Future Energy Scenarios: Pathways to Net Zero

Executive Summary

July 2025

NESO
National Energy System Operator

Foreword

I am proud to introduce our 2025 Future Energy Scenarios: Pathways to Net Zero. This is our fifteenth FES and our first since NESO was established in October 2024 as an independent, public corporation at the centre of the energy system.

FES provides an independent view of a range of future pathways for the whole energy system. It has become an important publication in the energy sector and is the result of a programme of close engagement with stakeholders across the industry, alongside our own extensive research and analysis.

This last year has been characterised by action, acceleration and ambition, with the government's *Clean Power 2030 Action Plan* setting out clear intent and pace. Progress is underway to deliver the infrastructure required to support this, with the extensive connections reform programme facilitating the faster connection of new supplies of clean, flexible power. We have also seen the Clean Energy Industries Sector Plan as part of the *Modern Industrial Strategy* as well as the first revenue support contracts for low carbon hydrogen and carbon capture projects in industrial clusters.

Our pathways in this year's FES, however, show the scale of work that remains. Change won't happen overnight and success relies on matching the pace and ambition of clean power, while looking beyond the power sector and beyond 2030. This means not only transforming our energy infrastructure but enabling homes and businesses to switch to low carbon energy sources for heat and transport, putting consumers at the heart of a new energy system and in control of the energy they use. Demand flexibility will play an important role here, getting more from low-cost renewable generation and helping both consumers and the energy system.

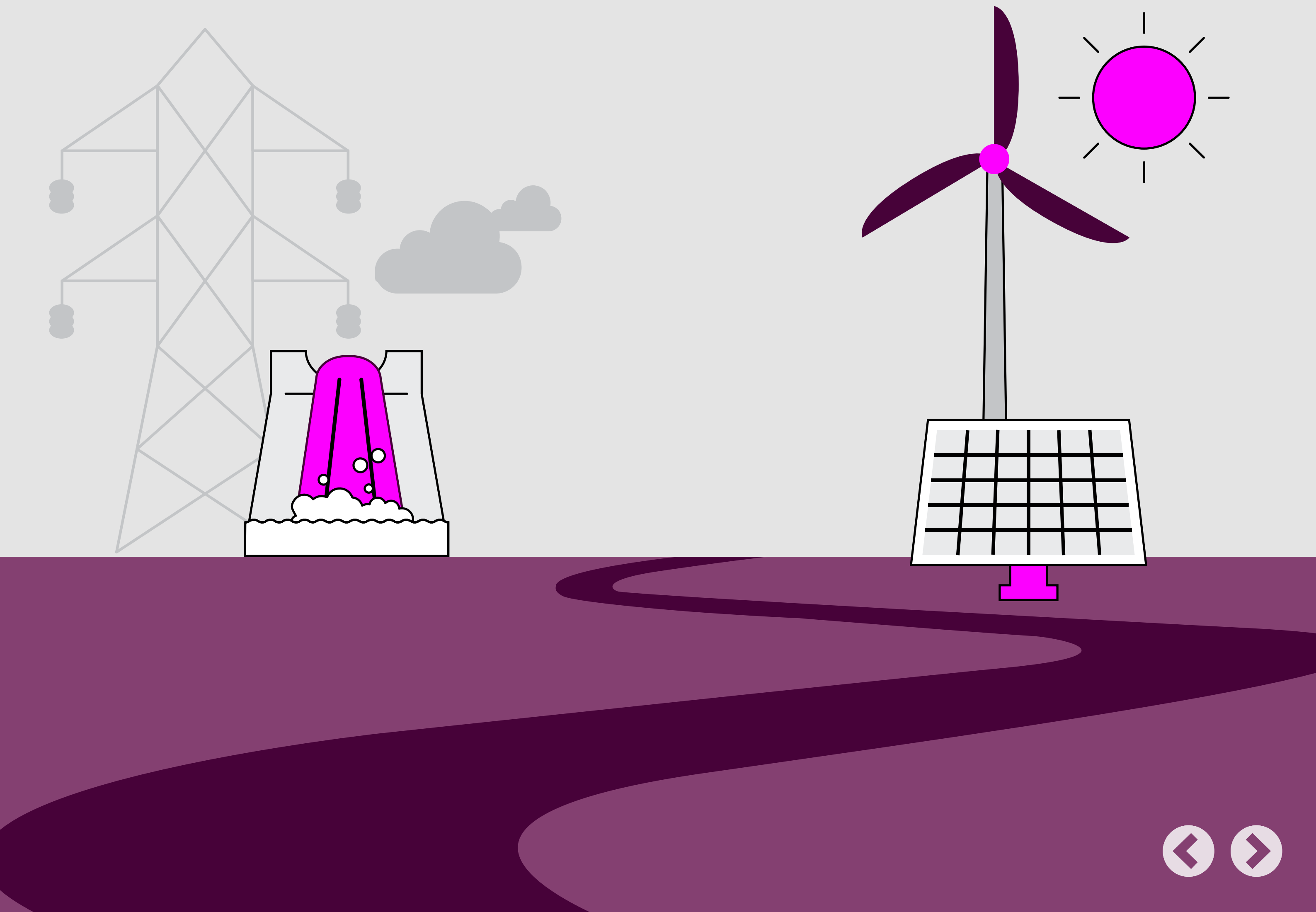
We are now in a new energy era. This era will be shaped by different waves of action. The last two decades have laid the foundations for the energy transition and the remainder of this decade will see rapid acceleration, followed by growth throughout the 2030s. All this will unlock the benefits of an affordable, secure and clean energy system on the 2050 net zero horizon.

We need to consider each of these waves now. Success along the route to 2050 will depend on the choices made today.

FES relies on robust insight and analysis. Our stakeholders are central to this, and I wish to extend many thanks for your input over the past year.

Claire Dykta
Strategy and Policy Director

Executive Summary



Unlocking the benefits of a secure, affordable and clean energy system for Great Britain requires bold ambition and progress in energy across all sectors of the economy.

Energy has always been a driver of progress in Great Britain. From the industrial revolution to the commissioning of the super grid, Great Britain has a proud history of innovation. Now, as we enter a smarter and cleaner energy era, leveraging this spirit of innovation and progress once again can unlock its full potential.

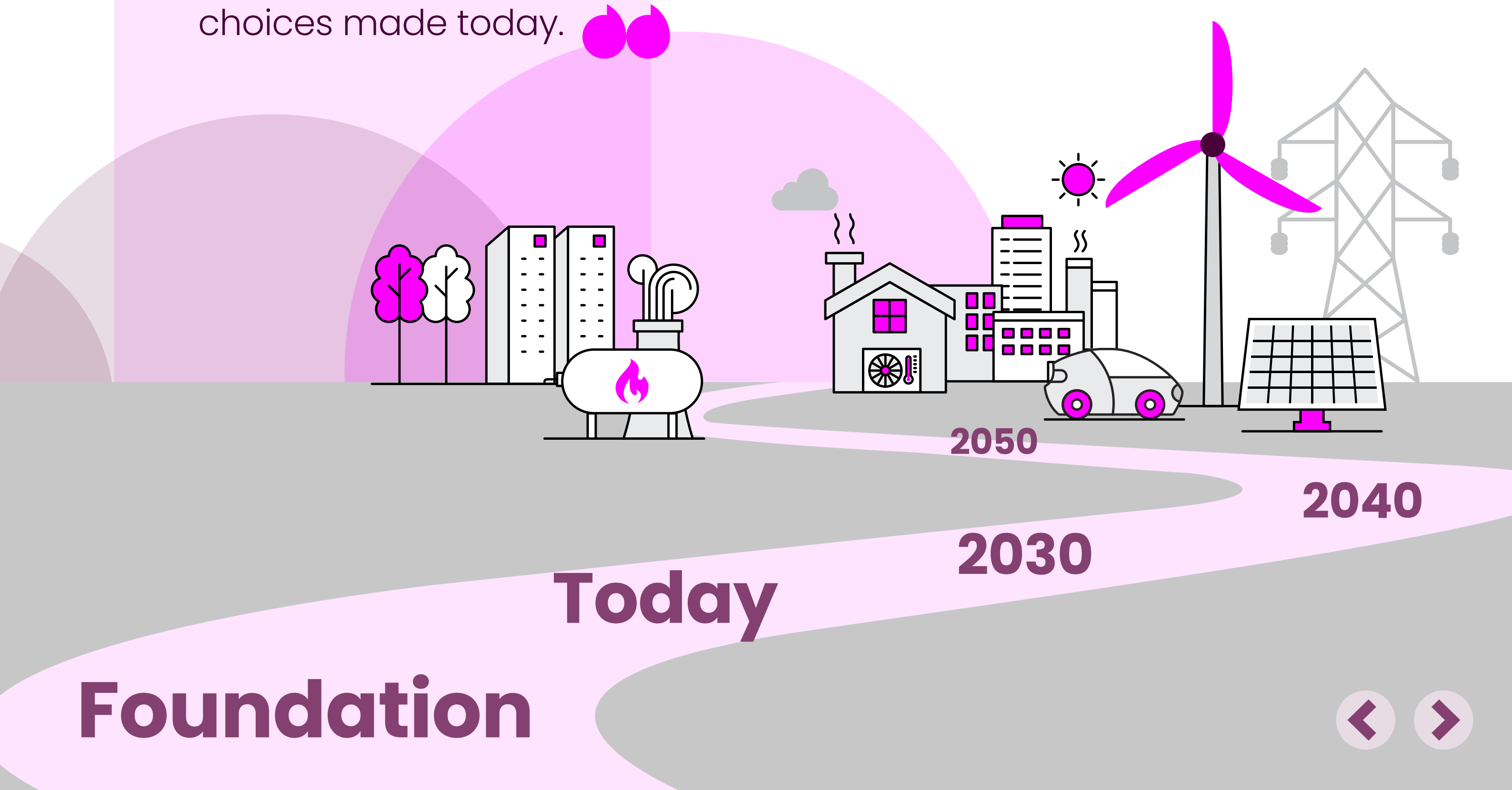
Four waves will shape the route to a resilient, net zero energy system with greater energy independence. Each will have its own defining characteristics and each will set up the progress for the following wave.

