July 2022

Future Energy Scenarios

nationalgridESO

Navigation

This version of the FES 2022 Publication document has been optimised for printing out or viewing on a tablet.

Content in orange and underlined are shown in full either on that page or subsequent pages. All charts are also shown rather than being accessed via a toggle.

Page navigation explained

Back a page

Forward a page

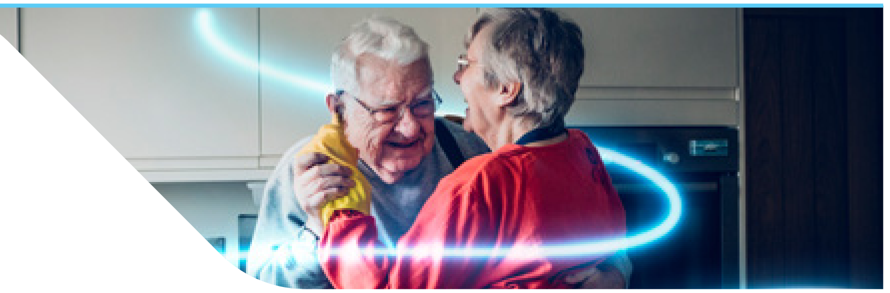
Return to contents

From here you can navigate to any part of the publication

Text Links

Click highlighted grey text to navigate to an external link. Or to jump to another section of the document

Contents



Foreword

Navigating to a Net Zero British energy system for all

Since last year's Future Energy Scenarios, the world has continued to change at pace. The impact from the pandemic is still being felt, while the devastating war in Ukraine is testing supply chains and access to fossil fuels for homes and industry. The past year has sparked recognition of the importance of a faster transition to Net Zero, to support energy security and reduce exposure to volatile international fossil fuel prices, by harnessing abundant renewable and low carbon resources. In the grips of a cost-of-living crisis, it is crucial that we never lose sight of the consumer while also focusing on delivering the broader societal benefits that can come from the transition. As a result, the Electricity System Operator (ESO)'s mission has never been more important: to drive the transformation to a fully decarbonised electricity system by 2035 which is reliable, affordable and fair for all.

The **Future Energy Scenarios** (FES 2022) sets out credible ways that the UK can achieve Net Zero by 2050, as well as the UK Government's commitment to a decarbonised electricity system by 2035. Based on extensive stakeholder engagement, research and modelling, each scenario considers how much energy we might need; where it could come from; and how we maintain a system that is reliable. We explore how different parts of the energy system can help lower emissions across the economy – whether through smart and digital technologies, electrification, deploying new hydrogen opportunities, or incorporating Carbon Capture Usage and Storage (CCUS) into industrial clusters.

We know the threat of climate change is not theoretical – we are all witnessing its impact. This has mobilised Great Britain (GB) to deliver one of the fastest decarbonising electricity systems in the world.

We are working hard with the industry to deliver carbon free operation by 2025, such as through our Pathfinder projects to find innovative new ways of operating the electricity system, keeping costs down for consumers. By 2035, we want to run a fully decarbonised electricity system all the time - helping the UK on its way to meeting its legally binding target of Net Zero by 2050. Through reducing our reliance on fossil fuels and moving towards 100% renewable and low carbon energy, we can create long-term energy security and deliver sustainable economic opportunities across the country.

Foreword

Changing our energy mix will make us less dependent on uncertain foreign supplies, create sustainable new jobs, grow our economy and help keep the UK's place as a global innovator in green technologies. In practice, we need to generate economy-wide solutions to help **investment in the infrastructure** across GB to onboard booming renewable generation. As an entire industry we need to **inform and support consumers** about straightforward ways to reduce their energy bills – with energy companies ensuring the best tariffs are readily available. We need **reform of the GB energy market**, to ensure we can best utilise the low-cost, low-carbon electricity where and when it is available. We recently published a detailed report to inform the debate on how to reform GB's wholesale electricity market to reduce consumer costs, and this summer we published our Pathway to 2030: incorporating the Holistic Network Design (HND) report, an integrated approach to support the delivery of electricity from offshore wind to consumers across GB.

As the cost of living is rising around the world, it is right for Government to look at various measures to reduce the impact on individuals and families. To stop decarbonising will mean higher costs for households, communities and businesses and put our vital energy security at risk. Investing in a renewable and low carbon future now will help bolster energy security in the future.

As custodians of this vital public service, and as we transition to the 'Future System Operator', it is our responsibility to clearly explain the impact we think that various energy scenarios will have now and in the future. Overall, the UK's Net Zero timetable is achievable if we work together, however there are many ways to get there. Delivering it will require a strong partnership between industry and policymakers, and full engagement across society and consumers. **Never before has collaboration been more important – and, as our Future Energy Scenarios 2022 demonstrates, we must be ready to act now to secure a clean and fair system for all.**

Fintan Slye
Executive Director,
Electricity System Operator (ESO)

FES 2022 / Foreword 05

Executive Summary

Introduction

What are the Future Energy Scenarios and why are they important?

Our Future Energy Scenarios (FES) outline four different, credible pathways for the future of energy between now and 2050. Each one considers how much energy we might need and where it could come from to try to a build a picture of the different solutions that may be required.

FES is widely used by our stakeholders across the energy industry to:

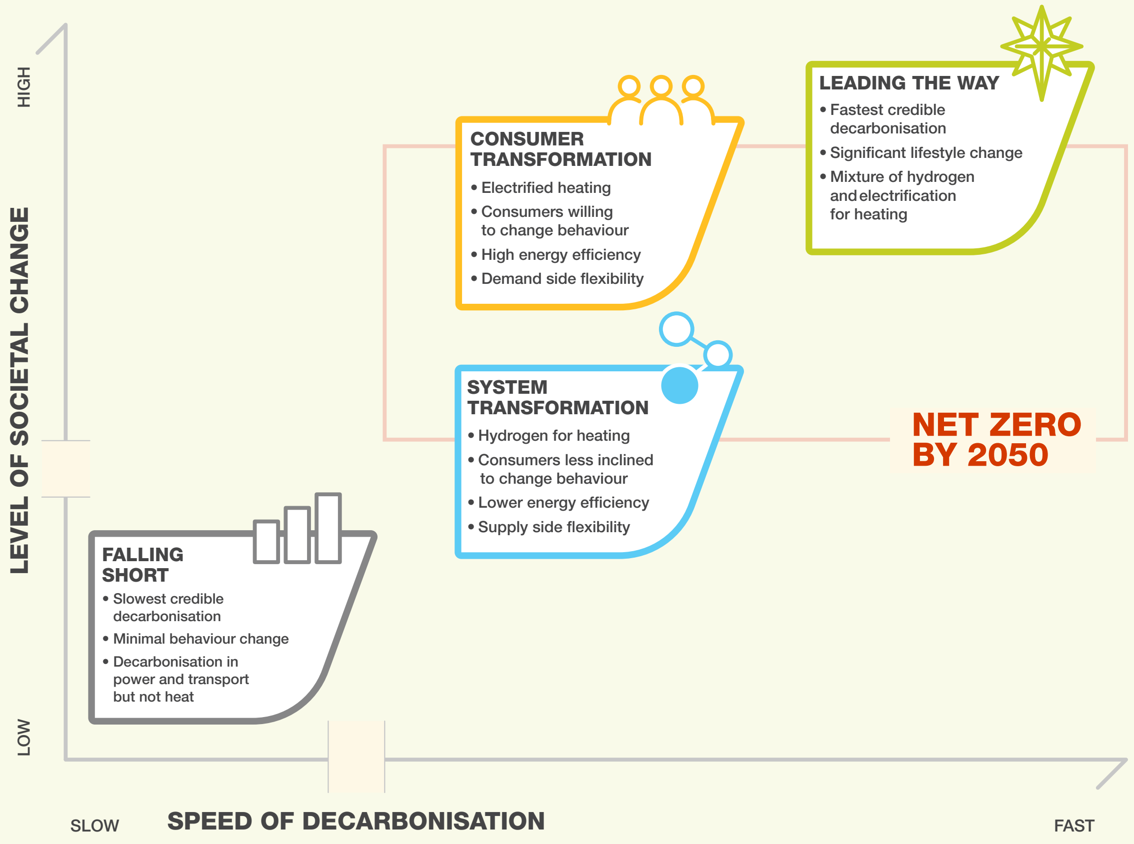
- underpin energy network development
- support investment decisions
- inform national and regional policy

As well as producing FES for our stakeholders, feedback is collected as part of our comprehensive engagement work and incorporated alongside our own analysis and research to ensure that our data and insights remain robust and up to date. We also endeavour to make our data publicly available so that it can be used in academic work and innovation projects as well as to encourage challenge and collaboration.

The COP26 event in Glasgow in November 2021 showed how important it is for the world to reach Net Zero emissions by 2050 if global temperatures are to remain below 1.5 degrees. Reaching this target in the UK while also delivering an energy system for all that is secure, clean, affordable and fair is possible but will require a transition in how energy is both consumed and supplied.

The Scenario Framework

In line with stakeholder feedback, the top-level scenario framework remains broadly unchanged compared to recent years. However, the Steady Progression scenario has been renamed as Falling Short to reinforce how this scenario does not meet the UK Net Zero target by 2050. All the scenarios meet the relevant security of supply standards across the different fuels in every year.

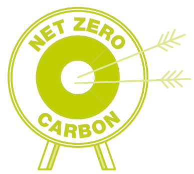


FES 2022 / ExecutiveSummary 07

Key Message

Policy and delivery

Significantly accelerating the transition to a decarbonised energy system can help to address security and affordability concerns at the same time as delivering Net Zero milestones.



Leading the Way reaches Net Zero in **2047**

Overall end consumer demand reduces by over 40% by 2035 in Leading the Way

Leading the Way has no unabated natural gas generation capacity after **2035**

Levelised costs of wind and solar are much lower than unabated natural gas generation for projects commissioning in 2025

Key recommendations

Demand side strategy

The British Energy Security Strategy addresses long term strategic priorities by ensuring greater levels of low carbon energy supply.

A corresponding demand side strategy that incentivises more flexible electricity consumption, long duration storage and early hydrogen uptake is also required to avoid significant volumes of renewable energy being wasted during periods of oversupply as well as to ensure capacity adequacy.

Energy efficiency

Improving energy efficiency is a no-regrets policy solution that can provide immediate benefits in terms of both affordability and energy security while also facilitating more enduring decarbonisation.

A plan to roll out thermal insulation to buildings alongside associated financing is urgently needed to unlock these benefits.

Regional focus on heat

A 'one-size fits all' approach to decarbonisation of residential heat is not optimal due to differences in consumer preferences, availability of resources and proximity to energy infrastructure.

Within a national strategy, delivery of the targeted solutions and investment required by consumers should take place at a more regional level to leverage local knowledge and improve affordability.

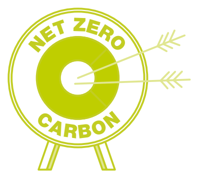
FES 2022 / ExecutiveSummary 08

Key Message

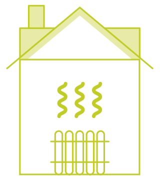
Consumer and digitalisation

Consumer behaviour is pivotal to decarbonisation – how we all react to market and policy changes, and embrace smart technology, will be vital to meeting Net Zero.

BEIS Public Attitudes Tracker, Spring 2022, UK



84% of people said that they were concerned about climate change, with 41% saying they were “very concerned”



82% of people said they had given either a lot, or a fair amount, of thought to saving energy in the home

In our scenarios, consumer engagement in smart EV charging ranges from 43% (FS) to 92% (LW) in 2035

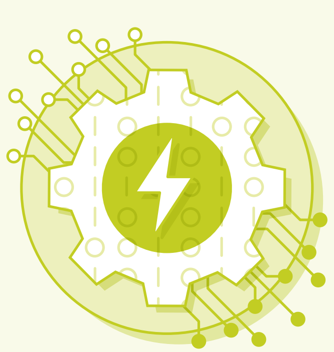
As at the end of March 2022, only 45% of installed energy meters were smart and operating in smart mode

Key recommendations

Driving change

Significant levels of demand side flexibility are required to operate the electricity system without unabated natural gas after 2035.

Suppliers must be further supported to increase the availability of flexible time-of-use-tariffs so that consumers can respond to market signals and benefit from low prices at times of high renewable output.



Digitalisation and innovation

Even the most engaged consumers won’t manually adjust their demand in line with prices and so smart digital solutions will be required to do this for them automatically and seamlessly.

To facilitate developments in smart technology and better understanding of regional trends, data must be made available to innovators while ensuring that appropriate consumer protection is maintained.

Consumer information

Consumers are willing to make changes to meet Net Zero but need to be reliably informed about both how they can help as well as the affordability benefits of low carbon solutions.

Targeted campaigns, led by trusted bodies, are required to provide consumers with the information they need to decarbonise and embrace new technology.

FES 2022 / ExecutiveSummary 09

Key Message

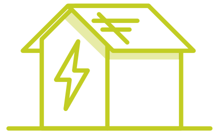
3 Markets and flexibility

Reforming energy markets to improve price signals will help unlock the flexible solutions needed to integrate renewables efficiently.

Wind and solar generation currently make up 43% of GB energy supply and this rises to at least 66% across the scenarios by 2030

Annual transmission constraint costs have increased from £170m in 2010 to £1.3bn in 2022 and are expected to continue rising

In Leading the Way, demand side flexibility reduces unmanaged peak demand by over 40% by 2035



Consumer Transformation and Leading the Way have more than 115 GWh of electricity storage in 2035 compared to less than 30 GWh today

Key recommendations

Flexibility requirement

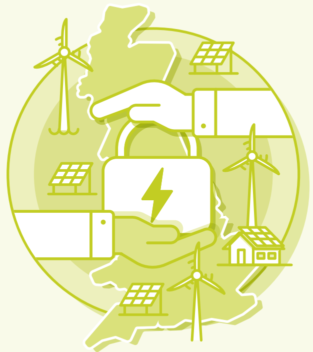
Operating a future energy system with high levels of renewables and no unabated natural gas generation will require significantly more flexible capacity than we have today.

Current market signals mean that flexible assets cannot contribute their full value to the system and may at times exacerbate network constraints - the impact of this will only increase in the future if changes are not made now.

Locational signals

ESO analysis shows that market reform is needed to provide the dynamic real-time locational signals required to optimise dispatch and siting decisions of flexible capacity on the whole energy system.

Improving locational signals has the potential to deliver significant cost savings to consumers without any adverse impact on renewable targets.



Market participation

The energy market of the future must harness the vast potential of demand side flexibility to integrate renewables and ensure security of supply at least cost for all.

Market changes must facilitate flexible tariffs, support innovation and reduce barriers to participation for new market entrants from the industrial and commercial sector or in the form of aggregated residential demand.

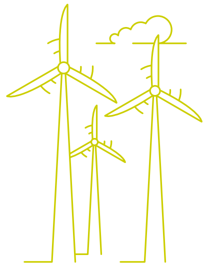
FES 2022 / ExecutiveSummary 10

4

Key Message

Infrastructure and whole energy system

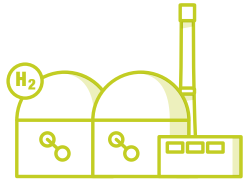
Strategic investment in the whole energy system is urgently required to keep pace with Net Zero ambitions and strengthen energy security.



