

Like other industrial nations, Great Britain needs a different electricity system than the one it has today. A stable, resilient, decarbonised, and flexible electricity system, about twice its current size, is needed to support the country's Industrial Strategy, power essential modern technology, and ensure security of supply. Such an electricity system is also an essential element of meeting the UK's emissions goals both by 2030 and out to 2050.

The new government has committed to delivering a clean power system by 2030, while maintaining a strategic reserve of unabated gas plants. While one can finesse the precise definition of 'clean power' and the precise percentage of unabated gas which should remain in the system by 2030, this bold promise sets the ambition for this important milestone on the path to a decarbonised economy. This report therefore sets out advice for a more radical approach to transforming the electricity system than has so far been presented.

Although the scale of the task should not be underestimated, and many aspects of the transition are moving much too slowly, there are positive precedents from the past, and progress has often surprised us.

Progress to date in decarbonising the GB electricity system has been faster than the Climate Change Committee's original 2008 pathway[i], with suitable reduction in consumption because of efficiency improvements and a faster fall in carbon intensity. In 2023, 55% of generation was low-carbon[2] and carbon-intensity had fallen by 70% since 2012.[1,3] (Figure 2, page 4).

Technology deployment globally has also led to major breakthroughs in the costs of key technologies – the last 15 years has seen major reductions in the costs of solar PV (82% real-terms reduction from 2010 to 2019)[4], batteries (over 90% reduction from 2010 to 2023)[5], onshore wind (67% reduction from 2009 to 2022)[6], and offshore wind (60% reduction from 2015 to 2022[7], primarily due to UK government policies).

The work contained in this report has been overseen by an expert working group drawn from the National Engineering Policy Centre (NEPC), led by the Royal Academy of Engineering, and is based on an intensive period of stakeholder engagement and literature review undertaken between February and June 2024. The work has been informed by a dedicated roundtable with engineering industry leaders convened by the Institution of Civil Engineers (ICE) and a series of five NEPC roundtables which predated the change to a 2030 target. This report was finalised shortly after the General Election on 4 July 2024, and will not comprehensively reflect the government's post-election announcements.

i The Climate Change Committee (CCC) set out the role of the grid in achieving emissions reductions in its first advice under the Climate Change Act in 2008 – *Building a low-carbon economy – the UK's contribution to tackling climate change*, Climate Change Committee, 2008.

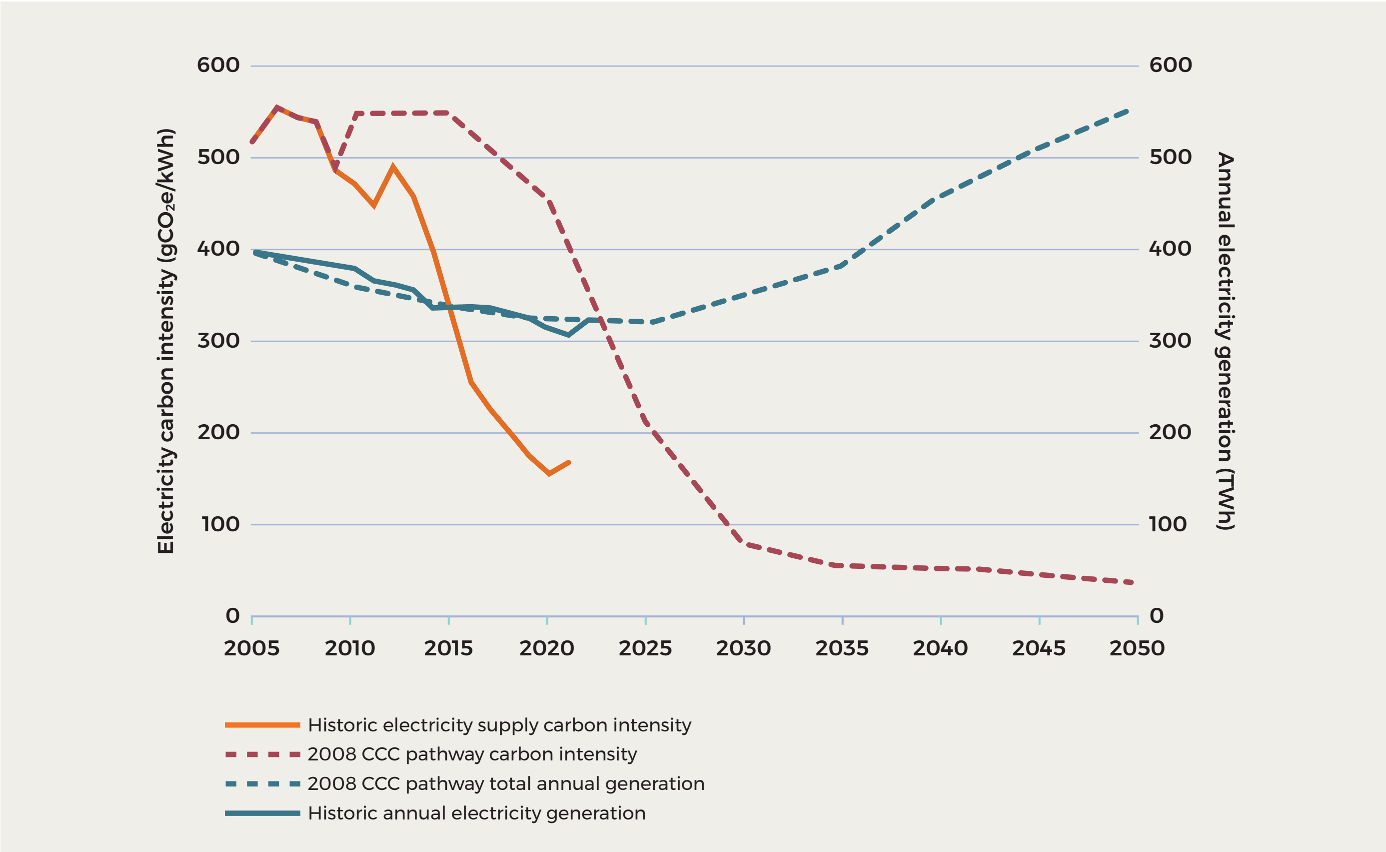

Figure 2 | The CCC 2008 projected electricity demand and emissions intensity compared to actual electricity decarbonisation

Nonetheless, the government's 2030 challenge sets the ambition very high. A plan for 2030 cannot simply be an acceleration of a 2035 plan. This report sets out what a radical approach to electricity system decarbonisation would look like, in three parts:

- **Part 1: Driving rapid system transformation** – how to approach electricity system decarbonisation as a major infrastructure programme.
- **Part 2: Building the system** – the elements of the 2030 electricity system and how to deliver them on accelerated timescales.
- **Part 3: Near-term progress needed primarily for post-2030** – what has to be done now to set a path for the much larger post-2030 electricity system serving transport, space heating and much of industry.

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1 | Driving rapid system transformation

Decarbonising the electricity system needs to be understood as a major infrastructure programme, a whole-systems challenge touching every part of society, and a different proposition from business-as-usual policy implementation, or indeed from a neat, self-contained project. Changing an existing system is not the same as building a new one from scratch, and the new electricity system must enable multiple other systems – of transport, heating, industrial processes, and much else – which are themselves complex, changing, and outside the control of the programme itself.

Planning such a change programme must go beyond deciding what assets should be put in place and when,[ii] to describe the methodology that will be employed to deliver the outcome. This will include the approach to supply chains, the resources needed, what should be delegated to local decision-making and the outcomes this needs to achieve. It will be essential to define the programme's scope, and how the interactions with elements which sit outside of its scope are to be managed.

Planning is an ongoing activity rather than a single event. Much is already known about the configuration of the new system, some things are already in-flight, and much else will be part of any realistic plan and can be set about while further planning is in train.[iii] But it will be vital to be clear about what the increased ambition means for these key elements of the programme, as a lack of clarity here will cause delays and cost escalations later down the line.

Actions for government

1. **Establish a plan for the accelerated transition programme, setting out approach, scope and dependencies.**

This section sets out advice on planning and delivering that programme, highlighting elements necessary for truly accelerated delivery.

1.1 Clarity of objectives and building support for the vision

Clarity of intended outcomes is the bedrock of any programme, and is a necessary condition of aligning and managing the many interests involved in it. Such clarity is also the basis of a durable agreement with the public. Rapid system decarbonisation can only be delivered if the government sets out the case for it strongly and communities get on board.

Government will need to set out a compelling vision of a decarbonised electricity system, how it can be delivered, and the contribution everyone will need to make to ensure success. This must include an evidence-based statement of benefits and opportunities couched in broad, far-reaching terms of relevance to everyone, not simply narrow political targets. While it is for government to articulate the case, elements might include the benefits of a stable, resilient, fit for purpose electricity system, which enables both broader decarbonisation and

ii See Section 1.3.

iii For example, delivery of National Grid's transmission plans or procurement of offshore wind at scale.

overall quality of life, and the associated benefits for security of supply and employment. It will require a transparent account of economic costs, risks, opportunities, and benefits, with particular attention to how they will be shared, including with bill payers and the communities who are asked to host the infrastructure which enables it. This is a two-way street: the new system must be designed with a well-formed understanding of industrial and domestic consumers' requirements, perceptions and values, and their capacity to engage with the new system.

Treating this as a national mission in the way the vaccines task force did may help garner public support, as might celebrating successes along the way such as days in which the system operates without any unabated fossil generation. Getting this right will be essential to allow rapid construction and programme delivery; without it delays are likely even with the best available technologies.

Actions for government

2. **Set out, within months, clear objectives for the transition, an evidence-based vision of how it will be achieved and the costs, risks, opportunities and benefits it will bring, and a plan to build the public support necessary to enable delivery at the required pace and scale.**

1.2 Governance

Overseeing this vital mission will require a paradigm shift to a much more proactive, adaptive, and expertise-enabled approach to decision-making and delivery.

Central to this governance reform is establishing clear, single-point cross-government leadership to provide purpose and direction, empowered and backed by direct Prime Ministerial authority. The creation of a Mission Board is welcome and must signal a shift towards a very different approach. As well as overseeing the full spectrum of delivery challenges, such central leadership needs to consider the way in which the many elements of the programme and the many interfaces between them combine to achieve the desired outcomes. This will require the creation of a Chief Engineer for the mission, or equivalent post. This is a new role with a specific remit for systems integration, and a seat at the table at the most senior levels.[iv]

This cross-government leadership must be supported by a delivery-focused energy system transformation office. It will need to include people with sufficient technical, engineering, portfolio management, programme management, and financial expertise to ensure decisions are implemented correctly, offer sound advice on complex issues, and enable effective interventions and adaptations when necessary.