The initial foundation wave has already laid much of the necessary groundwork for the transition, such as technology development. We are now in a period of acceleration, scaling up the markets for uptake of new low carbon technologies and delivering clean power. The momentum of rapid action over the next five years will enable a third wave, one that enables energy growth with the rollout of these low carbon technologies and expansion of infrastructure. A final wave will then embed the transition to a long-term, secure and clean energy system to 2050 and beyond.

The government's *Clean Power 2030 Action Plan* sets a clear benchmark for the required ambition and represents a critical milestone. While the next few years of the acceleration wave are critical, we must also focus efforts as equally on beyond 2030, looking ahead to future waves and across the whole energy system. All sectors now need to accelerate their efforts to match the clean power pace and ambition.

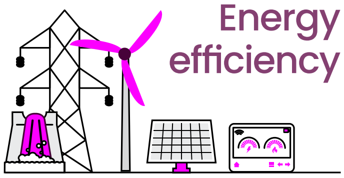
> We need to consider each wave now.
>
> Success along the route to 2050 depends on the choices made today.

Our *Future Energy Scenarios: Pathways to Net Zero (FES)* explores a range of routes to net zero in 2050 for energy demand and supply by considering the choices that can be made and the uncertainties.



The critical enablers for success fall within four main areas

1 Energy efficiency

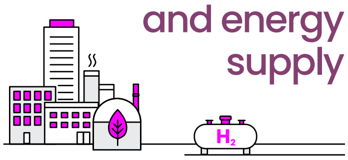


Energy efficiency can help manage demand growth and will reduce the cost of energy for consumers. Policy and innovation can enable efficiency improvements and adoption of measures across all sectors.

2 Demand flexibility

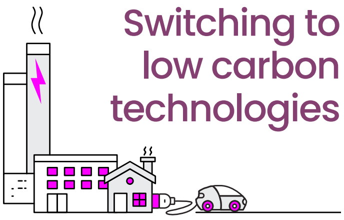
Greater levels of flexibility offer greater opportunities to make more efficient use of low cost renewable energy. Supply side flexibility provides most of today's flexibility and, while this must continue to grow, complementing this by increasing consumer flexibility can reduce the cost of other forms of flexibility, put consumers in control of their energy use and reduce their energy costs. Making participation effortless and fair would increase confidence in outcomes through consistent positive impact and so is critical for success.

3 Infrastructure and energy supply



Delivering energy security and resilience relies upon an expansion in infrastructure. Helping communities understand how they can directly benefit from clean energy, while recognising the impact of new infrastructure, will help support delivery of this at the necessary pace.

4 Switching to low carbon technologies



Adoption of low carbon technologies will play a vital role in the transition. Great Britain is an engineering powerhouse and harnessing this potential can enable development of electrification, carbon capture and low carbon fuels technologies.

The transition to the new energy era will deliver clean energy but the benefits go beyond securing a decarbonised future. It will mean protection against price shocks. It can offer energy security, national resilience and public trust. It can also unlock local economic growth and jobs.

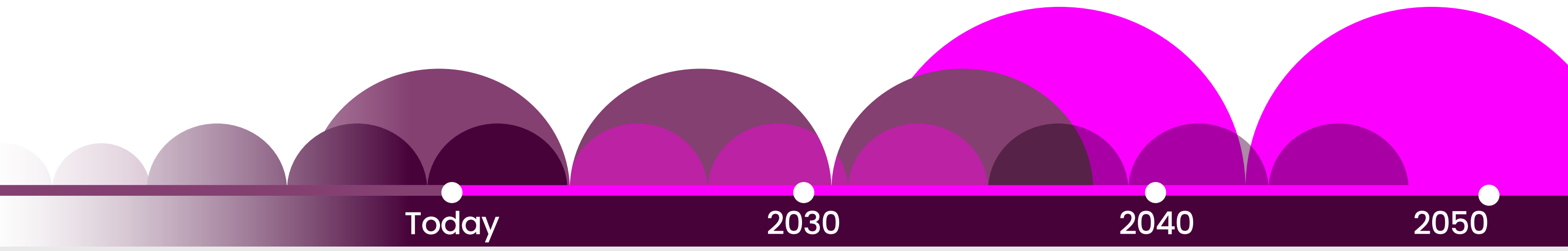
> Robust action now can futureproof this energy era and unlock the opportunities of a clean energy system.

Four distinct waves will shape the new era

The decisions for the future need to be taken now to stay on track

The waves of action

The government's *Clean Power 2030 Action Plan* sets the pace for other sectors to follow. Beyond 2030, this pace must continue to enable deeper decarbonisation and growth, laying the groundwork for the 2050 net zero horizon.



Foundation

The foundation wave.

Much of the progress over the last two decades has laid the groundwork for the transition. The development of key technologies, for example, has built a platform based on cost-competitive renewables, strong performing electric vehicles and emerging heat pump offerings. This progress has ensured a strong starting point for the waves ahead.

Acceleration

The acceleration wave from today to 2030.

Widespread action will define this period through clean power, boosting energy efficiency, driving uptake of low carbon heating and transport, and demand flexibility.

Growth

The growth wave from 2030 to 2040.

Building on the momentum of the acceleration wave, this will see the mainstreaming of clean technologies, expansion of infrastructure and transformation of industry.

Horizon

The horizon wave from 2040 to 2050 and beyond.

This wave will complete the transition. Remaining emissions will be reduced or removed to deliver a net zero energy system that is smart, resilient and built for the long term.

Delivering a clean power system in 2030 is an important milestone but there remains a great deal to do. The next few years are critical, both in making progress and in preparing for the waves to come.

Only bold and sustained action in all sectors will unlock the benefits of an affordable and secure, clean energy system. This means matching the ambition and pace of the clean power goal, accelerating progress across the whole energy system and looking beyond 2030.

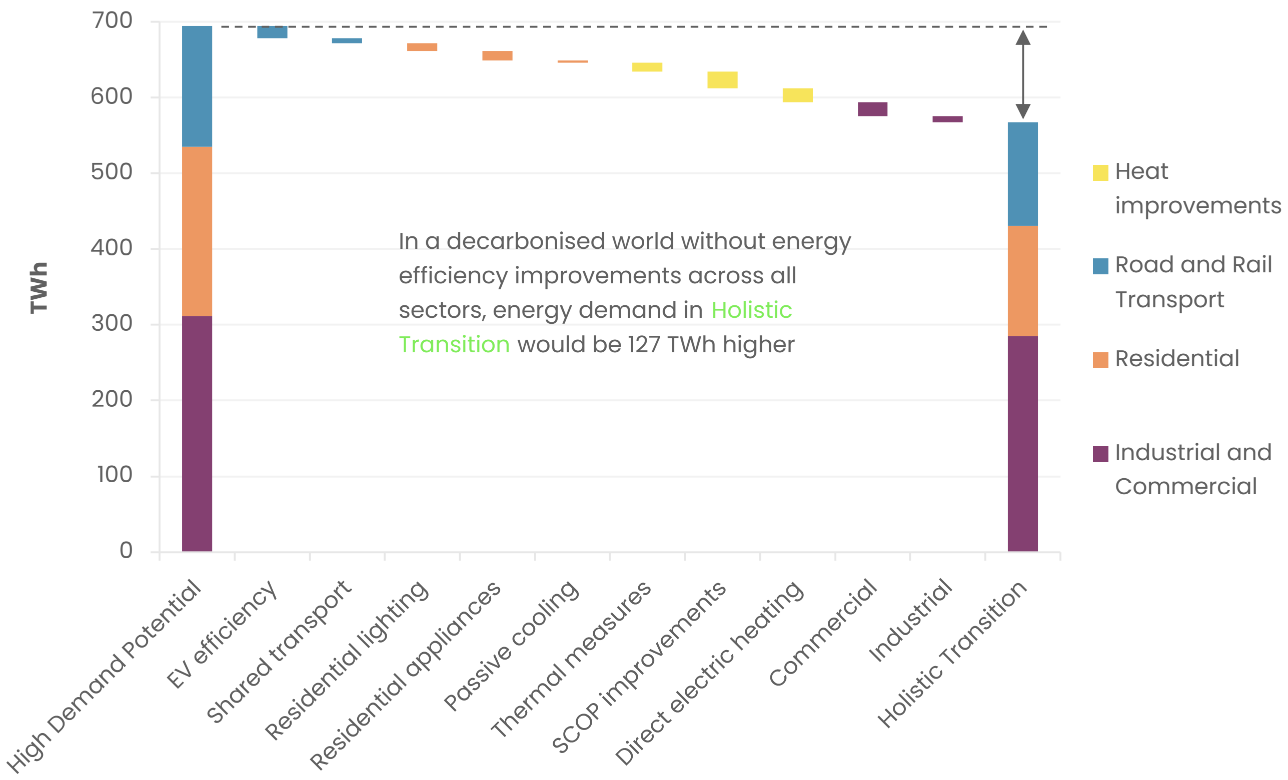
This means action to:

	Today – 2030: Acceleration	2030 – 2040: Growth	2040 – 2050: Horizon
1 Energy efficiency	Implement policy to accelerate widespread adoption of energy efficiency measures	Push forward with efforts to improve efficiency of heat pumps and electric vehicles over time	Maintain momentum on energy efficiency measures and embed optimal operating practices
2 Demand flexibility	Empower households and businesses willing and able to make informed energy choices	Rapid rollout of smart energy solutions, such as using electric vehicles to support the grid and making heating more flexible	Ensure effortless participation
3 Infrastructure and energy supply	Deliver coordinated strategic plans across electricity, gas, bioenergy, hydrogen and CO_2 transport and storage	Build the strategic whole system energy infrastructure at pace, considering electricity, gas, bioenergy, hydrogen and CO_2	Drive continuous innovation to fully realise and maximise the value of a net zero energy system
4 Switching to low carbon technologies	Implement policy to encourage homes and businesses to switch to low carbon energy sources	Deliver mass adoption of low carbon technology and infrastructure to provide certainty for industry	Further reduce reliance on unabated fossil fuels

1. Energy efficiency

Energy efficiency measures are crucial to managing demand growth. Driving adoption of measures provides near-term benefits by reducing infrastructure needs, cutting emissions and lowering energy costs.