Across the scenarios, at least 31 GW of offshore wind is connected in 2030 with 51 GW in Leading the Way

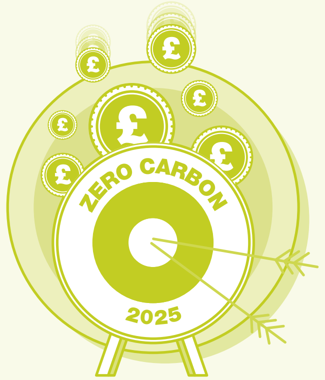
At least 15 TWh of electricity is curtailed in the Net Zero scenarios by 2030

There are over 40 GW of network-connected electrolysers in Leading the Way and System Transformation in 2050



56 TWh of Hydrogen storage is required in System Transformation by 2050

Key recommendations



Strategic whole system thinking

Delivery of the British Energy Security Strategy requires urgent anticipatory investment to ensure the energy system is not a blocker to Net Zero.

Strategic coordination and whole system thinking, especially across the electricity and hydrogen sectors, is required to achieve decarbonisation targets and avoid unmanageable network constraints and potential curtailment.

Inter-seasonal storage

The whole energy system of the future will require strategic storage to balance inter-seasonal demand and supply and increase resilience against external security of supply risks.

This will include large-scale geological hydrogen and electricity storage projects which must commence now to support an electricity system without unabated natural gas after 2035.

Whole system competition

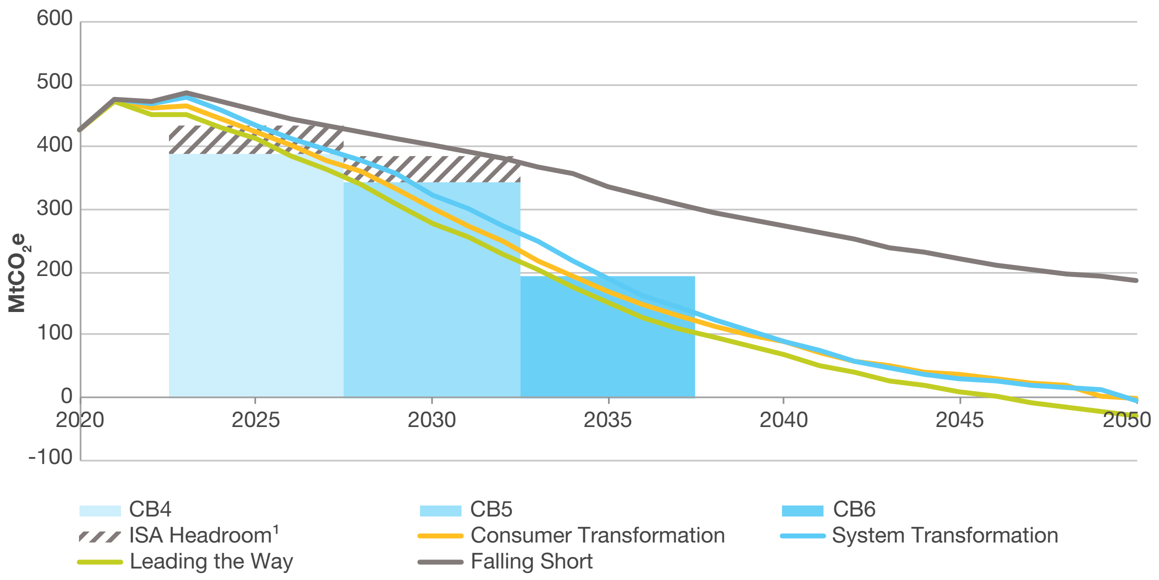
To ensure affordable delivery of new infrastructure, competition in delivery must be established for large projects.

Competition is also required at a local level to ensure different regions can adopt the low carbon solutions that are most suited to the needs of their consumers.

FES 2022 / ExecutiveSummary 11

Navigating a fair transition to Net Zero

The chart below shows how total greenhouse gas emissions from the different scenarios compare against both the 2050 Net Zero target and the associated Carbon Budgets (CBs).

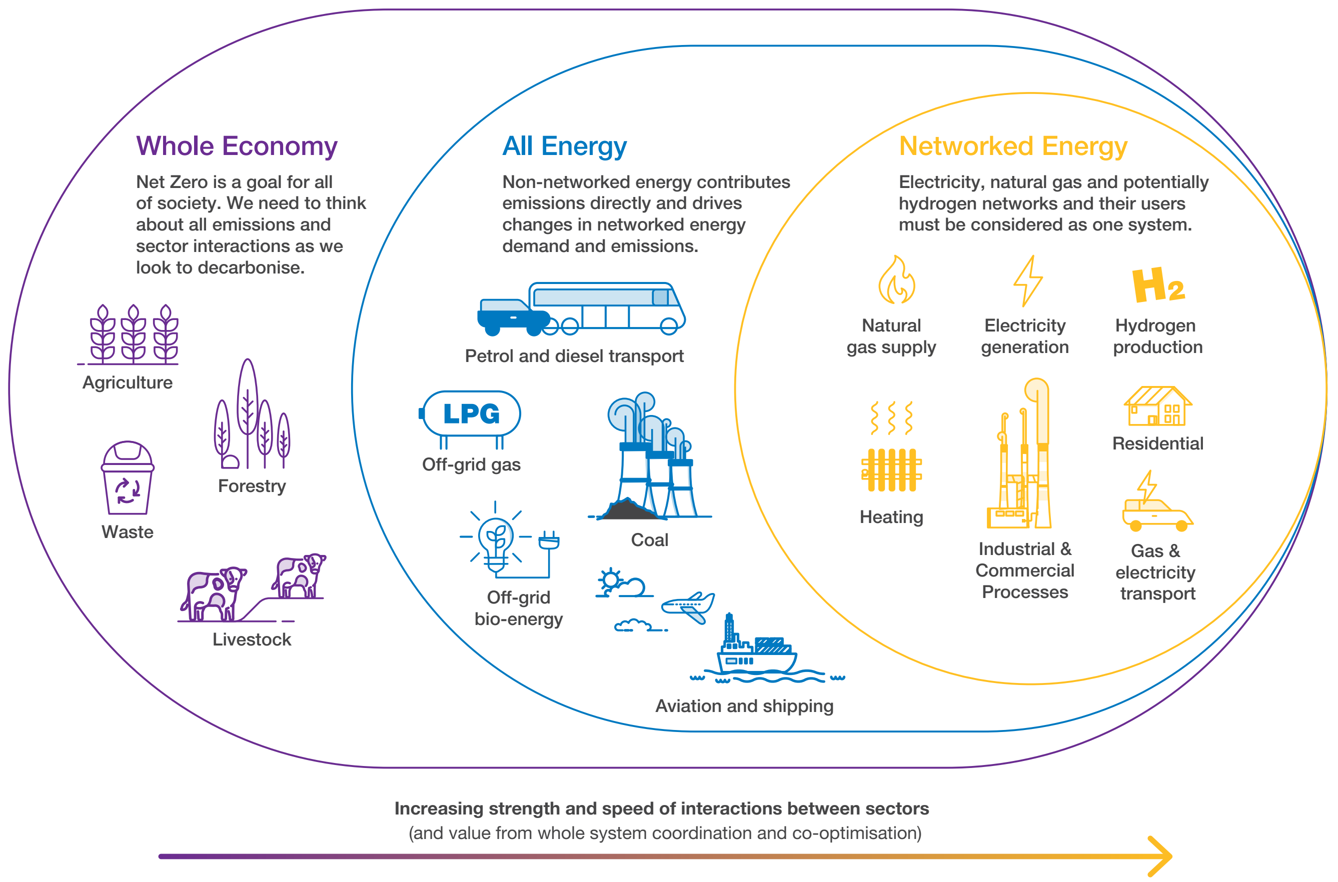


Consumer Transformation and System Transformation both **meet the target** of Net Zero greenhouse gas emissions by 2050 – as well as meeting all the interim carbon budgets. The ways they do this are very different and highlight the varying roles of supply and demand as well as different fuels like electricity and hydrogen.

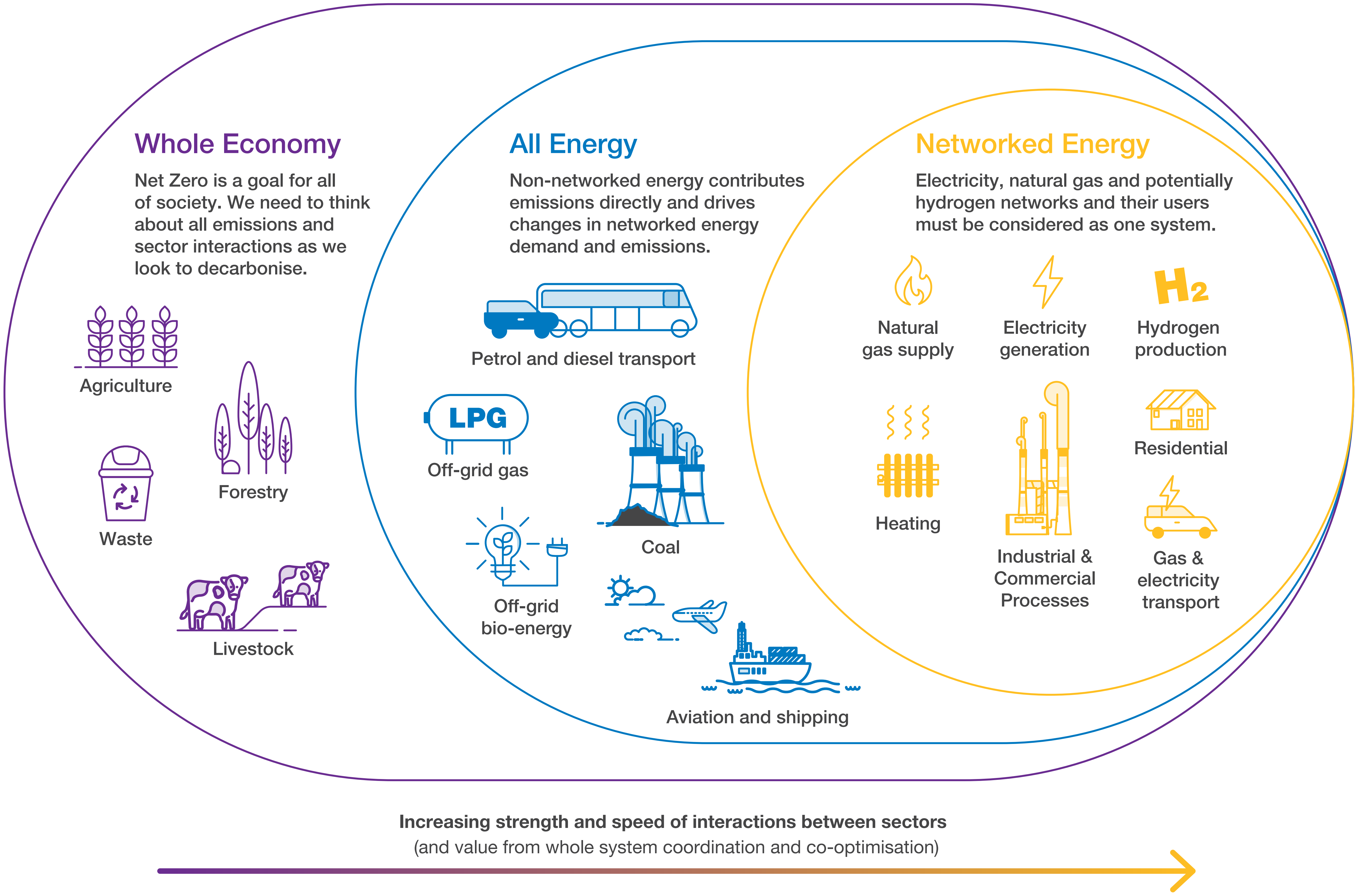
In Leading the Way, combining high consumer engagement with significant and innovative investment enables the Net Zero target to be met in **2047** with emissions net negative in 2050.

Whilst decarbonisation is slowest in Falling Short, emissions in 2050 are still reduced by almost **80%** of 1990 levels which would have been close to meeting the previous carbon reduction target.

Our FES analysis focuses on the GB energy sector but, as other sectors such as aviation and agriculture contribute greenhouse gas emissions, a whole economy view is needed when assessing Net Zero. Even by 2050, we assume that sectors like these don't fully decarbonise and so some of their residual emissions must be offset by the energy sector becoming net negative.



1 International Aviation and Shipping Headroom



FES 2022 / ExecutiveSummary 13

Seeing the whole picture

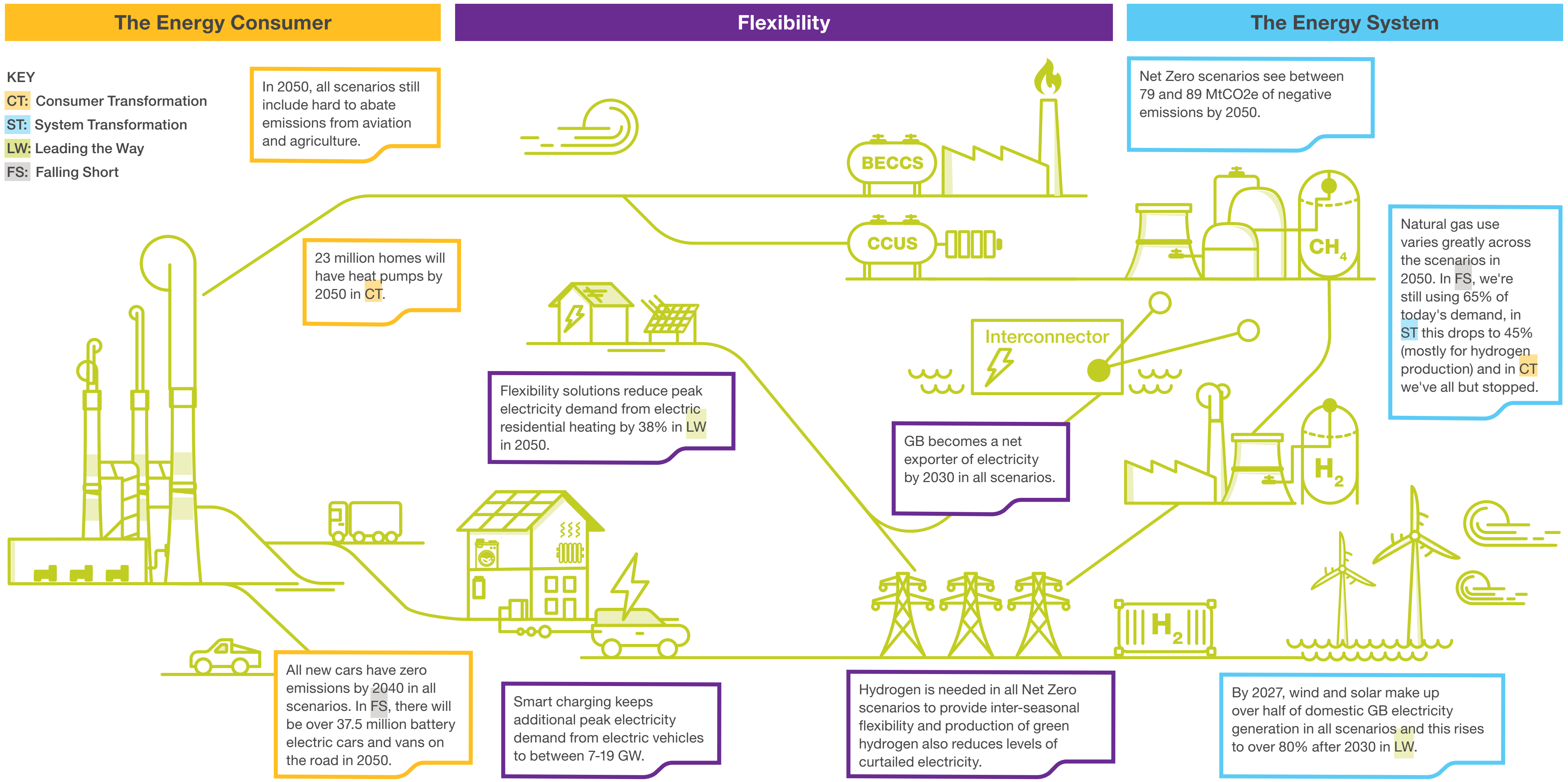
Today, the electricity system is designed and operated to allow flexible supply to meet whatever demand is required but, in the future, demand must be enabled to flex to supply which will come increasingly from weather-driven renewables.