Both the leadership and delivery functions should work closely with, and be supported by, the National Energy System Operator (NESO) in its role to provide strategic planning, advice, and other key enabling functions, and be supported by effective data and information reporting that captures, aggregates, and visually presents performance and other data on delivery against objectives and key metrics. All this must sit within a culture of openness in which 'bad news travels upwards fast'. The culture must embrace the truth that much will change, plans will need to evolve, and that this evolution should be celebrated as evidence of the adaptability any successful programme needs, not narrowly cast as so many targets missed. Much can be learned from Project 13, the industry-led response to the failures of traditional infrastructure delivery models and approaches to programme planning.[v]

This governance must drive urgent action on decarbonisation while retaining a wider, long-term perspective, building a system which is affordable, resilient, and able to deal with change as it emerges.

High complexity requires a high degree of central coordination, but this does not mean that the centre must make every decision. Rather, clear objectives, planning, governance, and reporting are the enabling conditions for good delegation to the level best equipped and informed to make

iv The concept of a Chief Engineer is common within industry, but less so in government, although not without precedent. It goes beyond the idea of having an engineer in a senior position, and is not the same as a CEO, CTO or head of Mission, but is specifically concerned with systems integration. The Academy would be pleased to discuss further how this might work in government.

v https://www.project13.info/

individual decisions, while minimising the risks which would come with an uncoordinated approach. Good data flows and data visualisation tools will help manage this process.

Outside of this central architecture it will be essential to ensure that other, more distributed elements of governance are well resourced, with systems and processes designed and scaled to the challenge. Specifically, the UK's current planning and consenting system does not enable rapid decisions. This will be a core constraint on progress on generation, transmission, and demand reduction. While a detailed discussion of the planning system is outside of the scope of this project, such constraints will be exacerbated if not addressed in ways which enable greater speed whilst ensuring appropriate interaction with impacted individuals and communities. Ensuring good levels of staffing in the Planning Inspectorate is almost certain to be cost effective given the huge costs of delay.

Finally, regulator behaviour and culture are major determinants of whether innovators can effectively navigate adapting regulatory frameworks, and government must ensure the regulatory system is clear and streamlined and focused on the level of ambition[vi] consistent with government priorities.

Actions for government

3. **Urgently establish clear, single-point, empowered, cross-government leadership within Mission Control, including a Chief Engineer role or equivalent**
4. **Quickly establish a delivery-focused energy system transformation capability staffed with sufficient technical, engineering, portfolio management, programme management and financial expertise, backed by effective data and information systems with visualisation tools**
5. **Ensure appropriate levels of resourcing at all pinch points, for example local authority planning officers, and recognise and deal with the blocks that exist in planning and regulatory approvals.**

A note on terminology. We talk in this report about three sorts of plans or planning: (i) planning as in local authority planning consent, (ii) strategic plans for what needs to be built where and when, and (iii) project or programme plans used to manage the physical delivery of these assets and essential parallel activities such as communication and building public support. This section principally discusses the second of these.

1.3 A whole system plan

An essential part of delivering the transition is developing a whole system plan of the emerging new energy system. Such a plan should be thought of as the 'bones' of the programme, a minimum viable product sequence of states which prevents teams getting lost in the detail. Such a plan must be both spatial and temporal, an overarching 'sequence to the finish' which should in turn enable a further series of aligned and more detailed plans.

Such a plan must pay particular attention to ensuring that interfaces between parts of the system are clearly understood, and that the physical, temporal, or functional dependencies they involve are discussed and clarified. And it requires clarity on the 'system boundary' – for instance, up to now the 'grid edge', where domestic, business, and industrial users now have significant capabilities including contributions to system flexibility has tended to be treated as outside the system boundary. This approach, while convenient historically, is now imposing large costs which will only increase in future.

A major part of this whole system plan will be the Strategic Spatial Energy Plan (SSEP) and first Centralised Strategic Network Plan (CSNP), which NESO was tasked with delivering by 2026.

The new government has asked NESO[vii] to provide independent advice on the pathway to 2030, and given the need for pace it will be better for NESO to

vi There are some parallels between the energy sector and the digital technologies sector. The *Pro-innovation Regulation of Technologies Review: Digital Technologies* found over 10 different regulators with digital technologies within their direct remit whose mandates often overlapped or were contradictory, adding burden and confusion to those trying to innovate within the system.

vii Or more properly the Electricity System Operator (ESO), soon to be the National Energy System Operator (NESO).

HOW TO THINK ABOUT END DATES

Dates matter for a variety of reasons. They can drive progress, can communicate to the public what they should expect and when, and can underwrite accountability. However, there are right and wrong ways to think of end dates within the context of a major infrastructure programme. Dates should not become ends in themselves, and in the worst case an immoveable target date can be very counterproductive, driving fear, division, and opacity to the truth, or behaviours which make the target easier to hit at the expense of the ultimate objective. Such dates garner great significance but are often really moments when certain important elements are switched on and brought into service; the start of a process of transition to full operational effectiveness, one moment on the glide path to the eventual outcome. The 2030 pledge is an important commitment to the country and sets the level of ambition. To deliver that ambition the governance of the overall programme must be empowered to adjust elements of it as progress is made and inherent uncertainties are narrowed and removed.

initially do something faster and adequate to the task rather than wait for the full SSEP, bringing forward to October 2024 the aspects of this advice relating to the near-term time horizon of 2030, before then returning to longer-term strategic planning for the post-2030 energy system, including CO_2 and hydrogen infrastructure, decarbonisation of heating and upgrades to distribution networks. This initial advice should support rapid delivery of investments currently in train under the Accelerated Strategic Transmission Investment (ASTI) framework, and be formally linked to both the planning and regulatory frameworks to ensure they are deliverable and consentable at the pace required.

Actions for government

6. **NESO should undertake a rapid assessment of the gap between the transmission network that is currently slated to be in place by 2030 and what is now required, initially reporting by October 2024, and finalised by mid-2025 at the latest.**

1.4 Cost, risk, and procurement

Government can have a huge influence on the costs, benefits, and success of the transformation by adopting an evolved approach to risk, including financial risk, to reflect a changing world.

While calculating the costs of achieving a decarbonised electricity system is beyond the scope of this report, experience of previous projects has demonstrated that a more rapid approach can increase or decrease costs, but delays always increase costs. Where supply chains are constrained, high ambition can certainly cause cost pressures, a risk government must actively manage. Conversely, simplifying and streamlining the processes to deliver infrastructure can make delivery faster and cheaper because of lower project complexity and reduced staffing and materials costs over time.

The costs and savings in delivery must be set alongside the effect of moving more quickly from over 30% share of gas-fired generation down to below 10%, with an increased share of generation from more price-certain renewables. It is not possible to know now exactly how this equation will work out, as international gas prices are volatile and cannot be predicted accurately six years in advance.[viii] What can be said definitively is that reduced reliance on gas-fired generation decreases geopolitical risks to security of supply and reduces the exposure of consumer bills to fluctuating international gas prices.

Risks are best allocated to those best placed to manage them. In the era of incremental system growth, government has previously sought to protect the exchequer by setting a high bar for new investments in the electricity system, leaving

viii The CCC set this out in 2023 in its report *Delivering a reliable decarbonised power system*.

DECARBONISATION AND MATERIALS

Electricity system decarbonisation will drive demand for an array of materials and critical minerals, some with already strained supply chains or whose extraction and processing comes at high environmental and social cost. Other materials such as copper and aluminium which aren't listed as critical materials in the UK could still experience supply gaps given a combination of grid build and EV uptake.[5] A whole-system approach to decarbonising the electricity system will manage this impact through good policy and technology choices and by putting in place the product design, capacity and skills which can maximise the life of material-rich assets.

investment in new assets until needed, making widespread use of competitive tendering and auctions to control costs, and pushing risk down the supply chain. The balance of risks is changing fundamentally due to the scale of the transformation and the increase in generation and transmission capacity now required. The stress now placed on global supply chains as the rest of the world does the same is high, and government's approach to risk must change with it.

In this new world, with fast-growing electricity demand, anticipatory investment is relatively low risk, as there is little chance of stranded assets (i.e. remaining underutilised in the long term); indeed, it is a necessity to ensure that future demands can be met. The negative impacts of underinvesting would be far greater than those of any temporary overcapacity and may leave the country at the risk of severely restricted supply chains and elevated prices. The ASTI framework already promotes anticipatory investment for onshore electricity transmission.

This will need to be broadened to ambitious deployment of a whole portfolio of infrastructure and flexibility solutions, including to combat underdelivery elsewhere in the portfolio.

And while markets have their place, a more proactive supply chain policy which gives industry sight of a substantial long-term order book and clear investment pipeline can enable supply chains to invest in capacity, and send a signal that the UK is an investor friendly market which can move quickly and efficiently. This, ultimately, will be the best way to ensure that the UK secures the equipment and services it needs in time, and at the right price, but requires companies to have visibility over their investment pipeline over a longer period than currently occurs.

This should be augmented by wider attention to the overall attractiveness of the UK to business such as helping R&D and support for skills, as part of the country's Industrial Strategy.[ix]

EMBODIED CARBON

While the carbon associated with operation of the energy system has been the main focus of decarbonisation efforts and is the primary focus of this report, manufacture and construction are themselves carbon emissions intensive and the scale of delivery needed will have a substantial carbon footprint. Analysis has shown that for certain infrastructure projects embodied carbon can be 40% of 60-year lifetime carbon emissions of that project.[19] Minimising embodied carbon through driving the uptake of standards such as BSI PAS2080:2023[8] needs to be a priority across all infrastructure sectors, including energy. There is an opportunity to progressively reduce the emissions attributed to energy system transformation through intelligent sourcing and materials innovation, which could catalyse wider construction decarbonisation and create export opportunities.

ix See *National Engineering Policy Centre: Late Stage R&D Business Perspectives* for technologists' insights on what creates such an environment.

Government must also avoid the mistake of thinking that reduced in-year expenditure will save money in the long run. Once mobilised with the correct and locked design, government must 'feed the fire': the highest productivity and shortest route to the finish will be to feed the resource and not constrain productive activity with reduced capital. Slow, uncertain progress is always far more costly than anticipated.