1. **Energy efficiency measures across all consumer sectors reduce 2050 electricity demand and consumer costs.**

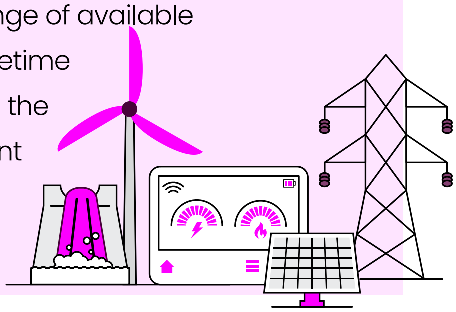


Energy efficiency reduces energy use at all times of the day. Many of these measures, such as thermal efficiency in buildings, reduce emissions in the short term while consumers remain heavily reliant on fossil fuels.

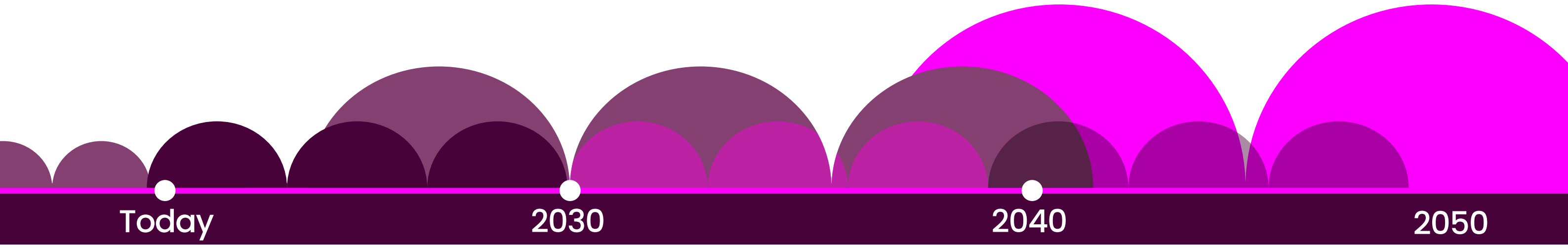
Improvements to energy efficiency of buildings and appliances could cut electricity demand by up to 127 TWh, an 18% reduction in demand from 694 TWh to 567 TWh in 2050.

18% reduction (2050)

Clearly communicating the benefits of energy efficiency solutions will encourage efficient operating practices. Affordability of solutions, balancing both upfront costs and long payback savings, must be addressed. Increasing consumer awareness of the range of available options will help boost uptake of higher efficiency products with lower lifetime costs. Heating installers will play an important part in fostering uptake of the most suitable efficient heating systems and insulation. Their engagement will be an important enabler to broader public awareness.



Realising the benefits for homes, businesses and industry requires a renewed focus on energy efficiency across all waves of the transition



Acceleration

Implement policy to accelerate widespread adoption of energy efficiency measures to benefit all consumers.

Driving widespread adoption of current best-in-class efficient appliances. Innovation bodies and industry R&D in efficiency will support this.

Improving insulation for new builds. This will be driven by implementation of the Future Homes Standards without further delay.

Growth

Push forward with efforts to improve efficiency of heat pumps and electric vehicles over time to further reduce the cost of energy for homes and businesses as electricity demand grows.

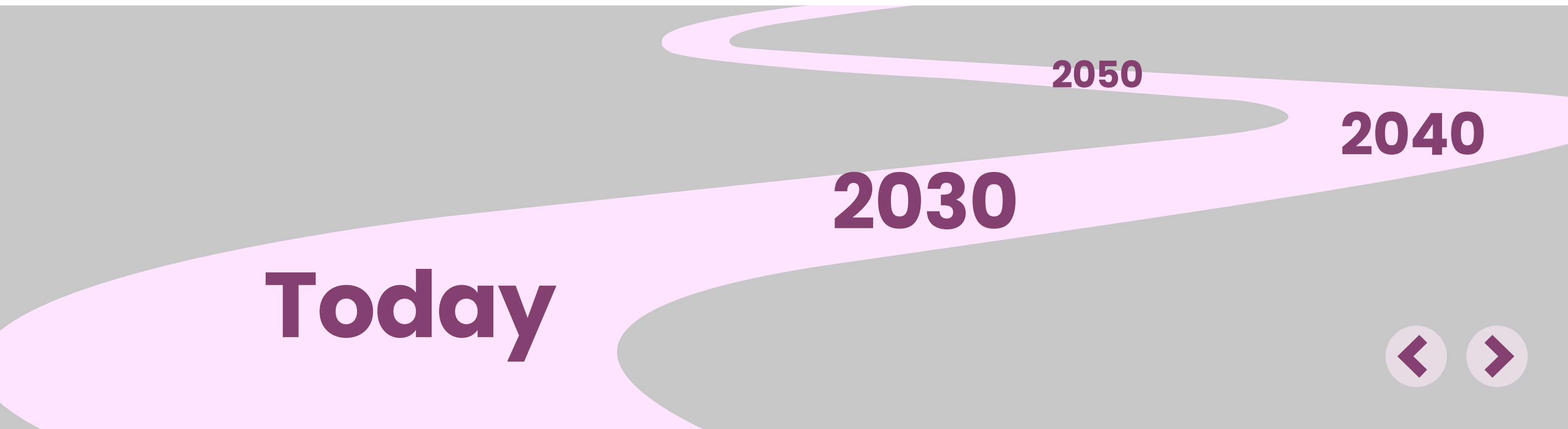
Extending energy efficiency measures. This includes rolling out minimum efficiency standards, similar to those to improve light bulb efficiencies, to other appliances and heat pumps.

Horizon

Maintain momentum on energy efficiency measures and embed optimal operating practices to save money for consumers and manage expected growth in demand.

Continuing support for improving industrial efficiency. This includes the adoption of more efficient equipment alongside ongoing automation and digitalisation to reduce wasted energy.

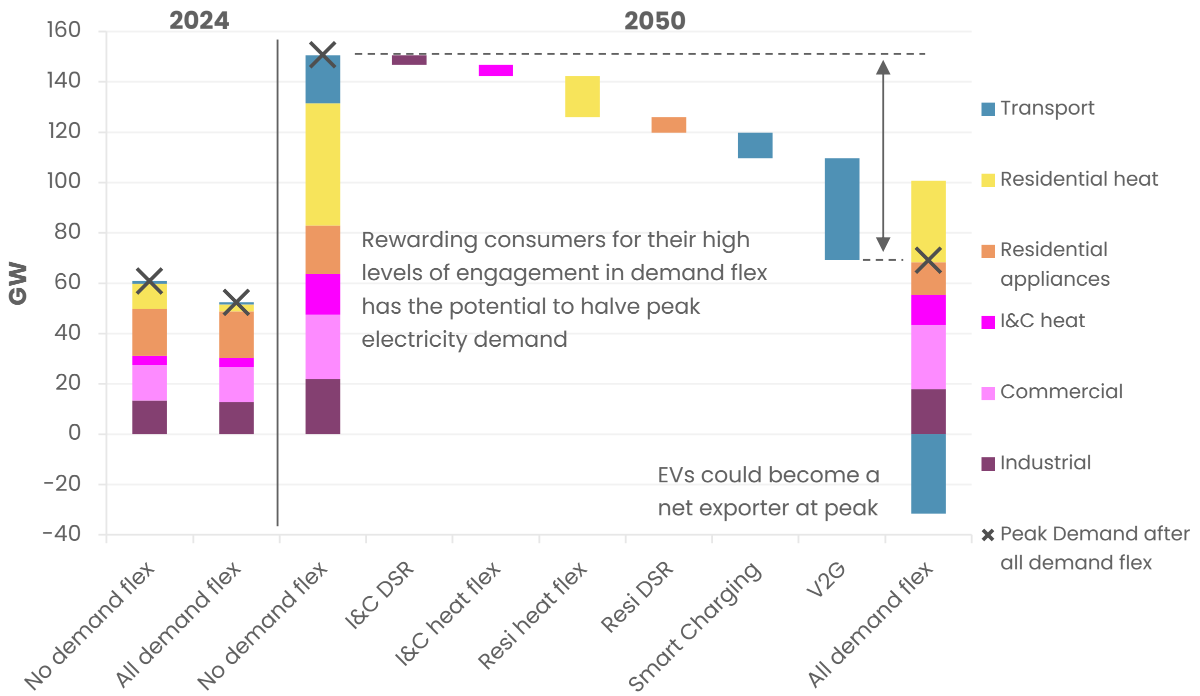
Unlocking opportunities around more efficient uses of transport. Reducing demand through new technologies such as autonomous vehicles as well as low carbon options, including public transport.