This will involve increased interaction across fuels like natural gas, bio-resources and hydrogen as well as significantly more non-fossil fuel and demand side flexibility.

As well as a chapter on reaching Net Zero, FES 2022 has the following dedicated chapters:

- “the energy consumer” covers the residential, industrial, commercial and transport sectors and considers how decarbonisation affects individual consumers
- “the energy system” explores how total GB demand is met using decarbonised energy sources such as electricity, hydrogen, natural gas and bioenergy
- “flexibility” ensures energy supply and demand are balanced, and security of supply criteria are met, as the energy system decarbonises

To develop and operate the whole energy system of the future and deliver value to consumers, each of these three areas must be fully considered.



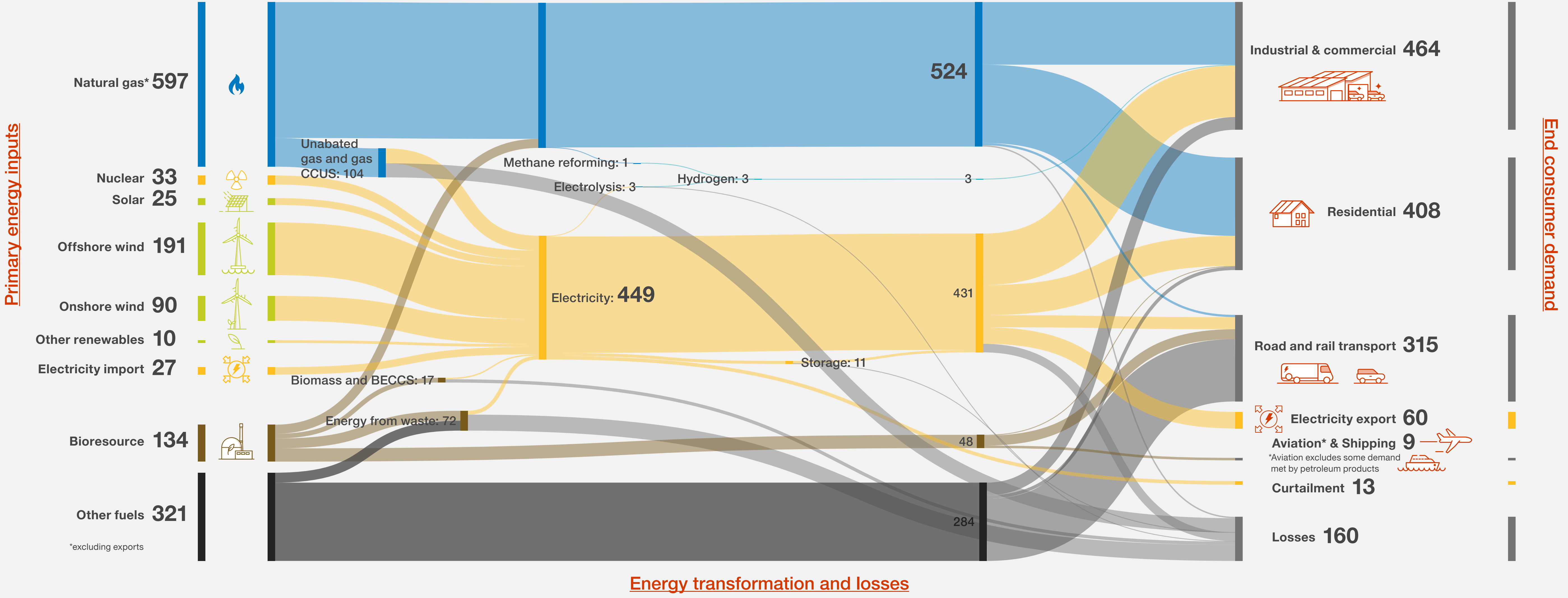
FES 2022 / ExecutiveSummary 14

2035 energy flows

For FES 2022, energy flow diagrams have been included for Falling Short and Leading the Way in **2035** to highlight the differences between the slowest and fastest decarbonising scenarios in relation to the target for no unabated natural gas in the power sector by this year.

Falling Short (1428 TWh)

- Minimal difference to today with continued reliance on both oil-based fuels as well as natural gas
- Main area of progress is in surface transport where increased electrification and use of biofuels reduces demand for oil-based products
- Significant increase in electricity generation from renewables but unabated gas-fired generation still contributes heavily
- Use of oil-based fuels in residential heating largely replaced by electric heat pumps

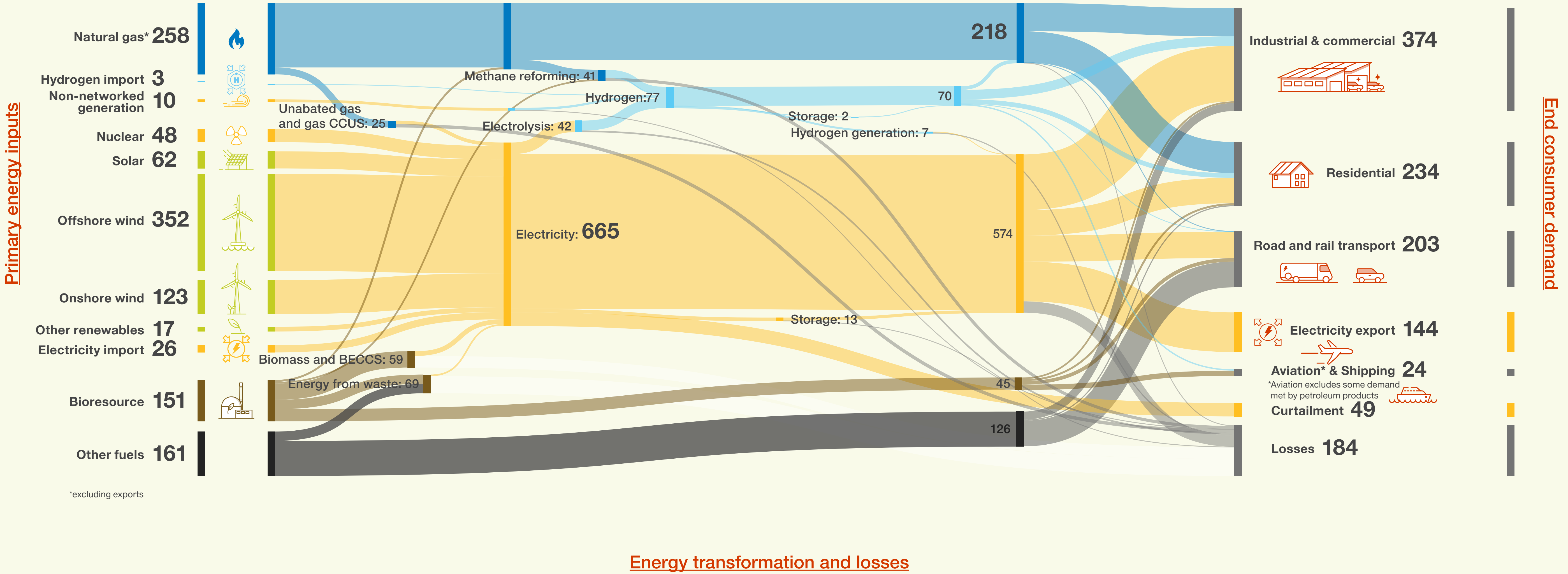


2035 energy flows

For FES 2022, energy flow diagrams have been included for Falling Short and Leading the Way in **2035** to highlight the differences between the slowest and fastest decarbonising scenarios in relation to the target for no unabated natural gas in the power sector by this year.

Leading the Way (1211 TWh)

- Virtually no unabated natural gas used for electricity generation
- Half of energy demand for road and rail transport sector is met by electricity
- Significant hydrogen production has commenced from a broadly equal combination of electrolysis and methane reformation
- High levels of electricity curtailment already beginning to be seen (this reduces to almost nothing by 2050)



FES 2022 / ExecutiveSummary 16

2035 energy flows

Primary energy inputs

The primary energy inputs we consider here are bioresources, natural gas, other fossil fuels, and renewable and nuclear electricity generation. It is possible to break some of these areas down in more detail; for example the natural gas we use comes from a range of different sources, but we have chosen the cut-off point to make the diagram as clear as possible. Sources of natural gas and the make-up of our total pool of bioresources are considered in more detail in the sub-chapters.

Energy transformation and losses

The diagram shows several points where energy is transformed between different fuels or forms of energy. This is often important for system reasons, for example using electricity to produce hydrogen allows electricity generated in the summer to be transformed into a form of energy that can be stored and used during the winter.

The use of hydrogen to generate electricity then provides additional flexibility to the energy system.

These conversions are usually associated with some form of energy loss, as none of these processes are 100% efficient. For example, thermal electricity generation involves combustion of fuels such as gas, hydrogen or biomass to create heat to generate steam to drive a turbine, with energy losses at each step. Other conversion points within the diagram include electricity converted to hydrogen via electrolysis, methane reformation of natural gas or biomethane to produce hydrogen, and energy moving in and out of electricity or hydrogen storage. Technologies such as Carbon Capture and Storage (CCS) are not shown, although any changes this may have on the efficiency of a conversion process is included in our analysis.

Losses on the energy system at different stages of energy transformation or transportation are shown by the light grey lines that combine in the bottom right corner of the diagram. We also include electricity transmission and distribution losses and natural gas pipeline shrinkage.

End consumer demands

Our total end consumer demands are split by sector: Industrial & Commercial, residential, road and rail transport, and aviation and shipping. These include energy used for different purposes, for example for electricity used for lighting and appliances within the home, but also energy used to produce heat. This is a measure of the energy used by the sector, in terms of electricity, hydrogen, natural gas and bioresources, and not the input energy needed to meet these demands. This is particularly important when considering the effect of different heating technologies.

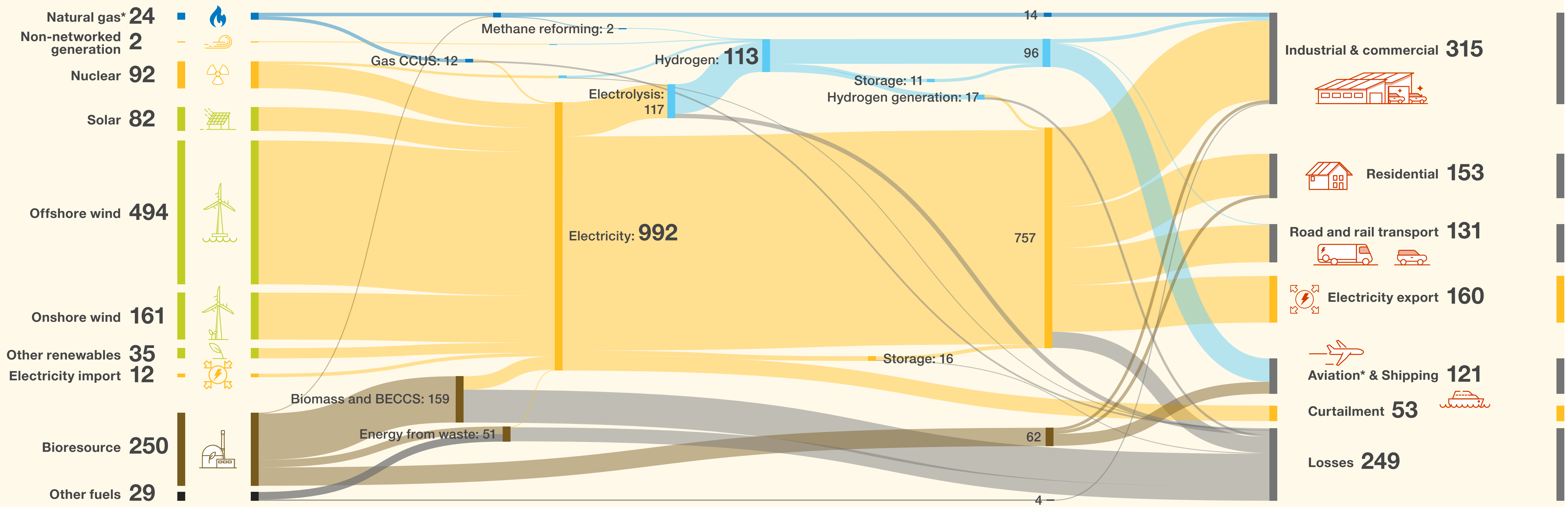
While Consumer Transformation and System Transformation have relatively similar heat demands, on the energy flow diagram these look markedly different in size. This is because System Transformation relies heavily on hydrogen boilers to produce heat – which are around 90% efficient – while Consumer Transformation primarily uses heat pumps. These have an equivalent efficiency of around 250%, as the electricity for heat pumps is used to run pumps and compressors that are able to extract additional energy from the air or the ground around the heat pump. This increases the difference for end user demand for electricity, gas and hydrogen between these scenarios. This is particularly apparent in the 'residential' end consumer demand section, which is dominated by heat.

FES 2022 / ExecutiveSummary 17

2050 energy flows

Consumer Transformation (1182 TWh)

- Home heating, transport and industry largely electrified
- High levels of energy efficiency combined with large-scale electrification lead to lowest end user energy demands across the scenarios
- Electricity generation capacity and output is highest in this scenario to meet high annual electricity demands
- High levels of renewable generation with low hydrogen production leads to highest levels of electricity curtailment across the scenarios



*excluding exports

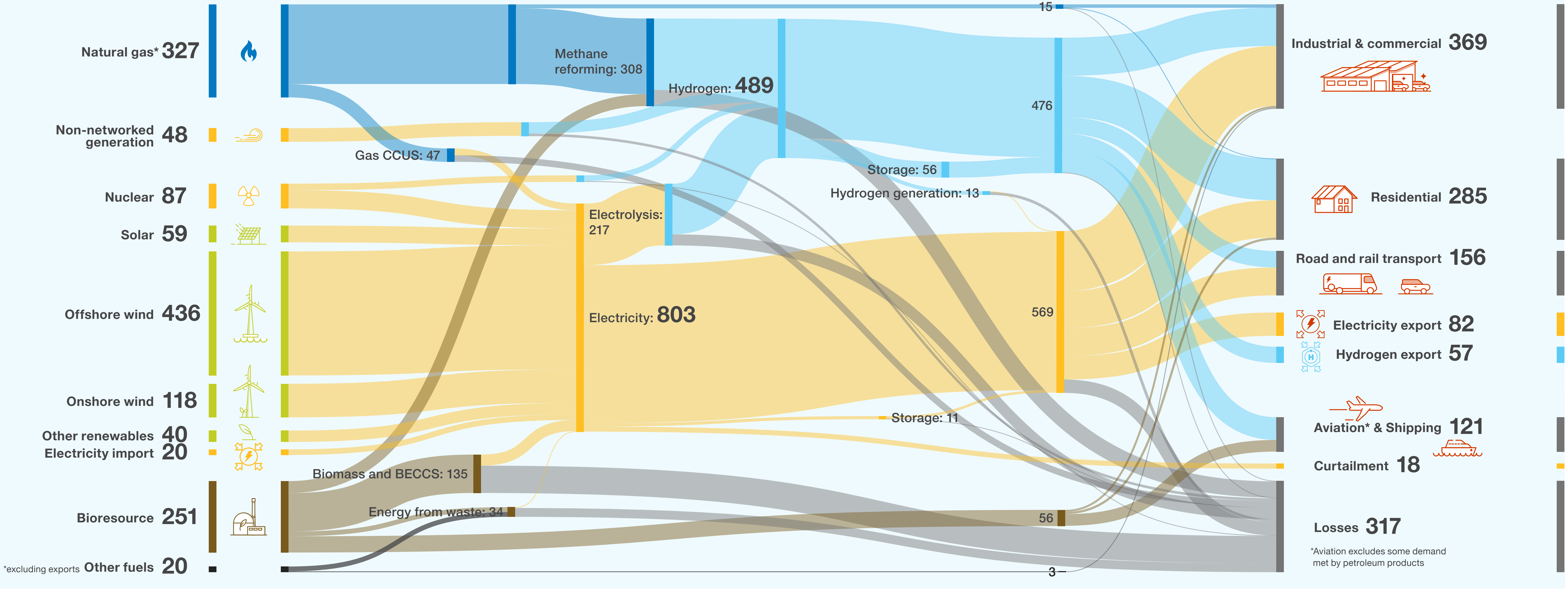
*Aviation excludes some demand met by petroleum products