Actions for government

7. **Accept a change in the balance of risks and communicate that to others, including the National Audit Office and relevant regulators. Decide the government's strategic approach to procurement and the global supply chain**
8. **Adopt new regulatory paradigms, with regulators assessing consumer value through methods such as benchmarking rather than over-relying on market competition to demonstrate cost efficiency.**

1.5 **Skills**

Ensuring a sufficient, skilled workforce is likely to be one of the most significant challenges for meeting rapid electricity decarbonisation ambitions. Analysis of current data across the energy sector suggests about an additional 200,000 workers are needed by 2030 to meet expansion demand on top of those required to replace the existing ageing workforce. While these numbers illustrate the scale of the challenge for the energy sector, there is also a wider engineering and technology skills challenge to meet business-as-usual and expected growth in activity across other sectors.

Department for Education analysis highlights declines in key parts of the workforce and high rates of hard-to-fill vacancies in critical occupations such as engineering project managers, electrical and mechanical engineers, engineering technicians, welding and engineering construction trades (e.g. crane drivers, steel erectors) alongside a wide range of other occupations key to energy transition.

At the same time, we are seeing stagnation or reduction in the supply of young people into these roles. Apprenticeships in engineering and manufacturing have seen a 34% fall over the last decade. Engineering degrees by UK students have remained fairly static at about 28,000 per year over the same period, and while some disciplines such as mechanical engineering have seen growth, electronic and electrical engineering have seen a decline. There are now just 3,500 UK graduates a year in electronic and electrical engineering from higher education institutions, a number that has halved since 2006.

There is also a regional dimension to the national skills shortfall. For example, electrical engineers and technicians to support offshore wind are needed in coastal areas such as Teesside and Humberside, North East Scotland, Cumbria, and West Wales. Specialist nuclear skills are needed in rural and coastal locations such as Somerset, Suffolk, and North Wales. National, aggregated datasets hide this additional geographical challenge.

Many of the short-term skills needs will be achieved by upskilling and reskilling within the existing workforce at all levels, from construction trades to developing new AI and data analytics capabilities of professional engineers.

The policy and delivery requirements to enable this upskilling are beyond the scope of this study, and stretch out well beyond 2030. But it is clear a national engineering and technology workforce strategy is needed to fully understand the skills demand and develop a coherent plan to address skills deficits, identifying and providing solutions to key challenges. This should range from:

- Short-term upskilling and reskilling in the existing workforce, much of which will be relevant to the 2030 challenge;
- Medium-term supply of higher-technical skills, apprenticeships and graduates in further and higher education, some of which will support 2030 ambitions; to
- Addressing longer-term skills pipeline challenges in schools and foundational education.

The lack of an adequately trained workforce has the potential to constrain delivery by 2030, but done correctly the Government's ambition in this area can also drive skills development. If the vision, ambition and policies are in place to create a visible pipeline of work, and the skills system is configured to support employer investment in skills, then all parts of the supply chain will feel more enabled to build the new and existing workforce capacity within their organisations.

Actions for government

9. **Establish a national engineering and technology workforce strategy within six months.**

1.6 Digitalisation of the electricity system

Digitalisation is an essential enabler both of the transformation process and of the future energy system itself. It can support planning, decision-making, and project execution for the transition. In the resulting, highly diversified electricity system, it is strategic digitalisation which will provide the granular, near real-time understanding of system performance and the automation and system control needed to optimise use of existing capacity, reducing the need for new construction, deliver better resilience, as well as enabling more efficient operations and condition-based maintenance. Digitalisation will be the basis of new customer offerings, allowing consumers to engage at device-level and flex their demand according to price signals, saving themselves money whilst, supporting a better-balanced, lower-cost, more resilient electricity system.[x]

Rapid expansion of this capability is likely to make decarbonisation easier, but realising the full promise of digitalisation is currently in its very early stages. The smart metering programme, has been slow[xi] and has failed to engage many consumers in the electricity system. Smart meters are an important enabler of digitalisation and their roll-out should be made an urgent priority.

Digitalisation is not a bolt on, rather this can be seen as a programme of cyber physical infrastructure development. It should be embedded through changes in technology, processes, and skills, and in the organisational culture of NESO, the networks and of the energy suppliers. Implementing half-hourly settlement will help to push suppliers in the necessary direction (see Section 2.4.1). The area has been extensively reviewed, with the Energy Data Task Force, the Energy Digitalisation Task Force, the Electricity Networks Commissioner and others having made relevant recommendations to government.

What is needed now is not further review, but a single point of coordination to prioritise the fruits of those reviews into a clear digital strategy, followed swiftly by an adaptive delivery plan for embedding digitalisation in the energy system, making data accessible, driving standards and interoperability, implementing digital processes, and building necessary digital infrastructure, including communications infrastructure. It should support parties in the energy system to exploit digital capability and infrastructure to accelerate transformation and to deliver products and services that drive decarbonisation.

Actions for government

10. **Establish a 'digital architect', ideally in NESO, responsible for developing digitalisation strategy and architecture, and a roadmap that aligns with and shapes the emerging plans for the energy system, available within four months**
11. **Establish a dedicated digitalisation delivery unit to drive integration of this roadmap into delivery of the new energy system, working with the digital architect to deliver an initial delivery plan within six months of commissioning.**

x For more about flexibility services and technologies, and demand response and how these can contribute to electricity decarbonisation, see *Consumers, flexibility and efficiency: how can consumption contribute to the decarbonisation of the electricity system* (2024).

xi https://committees.parliament.uk/work/7705/update-on-the-rollout-of-smart-meters/news/197947/delayed-smart-meter-programme-fails-to-hit-targets-and-secure-public-support/

2 | Building the system

2.1 Introduction – the shape of the 2030 system

The 2030 system will need to be based around solutions that are deliverable now, while preparing for longer-term solutions to come later on. What will define the radicalism of the Government's approach is not the elements of the future energy system, which are well known, but the way in which delivery is accelerated and scaled.

Low-carbon generation. On generation, most of the heavy lifting will need to be done via a sharp ramp-up in the pace of offshore wind delivery, deployment of onshore wind and solar in a way that the system can accommodate, and life extensions of existing nuclear fleet where possible.[xii] The bold moves needed will include a radically changed approach to procuring increasing amounts of renewables from a rapidly changing world market.

Transmission and distribution. New grid infrastructure is a central priority, together with increased distribution capacity capable of accommodating a changed world of electric vehicles (EVs) and electrified heating. The bold moves needed will include reducing the time taken to deliver new transmission infrastructure down from the 14 years at present to (or below) the seven years set out in the Electricity Networks Commissioner (ENC) 2023 report,[1] and addressing the queue for connections. Difficult choices await if government wishes to get transmission lead times below seven years as a 2030 target implies, which are not technical choices but surround cutting into the window in which affected

ENERGY EFFICIENCY
While the focus of this report is decarbonising electricity, it will also be necessary to take action on energy efficiency, both directly to reduce electricity demands but also more widely to ensure that overall energy system efficiency is improved so that the electrification of the wider energy system is not any more challenging than it needs to be.

The value from energy generation comes from being able to use it – there are few benefits in rushing to build new generation without considering how and when it can be connected to the grid in a stable and resilient way. While this document will consider generation and transmission in sequence, it will indicate points of connection in both directions, such as locating generation where the grid is strongest, and designing the grid around the variable nature of renewable power. In planning and delivering the future energy system, renewables and the grid they connect into must be considered jointly.

xii This must come alongside the first deployments of carbon capture and storage (CCS) in conjunction with conventional gas-fired capacity as back-up.

ACCELERATED ELECTRIFICATION
Moving towards a Net Zero economy will require widespread electrification of the transport, buildings, and industry sectors (supplemented by other solutions where needed). While the scope of this transition is beyond this report, accelerating the pace of electrification will maximise the benefits that a decarbonised electricity system can provide, for wider decarbonisation of the economy, air quality, and reduced fossil fuel dependence. Deployment needs to accelerate this decade, to scale up solutions, broaden progress on decarbonisation, and provide opportunities to make electricity demand flexible. Accelerating electrification will require that the relative prices of electricity and fossil fuels are rebalanced to provide the incentive to switch.

communities are consulted. Here, the greatest constraints to the programme must be confronted: (i) new transmission timelines and planning; (ii) grid connection queue delays; and (iii) supply chain constraints. Given limits to transmission build out, it will be helpful for renewable capacity, especially onshore wind and solar, to be added in locations that can readily be accommodated without new transmission lines where possible.

Enhanced system flexibility & security of supply. In the new system, generation will be dominated by renewables, where supply varies with weather and time of day and cannot be ramped up on demand, alongside nuclear operating largely as baseload. Such a system will inevitably have times at which non-dispatchable generation falls short of meeting demand, while at other times there will be an excess. Enhancing system flexibility through demand response management and the use of energy storage and interconnectors will be necessary to deliver energy services when they are needed, while absorbing and using as much of the non-dispatchable generation as possible. Dispatchable low-carbon capacity will also be needed, including gas-fired plants with carbon capture and storage. The new government has already committed to maintaining a supply of unabated gas to ensure security of supply and system resilience.

Strategic challenges to start now. 2030 is one, important, milestone on the path to a cleaner, more resilient electricity system within a sustainable and prosperous UK. There are major elements of the future system which will need to be radically different from where we are now, and which require a long-term, strategic approach, but where that approach cannot realistically fully deliver in time for 2030. There is also uncertainty – the full extend of demand from technologies such as AI is not yet clear, and the future system will be emergent as new and potentially disruptive technologies and business models come to market, creating new forms of opportunity. We address these in Section 3.

2.2 Low-carbon generation: variable renewables and nuclear

2.2.1 Offshore wind

The sharp ramp up in delivery of decarbonised generation this decade must come primarily from wind and solar capacity, because of their relatively short lead times and ease of scaling. The UK needs to significantly accelerate progress towards already stretching plans for 50 GW of offshore wind by 2030, from about 14 GW today, on the path to the level of capacity needed by 2050, which could be up to 125 GW.[9] There is a pipeline of projects in train, but even delivering 50 GW – for which the transmission infrastructure is being put in place – would require significant acceleration of projects currently expected to deliver in the period 2031–33.