2. Demand flexibility

Enabling demand flexibility empowers households and businesses, which can lower consumer costs and accelerate the shift to a cleaner, smarter energy future.

2. Demand flexibility reduces both peak electricity demand and the need for supply side infrastructure.

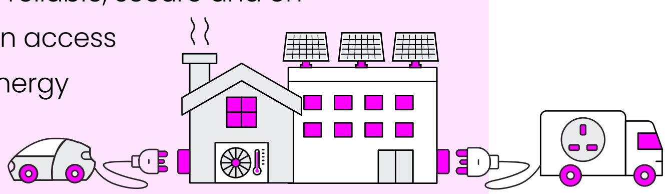


A net zero energy system will rely upon flexibility in both supply and demand. Demand flexibility benefits both consumers and the energy system, getting more from low-cost renewable generation. It can offer households and businesses greater resilience against exposure to volatile prices and help reduce energy costs. Greater uptake of demand flexibility also means less need for infrastructure investment, reducing the deployment of energy storage.

54% reduction by 2050

Households and businesses could help reduce peak demand by up to 54% peak demand reduction (2050). Smart charging could shift EV peak demand by 83%, while heat pumps could shift their peak by 36%.

Demand flexibility as a choice. It is important to consider consumers or businesses unable to manually shift energy use (for example, due to work patterns, caring responsibilities or how they operate). Smart technologies and automation can make it easier, but consumer trust that these tools are reliable, secure and on their side is key. Access to demand flexibility relies upon access to low carbon technologies and innovation in smart energy tariffs and offerings.



To unlock the full value of demand flexibility, targeted action is needed now considering all waves of the transition

Acceleration

Empower households and businesses willing and able to make informed energy choices through innovative and flexible energy tariffs.

Developing a clear strategy for targeting different sources of flexibility. The *Low Carbon Flexibility Roadmap* is a first step towards this.

Ensuring consumers can access the value of personal flexibility. Upgrading the energy system (including rapid progress of the Market-wide Half Hourly Settlement) would enable providers to use smart meters to offer better deals based on usage.

Growth

Rapid rollout of smart energy solutions, such as using electric vehicles to support the grid and making heating more flexible, to help consumers use energy flexibly while meeting their needs and working around lifestyles.

Providing consumers with seamless tools that integrate into their daily routines. Through simple, innovative tariffs, consumers will have more control over how and when they use electricity — without needing to be tech experts.

Ensuring a flexible energy system works for all consumers. This means fair and equitable access to low carbon technologies so that no consumer is left behind.

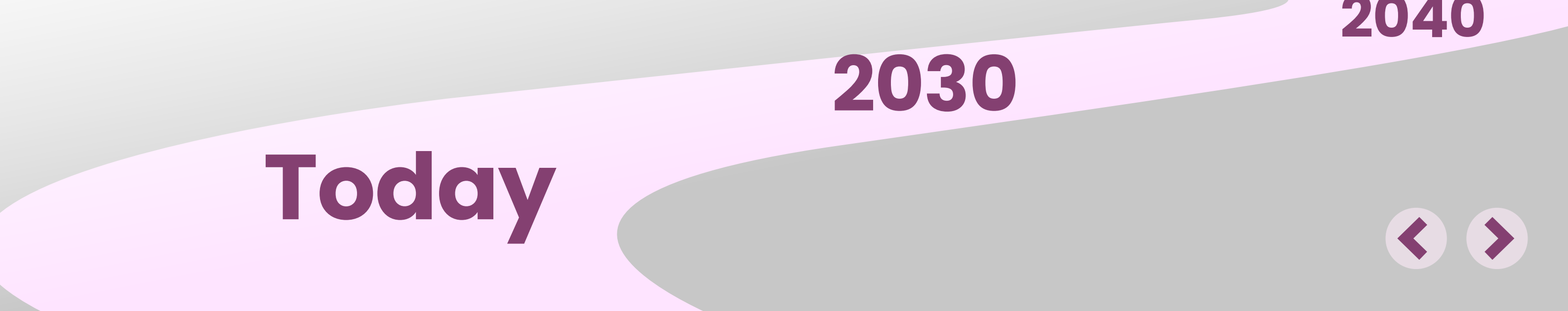
Increasing industrial and commercial participation in demand flexibility. This includes shifting demand with thermal storage for high temperature heat requirements or cooling demand in data centres.

Horizon

Ensure effortless participation with the widespread rollout of user-friendly, smart technology.

Supporting innovation in previous waves has built the foundation for energy products and services in 2050. These will keep consumers engaged, informed and empowered by choice.

Enabling consumers to connect to innovative low carbon technologies and services by unlocking the full potential of low-cost renewable energy. Vehicle-to-grid alone has the potential to supply 41 GW of flexibility at peak.

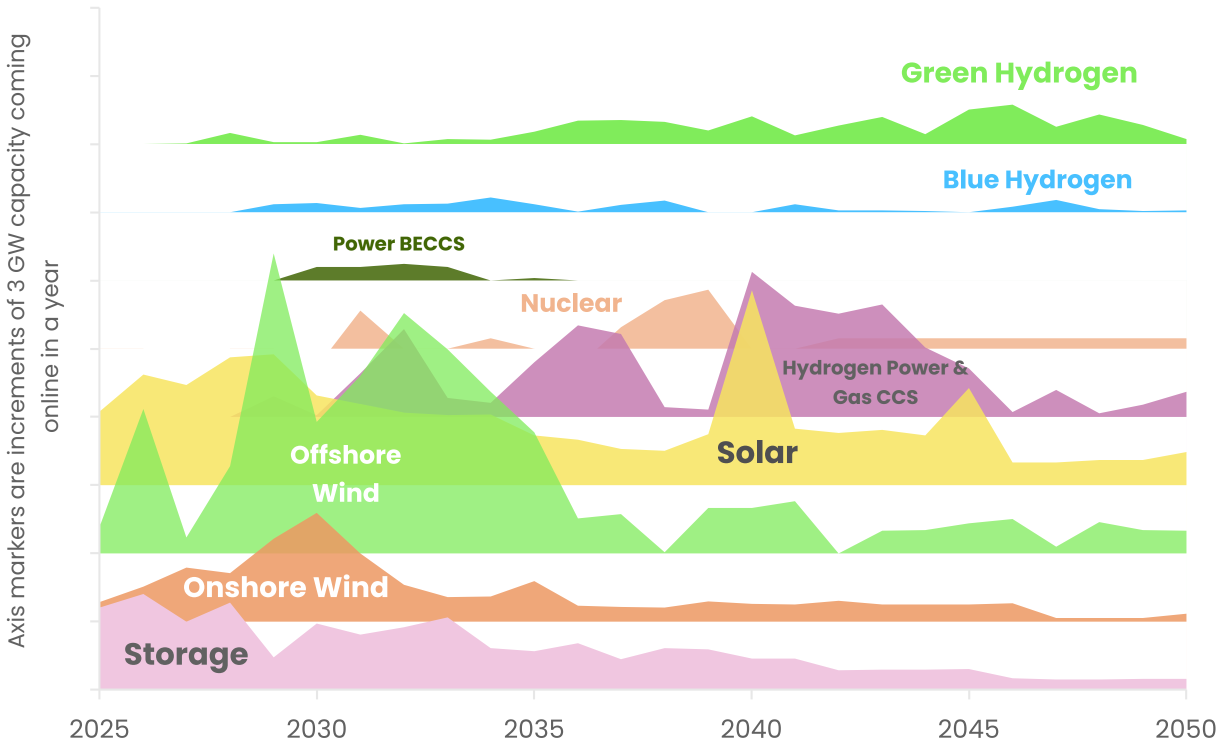


3. Infrastructure and energy supply

Developing low carbon electricity and hydrogen production, transport and storage infrastructure at pace, alongside carbon capture and storage (CCS) infrastructure, will offer greater certainty for industry and unlock opportunities for private investment and economic growth.

A net zero energy system will look very different to today. It will no longer rely on fossil fuels and will instead need to shift to low carbon fuels and homegrown renewables, transforming how we produce, store and use energy. Electrification of demand increases the efficiency of the whole system, reducing overall system losses. The increased linkage between electricity, gas, hydrogen, bioenergy and carbon necessitates a change in thinking. Coordinated, whole system planning will unlock investment, flexibility and support a faster, more cost-effective transition.

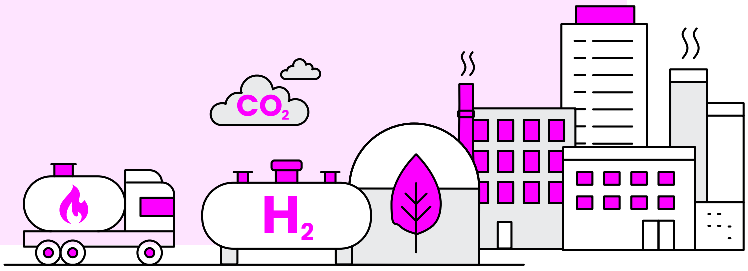
3. Our pathways see the significant build-out of new, additional energy capacity of all forms to 2050. Example: Holistic Transition.