FES 2022 / ExecutiveSummary 18

2050 energy flows

System Transformation (1406 TWh)

- Highest proportion of hydrogen across the scenarios with widespread use for home heating, industry and HGVs
- All hydrogen is produced in the UK from a combination of methane reformation and electrolysis
- High levels of hydrogen production enable an export market to form
- Joint highest level of bioresource use with Consumer Transformation - biomass used to produce both hydrogen and electricity

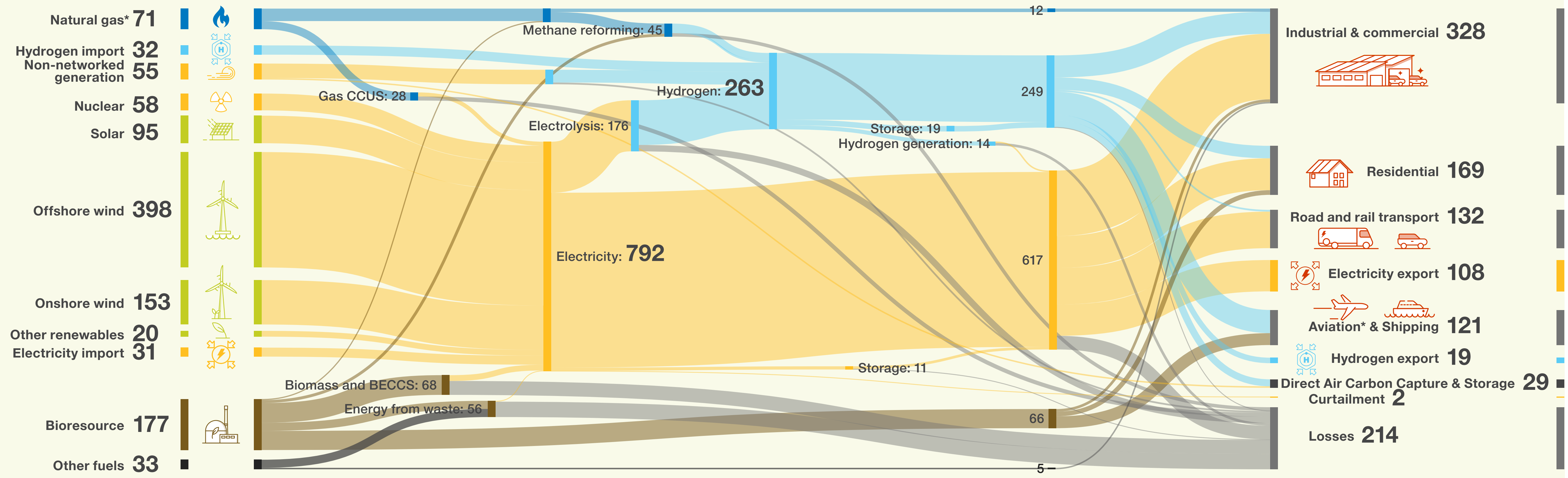


FES 2022 / ExecutiveSummary 19

2050 energy flows

Leading the Way (1123 TWh)

- Combination of hydrogen and electricity used in industry and to heat homes
- Imports and exports of hydrogen to provide maximum levels of system flexibility
- Lowest level of electricity curtailment across the scenarios
- Direct air carbon capture and storage (DACCS) used for negative emissions



*excluding exports

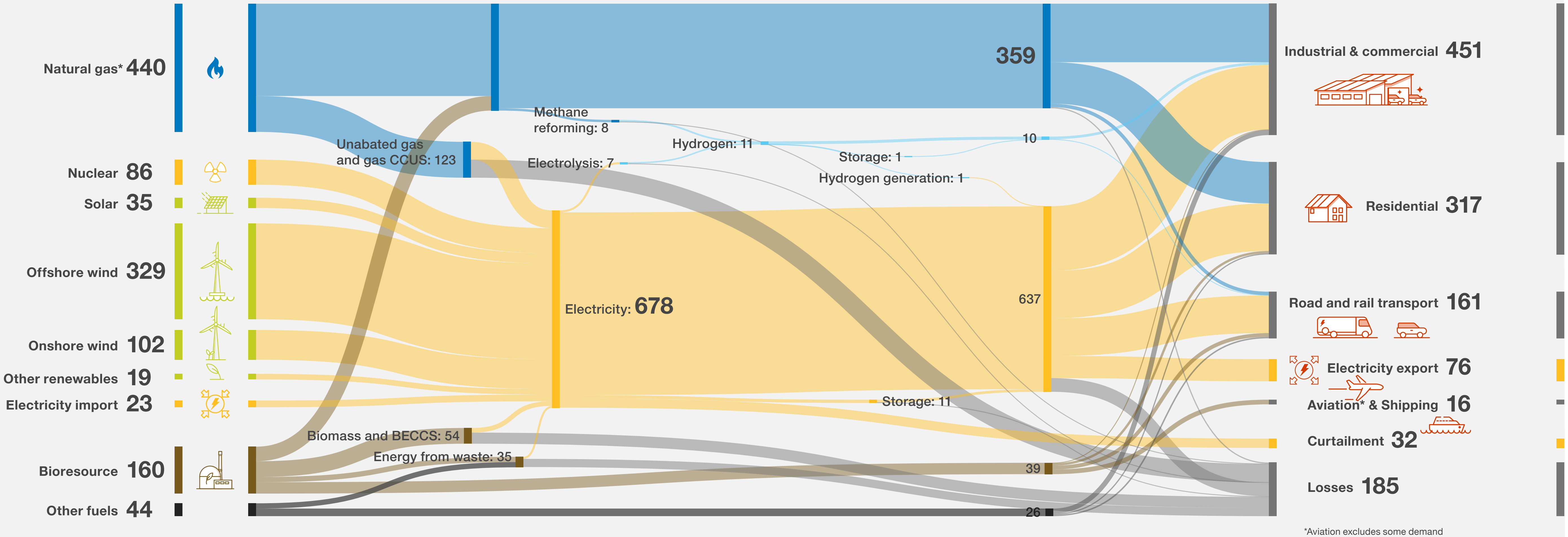
*Aviation excludes some demand met by petroleum products

FES 2022 / ExecutiveSummary 20

2050 energy flows

Falling Short (1237 TWh)

- Continued high usage of natural gas, particularly for domestic heating and industry
- Small private vehicles fully electrified (including some plug-in hybrids) whilst HGVs rely on fossil fuels
- Low use of hydrogen as production isn't decarbonised
- Highest total end-user energy demand due to minimal increase in energy efficiency measures and reliance on inefficient fossil fuels



*excluding exports

*Aviation excludes some demand met by petroleum products

Introduction to the FES

nationalgridESO

As we emerge from the COVID-19 pandemic, we find ourselves in a world which continues to change. Since our Future Energy Scenarios 2021, we have continued to see unprecedented changes, such as rapidly increasing oil and gas prices, the devastating war in Ukraine, and a cost-of-living crisis.

At the same time, 2021 was a critical year in the UK and internationally for climate action, and we are all witnessing the impacts of climate change today. We saw the world come together in Glasgow for COP26 to deliver the Glasgow Pact, to try and avoid the worst impacts of climate change.

In the face of the unprecedented changes we have seen in the UK and around the world, it has become even more clear that the transition to a renewable led system, and a reformed market to underpin it, will deliver many benefits – not just environmentally, but in relation to the challenging energy and cost of living crisis that we see today.

Through our Future Energy Scenarios it is clear that achieving a Net Zero energy system by 2050 is possible and credible, and that there are many ways to get there. In this report, we bring together the latest insights from across the market, stakeholders and the newest innovations, as well as from our own modelling, to dive deeper into the transformation required across society and infrastructure. The benefits are clear: it is increasing momentum on delivery that is critical.

At National Grid ESO, we are dedicated to enabling the transition in the energy industry while continuing to provide the highest levels of reliability and value for our consumers. We believe reaching Net Zero by 2050 in a sustainable way is possible, as long as we work together urgently to reduce our emissions and deliver a clean, reliable and fair energy system for all.

FES 2022 / Introduction to the FES 23

What are the Future Energy Scenarios?

Scenario Framework

The Future Energy Scenarios explore how the energy system could evolve between now and 2050, through changes in infrastructure, technology, innovation and behaviour change. It also explores the implications of the decarbonisation choices that are available, such as focusing more on societal change, the development of infrastructure, or changing the speed at which aspects of the energy system transform.

In FES 2022, we use four scenarios to show the credible range of possibility for the future of energy between now and 2050 along the two axes you see in the image on this page. The 'Societal Change' axis combines innovation, engagement and mandatory change. This high-level scenario framework has been kept consistent since FES 2020.

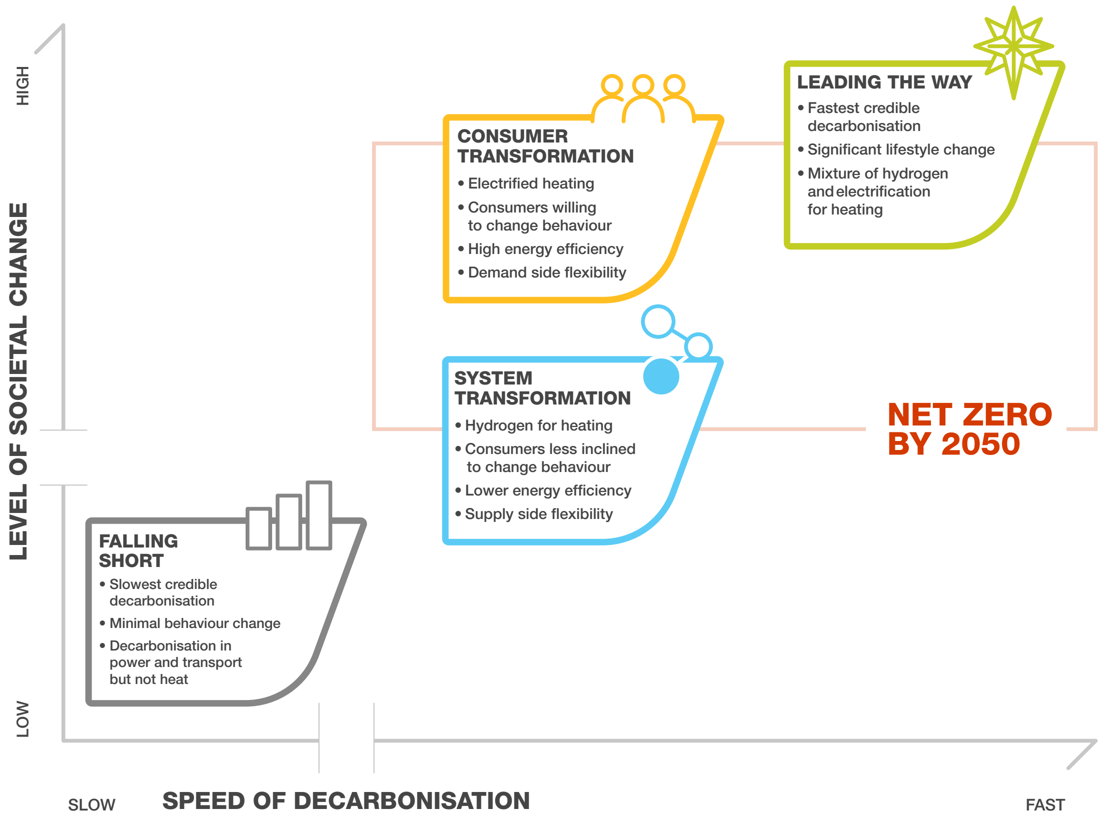
Consumer Transformation and System Transformation represent two different ways to reach Net Zero by 2050 – either by changing the way we use energy or by changing the way in which we generate and supply it.

Leading the Way describes our fastest credible decarbonisation journey, achieved through a combination of high consumer engagement with world leading technology and investment – allowing GB to reach Net Zero before 2050.

Falling Short represents our slowest credible speed of decarbonisation and does not reach Net Zero, although it has accelerated relative to FES 2021.

FES 2022 explores what these scenarios mean for society and for the energy system in detail.

Learn more about the Scenario Framework here



The Steady Progression scenario has been renamed to Falling Short to highlight that it does not reach Net Zero. It is not a new scenario.

FES 2022 / Introduction to the FES 24

What are the Future Energy Scenarios?

Consumer Transformation

The 2050 Net Zero target is met with measures that have a greater impact on consumers and is driven by higher levels of consumer engagement. A typical homeowner will use an electric heat pump with a low temperature heating system and an Electric Vehicle. They will have made extensive changes to improve their home's energy efficiency and most of their electricity demand will be smartly controlled to provide flexibility to the system. The system will have higher peak electricity demands managed with flexible technologies including energy storage, Demand Side Response (DSR) and smart energy management.

System Transformation

The typical domestic consumer will experience less disruption than in Consumer Transformation as more of the significant changes in the energy system happen on the supply side, away from the consumer. A typical consumer will use a hydrogen boiler with a mostly unchanged heating system and an Electric Vehicle or a fuel cell vehicle. They will have had fewer energy efficiency improvements to their home and will be less likely to provide flexibility to the system. Total hydrogen demand is high, mostly produced from natural gas with Carbon Capture and Storage (CCS).

Leading the Way

We assume that GB decarbonises rapidly with high levels of investment in world-leading decarbonisation technologies. Our assumptions in different areas of decarbonisation are pushed to the earliest credible dates. Consumers are highly engaged in reducing and managing their own energy consumption. This scenario includes more energy efficiency improvements to drive down energy demand, with homes retrofitted with insulation such as triple glazing and external wall insulation, and a steep increase in smart energy services. Hydrogen is used to decarbonise some of the most challenging areas such as some industrial processes, produced mostly from electrolysis powered by renewable electricity.

Falling Short

There is still progress on decarbonisation compared to the present day; however it is slower than in the other scenarios. While home insulation improves, there is still heavy reliance on natural gas, particularly for domestic heating. Electric Vehicle (EV) take-up grows more slowly, displacing petrol and diesel vehicles for domestic use; however decarbonisation of other vehicles is slower with continued reliance on diesel for heavy goods vehicles. In 2050 this scenario still has significant annual carbon emissions, short of the 2050 net zero target.

FES 2022 / Introduction to the FES 25

We need to account for the long term effects of recent world events

Energy prices

We have seen dramatic changes in oil and gas prices in the past year, which have been driven by a number of factors including the devastating conflict in Ukraine and supply chain issues as economies start to bounce back following COVID-19.