Going even beyond this level would require not only bringing forward the generating capacity much more quickly, but also ensuring that there is sufficient transmission capacity for it to get to market. Given these challenges, there may be a case to prioritise onshore renewables in locations where the grid can absorb the generation in preference to going even harder on offshore wind by 2030.

Floating offshore wind is not yet commercialised and will need financial and broader support if it is to scale quickly, including considerations on risk, infrastructure (e.g. ports), technology, and supply chains.

Offshore wind is a classic example of the need, discussed in Section 1.4, for the GB system to make a break from mechanisms that successfully drove

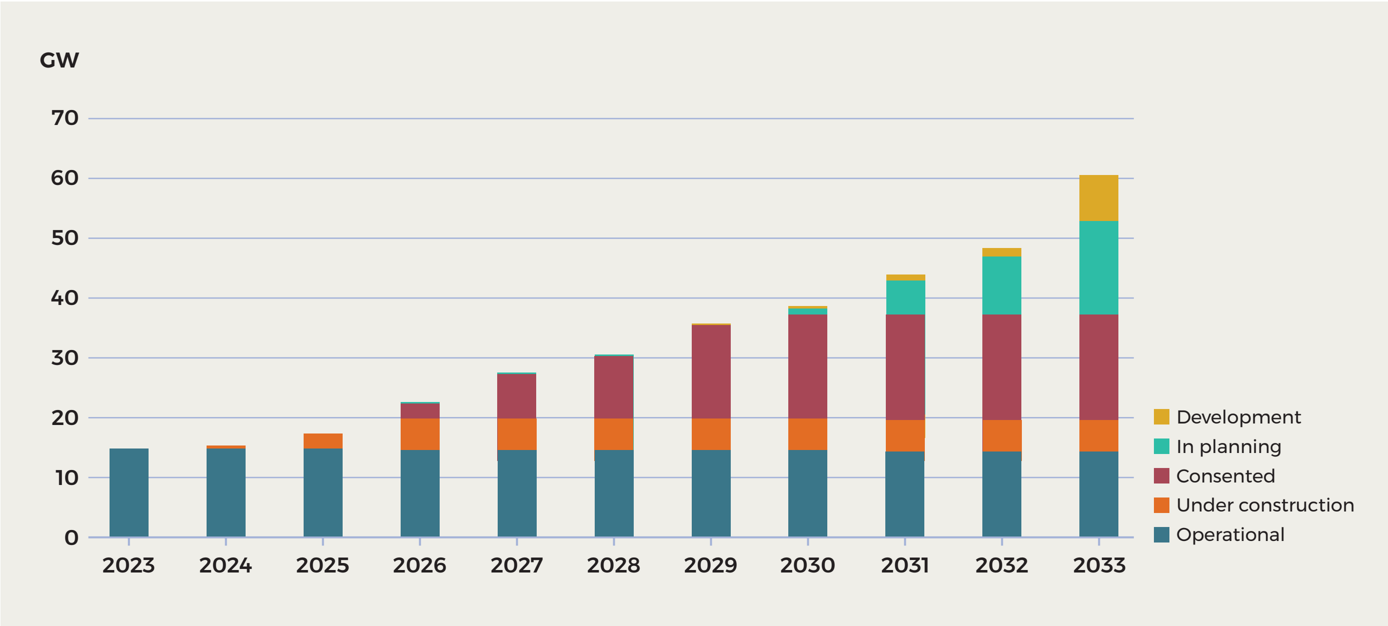

Figure 3 | Cumulative modelled GB offshore wind project capacity operational in each year by current summary status
Sourced from: Renewable UK Energy Pulse Database

down costs in a buyers' market to those which can provide the secure equipment and services supply that the country needs in the sellers' market we have now, with the rest of the world looking to accelerate deployment in parallel and rapid expansion needed across the whole supply chain.[xiii] This will entail replacing the current project-by-project approach to procurement with mechanisms that deliver much greater long-term certainty, going beyond 2030, enabling the supply chain to invest with confidence rather than compete for limited resources. It will also mean adopting a new approach to risk allocation by underwriting risks such as escalation of construction material costs that it has in the past transferred to developers, and which developers have in turn passed to the supply chain.

In the nearer term, there are also strategic decisions to make. Government must decide whether to build as much supply chain capacity as it can in the UK, supporting selected manufacturing and services to locate here and investing to fill what gaps remain, or to form long-term supply partnerships with large vendors or potentially, and more controversially, non-European countries such as China instead, weighing the employment and economic development of a local supply chain against the potential speed and savings offered by striking agreements with others. It might also consider whether to intervene to shape a market in which major turbine vendors are competing to provide ever larger unit sizes, whereas improving volumes and operational reliability are becoming more important. One solution might be to work with European and other partners to agree a common turbine size.

Finally, there are short-term tactical decisions to make, with the sixth auction round (AR6) for pre-2030 capacity arriving almost immediately following the election and presenting an immediate opportunity to accelerate delivery and build supply chain confidence.

The quicker these changes are signalled in the new Parliament, the better. Establishing Great Britain as a pacesetter in accelerated delivery will be essential to ensuring that investment is directed towards here rather than elsewhere. We are in a race.

xiii Notable challenges include wind turbines, subsea cables, HVDC systems, specialist vessels for wind turbine erection and cable laying, and skilled people.

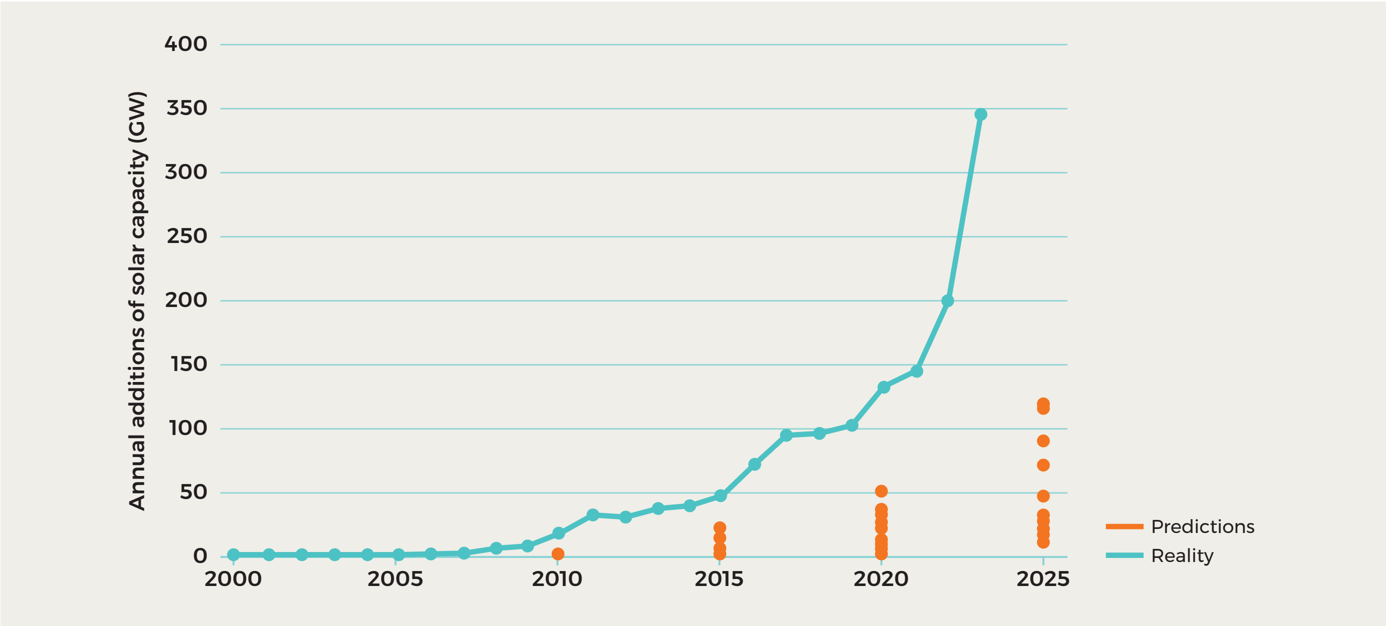

Figure 4 | Annual additions of solar capacity globally
Sourced from: The Economist and predominantly based on IEA data

Actions for government

12. **Decide, signal, and begin to implement a new offshore wind procurement and risk allocation approach as soon as possible and by the end of 2024 at the latest, and decide which supply chain elements should be UK based**
13. **Immediately change the budget for AR6 to procure as much pre-2030 offshore wind capacity as possible at an acceptable strike price, from projects already with development consent.**

International comparison: Uruguay increased its onshore wind capacity from 1% to 34% of its energy mix over a 5-year period, from 2013–2018.[10]

2.2.2 **Onshore wind and solar**

Onshore wind and solar can be built quickly and help to provide a step change in delivery of renewable generation, especially if built in places where the transmission grid already has capacity to absorb it. Hitherto, the constraints have been grid connections and planning and consenting, with the planning system treating wind and solar quite differently.

Locating onshore renewables in areas where the grid has capacity is a potentially valuable route to a sharp acceleration in renewable generation. Removing wind from the Nationally Significant Infrastructure Project (NSIP) regime and lowering the bar for objections has resulted in a de facto moratorium; the government's immediate post-election amendment to the National Planning Policy Framework and announcement of an intention to consult on returning onshore wind to the NSIP regime is therefore a significant step. Much of the potential for onshore wind is in Scotland, where the Scottish Government has set a target to increase onshore wind capacity from the current 10 GW to 20 GW by 2030.

Globally, solar deployment has really taken off, due to the major cost reductions of the last decade, as well as its modularity and short lead times. Government must set out its vision for solar and onshore wind early in the Parliament and carry this through to its approach to public engagement and planning.

Actions for government

14. **Return onshore wind to the NSIP regime as soon as possible, so it is treated in the same way as other energy infrastructure**
15. **Ask NESO in its October 2024 plan to identify zones for onshore renewable deployment where the transmission grid has capacity to absorb the generation and run a process (e.g. spatially-zoned CfD auctions) to progress these projects rapidly**
16. **Introduce mechanisms to further encourage development of local community renewable generation projects.**

Actions for government

17. **Ensure rapid progress on the current construction project, Hinkley Point C (HPC), with licensed owner EDF encouraged and supported to expedite its successful and safe completion and commissioning**
18. **Work with EDF to assess options for safely extending the lives of existing AGR nuclear plants where possible**
19. **Ensure strategic resilience of nuclear fuel sourcing by plant operators, where possible facilitating the UK sourcing of nuclear fuel.**

2.2.3 Existing nuclear and Hinkley Point C

The UK's existing nuclear fleet provided 14% of generation in 2023. The four remaining Advanced Gas-cooled Reactors (AGRs), totalling 4.9 GW, remain a significant part of low-carbon baseload, but all are currently scheduled to be taken out of service by 2028. The existing 1.2 GW Pressurised Water Reactor (PWR) at Sizewell B will remain in service until at least 2035 and potentially longer with policy support.