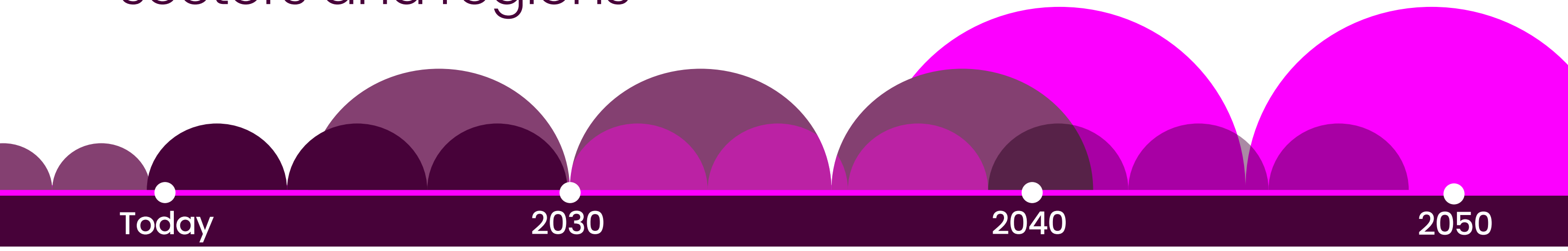
Total installed generation capacity in our pathways increases by 60-73% from today to 2030 and approximately doubles from 2030 to 2050. Low carbon hydrogen production for energy in our pathways increases from zero today to 98-325 TWh by 2050. Delivery hinges on ensuring that the enabling infrastructure, such as networks and storage, are in the right place at the right time.

Establishing the necessary infrastructure at pace not only accelerates decarbonisation but also opens up opportunities for economic growth, supporting new industries, providing certainty to support and attract private investment, creating skilled jobs and powering thriving communities.

Infrastructure must be delivered at pace while carefully navigating public consent. Success lies in getting this balancing act right. Strategic energy planning across all vectors will enable this and reaching clean power by 2030 will set the pace.



Delivering the right infrastructure at the right time requires coordinated action across all sectors and regions



Acceleration

Deliver a clean power system and coordinated strategic plans across electricity, gas, bioenergy, hydrogen and CO_2 transport and storage to provide greater certainty on options.

Optimising cross-vector interactions through strategic energy planning. Considering carbon alongside hydrogen, gas, electricity and bioenergy will provide greater clarity beyond delivery of the first industrial clusters.

Clarifying the optimal use of infrastructure and end-uses across gas, hydrogen and biomethane. This will mean greater certainty over prioritisation of applications and how low carbon gases can work together across the energy system.

Investing in low carbon technology supply chains. Taking action now will de-risk delivery whilst boosting economic growth, creating jobs and strengthening resilience for a fair and competitive transition.

Growth

Build the strategic whole system energy infrastructure at pace, considering electricity, gas, hydrogen, bioenergy and CO_2 to provide access for decarbonisation, delivery of negative emissions and enable economic growth.

Continuing the focus on reforming connections and planning. This will be vital to ensure timely low carbon energy production capacity and provide access to networks.

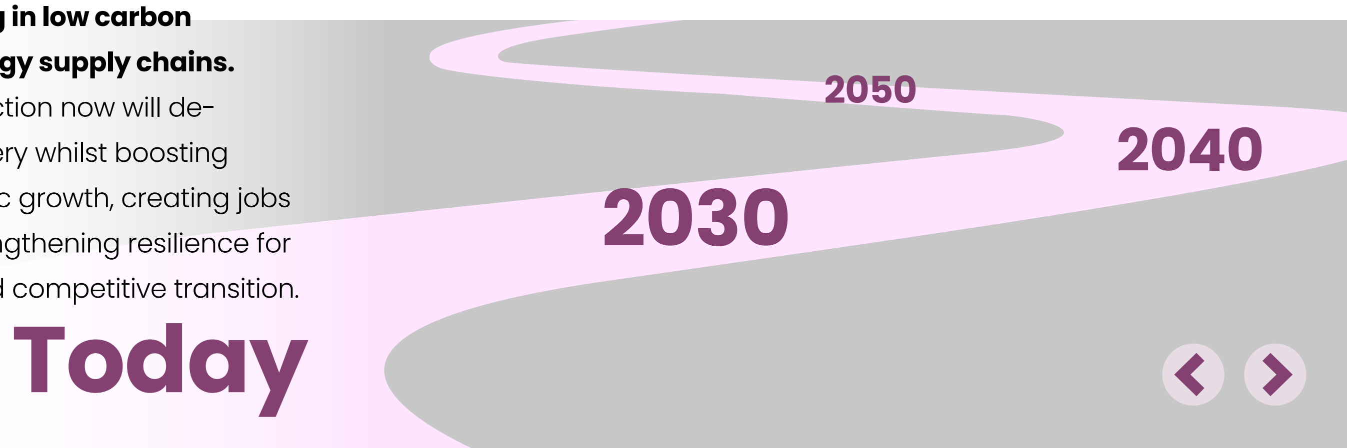
Building infrastructure at pace. Following through on strategic energy plans will deliver the necessary electricity, gas, hydrogen and carbon infrastructure.

Horizon

Drive continuous innovation to fully realise and maximise the value of a net zero energy system. This includes whole system flexibility and delivering around 25 million tonnes of engineered carbon removals by 2050 to offset residual emissions in the economy.

Continuously innovating across the whole energy system and entire value chain. The speed and scale of delivery necessitates innovation which will, in turn, further enable new products and services.

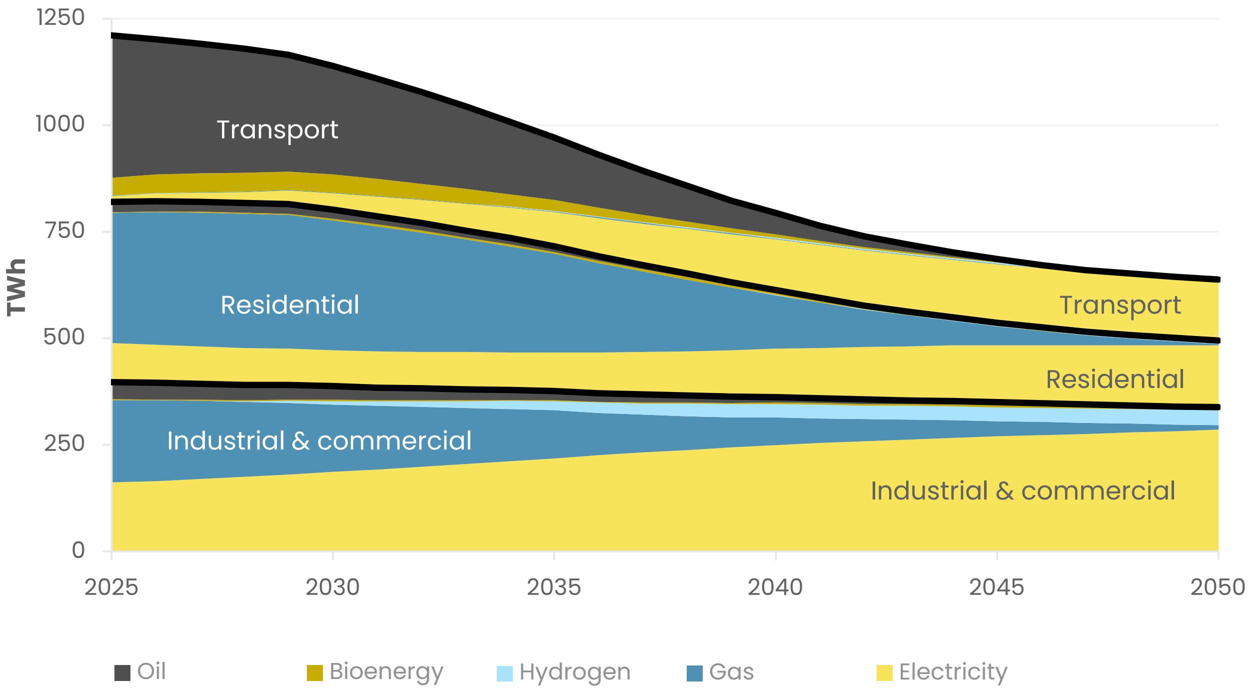
Delivering negative emissions technologies. Innovation in this area will be crucial to achieving net zero in sectors that cannot fully decarbonise by 2050.



4. Switching to low carbon technologies

Adoption of low carbon technologies is a critical enabler of decarbonisation. The timely transition from high emission energy sources for heat, transport and industry is particularly vital to achieve emissions targets.

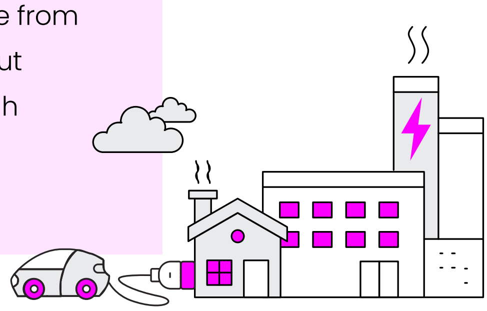
4. Electrification offers improved efficiency compared to today's fossil fuel technologies, facilitating demand reduction alongside decarbonisation.



Adoption of low carbon technologies enables consumers to reduce direct unabated fossil fuel use while reducing consumer energy demand by 47%.