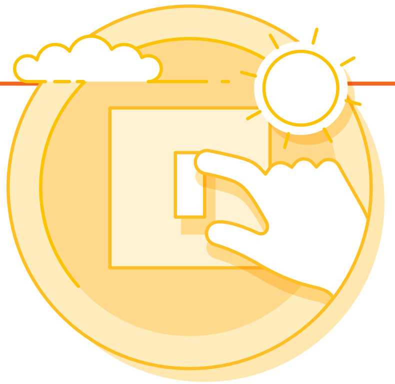
From a modelling perspective, the higher energy prices will not change our outputs significantly, as high gas prices were already modelled based on increases in energy prices through to last autumn. If high prices do cause a fall in demand this would still fall within our range for demand across the scenarios. We use price forecasts from third party experts and combine with stakeholder feedback to understand the impacts of these price changes on energy demand and supply. While the data used in our modelling reflected potential increasing prices, we have continued to see new economic challenges emerging. We will continue to consider the implications of these in our next Future Energy Scenarios publications.

Government policy

Since FES 2021, Government has built on the Prime Minister's Ten Point Plan for a Green Industrial Revolution and Energy White Paper. This has included the publication of the British Energy Security Strategy (BESS), the Net Zero Strategy and a number of sectoral decarbonisation strategies, such as for heat and buildings and hydrogen. These policies inform our scenario assumptions and the chapter overviews (and FES-in-5) compare progress against policy timelines for each of the scenarios. If a policy milestone is not met, this does not mean it is unfeasible but may indicate that policy and market dynamics within that scenario do not fully support it. Specifically in relation to the BESS, as it was published midway through our FES 2022 analysis, some elements that we may have wanted to include have not been fully reflected.

FES 2022 / Introduction to the FES 26

We need to account for the long term effects of recent world events



Changes in behaviour

We continue to monitor the impact on energy demand from broader societal behaviour changes, such as working from home, or the impacts from cost of living on the ability of consumers to invest in low carbon technologies (which may have higher upfront costs). Our scenario framework considers what levels of societal change may be possible. This year we go further to explain the forces which enable or inhibit change, and how they may evolve over time.

Technology and funding

We continue to see advances in existing technology, but also in some which have potential to be part of the energy system in future, such as nuclear fusion. We also see a steady stream of funding schemes to enable deployment at scale.

We consider what to include in FES based on commercial readiness level and technology readiness level – as they are now, and where we expect them to be in future. Political appetite is one of the factors accounted for through the 'level of societal change' axis of the scenario framework.

FES 2022 / Introduction to the FES 27

We aim to continuously improve the quality of our engagement, modelling and insights

Stakeholder Engagement

We continue to engage with a broad range of stakeholders from the energy industry and more widely ensuring a rich and varied output to our engagement. New stakeholders and organisations have provided a different perspective to more long-standing and established views.

For FES 2022 we engaged with 1020 stakeholders including 329 existing organisations, 204 new organisations and engagement activities spanned all nine stakeholder categories. This covers consumer groups, research & academia, government departments, energy producers, storage & flexibility providers, and utility networks.

Modelling, Analysis and Insight

We use our stakeholder engagement and market research to inform our analysis and insights into what the future may look like. We also publish thought pieces through the year to inform industry and gain wider feedback.

Modelling improvements this year include:

- Distributed Generation Capacity modelling to incorporate embedded capacity registers from the DNOs (Distribution Network Operators)
- Regional modelling: spatial heat analysis and regional transport mileage disaggregation
- Improvements to our spatial modelling are ongoing, and there will be more to come from a regional perspective later in the year

The results

The resulting scenarios and insights in FES 2022 represent the credible range of possibility for the different ways we might supply and consume energy between now and 2050.

FES is used by National Grid ESO and other organisations for:

- Network planning – what we need to build, where and when
- Operability analysis – how we can run the whole energy system to get energy where it needs to be
- Supporting policy development

FES 2022 includes:

- Greater emphasis on interim milestones such as 2035
- Deeper insight into how the whole energy system works together

FES 2022 / Introduction to the FES 28

Our Future Energy Scenarios are used for a number of regulated activities and referenced by a wide range of energy industry participants and stakeholders

How & Where FUTURE ENERGY SCENARIOS are used

REGULATED ENERGY SYSTEM ACTIVITIES

OPERABILITY

- Distribution System Operability Framework
- System Operability Framework
- Gas Markets Plan
- Gas Future Operability Planning

NETWORK INVESTMENT

- Network capability
- Network Options Assessment
- Price controls
- National & local planning
- Ten year statements (Electricity, Gas)
- European electricity and gas operators also use FES data for their ten year development planning (Electricity, Gas)

SECURITY OF SUPPLY

- Electricity Capacity Market
- Winter & summer outlooks (Electricity, Gas)

KEY STAKEHOLDERS

PRIVATE SECTOR & ENERGY INDUSTRY

- Energy and low carbon industries
- Generators & flexibility providers
- Suppliers
- Independent thought leaders
- Shippers & producers
- Energy systems catapult

POLICY & REGULATION

- BEIS
- Local & central government
- Academia, research and innovators
- Ofgem
- Climate Change Committee
- Consumer Groups

Return to Executive Summary

FES 2022 / Introduction to the FES 29

Sphere of Influence

NETWORK INVESTMENT

Network capability
Assessment of the capability of the gas network.

Network Options Assessment
NOA uses the scenarios in its economic analysis of network reinforcements. It also uses them to calculate the optimum levels of interconnection between GB and European markets.

Price controls
Ofgem and RIIO2.

National & local planning
National Grid Gas has a licence obligation to forecast gas demand for the National Transmission System and the Local Distribution Zones. FES data informs this process.

European electricity and gas operators also use FES data for their ten year development planning.
Electricity: ENTSOE
Gas: ENTSOG

Ten year statements
Electricity and Gas Ten Year Statements are used for investment planning by SOs and DNOs.

SECURITY OF SUPPLY

Electricity Capacity Market
Electricity Capacity Report recommends to BEIS the amount of capacity to secure through auction.

Winter & summer outlooks
The outlook reports look at the coming six months, assessing any potential issues or opportunities for both gas and electricity.

POLICY & REGULATION

Ofgem
FES is a licence obligation of National Grid Electricity System Operator set by Ofgem, to help them understand how the energy industry may develop in Great Britain.

Local & central government
For example, OLEV, DfT, Defra.

BEIS
The department of Business, Energy and Industrial Strategy refer to FES when considering new energy policy.

Climate Change Committee
CCC also produce pathways for decarbonisation.

Academia & research
Universities are active contributors to the development of FES and our work also informs their research.

Consumer Groups
Ranging from large industrial plants to residential houses, consumers are the direct users of energy.

PRIVATE SECTOR & ENERGY INDUSTRY

Shippers & producers
Gas shippers and producers look at FES to understand how their markets may evolve over time.

Suppliers
Energy suppliers look at FES to understand how their markets may evolve over time.

Generators & flexibility providers
FES is used to help assess how much investment to make in generation and flexibility facilities.

Energy systems catapult
Energy Systems Catapult works towards ways to decarbonise energy.

Independent thought leaders
Changes to energy supply and use is a topic of much debate by independents observers and think tanks.

Energy and low carbon industries
This includes a wide range of stakeholders and activities such as R&D and innovation. Industries include major energy users (incl. power stations, ceramics etc), vehicle manufacturers heat pumps, insulation thermal stores, house builders, investment banks, etc…

OPERABILITY

Gas Future Operability Planning
Gas network operability planning by National Grid.

System Operability Framework
SOF combines insight from FES with technical assessments to identify medium-term and long-term requirements for operability.

Gas Markets Plan
GMaP considers market change over a ten year time frame.

Distribution System Operability Framework
Distribution Network Operators also produce SOFs.

FES 2022 / Introduction to the FES 30

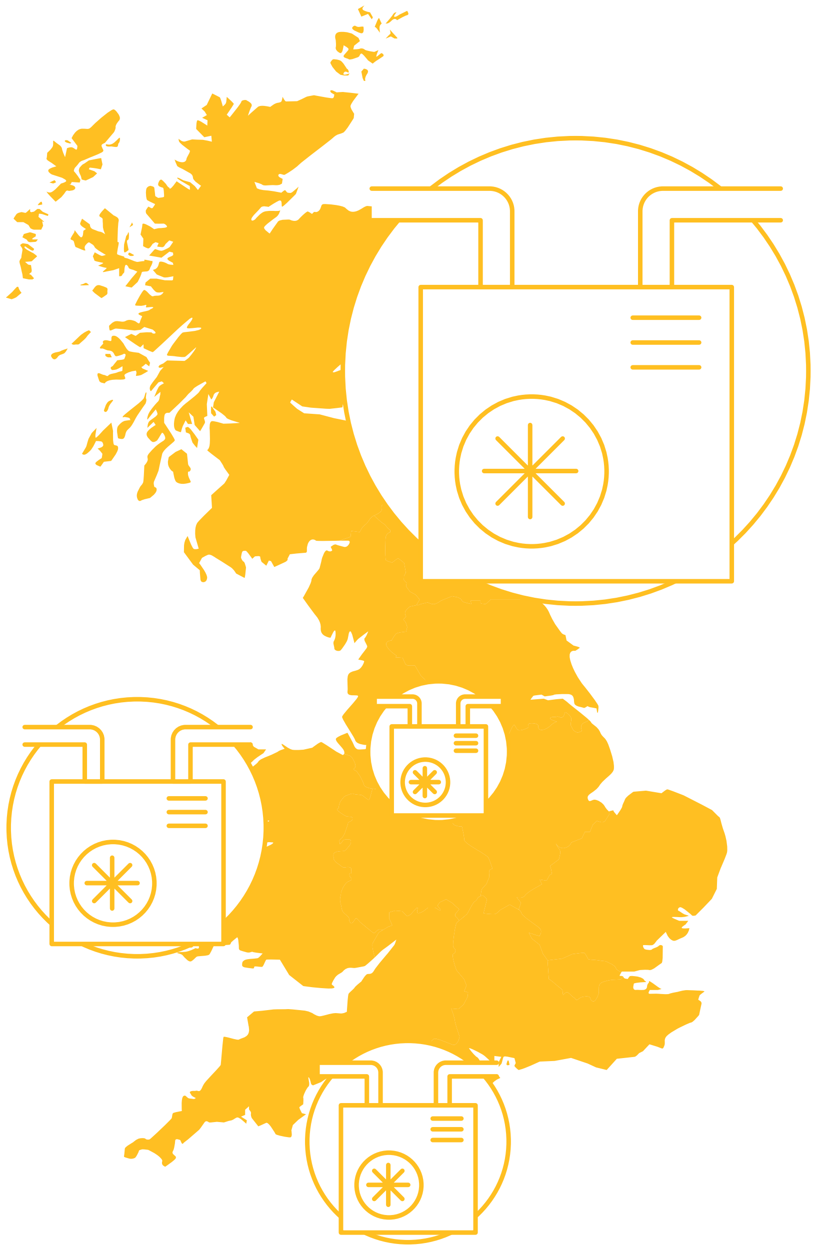
Regionalisation

Regionalisation will enhance FES to accelerate GB towards Net Zero, through greater granularity, broader engagement and more regional insights.

Regional scenarios mean we will work closely with the regional network companies and other regional stakeholders and adopt a more "bottom-up" approach on a regional basis (where it is relevant and material to do so), therefore improving our data and insights, allowing us to model spatial and temporal variations to a greater level of accuracy and comparability.

Last year we introduced our new spatial heat model which received good feedback and we have been able to update our regional assumptions to further improve the outputs.

This year we also made improvements to our regional assumptions in our transport model and we made better use of Distribution Network Operators' data to model embedded generation. We will continue to enhance our regional modelling and insights and more details on our plans can be found here.



FES 2022 / Introduction to the FES 31

Scenario collaboration between network companies

Regionalisation of FES will simplify and optimise the interface with the scenarios currently developed by gas and electricity network companies, such as the DFES, which we will be using to enrich future iterations of FES and further development of the regional breakdown of the GB scenarios.

Working collaboratively with stakeholders, National Grid ESO develops the FES scenario framework which is used as a common basis for the GB-level FES and the regional scenarios developed by other network companies. This allows for comparison of datasets for all network and system operators. Whilst a common scenario framework is used, regional variations in projections from local network companies mean that the summation of the regional forecasts may not have identical alignment to the GB FES forecast.

FES 2022 / Introduction to the FES 32

Net Zero

Introduction

Reaching Net Zero greenhouse gas emissions is now widely recognised as critical to the future of our society, with climate scientists emphasising the urgent need to rapidly reduce emissions.

In November 2021 the UK hosted COP26, the United Nations' annual global climate change summit, where the UK and many other countries made a series of pledges to reduce greenhouse gas emissions and limit global warming. Over the last 12 months the UK Government has also released a range of decarbonisation policy documents to facilitate the UK's own journey to Net Zero.

Net Zero will continue to heavily influence decisions made in the energy sector for many years to come. In this chapter, we explain what Net Zero is, examine the results of our FES modelling, and discuss what they mean for the consumer and the energy system.

Key insights:

- Leading the Way reaches **Net Zero by 2047** and achieves annual net negative emissions[1] of -30 Mt by 2050 (i.e. 30 Mt are removed from the atmosphere). Consumer Transformation and System Transformation reach Net Zero by 2050. These three scenarios also meet all carbon budgets, including the 6th Carbon Budget.

- Falling Short **doesn't get to Net Zero** by 2050, diverging from carbon budgets around 2025, resulting in 186 Mt of residual annual emissions by 2050.

- The heat and road transport sectors are largely decarbonised by 2050 across all scenarios except Falling Short. However, even for the Net Zero scenarios, some sectors such as waste and aviation do not reach zero emissions by 2050, so the energy sector, particularly the power sector, must reach net negative emissions to balance this out.

- The power sector gets to net negative emissions by 2033 in Leading the Way and Consumer Transformation, and by 2034 in System Transformation. This broadly aligns with the Government ambition to have a Net Zero power sector (subject to Security of Supply) by 2035.
This is a **prerequisite for fully decarbonising other sectors through electrification.**

- For sectors to reach net negative emissions, solutions which remove emissions from the atmosphere are required. Natural negative emission solutions (e.g. reforestation) feature, although in all scenarios engineering-based negative emission technologies play the largest role: Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS), with BECCS being the largest provider. Sustainability and carbon accounting must be considered when deploying BECCS.

- Consumers will need to be **supported and enabled** to accelerate the rate at which they adopt new, smarter technologies and change the way they use energy to reach Net Zero. Under some scenarios, a doubling or even trebling in uptake of some technologies is needed by 2035. At National Grid ESO we are continuing to develop our understanding in this area, such as through our 'Empowering Climate Action' research.

1 When more carbon is removed from the atmosphere than is emitted into the atmosphere, this is termed negative emissions. For more detail and examples of negative emission technologies see nationalgrideso.com/document/189846/download

Where are we now - the UK and climate change

The impact of climate change

Net Zero has become a well-known, if not fully understood, concept since the United Nations Climate Change Conference in 2015 in Paris, where an agreement was signed to limit global warming to under 2°C compared to pre-industrial levels. To do this, greenhouse gas emissions need to be at Net Zero by the second half of the 21st century. Signatories also agreed to pursue efforts to limit the temperature increase to 1.5°C. Net Zero is important because it is now well evidenced[2] that the increase in greenhouse gas emissions (most notably CO_2) due to human activity since the industrial revolution is linked to global temperature rise.

The **Intergovernmental Panel on Climate Change (IPCC)**, the United Nations (UN) body for assessing the science related to climate change, has stated that the planet has already warmed by 1.1 degrees and human-induced climate change is already affecting weather and climate extremes. The consequences of this have been felt across the planet in the form of fires, droughts, hurricanes and flooding. This first-hand experience is helping to focus the world's attention, with Net Zero commitments now covering over 80% of the world's GDP (Gross Domestic Product), up from 50% in FES 2021. However, more urgency is still required, as just this year the **IPCC confirmed** that to limit warming to 2°C rapid, deep and in most cases immediate emission reductions are required. Globally, urgent progress towards Net Zero must happen now and cannot wait until 2030 or beyond.