EDF is hopeful of further extending the lifetime of the AGRs slightly through constructive regulatory dialogue, and with government support. Government must urgently assess the potential for doing so, both in engineering and in economic terms, with any consideration for delaying decommissioning carefully evaluated and with a safety case deemed suitable by the Office for Nuclear Regulation, and build the results into NESO planning.

The new nuclear plant at Hinkley Point C (HPC) has been delayed several times, and EDF now estimates that the first reactor could commence operation between 2029 and 2031.[11] Lead times for further new nuclear plants mean that they will not be delivered until the 2030s, though that should not slow action to deliver these options given the long lead times for nuclear construction (see Section 3.3).

Current and future supply chains for nuclear fuels will be important and decision-making must prevent the risk of over reliance on imported nuclear fuels. Work to find long-term solutions to the storage and disposal of nuclear waste needs to be progressed to a conclusion.

2.3 The electricity grid: transmission and distribution

2.3.1 The transmission system and connections

The precise requirements for new grid transmission must be considered alongside plans for generation and flexibility, notably in the accelerated NESO planning referred to in Section 1.3. Total grid requirements are not fixed, but may be eased by reducing peak demand through flexibility, and by moving generation nearer to where the grid is strongest (or even in time by moving some heavy users of power nearer to both). But in all conceivable worlds, a greatly strengthened and extended grid will be needed.

In the GB system, development of new transmission lines has historically taken about 14 years from identification of the need to commissioning. This is far too long for efficient system development. The Electricity Networks Commissioner (ENC) set out in 2023 how to reduce these lead times to seven years and its recommendations were accepted in full in the 2023 Autumn Statement. Alongside this, the government published its Transmission Acceleration Action Plan and a revised suite of National Policy Statements (NPS) for Energy.

Even on this accelerated seven-year timeline, which will require strong government commitment to deliver, a project being initiated now would not be operational until after 2030.

This is one of the most significant and difficult constraints to rapid progress. The challenge for government if it wished to go faster than seven years is not a technical one, but that doing so cuts into the window in which affected communities can engage with these plans and their views can be heard. Government will need to make an early decision on what it is prepared to do here, and then plan realistically on that basis, including considering alternative strategies such as locating renewable capacity where it can readily be accommodated by existing grid infrastructure where possible.

Many necessary near-term transmission reinforcement projects were already 'in flight' before the most recent set of changes, through the Accelerated Strategic Transmission Investment (ASTI) framework. This is sufficient to support 50 GW of offshore wind by 2030.

Government and regulators will need to pay close attention to these existing projects and drive them through the existing process quickly, addressing major challenges constraining further development, including the long lead times affecting new grid lines, changes in the supply chain for skills and materials, and a bulging queue for connections. Many of the most truly transformational, but also most difficult, options for accelerating progress lie here.

As discussed above, NESO will need to identify what is required to fill the gap between the ASTI projects and what is required for 2030. To the extent that some further transmission lines are required, there would need to be a rapid one-off ad hoc process to plan for this, with initial SSEP and CSNP plans drawn up by the NESO within four months and finalised by mid-2025 to enable the projects to proceed on a timely basis.

Transmission is another area where the supply chain already looks very stretched[xiv] as other countries seek to decarbonise and, in some cases, are more strategic about securing access to finite capacity. Government will need to decide where market forces will not deliver the supply the UK needs and a more proactive approach is required, for instance asking Ofgem to work with transmission companies to enable long-term commitments to partners in equipment supply and design and construction services. Considerable work has been done in this area already by industry and the Department for Energy Security and Net Zero (DESNZ), which should be reviewed against an accelerated timescale.[12]

Finally, connections to the grid have been managed to date on a first-come-first-served basis, and the queue to connect has now grown to over 700 GW.[13] The DESNZ / Ofgem Connections Action Plan[14] concluded that the connection process was not 'fit for purpose', and NESO has put in place a process to remove so-called 'zombie' projects so that more viable projects can be accelerated.[15] A more radical process would be to make a break from the current first-come-first-served basis altogether and repopulate the queue on the basis of strategic need according to the NESO strategic plan, while moving forward on those projects that have already been assessed and prioritised by government. This approach might be considered to infringe the 'property rights' of projects currently in the queue with connection dates, a legal and political issue outside the scope of this report.

The issues caused by the long queue for grid connections need to be resolved by the end of 2024, so projects become unlocked for construction.

Actions for government

20. Accelerate progress on implementation of the recommendations of the 2023 ENC report, and assess whether and where government is prepared to accelerate progress beyond the seven-year process it sets out

21. Decide approach to the queue for grid connections to accelerate project delivery. This could include taking a strategic and managed approach to the queue, but this may come with legal and other issues that are beyond the scope of this report.

2.3.2 Distribution

An expanded and upgraded distribution grid is essential to the flexibility and demand-side response upon which the future energy system relies. While

xiv particularly at present for HVDC cables and inverter equipment.

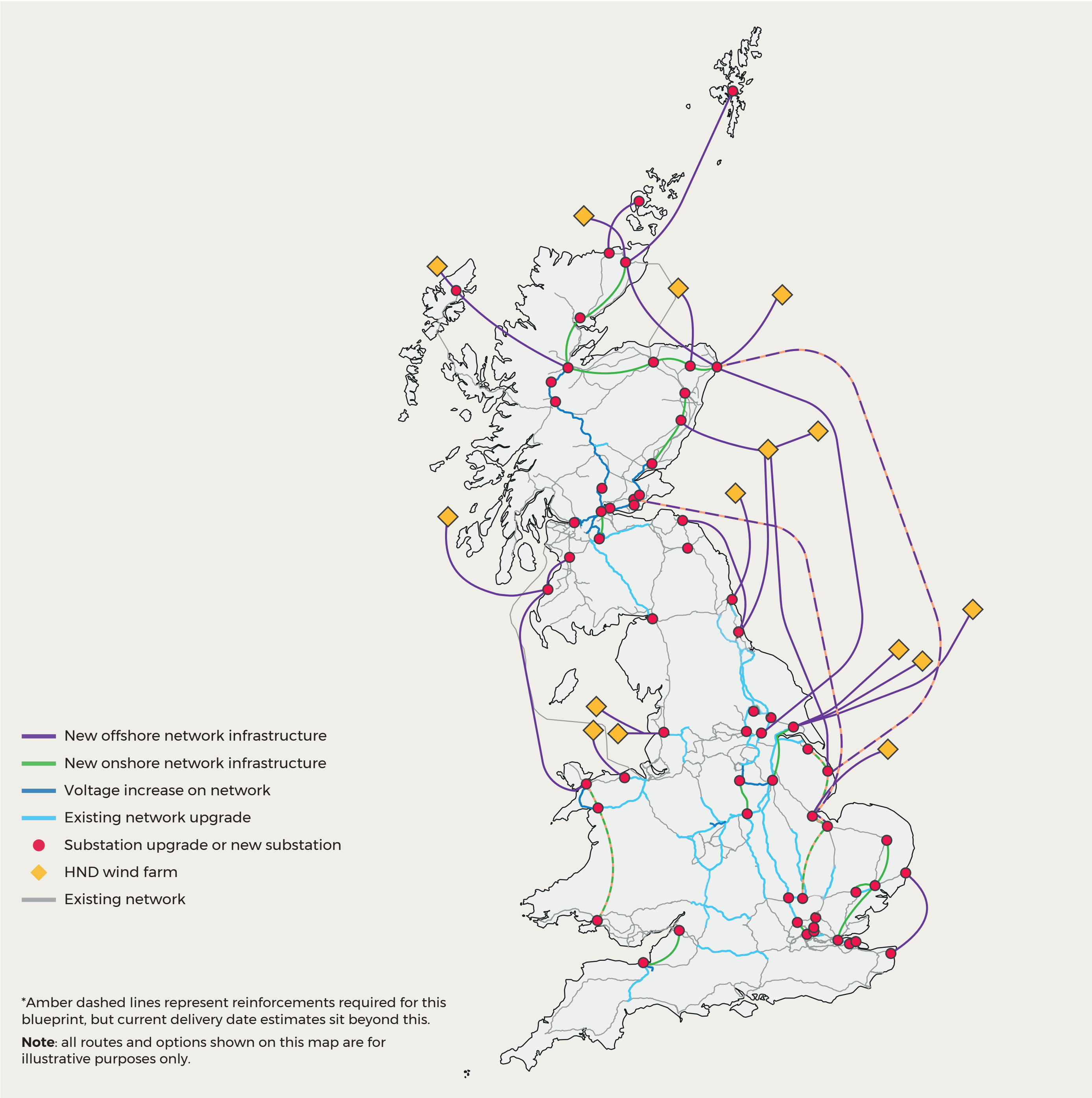

Figure 5 | Map of network infrastructure to be delivered by 2030

Lead times for building transmission infrastructure in Norrbotten in North Sweden were cut dramatically through innovative enablers such as parallel sign off processes, environmental permitting completed ahead of siting, interactive permitting procedures and pre-awarding supplier contracts. These investments in Sweden have a standard schedule of 10–12 years and these enablers allowed the process to be cut back to 5–6 years.

> An expanded and upgraded distribution grid is essential to the flexibility and demand-side response upon which the future energy system relies. While much of that expansion will take place after 2030 as EVs and heat pump uptake really start to scale, critical investment and regulation decisions will be needed well ahead of that date

much of that expansion will take place after 2030 as EVs and heat pump uptake really start to scale, critical investment and regulation decisions will be needed well ahead of that date. Even now, there are already significant congestion hotspots impeding commercial and industrial demand connections and the economic growth that would come with them, as well as delays to local renewable energy schemes.

Under the current price control mechanism, Ofgem sets Distribution Network Operators (DNOs) a fixed five-year investment level. So-called 'volume driver' payments are then granted on an automated basis as connection requests for new EVs or heat pumps arise. Significant alteration to the overall cost envelope is enabled only on a very limited basis through a so-called 're-opener' mechanism, allowed just twice during the five-year price control period, on the basis of new demand for connections such as public EV charge points. This demand-led process served to limit the levels of investment feeding back into bills during a period of incremental grid expansion, but is not set up to enable the considerable anticipatory investment and uptake of EVs and heat pumps needed to support wider decarbonisation in an era of sharply increased ambition.