47% reduction by 2050

Infrastructure investment and reducing the price of electricity are crucial considerations for successful uptake of low carbon technologies.
Initial investment costs for residential consumers may prevent some from considering the switch to low carbon alternatives, particularly without short-term payback. Businesses also face similar challenges through high capital costs along with uncertainty regarding infrastructure access and system readiness.



Insight from the *Decarbonising Heat: Consumer Choice and Affordability* survey conducted for NESO by Public First can be found on the FES website.

Switching to low carbon fuels at scale won't happen on its own and demands early action and clear direction

Acceleration

Implement policy to encourage homes and businesses to switch to low carbon energy sources and accelerate system-wide adoption by reducing the price of electricity relative to gas.

Reducing energy costs. Reforming the electricity market and addressing high levies will enable this.

EV car uptake is assumed to accelerate to reach 100% of new sales in 2030.

Increasing heat pump rollout. Heat pump installation rates require a 31% year-on-year average increase until the full phase out of new gas boiler installations in 2035.

Growth

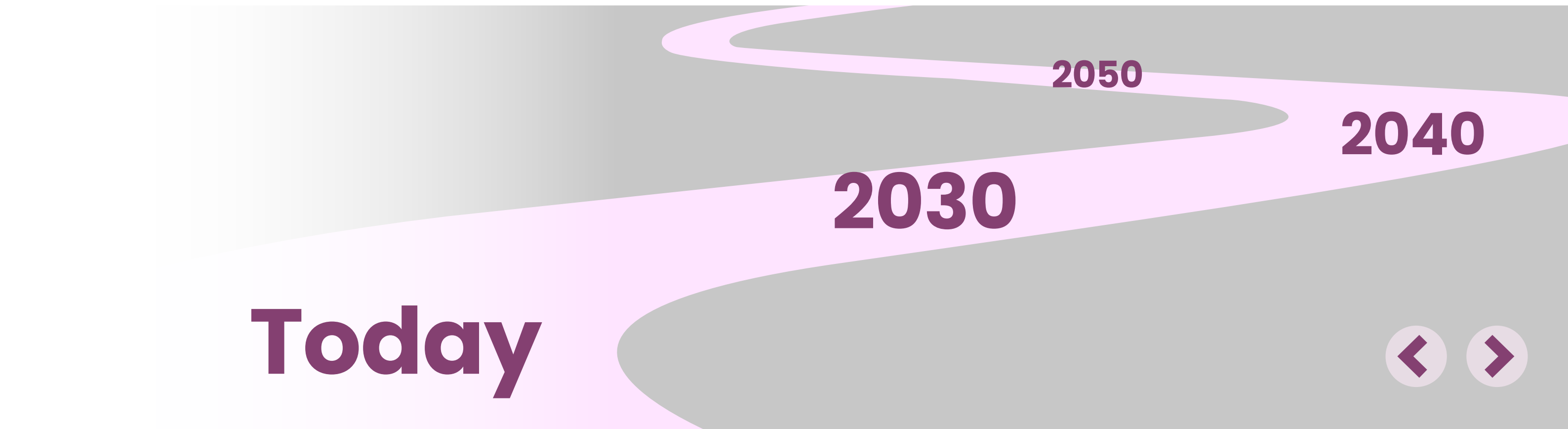
Deliver mass adoption of low carbon technology and provide certainty for industry where investment cycles are longer.

Incentivising decarbonisation of industry. Industrial emissions need to decline rapidly through the 2030s by switching to low carbon fuels and carbon capture and storage (CCS). This will be supported by clear carbon accounting policies for industrial imports of materials and products. This will need to be in place within this decade.

Horizon

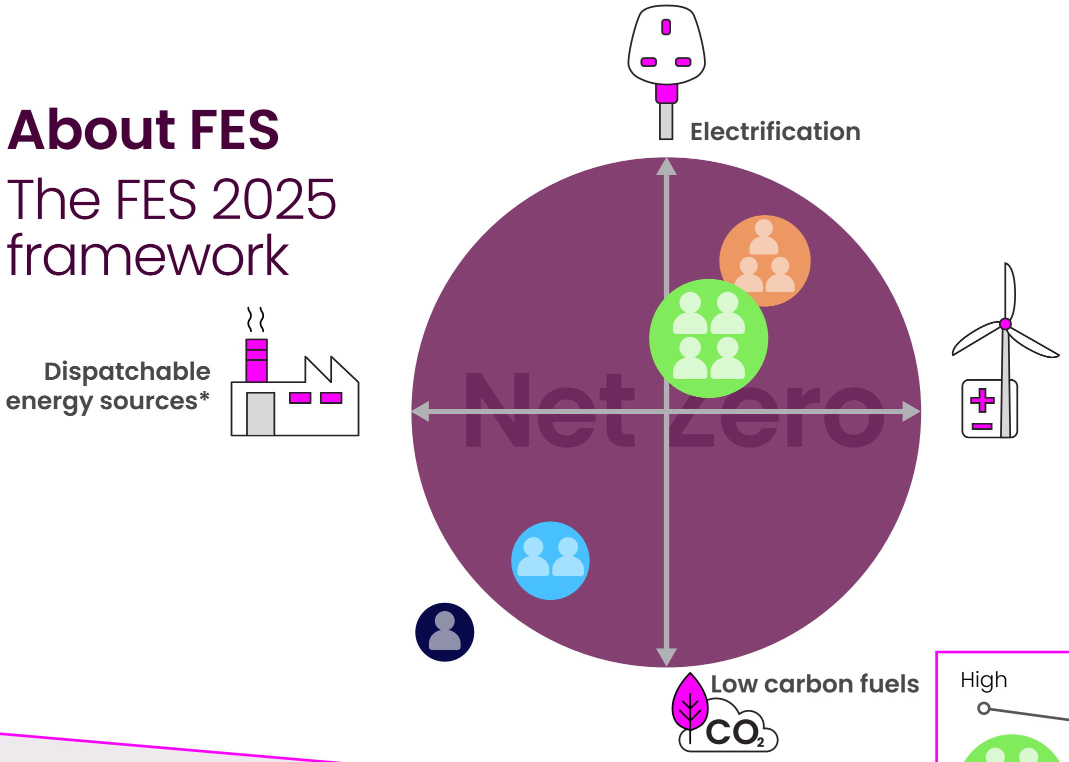
Remove remaining reliance on unabated fossil fuels, providing opportunities for reduced energy costs and emissions reductions of 221 million tonnes to 2050.

Completing the switch to low carbon technologies. Careful management of the final switchover from fossil fuels, without leaving consumers behind.

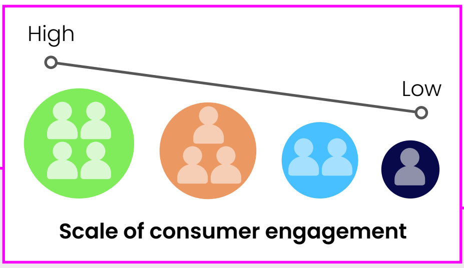


About FES

The FES 2025 framework



*Includes electricity and hydrogen production



Future Energy Scenarios outputs

Holistic Transition

Net zero is met in Holistic Transition through a mix of electrification and hydrogen, with hydrogen mainly used around industrial clusters. Hydrogen is not used for heat except as a secondary fuel for heat networks in small quantities. Consumer engagement is very strong through the adoption of energy efficiency improvements and demand shifting, with smart homes and electric vehicles providing flexibility to the grid.

Holistic Transition is a high-renewable capacity pathway, with unabated gas dropping sharply. This pathway sees moderate levels of nuclear capacity and the lowest levels of hydrogen dispatchable power. Supply side flexibility is high, delivered through electricity storage and interconnectors. No unabated gas remains on the network in 2050.

Electric Engagement

Net zero is achieved in Electric Engagement mainly through electrified demand. Consumers are highly engaged in the transition through smart technologies that reduce energy demand, such as electric heat pumps and electric vehicles.

Electric Engagement has the highest peak electricity demand, requiring high nuclear and renewable capacities. It also has the highest level of bioenergy with carbon capture and storage across all the net zero pathways. Supply side flexibility is high, delivered through electricity storage, interconnectors and low carbon dispatchable power.

Hydrogen Evolution

Net zero is met in Hydrogen Evolution through fast progress for hydrogen in industry and heat. Widespread access to a national hydrogen network is assumed. Some consumers will have hydrogen boilers, although most heat is electrified. There are low levels of consumer engagement within this pathway.

Hydrogen is used for some heavy goods vehicles, but electric vehicle uptake is strong.

Hydrogen Evolution sees high levels of hydrogen dispatchable power plants, leading to reduced need for renewable and nuclear capacities. Hydrogen storage provides the most flexibility in this pathway.

Falling Behind

Falling Behind considers a world where some decarbonisation progress is made against today, but at a pace not sufficient to meet net zero.

Falling Behind is used in downstream gas and electricity security of supply processes – it is important that we use Falling Behind alongside the net zero pathways to consider the full range of potential demand levels for possible remaining reliance on unabated fossil fuels.