2 https://www.ipcc.ch/report/ar6/wg1/#SPM

FES 2022 / Net Zero 35

Where are we now - the UK and climate change

Net Zero

Net Zero is closely linked to the natural carbon cycle, which is the emission and absorption of carbon from animals and plants. Humans' use of fossil fuels and deforestation has upset this balance, so more carbon is emitted than absorbed. Net Zero acknowledges that we might not be able to stop all carbon and other Greenhouse Gas Emissions (GHGs); however, we can increase the amount being absorbed and stored (either naturally or artificially), so that overall the net greenhouse gas emissions are zero.

Greenhouse gas emissions

Net Zero requires an overall balance between all greenhouse gases released into and removed from the atmosphere. Greenhouse gases are most commonly recognised as the following seven gases: carbon dioxide (CO2), methane, nitrous oxide, and the fluorinated or F gases (hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride and nitrogen trifluoride).

2 https://www.ipcc.ch/report/ar6/wg1/#SPM

Where are we now - the UK and climate change

The Climate Change Committee (CCC) advises the UK and devolved governments on emissions targets, and reports to Parliament on progress in reducing greenhouse gas emissions. The CCC has shown that the UK has made significant progress in reducing emissions (Figure NZ.01), with the power sector responsible for much of this (Figure NZ.02). The 65% reduction in power sector emissions from 2009-2019 is largely due to the switch from coal towards renewables. To meet the 6th carbon budget, total emissions reduction is even harder: all non-power sectors must increase their emissions reduction from just 5 $MtCO_2e$ per year on average between 2009-2019 to around 17 $MtCO_2e$ per year from now until 2035. The power sector must also continue to decarbonise whilst meeting increasing demand. In the UK's Net Zero Strategy, published in October 2021, the Government committed to fully decarbonise the power sector (subject to Security of Supply (SoS)) by 2035.

Figure NZ.01 highlights a large drop in emissions in 2020 (a record annual drop of 13%). Figure NZ.02 shows this was mainly due to emission reductions in surface transport (19%), aviation (58%) and shipping (16%) during COVID-19 restrictions. However, much of the 2020 fall is likely to be temporary as restrictions are now removed, although that partly depends on the decarbonisation policies put in place going forward.

Prior to hosting COP26, the UK set its Nationally Determined Contribution (NDC), the limit for each country's carbon emissions, at a 68% reduction by 2030 (compared to 1990 levels). As well as setting one of the world's most ambitious NDCs, meeting the 6th carbon budget means a 78% reduction by 2035. This is aligned to the UK's 2050 Net Zero target and to the broader aim to keep global temperature rise below 1.5°C. The CCC has acknowledged that whilst the Net Zero strategy provides a strong foundation for delivering the target, it must proceed at pace, with credible policies in place by 2024, if these targets are to be met.

If the UK is to contribute to limiting global warming to as close to 1.5°C as possible by meeting Net Zero, we need to start implementing measures now, we can't wait until 2050 or even 2030. This is not only because the longer we wait the more Greenhouse Gasses (GHG) we emit, but also due to long lead times on many decarbonisation options. For example, fitting all houses with low-carbon heating, or switching all vehicles away from fossil fuels will take many years and require supporting infrastructure. This is a view shared with the CCC; in their 2022 "Progress Report to Parliament" a key message is that progress is lagging behind policy ambition, and greater emphasis should be placed on the delivery of the Net Zero Strategy.

During the build-up to COP26 the UK Government released a range of decarbonisation policy documents to support the UK's own journey to Net Zero and provide global leadership at COP26. Whilst some of these focused on decarbonising specific areas, several covered the whole system, highlighting the coordinated approach needed to reach Net Zero. Figure NZ.03 shows some of these documents and key policy publications that have come out since, including the recent British Energy Security Strategy. A brief description of each document is available when the relevant image is hovered over, whilst pages 71 and 177 show how some of the aims and policies in these documents are met in our scenarios.

FES 2022 / Net Zero 37

Where are we now - the UK and climate change

Carbon Budget

Carbon budgets set legally binding targets for cumulative greenhouse gas emissions over a ‘budget period’ for example the 6th carbon budget period is 2033-2037. The carbon budgets shown in Figure NZ.1 represent the average maximum annual emissions over a budget period required to meet the target.

MtCO_2e

Mega Tonnes of CO_2 Equivalent (MtCO_2e)
The equivalent of 1,000,000 tonnes of carbon dioxide, the standard unit for measuring national and international greenhouse gas emissions.

FES 2022 / Net Zero 38

Where are we now - the UK and climate change

Figure NZ.01: Historical emissions and carbon budgets

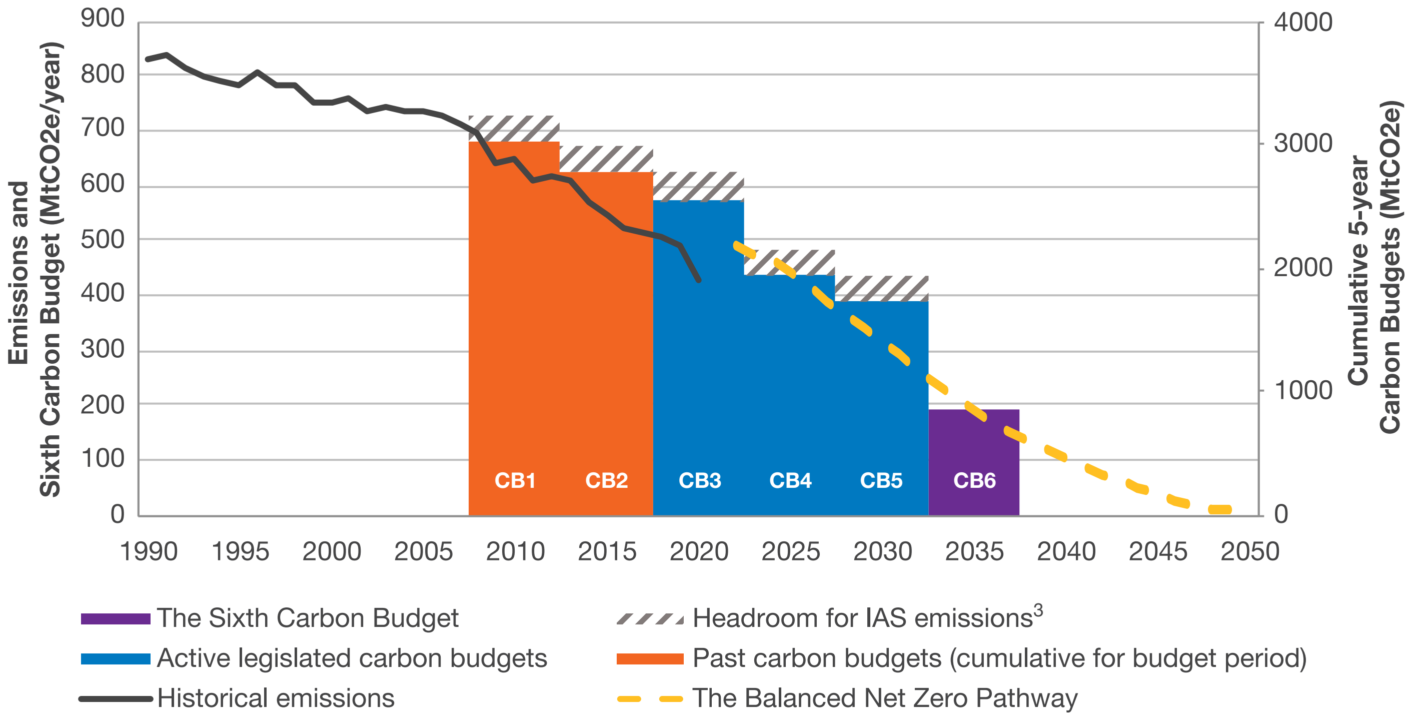
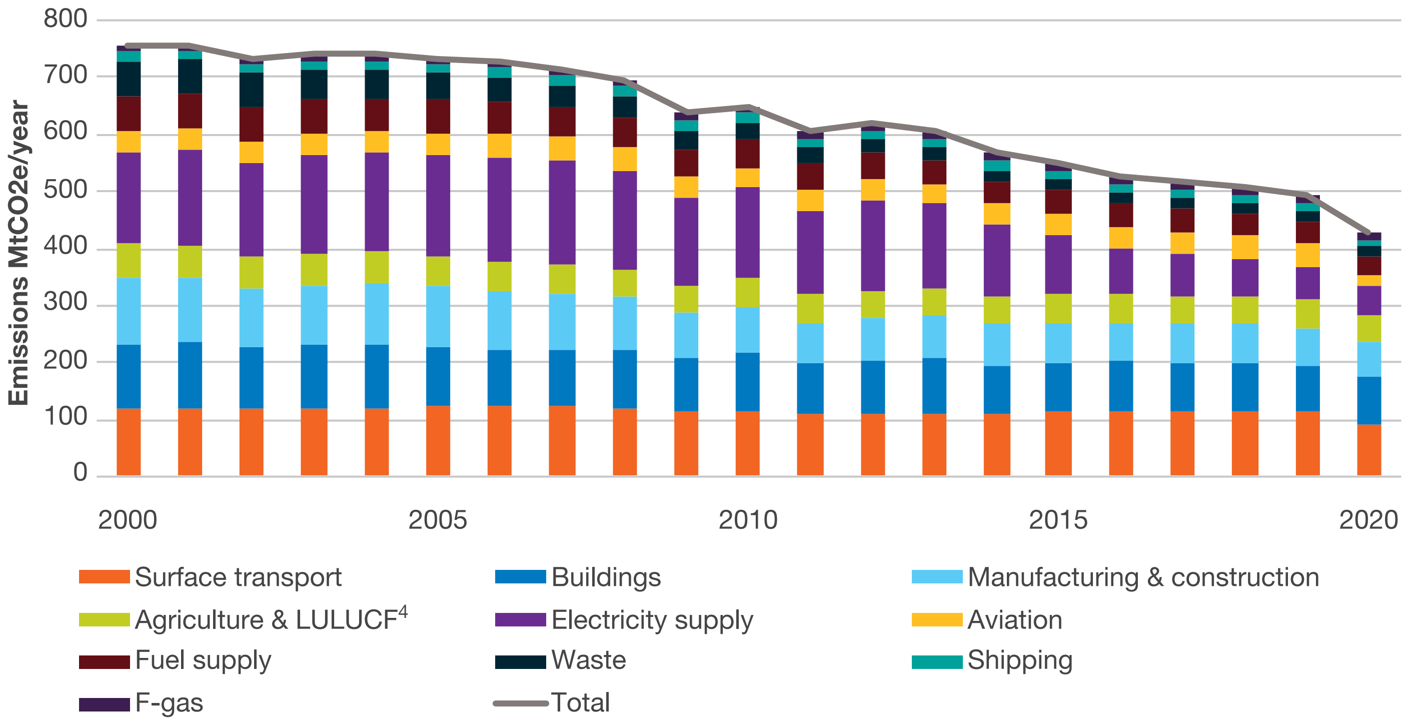


Figure NZ.02: Historical emissions by sector



Source: CCC 6th Carbon Budget - Charts and data in the report, theccc.org.uk/publication/sixth-carbon-budget/

Final UK greenhouse gas emissions national statistics: 1990 to 2020 - gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2020

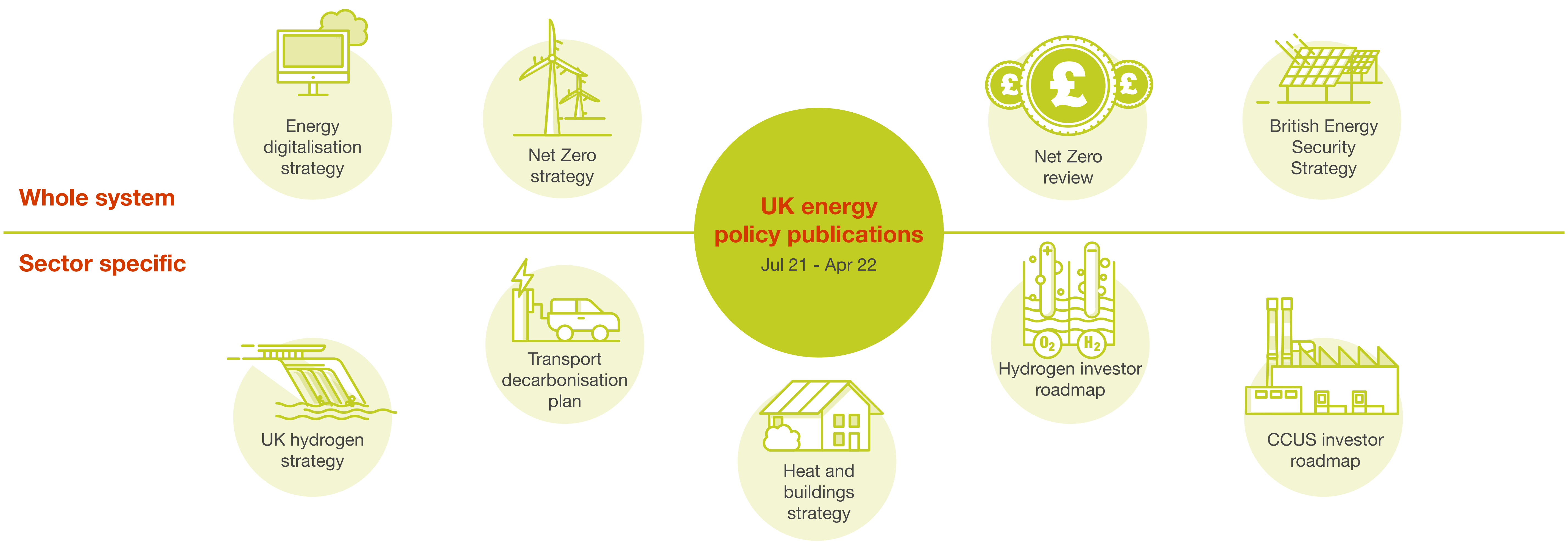
Source: Final UK greenhouse gas emissions national statistics: 1990 to 2020 gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2020

3 IAS emissions: International Aviation and Shipping emissions. Previous carbon budgets did not directly account for these emissions, instead allowing them headroom. For the 6th carbon budget these emissions have formally been included.
4 LULUCF represents emissions from Land Use, Land Use Change and Forestry.

FES 2022 / Net Zero 39

Where are we now - the UK and climate change

Figure NZ.03: Selected policy documents published over the last 12 months



FES 2022 / Net Zero 40

Where are we now - the UK and climate change

Energy digitalisation strategy

Sets out a vision and suite of policies to digitalise the energy system, which will enable millions of low carbon assets, including solar PV, Electric Vehicles (EVs) and heat pumps, to be optimised across our energy system.

Net Zero strategy

Sets out policies/proposals for decarbonising all sectors of the economy to meet Net Zero by 2050.

Net Zero review

Analysis of the economic effects of the low carbon transition.

British Energy Security Strategy

Sets out actions to ensure our energy is secure, clean and affordable in the long term. It sets more ambitious targets which exceed some from previous strategies (e.g. 50GW offshore wind by 2030 and 10GW of hydrogen production by 2030).

UK hydrogen strategy

Sets out the approach to developing a low-carbon hydrogen sector.

Transport decarbonisation plan

Sets out the Government's commitments and the actions needed to decarbonise the entire transport system.