In addition, DNOs report widely varying understanding of the constraints on their system, hampering their ability to develop new capacity and actively manage the network (e.g. voltage levels). This is caused by scant monitoring of the capacity in the low voltage networks, low levels of digital information from smart meters due to the underperforming smart meter roll-out, and EV and heat pump connections made without notifying the DNOs. DNOs are further impeded by uncertainty over the scale of coming demand, which depends upon the ambition and progress of government policy for EVs and (particularly) heat pumps.

All of this needs focus and action in the short term, and the system should be redesigned before the next scheduled regulatory regime (RIIO-ED3) due to come into force in 2028. Government should accelerate development of the Regional Energy Strategic Planners (RESPs) to support better strategic planning across DNOs in time for ED3 business plans, and clarify the roles and responsibilities of DNOs, Local Authorities, RESPs, the NESO, Local Area Energy Plans and Ofgem in directing activities. The National Infrastructure Commission is also due to report on the distribution network.

Actions for government

22. **Make strategic decisions on the decarbonisation of buildings heat as quickly as possible, to provide clarity on heat pump ambition and the necessary long-term capacity for distribution networks**
23. **Government should direct Ofgem to redesign the uncertainty mechanisms in current and future price controls, to deliver a regulatory regime which meets the Government's ambitions and supports anticipatory investment. This should be completed in the first half of 2025**
24. **Publish the planned Ofgem consultation on the RESPs as soon as possible and clarify the respective roles of DNOs, Local Authorities, RESPs, the NESO, Local Area Energy Plans, and Ofgem in decision-making for distribution grid investment.**

2.4 Operating a high-renewables system: flexibility and security of supply

Decarbonisation will improve the security of the system from a geopolitical and price-volatility perspective, with much lower reliance on imported fossil fuels. However, the electricity system will need to change significantly if it is to avoid exchanging one sort of insecurity for another. A decarbonised system, heavily dependent on renewables, lacks the inherent stability which comes from large quantities of firm, schedulable power, with a positive form of inertia which enables a consistent supply. It must also cope with changes in weather and in seasons bringing sustained high demand in cold periods and reduced supply when it is dark, cloudy or the wind is still.

Ensuring a reliable electricity supply which matches demand as it rises and falls is technically possible, and doing so well can increase efficiency, manage the peaks which would otherwise increase how much grid infrastructure must be built, maximise the use of renewable generation and reduce expensive curtailment.[xv] It will require that a portfolio of solutions is embraced, which include:

- Short-term flexibility to manage and coordinate supply and demand and provide system services. This will involve demand-side response, where price signals encourage consumers to shift demand to match available supply not vice versa, and short-term energy storage, as well as providing services such as inertia and frequency response.
- Shifting excess supply or purchasing additional supply as needed from neighbouring countries through interconnectors, and
- Keeping a reserve of 'schedulable' energy to be switched on when demand peaks.

Making such a system work well will require strategic digitalisation discussed in Section 1.6, providing granular data and real-time control of flexibility (in generation, demand, and network topology). NESO will need to be regulated and supported to become a digital-first organisation, drawing on best-in-class modelling and automation across control room operations, data sharing, market platforms and asset registers, and thereby able to make best use of the flexibility options available to it in preference to thermal (and in the short-term carbon intensive) generation.

Given the fast pace of change it will be sensible to prioritise stability and ensure development of more capability not less, planning on the basis of the wind generation in a low-wind year. Planning will need to take into account the potential impact of climate change as heatwaves increase demand, weather patterns impact on renewable generation, and extreme weather disrupts systems and potentially changes the contribution of interconnectors, as weather systems that affect the UK may affect large parts of Europe.

Actions for government

25. Ensure that the NESO has a mechanism in place for quantifying the level of resilience of the energy system and that this is appropriately managed and tracked during the system transition.

2.4.1 Flexibility, demand-side response, and within-day storage

Flexibility, short-term storage and demand side response must be considered together – indeed the boundary between them is fuzzy as in many cases demand flexibility relies on some kind of

Resilience should be core to this programme with outcome-based resilience standards for energy. Maintenance is a vital consideration and new infrastructure should be designed with maintenance and repair in mind, with maintenance standards integrated into operational contracts for infrastructure's lifetime and the skills provision to maintain existing and future assets.

xv The process through which generators are paid to cease generation, which cost the UK in excess of £300 million in 2023. https://reports.electricinsights.co.uk/wp-content/uploads/2024/02/ElectricInsights_23Q4.pdf

Flexible demand has two key functions and meanings. It can simply mean *matching* supply and demand by moving demand into times of peak renewable generation (e.g. very windy or sunny periods). Or it can mean actively *flattening* the profile of demand to help manage capacity constraints in the network and to defer the need to build out additional infrastructure. The two are not equivalent, and may at times be in conflict with each other, and have different benefits to the system, with flattening demand being particularly valuable when grid capacity is tightly constrained (with operational limits and plant lifetime impacts taken into account).

storage capability in the relevant appliance e.g. the battery in an EV, thermal mass of an electrically heated building, molten salt storage integrated into industrial steam production.

Domestically, maximising the contribution of flexibility to reduce costs and emissions could deliver considerable additional capacity[xvi] given sufficient uptake of appliances. EVs offer particular opportunities if they are charged flexibly. Realising this potential requires optimising the over one million EVs in the UK today for smart management through well-designed incentives and digital control of both EV and charge-point. It will also require investment in the distribution networks (see Section 2.3.2) and ambitious and sustained policies to support EV uptake and charge point roll-out.

Government will also need to engage with industrial electricity users to discover untapped potential for flexibility at scale, and support a portfolio of within-day storage solutions on the basis of their characteristics (e.g. storage duration) rather than specific technologies. Some projects (e.g. pumped hydro projects in Scotland) are ready for Final Investment Decisions (FID) with the right policy support.

Finally, market mechanisms will be essential to unlocking the flexibility of the system. Accelerating the switch to half-hourly settlement will sharpen market incentives, while revitalising smart meter roll-out will enable their use. Interoperability issues around smart technology, metering, EV Charger API (Application Programming Interface), and charge-point protocols also need to be addressed.

Actions for government

26. **Introduce half-hourly settlement to the electricity market and deliver a plan within three months to set accelerated smart meter roll-out on a sound engineering basis**
27. **Provide sustained policies and positive messaging to accelerate EV, electric heating and industrial electrification, and the hardware, infrastructure and tariffs needed to operate them flexibly. Accelerate roll-out of the public EV charging network with good geographical distribution through schemes such as the Local Electric Vehicle Infrastructure (LEVI) funding**
28. **Move ahead actively with procuring within-day storage in a technology-neutral way, based on required characteristics rather than picking certain technologies.**

2.4.2 Interconnectors

Flexibility, demand response, and most forms of storage can shift consumption on a within-day basis, but there will still be some more extended periods of up to multiple weeks of excess or shortfall from these sources that need to be managed.

Exporting to, or importing from, interconnected markets in the rest of Europe can balance supply over a longer time period.[xvii] There remain issues

xvi Analysis carried out by Octopus Energy for this project suggested that fully optimised domestic flexibility could deliver flexibility of between 12.4 and 17 GW, based on the level of EVs (cumulative 8.3 million by 2030) and heat pumps (cumulative 2.3 million by 2030) at an average of the levels in the 2023 ESO's Future Energy Scenarios, alongside flexible operation of storage heaters, hot water tanks and residential batteries. This assumes that the share of number of customers on smart tariffs grows to between 40% and 75% by 2030. Implementing vehicle-to-grid flexibility could potentially provide around an additional 3 GW.

xvii A 2020 study *The impact of interconnectors on decarbonisation*, prepared by Aurora for BEIS found that an increase in interconnector capacity would lead to: a decrease in emissions in GB & EU, a reduction in total power market costs in GB, less thermal generation in GB and less curtailment of renewables.

to resolve. In the existing electricity system, it is not uncommon for Scotland to be in oversupply while the South East of England is in undersupply because of transmission constraints. The UK operates a single price for electricity, which in this instance could incentivise interconnectors in the South East to export to the EU rather than import. Centralised Strategic Network Planning (CSNP) will need to address this, by providing locational investment signals for new and reinforced critical energy infrastructure.

Interconnectors are predicated on cooperation between the EU and the UK for mutual security of supply. Priorities will include development of offshore hybrid assets infrastructure in the North Sea and the Irish Sea, both connecting offshore windfarms and acting as interconnectors between countries, alongside eliminating trade barriers by aligning carbon pricing regimes such as Emissions Trading Systems, and border adjustment mechanisms..

More immediately there is a need to clarify support for six new point-to-point interconnector links and one offshore hybrid asset connecting offshore wind after their applications for inclusion within cap-and-floor support were rejected by Ofgem in spring 2024.

Actions for government

29. **Work with NESO and Ofgem to develop a revised needs case for interconnectors, including offshore hybrid assets, in the context of accelerated ambition for electricity system decarbonisation**
30. **Revisit the Spring 2024 decision and include the additional transmission infrastructure to ensure their efficient operation in the first draft of the CSNP**
31. **Work with NESO and Ofgem to consider how CSNP can provide appropriate locational signals for energy infrastructure investment and the interaction of this with market arrangements**
32. **Work with the EU to align emissions trading schemes and carbon border adjustment mechanisms.**

2.4.3 Unabated gas capacity

Where interconnectors do not suffice, back-up capacity is required in the form of dispatchable thermal capacity. While CCS and hydrogen provide important opportunities to do this in a low-carbon way in the longer term, and can make some contribution this decade, the default in the period to 2030 will be using unabated (i.e. non-CCS) fossil gas capacity. Modelling provided to this project by LCP-Delta suggests that even in a highly decarbonised system, some unabated fossil capacity may be called upon in at least 25% of hours across the year in 2030 even if only for a small proportion of total generation.