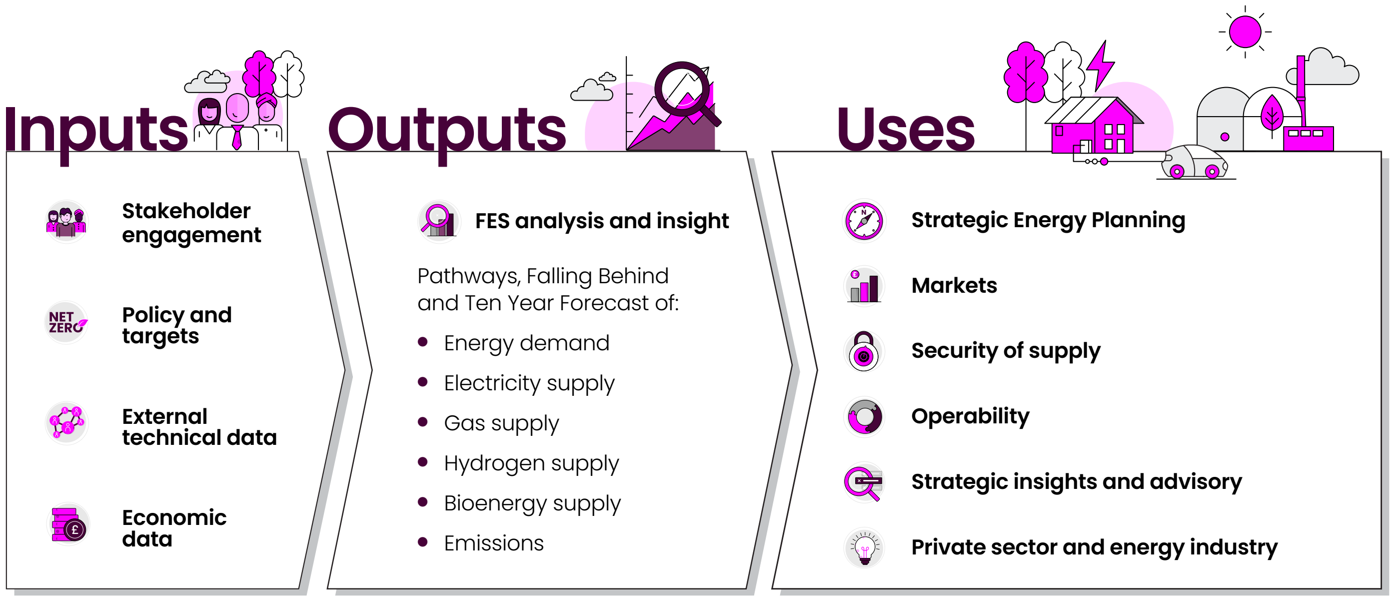
With the current level of low carbon projects in the pipeline and increased policy ambition, we consider some level of progress in Falling Behind in areas where there is increased certainty or progress. It is not a 'status quo' scenario.

FES models energy supply (electricity, gas, hydrogen) and demand (residential, transport, industrial and commercial) out to 2050. Our three net zero pathways explore credible routes to reach net zero. They are not forecasts of what will happen, the lowest cost route or what could happen at the margins of what is possible. They are developed in line with the levers set in the framework.

Alongside these we produce a Falling Behind scenario and Ten Year Forecast (10YF). Falling Behind represents the slowest credible progress towards decarbonisation but does not meet net zero by 2050. This scenario provides a benchmark, highlighting the impact of delayed or insufficient action to decarbonise. The 10YF is used for downstream security of supply planning. It represents our current view of the next ten years, taking account of where we are today, existing project pipelines and action on policy, highlighting potential gaps between stated ambition and delivery. This is the difference between where we are heading compared to where we need to get to and highlights where intervention is most needed.

Since *FES 2024*, we have engaged with more than 84 organisations and 144 stakeholders to refine our modelling. For emissions arising from sectors that fall outside our modelling, such as agriculture, land and aviation, we use the Climate Change Committee's (CCC) Balanced Pathway from its recommended Seventh Carbon Budget, published in February 2025. These sectors fall outside the scope of our internal modelling due to their emissions arising largely from non-energy sources or the international share of their emissions.

More detail on our modelling is outlined in our *Modelling Methods* document, published on the FES webpage.

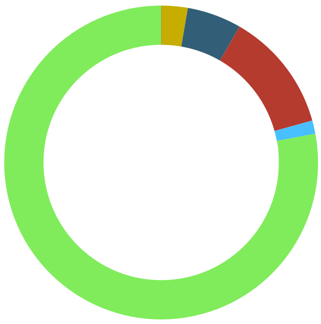
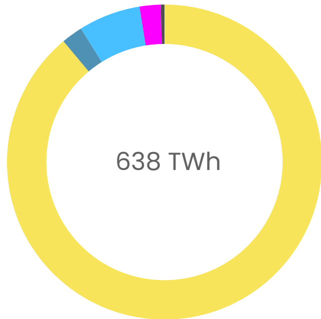
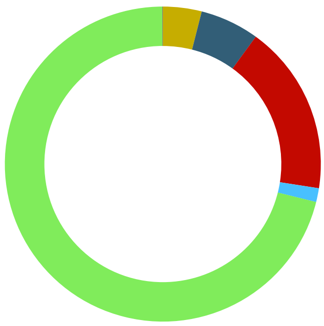
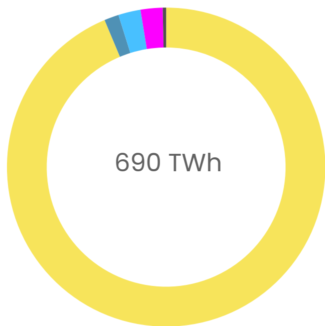
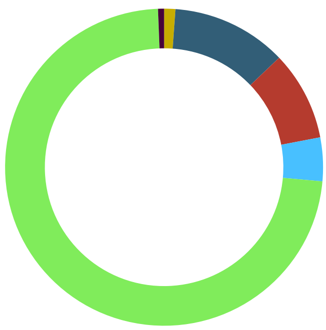
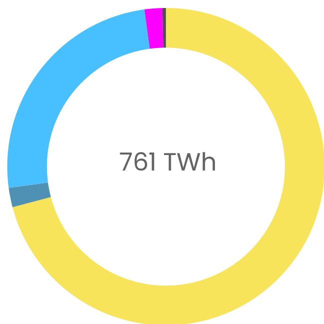
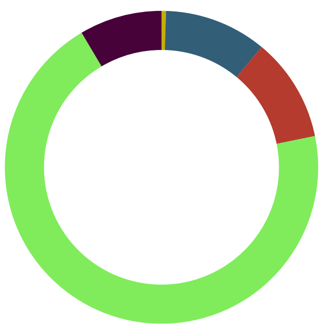
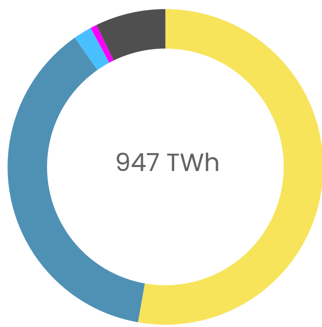


Comparing our pathways

Pathways are narrowing but optionality and uncertainty on the route to net zero remain.

Our pathways consider the different ways Great Britain can reach a net zero energy system and interim emissions reductions along the way. They explore the choices and uncertainty ahead in areas such as the speed of technology uptake, the role of both electrification and low carbon fuels and the level of consumer engagement.

Table 1: Pathways at a glance

	Power generation (TWh in 2050)	Demand (TWh in 2050)	Hits net zero
Holistic Transition			Yes
Electric Engagement			Yes
Hydrogen Evolution			Yes
Falling Behind			No

Renewable, Nuclear, Hydrogen, Electricity, Bioenergy, BECCS, CCS Gas, Unabated Fossil, Gas, Oil

Pathway statistics

Table 2: Key statistics

Emissions	2024	2050			
	10YF	HT	EE	HE	FB
Annual average carbon intensity of electricity (g CO_2/kWh)	118	-25	-37	-7	26
Net annual emissions ($MtCO_2e$)	407	-6	-2	0	187

Electricity	2024	2050			
	10YF	HT	EE	HE	FB
Annual demand (TWh)[1]	290	705	785	797	559
Electricity demand for heat (TWh)	38	151	183	149	98
Peak demand (GW)[2]	58	120	144	122	107
Total installed capacity (GW)[3]	125	439	450	384	314
Wind and solar capacity (GW)	49	248	248	226	180
Interconnector capacity (GW)	10	22	24	18	17
Total storage capacity (GW)[4]	10	96	81	56	35
Total storage capacity (GWh)[5]	63	285	295	230	235
Maximum Vehicle-to-Grid capacity (GW)[6]	0	81	49	23	9

Natural Gas	2024	2050			
	TYF	HT	EE	HE	FB
Annual demand, with exports (TWh)[7]	743	168	166	398	640
1-in-20 peak demand (GWh/day)	5214	1382	1671	2603	4693
Residential demand (TWh)[8]	301	3	3	2	204
Imports (TWh)	448	92	155	323	580