Heat and buildings strategy

Sets out how the UK will decarbonise our homes and our commercial, industrial and public sector buildings.

Hydrogen investor roadmap

Summarises the Government policies to support the development of a thriving UK low-carbon hydrogen economy.

CCUS (Carbon Capture Utilisation & Storage) investor roadmap

Outlines key opportunities to invest in CCUS in the UK.

FES 2022 / Net Zero 41

Where are we now - the UK and climate change

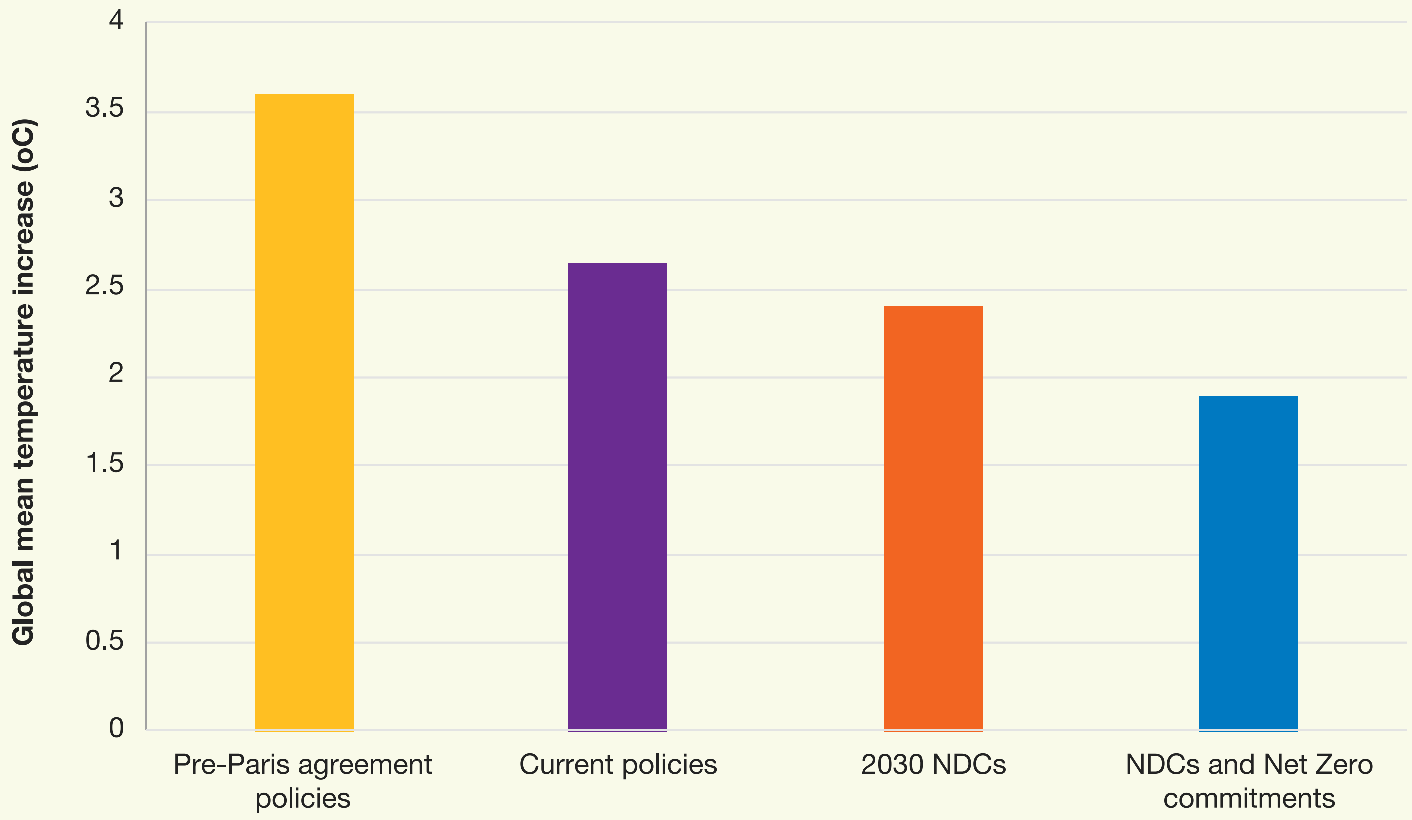
COP26 and beyond

In November 2021 the UK hosted COP26, the United Nations 26th annual global climate change summit, in Glasgow. COP26 was particularly important as it was the first opportunity since the 2015 Paris Agreement to strengthen countries' plans to reduce carbon emissions (NDCs) and keep 1.5ºC warming within reach.

Many countries, and consortiums of countries, made climate pledges, culminating in the Glasgow Climate Pact which consisted of several commitments. These include the phasedown of unabated coal power, the strengthening of emissions reduction plans by 2022 and increased finance for climate change adaptation.

This increase in ambition has led to a decrease in the expected global warming from approximately 2.7°C under current policies before COP26 to under 2°C (see Figure NZ.04), although this is dependent on all NDCs and Net Zero commitments being met, many of which are not yet legally binding. Whilst this is commendable progress, significant further work is required to ensure these commitments are not only met but also ratcheted up to limit warming to as close to 1.5°C as possible.

Figure NZ.04: Impact of global policies and commitments on expected global warming since the Paris Agreement[5]



5 Source: CCC, COP26: Key outcomes and next steps for the UK, https://www.theccc.org.uk/publication/cop26-key-outcomes-and-next-steps-for-the-uk/

FES 2022 / Net Zero 42

Where are we now – decarbonisation of the power sector

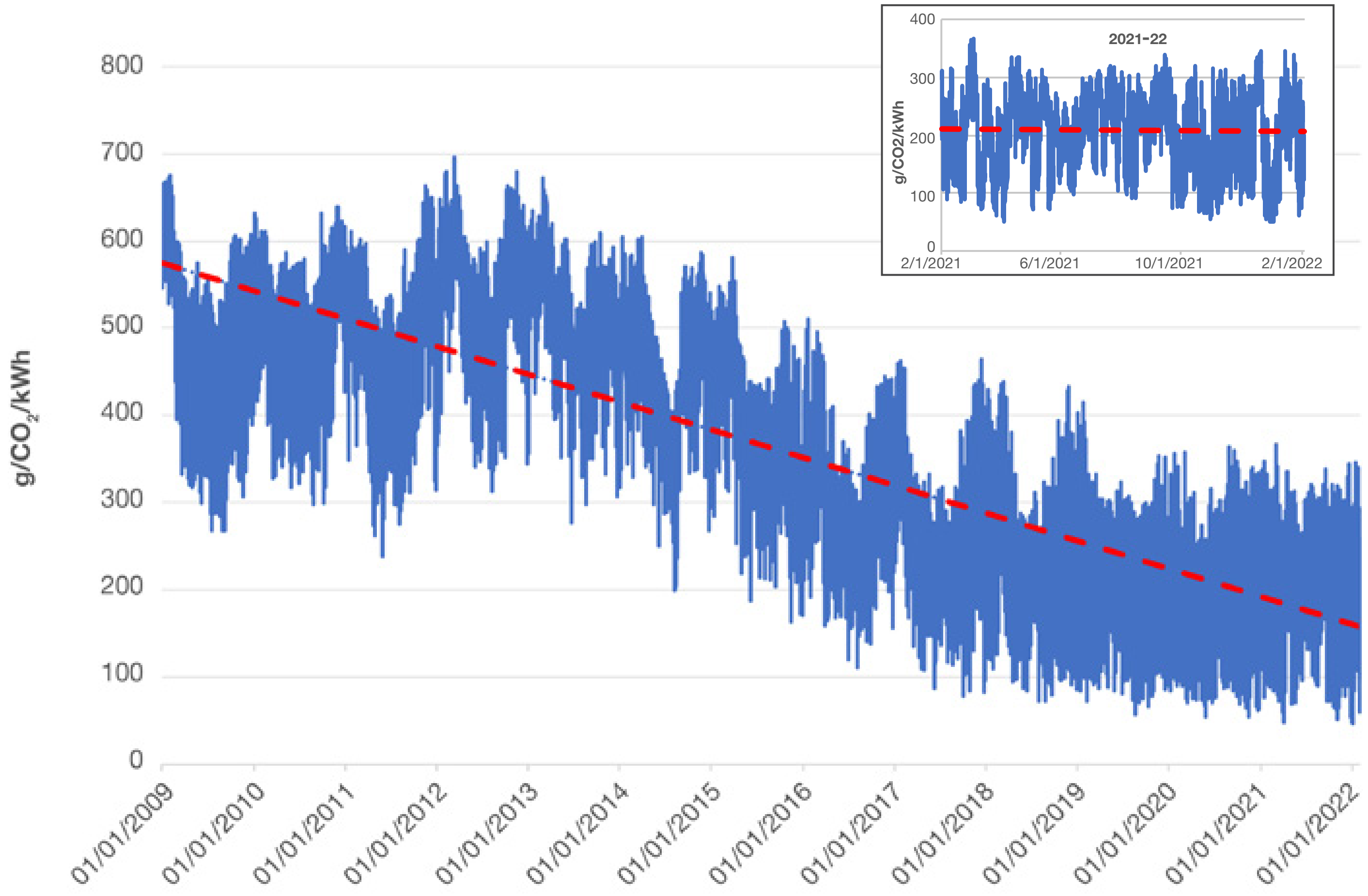
As already shown (Figure NZ.02) electricity supply has been responsible for much of the UK's decarbonisation to date. This has resulted in the average carbon intensity of the GB transmission system falling by over 60% from 2009 to the beginning of 2021 (Figure NZ.05), making it the fastest decarbonising electricity transmission system in the world. However, the increase in gas prices and closure of some nuclear plants has led to a slight increase in coal use over the last year which has resulted in emission intensity for the transmission system steadying. This is shown by the smaller chart in Figure NZ.05 which shows transmission system carbon intensity for 2021-22 only. This is temporary, with all coal generation still on course to be phased out by 2024. Although to continue to lower emissions from electricity supply and consequently the carbon intensity of the transmission system the UK needs to continue promoting low carbon generation options.

Decarbonising the UK's power sector is vital, not only to reduce its contribution to UK emissions but also from a whole energy system perspective. Many of our options for decarbonising other sectors involve electrifying them, for example heat pumps for domestic heating or Electric Vehicles (EVs) for transport, so a prerequisite of decarbonising these sectors is a low-carbon power sector.

The ESO has a key role to play in facilitating the continued decarbonisation of the power sector. We are already implementing future changes needed to ensure the electricity transmission system facilitates Net Zero as opposed to being a barrier. These include exploring energy market reforms and the development of new markets, a review of network planning processes, and innovation projects like our virtual energy system. These activities will create an environment where the latest technologies and the right supporting infrastructure can deliver a secure, low-carbon, reliable power system. For more information on our work to help reach Net Zero by 2050, and a decarbonised electricity system by 2035, click here.

We also cooperate globally to help deliver greener grids around the world.

Figure NZ.05: GB transmission system carbon intensity



Where are we now – decarbonisation of the power sector

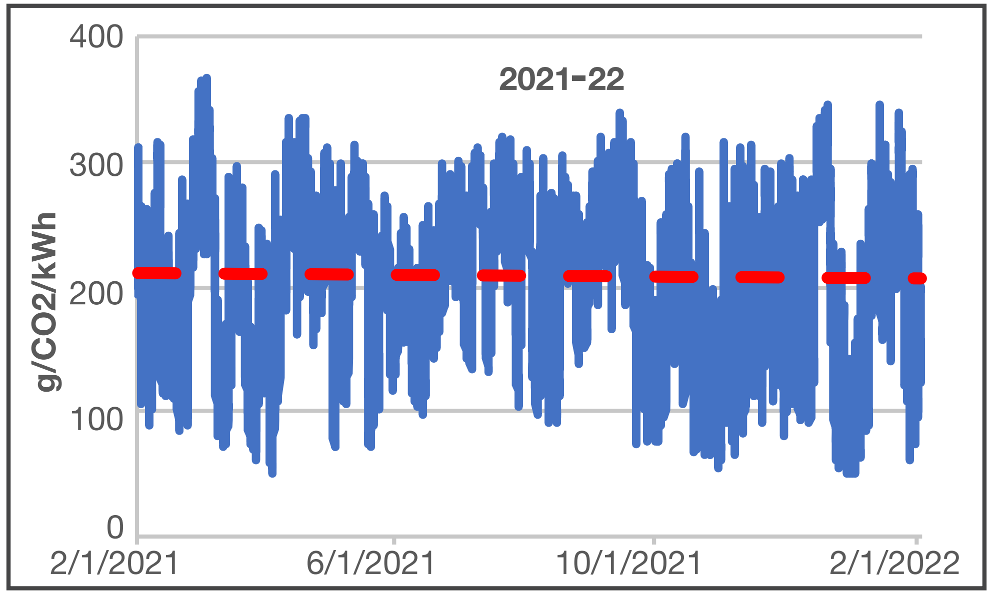
ESO Global networks

Tackling climate change requires international cooperation. Although focused on Great Britain, National Grid ESO is a leading member of many global energy organisations helping to deliver greener grids around the world such as:

Powering Past Coal Alliance (PPCA), a body advancing the transition from coal generation to clean energy. The PPCA is at the forefront of the global effort to deliver the Paris Agreement, helping to phase out coal-fired electricity and sharing best practice on zero carbon operation of electricity systems.

CIGRE (International Council on Large Electric Systems), a collaborative global community committed to developing and sharing power system expertise. As a member of the CIGRE community, we are encouraging knowledge-sharing among power system professionals globally to enable the sustainable provision of electricity for all.

The Global Power System Transformation Consortium (G-PST), a body to discuss the challenges of rapidly transforming power systems to low carbon. We are a leading member of the group, helping to deliver the technical collaboration, peer learning and advanced engineering solutions needed to assist global power systems transitioning to low carbon.