This requirement comes against a background in which many firm and/or dispatchable plants, including coal and many nuclear units, have left the system or are scheduled to do so later this decade.[xviii]

The government's commitment for a strategic reserve of unabated gas capacity is therefore a crucial aspect of ensuring security of supply. Policy will need to ensure that short-term signals do not encourage existing gas-fired capacity to close down while still needed, extending the life of some, where possible. With this done, it may still be necessary to build new gas-fired capacity. This counterintuitive measure can be made consistent with the path to fully decarbonised energy by ensuring that any plant expected to operate at a significant load factor is made 'low-carbon-ready'. Readiness requires three key components:

- **Technical readiness**. Making it relatively straightforward to modify plant to operate as low-carbon capacity
- **Location**. Located in proximity to routes identified by NESO for future hydrogen or CO_2 infrastructure so that plants can connect once this infrastructure is available
- **Incentives/regulations**. Ensuring the financial incentives and regulatory requirements are in place to motivate conversion when feasible.

Carbon-capture-readiness rules have been in place since 2009[16], but these rules only meet the first criterion and only cover CCS-readiness. Government

xviii All but one of the coal power stations and some nuclear power stations have left the system over the last five years, while four more nuclear power stations are due to retire by 2028. Many of the gas CCGT units built in the 1990s are also close to their scheduled end-of-life dates. The effect of these exits will be affected by the extent to which nuclear AGRs can be extended, and whether biomass can be operated sustainably post-2027.

will need to close loopholes such as those which have seen plant built in unsuitable locations at 299 MW, just below the threshold at which CCS-readiness requirements apply.

Actions for government

33. By the end of 2024, set out low-carbon readiness requirements for new gas-fired capacity, including addressing the locational aspects, the need for a conversion mechanism and thresholds around capacity and load factors

34. Request that the NESO sets out an initial view, for subsequent refinement, on the future locations of hydrogen and CO_2 infrastructure to enable rules to be implemented on the locations of new gas-fired capacity.

2.4.4 **Carbon capture and storage (CCS) and hydrogen**

A renewables-based electricity system, supported by a range of flexibility measures and backed by dispatchable power from unabated gas will, by its nature, have some residual carbon emissions, perhaps equating to about 10% of its generation. Reducing that to close to zero requires on-demand dispatchable low-carbon capacity to balance the system, pushing out unabated fossil capacity. The two main options to do this are gas-fired plants with CCS, and hydrogen-fired plants (e.g. turbines). CCS capacity and development of a hydrogen infrastructure can unlock other advantages, such as difficult-to-electrify parts of industry, and greenhouse gas removals to balance residual emissions as part of Net Zero.[17,18]

Only a subset of hydrogen and CCS solutions can be realised in time for 2030 because of a range of factors including a current lack of a fully developed infrastructure, technical immaturity, long lead times in some parts of the infrastructure and supply chain immaturity. Beyond ensuring that short-term unabated gas is convertible to CCS/hydrogen in future as described above, a sensible strategy will involve two things:

- Taking FIDs on the two 'Track 1' clusters in Teesside and HyNet in the north west of England, which have supply chains and contracts lined up ready for FID in September 2024, for delivery by 2030. Subject to business case, green-lighting these projects would mean that the UK has finally started on CCS, after three failed attempts, whereas even a few months delay in deciding would require the projects to return to the supply chain for revised quotes leading to potentially much greater delays.
- Pursuing a wider expansion of CCS and, with it, blue hydrogen production. In the short term this might mean 'Track 1 expansion' projects (e.g. Keadby) and Track 2 projects (e.g. Peterhead). It would also require addressing operational limitations to the extent to which power-related CCS facilities can be operated variably to balance the system.[xix]

Between them, these projects offer the opportunity for 2–3 GW of dispatchable capacity to be on the electricity system by 2030, making an important contribution to decarbonised dispatchable capacity as well as creating the option for CCS to decarbonise other sectors.

Progress will also need to be initiated on a range of hydrogen production and geological storage solutions, so that where possible these can be operational by 2030 or as soon afterwards as possible (see Section 3.1).

Actions for government

35. Take FIDs on the Track 1 CCS clusters and immediately move to negotiations on further power plants as part of the 'Track 1 Expansion' and Track 2 set of projects.

2.4.5 **Biomass and Bioenergy with Carbon Capture & Storage (BECCS)**

Biomass-fired generation is accounted for as low carbon, because of carbon sequestration during its growth. It is schedulable, so can provide either semiflexible thermal capacity or reliable baseload as required. Where biomass is combined with CCS

xix For example, the CO_2 infrastructure will have to be able to cope with variable CO_2 flows, which is likely to require that these projects are delivered alongside those that operate with a flatter profile so that the volatility of flow rates is kept within manageable limits. This is the plan in the industrial clusters.

(BECCS), it can contribute greenhouse gas removals that are key to achieving overall Net Zero. BECCS therefore holds an important strategic position in many models of the future power system.

Biomass generation is only worth supporting, however, and if the emissions savings are genuine and based on sustainable feedstocks, which is contested for biomass pellet imports to the UK.

Making generation carbon negative depends upon CCS coming on stream. Even then, while BECCS for power generation gives a similar emissions benefit to other forms of BECCS, there may be greater value in using the finite BECCS resource for aviation fuels or hydrogen.

Existing large-scale biomass power plants (e.g. the 2.6 GW capacity at Drax) could be retrofitted with CCS relatively quickly and at lower cost than new-build plants, though as ex-coal units designed for pulverised fuel they are currently tied to controversial imported North American feedstocks, and might be less well suited to UK grown crops even if this were considered the best use of land.

The current set of subsidies for biomass generation expire in 2027, so government must decide soon whether to support a sustainable version of biomass generation for grid flexibility in 2030, to be retrofitted with CCS as soon as possible, or to end subsidies at that point and explore other options for greenhouse gas removals post-2030, such as new-build BECCS plants using domestically grown feedstocks or Direct Air Carbon Capture and Storage (DACCS).

Actions for government

36. **Alongside power station owners, rapidly identify what if any solutions exist for transition of existing biomass plants to be fully sustainable, well-governed (e.g. domestic) biomass supplies**
37. **On the basis of this, take stop-go decisions on future support for existing biomass-fired units by the time any post-2027 support needs to be put in place.**

The current set of subsidies for biomass generation expire in 2027, so government must decide soon whether to support a sustainable version of biomass generation for grid flexibility in 2030, to be retrofitted to CCS as soon as possible, or to end subsidies at that point and explore other options for greenhouse gas removals post-2030, such as new-build BECCS plants using domestically grown feedstocks or Direct Air Carbon Capture and Storage (DACCS)

3 | Near-term progress needed primarily for post-2030

While near-term decarbonisation of the electricity system is a crucial step, it is ultimately a milestone on the path to an overall Net Zero energy system by 2050, itself serving a decarbonised industry, transport, and much-changed consumer demand. While much of this is beyond the scope of this report, we set out here what needs to be put in place in the next few years to create viable pathways and options for deployment at scale in the 2030s and 2040s.

Over this timescale much will change, including technology maturity and costs, so it is important to conceive of a portfolio of development investments to create choices, taking account of where development is also taking place in other countries. There will remain a lot to do in the 2030s and 2040s to achieve this. Figure 6 helps guide thinking about what should be considered near term and can be accelerated with confidence, and what requires substantial development before being deployable.

Further expansion of generation, including further nuclear projects and potentially including a broader range of renewables such as tidal, will be required post-2030 to support widespread electrification of the energy system and wider demand increases (e.g. data centres), alongside commensurate further expansion in transmission and distribution network capacity. Some of this can be parked for later, but in many cases will need to be initiated soon, with strategic decisions taken in the first half of this Parliament. Government should also continue to review the development of nuclear fusion technologies in both public and private sectors and support as appropriate.

There is an extensive and diverse global ecosystem of cleantech innovation that has every chance of bringing forward scalable technologies that could create fresh options for the electricity system post-2030. We cannot necessarily see or predict what these might be at the moment. Generally, cleantech struggles when it is trying to deploy into systems designed to be governed in a conventional way. It is inherently disruptive to such governance and either fails to deploy, or deploys in ways that are not thought through from a system perspective, throwing up perverse consequences.

Work should be done to create agility in system governance, and an enabling environment to make the UK an attractive location for new technologies to be piloted, to learn and to scale through deployment on the electricity system. This is likely to yield some deployment before 2030, but mainly to create additional options to be scaled post-2030.

3.1 Hydrogen storage, generation and transportation

Beyond the value of flexible demand, short- and medium-duration storage and interconnection in managing demand and supply, the energy system will need low-carbon long-duration storage, capable of underpinning supply during multi-week periods of low wind and/or high electricity demand (e.g. extended still periods in winter) and making the most of the excess renewable generation (e.g. at times of high wind).