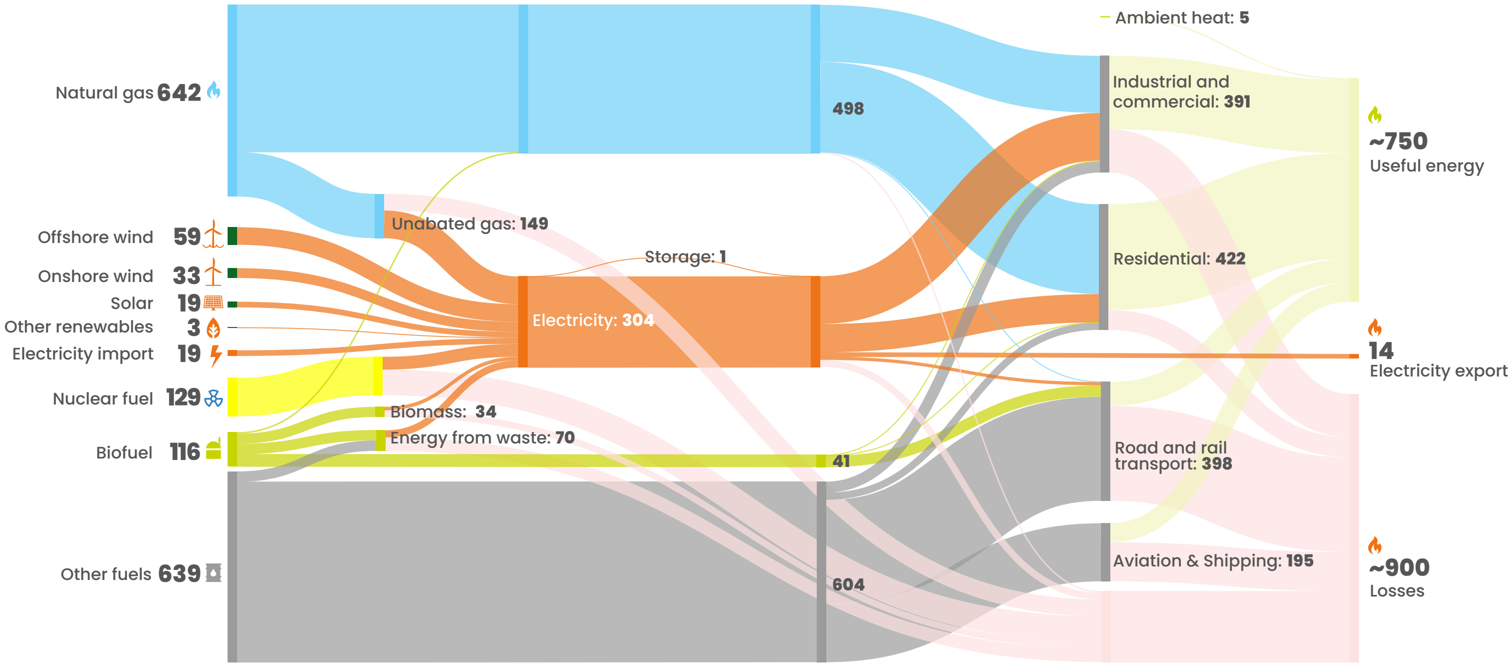
Hydrogen	2024	2050			
	10YF	HT	EE	HE	CF
Annual demand (TWh)	0	119	98	328	18
Residential hydrogen demand for heat (TWh)	0	1	0	69	0
CCS enabled hydrogen production (TWh)[9]	0	45	32	131	5
Electrolytic hydrogen production (TWh)[10]	0	74	67	173	12

Bioresources	2024	2050			
	10YF	HT	EE	HE	FB
Bioresource demand (TWh)	160	216	191	173	114

1 Customer demand plus on-grid electrolysis meeting GB hydrogen demand only, plus losses, equivalent to GBFES System Demand Total in ED1 of data workbook.
2 Refer to data workbook for further information on winter ACS peak demand.
3 Includes all networked generation as well as total interconnector and storage capacity (including V2G available at winter peak).
4 Includes V2G capacity available at winter peak.
5 Excludes V2G.
6 Less capacity will be available during peak 5-6pm due to vehicle usage.
7 Includes shrinkage, exports, biomethane and natural gas for methane reformation.
8 Residential demand made up of biomethane and natural gas.
9 CCS enabled hydrogen is created using natural gas as an input, with CCS.
10 Electrolytic hydrogen is created via electrolysis using zero carbon electricity (this figure does not include hydrogen produced directly from nuclear or bioenergy).

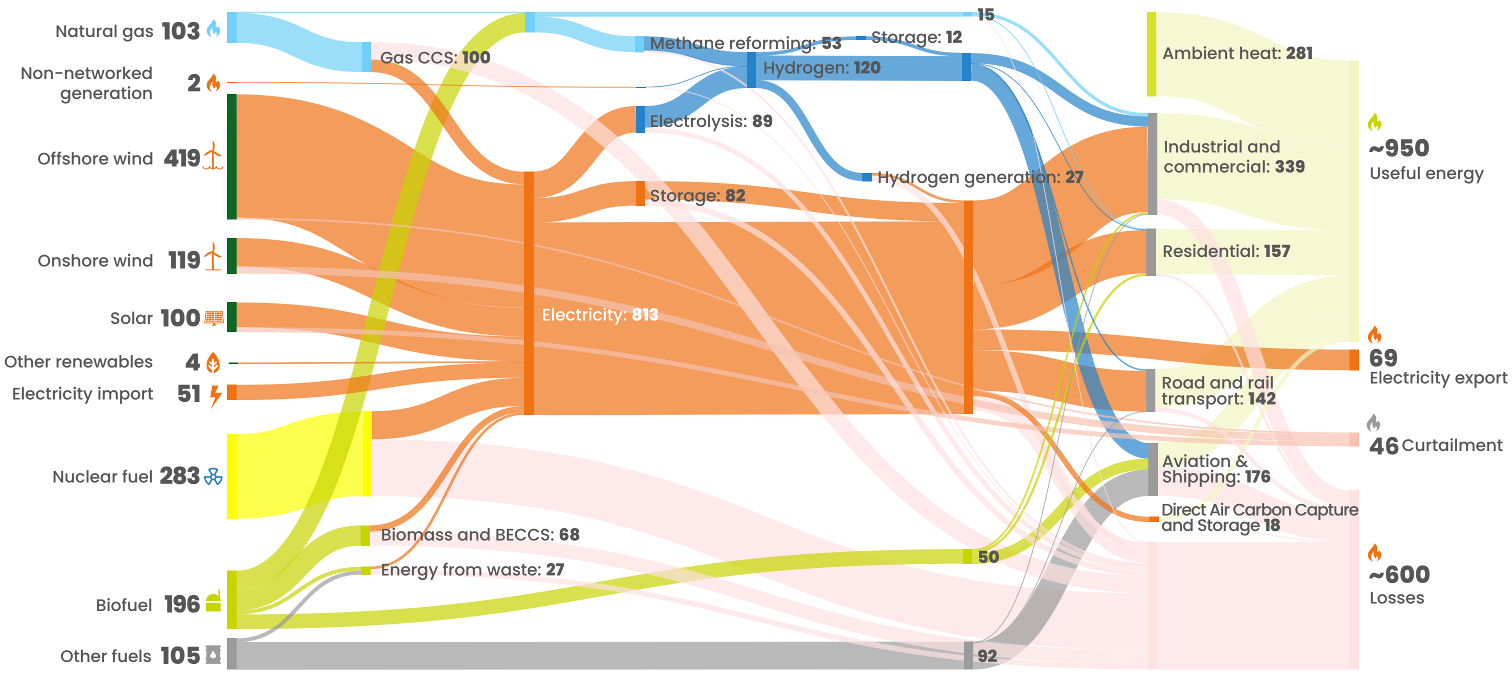
Picturing the energy future

5. Our current energy system has a high reliance on fossil fuels, with large losses of energy. Sankey diagram showing energy flows, interactions, usage and losses across the whole system today.



Much of the primary fossil energy we extract today is wasted, predominantly as heat, in power stations or internal combustion engines. A heavily electrified decarbonised energy system leads to higher overall and round-trip efficiencies. Electric vehicles convert 80-90% of electrical energy into mechanical energy by their motors, compared to internal combustion engines converting 20-30% of their fossil energy into useful energy. Similarly, gas condenser boilers have an efficiency of 80-90% compared to heat pumps with efficiencies of more than 300% by using electrical energy to extract useful energy from the air, ground or water by a compression cycle.

6. Holistic Transition shows an example of a net zero energy system where there are significant changes across supply and demand versus today, and a reduction in overall losses of energy. Sankey diagram showing Holistic Transition in 2050.



Costing the pathways

Our net zero pathways see a shift away from operational spend, including significant outlay on imported fossil fuels, towards upfront investment. We will also see a shift in patterns of expenditure away from oil and gas towards the electricity sector.

Cost volatility, while not completely eliminated, will be significantly reduced in the net zero pathways compared to a system that remains reliant on oil and gas.

There are a range of uncertainties and unknowns that will affect the cost of how Great Britain's energy system develops in the future. These include consumer choices, such as the level of consumer engagement in demand flexibility, international conditions, such as the prices of oil and gas, and wider uncertainties, including uptake of AI and other technologies alongside GDP and population growth. These factors are likely to have a significant effect on the overall cost of the energy system in the next decades.

While these factors are not all within the gift of energy stakeholders or the government to control, our work within FES aims to further our understanding of the range of available trade-offs, choices and levers that can be influenced to impact overall cost. This work will then be further progressed in the Strategic Spatial Energy Plan to design energy pathways that are economically and spatially optimised.

We are currently finalising our costing analysis of the *FES 2025* Pathways and will publish a Technical Annex, with methodology details and costings for each pathway, in 2025.

Each of the net zero pathways sees a sizeable shift in patterns of expenditure in the energy system – from ongoing operational costs, such as fuel purchase and maintenance, to upfront capital investment and from fossil fuels to low carbon electricity. As these patterns change, there is potential to support economic growth, high value jobs and wider environmental and health benefits across Great Britain's economy.

While there will still be some cost volatility in a net zero energy system (for example, spend on energy will be higher in cold years or in years with less wind and sun), this will be materially reduced compared to the existing fossil-based system. In particular, exposure to gas and oil price shocks will be much reduced.

How costs translate to consumers will depend on policy choices that we do not attempt to predict in this report. Policy will also have a key role to play in keeping costs as low as possible and our pathways suggest some priority areas for focus.

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