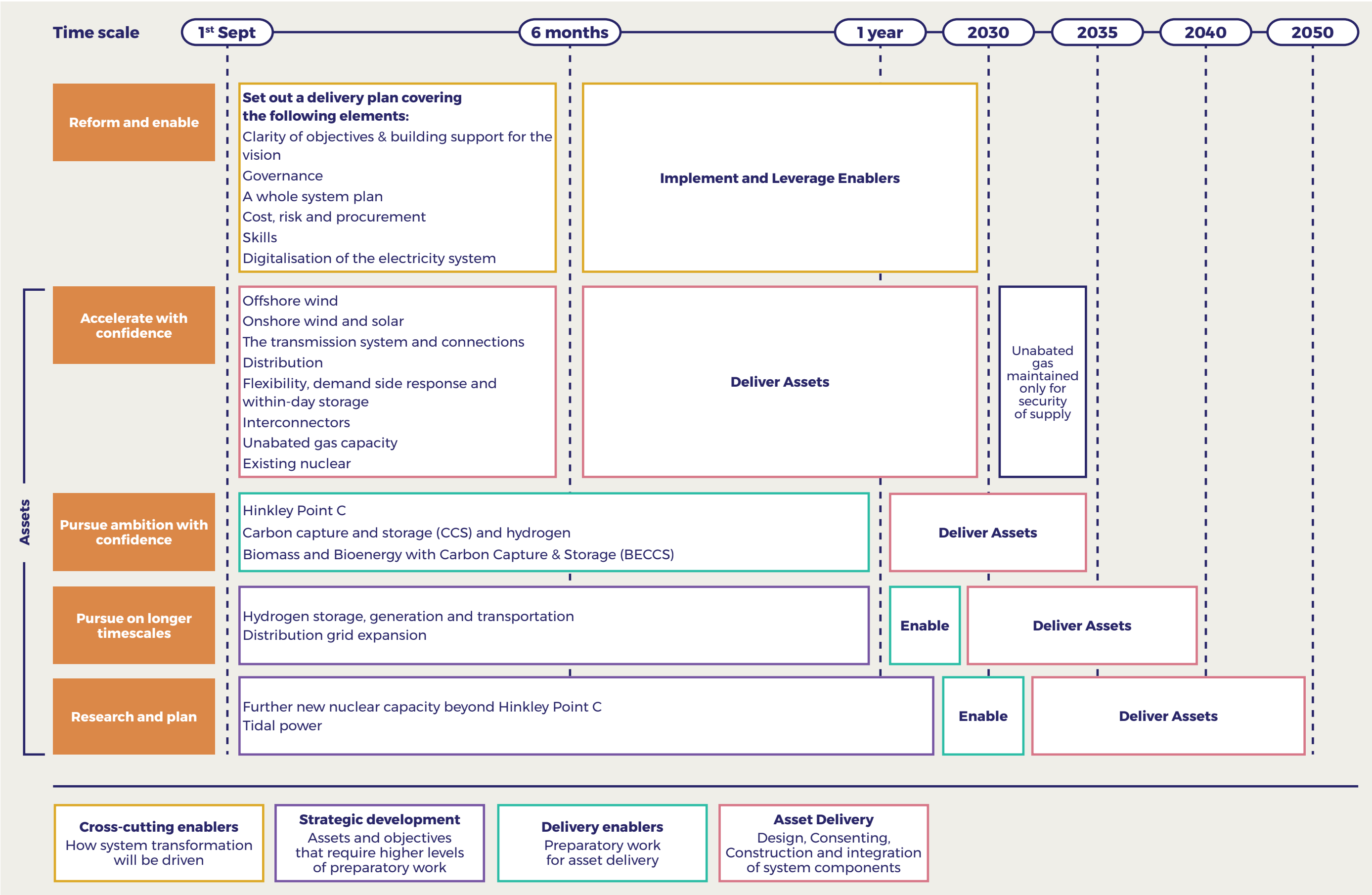

Figure 6 | A high level plan for delivering rapid grid decarbonisation out to 2050

Geological hydrogen storage is the main candidate for this role, and will be key in contributing to security of supply and helping to replace the role of fossil gas in meeting seasonal and weather-dependent swings in heating-related energy demand. New geological salt cavern stores have relatively long lead times of about eight years to develop, so it is essential that government acts now to facilitate their development, while assessing the shorter-term tactical options ahead of 2030.

Alongside hydrogen storage development, it will be necessary to develop hydrogen production and use cases.

- Both green hydrogen (i.e. electrolysis) and blue hydrogen (i.e. reformation of fossil gas with carbon capture and storage) are likely to be necessary and need to be developed this decade. While green hydrogen is likely to dominate in the longer term, blue hydrogen has value in the near term in scaling production and in more of a back-up role in the longer term for security of supply.[xx]
- Hydrogen-to-power solutions are increasingly becoming available, with companies such as Siemens and GE starting to produce versions of their gas turbines that can operate on blends of hydrogen and fossil gas up to 100% hydrogen. Providing market opportunities for deployment in the GB system could help accelerate this process.

Further development of a hydrogen system involves coordination across hydrogen use, low-carbon production, and transportation and storage infrastructure, in which the initial absence of any one component poses risks to the others (e.g. demand without production). Government intervention may be necessary to manage risks until industry scale is achieved, by underwriting risks or exploring ways to break interdependence between system components, for instance by deploying

xx See *The role of hydrogen in a net zero energy system* for a more detailed discussion of the future of low carbon hydrogen.

hydrogen-ready turbines (burning fossil gas and hydrogen) and blending green hydrogen into fossil gas power plants.

It will also be important to manage the impacts of years with relatively low renewable generation, including the possibility that multiple such years occur consecutively. Developing options to recharge hydrogen stores with imported energy (e.g. imported green hydrogen or domestic blue hydrogen production using imported fossil gas with CCS) will be important to ensure that multi-year periods of low renewable output do not undermine the value of this hydrogen storage to security of supply.

Converting the existing Rough gas storage facility in the Humber region to hydrogen could be of value by 2030, if the hydrogen production and usage technologies can also be put in place to use it. However, converted gas storage capacity would store only one-third the energy as hydrogen as it does of fossil gas, potentially reducing the overall resilience of the energy system.

Actions for government

38. Initiate development of hydrogen salt cavern storage in suitable locations, so that they can be available by 2030 or as soon as possible thereafter

39. Commission first of a kind hydrogen-fired power plant, located where there is an available source of low-carbon hydrogen, to get a route to market as soon as possible for this technology.

3.2 Distribution grid expansion

At present, at the aggregate level, the distribution networks mostly have sufficient capacity to manage an uptick in connections in the near term, although as discussed in Section 2.3.2 there are serious localised problem areas that need addressing quickly. However, in the 2030s and 2040s, the networks will need significant investment and expansion to manage further growth in the electrification of heat and transport, as well as local generation connected into distribution networks. Analysis from the Local Area Energy Plans shows a need for an overall distribution network three times the size we have today to achieve a fully-decarbonised local area.

To avoid significant disruption and to minimise costs, distribution network upgrades should be undertaken on the principle of 'touch the network once' rather than repeatedly upgrading the same part of the network. To achieve this, plans will need to be developed to determine the expected network capacity required in a given area to connect future industrial and commercial developments, as well as expected EV and heat pump connections as set out in a decarbonisation of domestic heat strategy, as discussed in Section 2.4.1.

A strategic understanding of future capacity demand should then inform the anticipatory investment needed in different areas. Upgrades will need to happen in an anticipatory way, building ahead of need, supported by amended regulation and investment decision-making set out in Section 2.3.2, as opposed to the reactive, demand-led approach adopted currently. Whether the required grid upgrades then proceed on a street-by-street basis or prioritised by need will be a decision for Ofgem, which should be undertaken in collaboration with other utilities which may require street digging where possible. This will allow the distribution network to be future-proofed when planning for connections, such as housing developments for example, where capacity demand will need to be in place at the outset to allow for future installation of heat pumps and domestic and/or charge points.

This level of expansion in the 2030s will require access to skills and supply chains, and the broad consent of the public, in much the same way as the transmission expansion of the 2020s is currently demanding, which will need planning for in advance. It is also an economic opportunity that by its nature touches the whole of the country.

3.3 Further new nuclear capacity beyond Hinkley Point C

Further new nuclear plants can play a major role in the wider electrification of the economy. Their lead times mean that they will not be delivered until the 2030s, but also implies that action is needed now to ensure these options are available at that time. Decisions will be needed soon to facilitate development of both proven large-scale and small modular reactor designs. Applying lessons from UK and international experience on procurement and delivery will be vital, and aligning with best-in-class infrastructure standards will be key.

Actions for government

40. Continue to progress the Sizewell C (SZC) project with EDF, maintaining the pace of development

41. Explore potential alternative technologies for future large nuclear power stations and benchmark them against the option to progress further series build of the EPR design used at Hinkley Point C. Progress with vigour the development and deployment of further large nuclear power plants

42. Support the continuing development of small modular nuclear power plant (SMRs) and maintain a watching brief on SMR developments outside the UK.

3.4 Tidal power

Tidal barrage technology is proven in application, with plants having operated in France and South Korea for some time. The UK has excellent tidal resources, and there are several large-scale tidal barrage projects in various stages of development, some being developed by the private sector and some by local authorities. By providing connections across rivers or estuaries these projects could also make wider contributions to economic development and regeneration of coastal communities through enhancement of connectivity.

As one-off projects, these projects face a number of challenges:

- significant upfront capital costs for assets with a very long design life (80 years)
- substantial planning and consenting challenges due to the impact such projects have on the surrounding environment
- demonstrating the value of the variable nature of the generating capacity over time with the tide. Whilst predictable, it is not fully dispatchable
- substantial investment requirements of the development phase.

For these reasons, there are no large-scale projects operating or under construction in the UK currently. More recently ideas of tidal lagoons have been put forward, which could provide a path to UK deployment that is more accessible, with smaller project sizes, cost reduction through the possibility of standardisation of core components such as turbines, and more contained environmental impacts. These options should be explored further.

Actions for government

43. Rapidly identify whether a portfolio of tidal barrages and/or lagoons could be deployed at faster pace, making a contribution to accelerating the achievement of a zero-carbon electricity system, at a competitive whole energy system cost.

The actions in this report collectively comprise a set of changes which can enable the UK to rapidly accelerate energy system decarbonisation, and do so in a way which enables it to press on to wider decarbonisation of the economy by 2050. The Royal Academy of Engineering and its partners in the National Engineering Policy Centre are happy to provide further advice to government as it puts in place the changes needed to enact its ambitions for a decarbonised grid.

Glossary

Acronym	Definition
AGR	Advanced Gas-cooled Reactor
ASTI	Accelerated Strategic Transmission Investment
BECCS	Bioenergy with Carbon Capture and Storage
CCS	Carbon Capture and Storage
CSNP	Centralised Strategic Network Plan
DESNZ	Department of Energy Security and Net Zero
DNO	Distribution Network Operator
ENC	Electricity Networks Commissioner
EV	Electric Vehicle
FID	Final Investment Decision
NESO	National Energy System Operator (currently the Energy System Operator)
NPS	National Policy Statements
NSIP	Nationally Significant Infrastructure Projects
PWR	Pressurised Water Reactor
RESP	Regional Energy Strategic Planner
RIIO-ED3	Third iteration of the electricity distribution price control mechanism, introduced by Ofgem
SSEP	Strategic Spatial Energy Plan

Acknowledgements

The report has been developed by the Royal Academy of Engineering and partners in the National Engineering Policy Centre (NEPC).

This policy project was funded by a grant from The Gatsby Charitable Foundation. We would like to express our gratitude to the Foundation for supporting this work.

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Additional thanks

The Royal Academy of Engineering expresses its thanks to the various contributors to this work, including the Professional Engineering Institutions, and notably the **Institution of Civil Engineers** (ICE) and **Institution of Engineering and Technology** (IET).

Additional input has been provided by Professor Rob Gross, Martin Högel, Mark Wild OBE FREng, Professor Sir Peter Bruce FRS, Mark Enzer OBE FREng, and Mark Neller.

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> Rapid transformation to a decarbonised electricity system will significantly reduce our reliance on fossil fuel imports whilst providing a range of opportunities to create economic, employment, health and other benefits

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