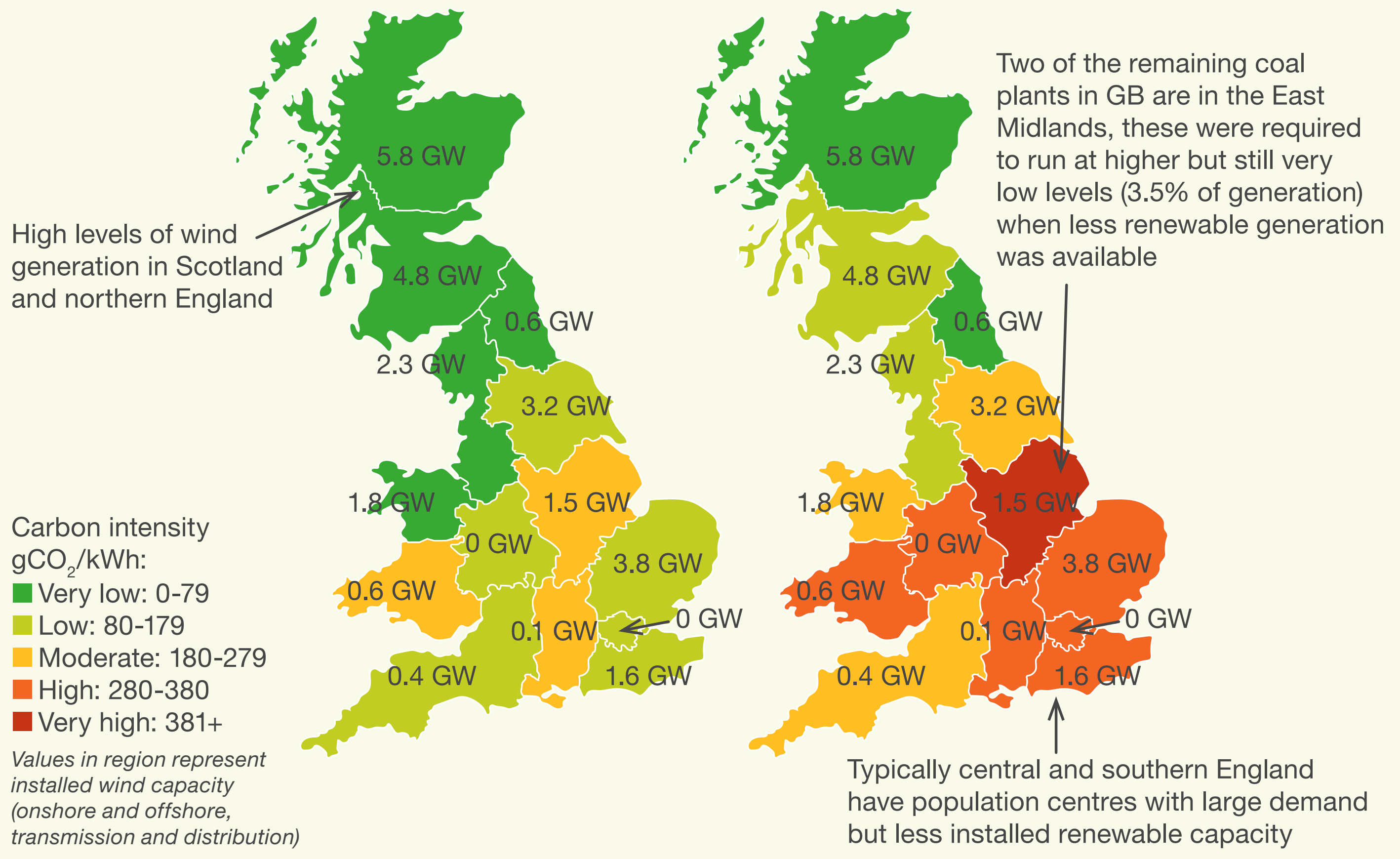
Regional carbon intensity

While average carbon intensity for the whole network shown in Figure NZ.05 is useful to track progress, it hides regional variation. Each region has different levels of renewable resources as well as different domestic, industrial and commercial demands. If we are to decarbonise the entire UK power sector and wider economy, understanding the impact of these differences is critical. They have already contributed to national policy differences with Scotland, which has high levels of wind capacity relative to its demand, setting a target to reach Net Zero by 2045, whilst the other home nations are aiming for 2050.

Figure NZ.06 shows wind capacity per region alongside regional carbon intensity on the transmission network for two days this winter, a higher wind generation day (8 February 2022) and a lower one (14 January 2022). On both days there is clear regional variation, with Scotland generally having lower carbon intensity than English and Welsh regions, due to the high levels of renewable capacity (wind and hydro) in Scotland compared to its relatively small population density.

This is further highlighted when we compare the two days. On the higher wind generation day low carbon energy provided 68% of total generation, with 44% of the total coming from wind energy. This led to a relatively low average daily carbon intensity of 125g/CO_2/kWh, with power broadly flowing from the north to the south as wind energy from Scotland flowed across the border. On windy days such as these, network constraints can occur where more electricity than the network can permit is trying to flow, typically around the Scottish border and north England. This occurred for a few hours on the higher wind generation day and can impact carbon intensity as wind energy has to be replaced with less clean alternatives.

Figure NZ.06: Carbon intensity of UK electricity transmission system (gCO_2/kWh) and wind generation capacity (GW) per region: left; higher wind generation day, right; lower wind generation day



FES 2022 / Net Zero 45

Regional carbon intensity

On the lower wind generation day low carbon energy only provided 33% of total generation with 7% from wind energy. This resulted in higher carbon intensities in all regions, with central and southern England having the highest intensities. The East Midlands has two of GB's remaining coal stations which operated more on this day. These regions broadly have less renewable capacity compared to demand, and low renewable generation on this day meant low carbon intensity power was not flowing from Scotland. The higher carbon intensity in each region led to a much higher average daily carbon intensity of 279g/CO_2/kWh.

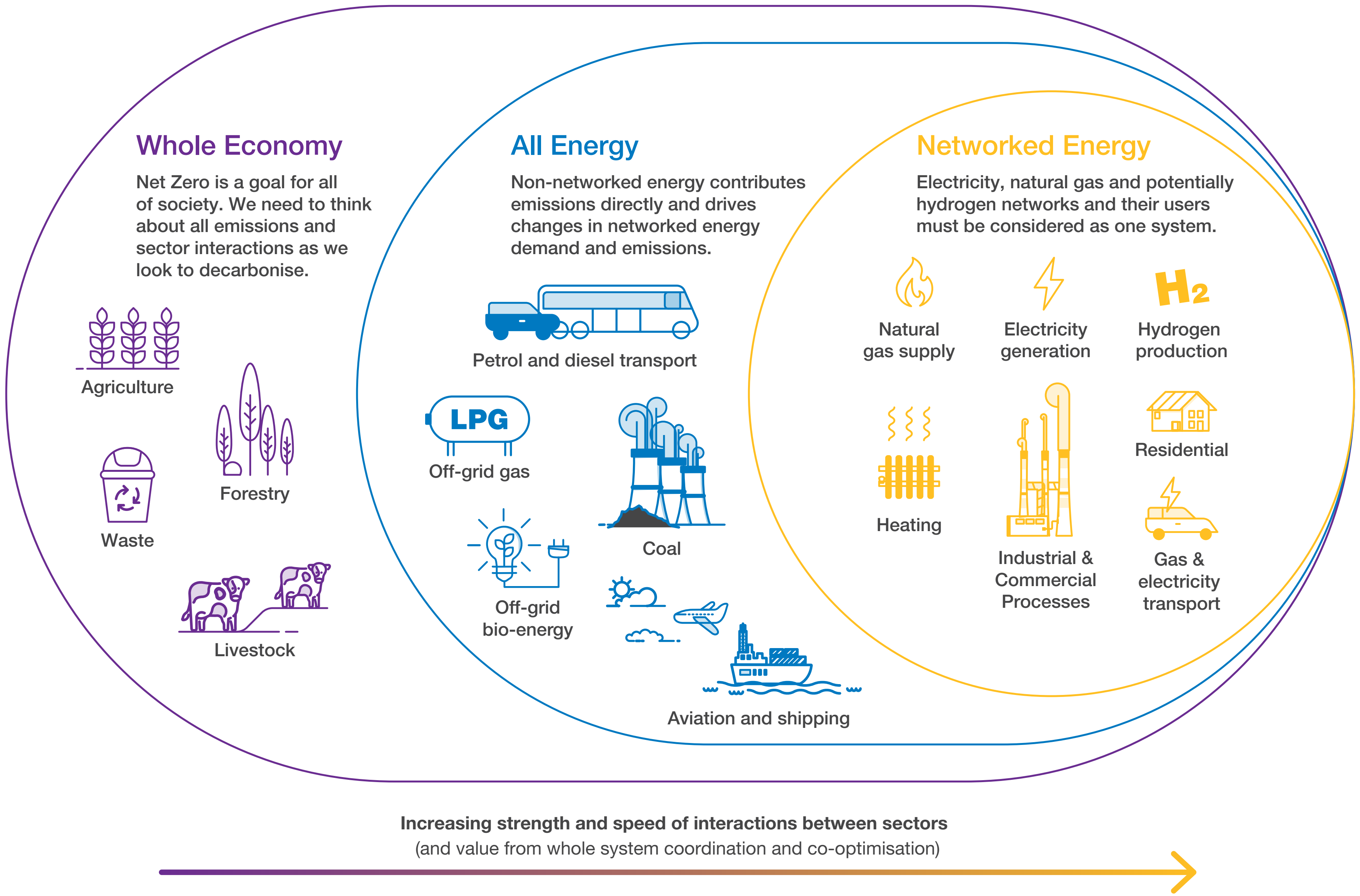
This highlights the impact of daily variation in renewable generation on the carbon intensity of individual regions. But it also shows how future electricity supply assumptions in FES could impact emissions on a regional scale. For example, large single nuclear plants could have a significant impact on the carbon intensity of individual regions, while increased concentration of renewable generation in specific regions could also have an effect. FES will continue to become more regionalised to help understand the impacts of these assumptions; see here for more detail.

FES 2022 / Net Zero 46

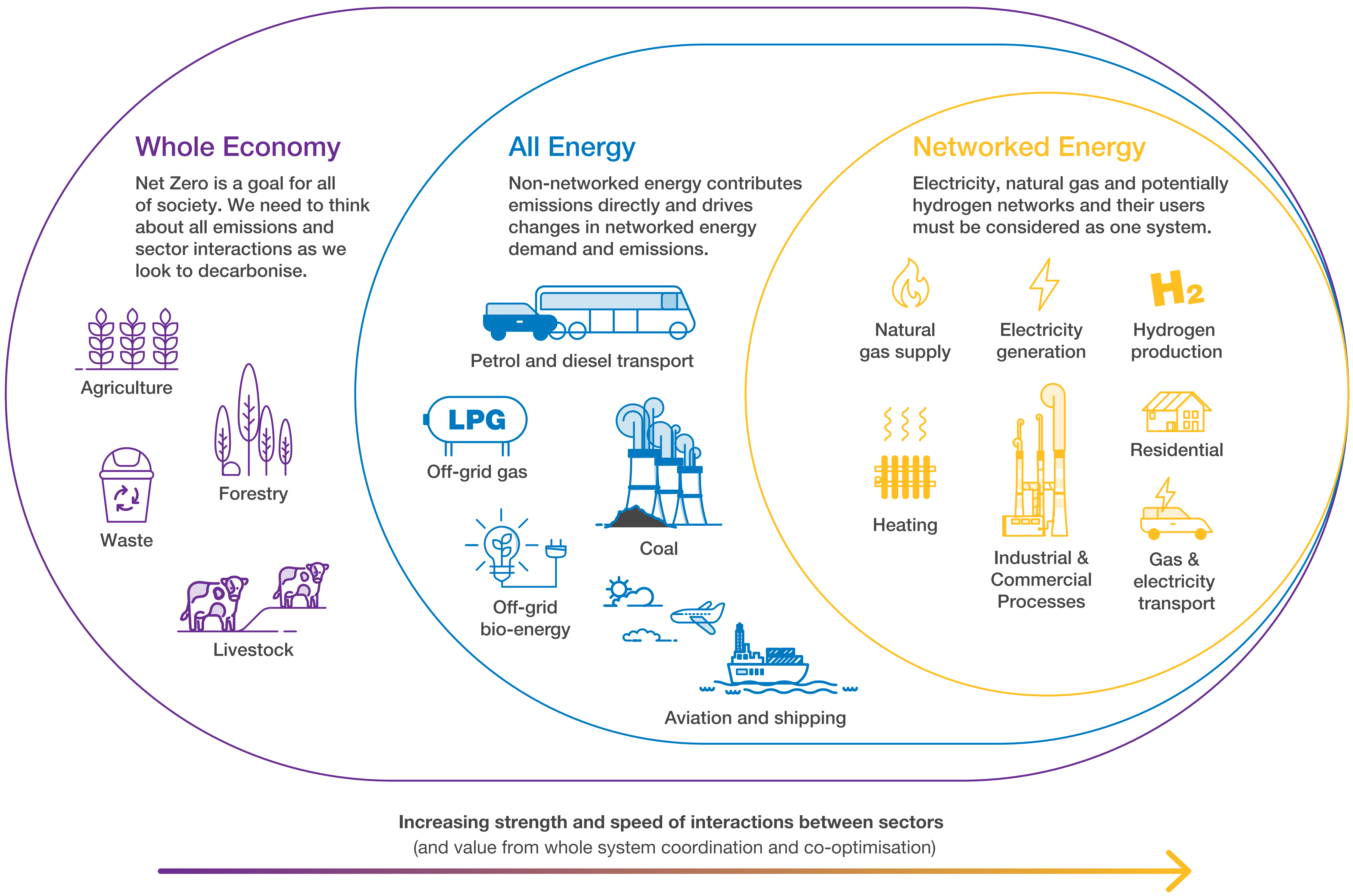
Where are we now - scenario assumptions

Our FES analysis directly models the UK energy sector, but other sectors (for example aviation, maritime and agriculture) emit greenhouse gases, so a whole economy view is needed when assessing Net Zero (see Figure NZ.07). For these other sectors, we've used the CCC pathways in their **6th Carbon Budget Analysis** as our basis. These sectors are typically those in the whole economy circle of Figure NZ.07, but include shipping and aviation in the all energy circle as shown below.

Figure NZ.07: Whole System Interactions



FES 2022 / Net Zero 47



FES 2022 / Net Zero 48

Where are we now?

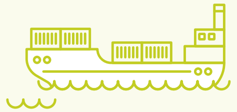
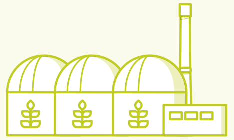
Table 1 shows some of the key areas where we've used CCC data and the assumptions we've made. For System Transformation and Consumer Transformation, we have generally followed the CCC's Balanced Pathway and for Leading the Way, we have largely used Widespread Innovation. Where we have differed from these assumptions it is noted in Table 1.

Away from non-energy sectors, one other key assumption in FES relating to Net Zero is around interconnectors. We model interconnectors directly in FES, and we follow international carbon accounting rules where emissions are accounted to the country that generates them. So, any electricity which is imported to the UK via interconnectors is assumed to be zero carbon from a UK perspective.

Ammonia

Hydrogen reacts with nitrogen, producing ammonia which can be transported as a liquid at far less extreme pressure and temperature than hydrogen. It is less costly to transport since ammonia stores almost twice as much energy per unit as liquid hydrogen. This, alongside the fact that is emits no carbon and has a much higher energy density than batteries, make it an option for powering ships, although care must be taken as it is a toxic substance.

Table 1: Assumptions taken from CCC[6]

	System Transformation and Consumer Transformation (based on CCC Balanced Pathway)	**Leading the Way (based on CCC Widespread Innovation)**
Aviation 	• 41% emissions reduction (compared to 2018) due to slower demand growth (only 25% increase compared to forecast 65%), improvements in aircraft efficiency and a modest share of sustainable aviation fuels at 25%	• 63% reduction in emissions despite 50% increase in demand (both compared to 2018) • Achieved through 25% carbon neutral synthetic jet fuel, 25% biofuels and efficiency improvements for planes
Shipping 	• Emissions reduce to close to zero by 2050 using zero carbon fuels • 87% of the emissions savings come from using ammonia • Remaining reductions come from electrification	• Widespread adoption of low carbon fuels over the 2030s, so that by 2040 shipping is at practically zero emissions • System Transformation followed the Widespread Innovation pathway for Shipping
Agriculture 	• 35% reduction in emissions from agriculture by 2050 (compared to 2018) • By 2050, reduction by a third for weekly meat consumption and 20% reduction for dairy	• 55% reduction in emissions from agriculture by 2050 (compared to 2018) • By 2050, 50% less meat and dairy, with 30% of meat coming from lab-grown sources
Land Use 	• 50,000 hectares of trees planted annually by 2035 • 79% of peat land restored • 700,000 of perennial energy crops by 2050	• 70,000 hectares of trees planted annually by 2035 • All peatland restored by 2045 • 1.4m hectares of energy crops by 2050
Waste 	• All Net Zero scenarios follow the Widespread innovation pathway • 51% fall in edible food waste by 2030 and 61% by 2050 (compared to 2007)	• 50% fall in inedible food waste by 2050 and more widespread wastewater treatment improvement • Emissions fall just over 75% from today's levels by 2050

6 As Falling Short does not reach Net Zero, CCC pathway assumptions were not used. Instead we assumed slower rates of emission reductions in line with the wider scenario narrative that Falling Short represents the credible slowest decarbonisation.

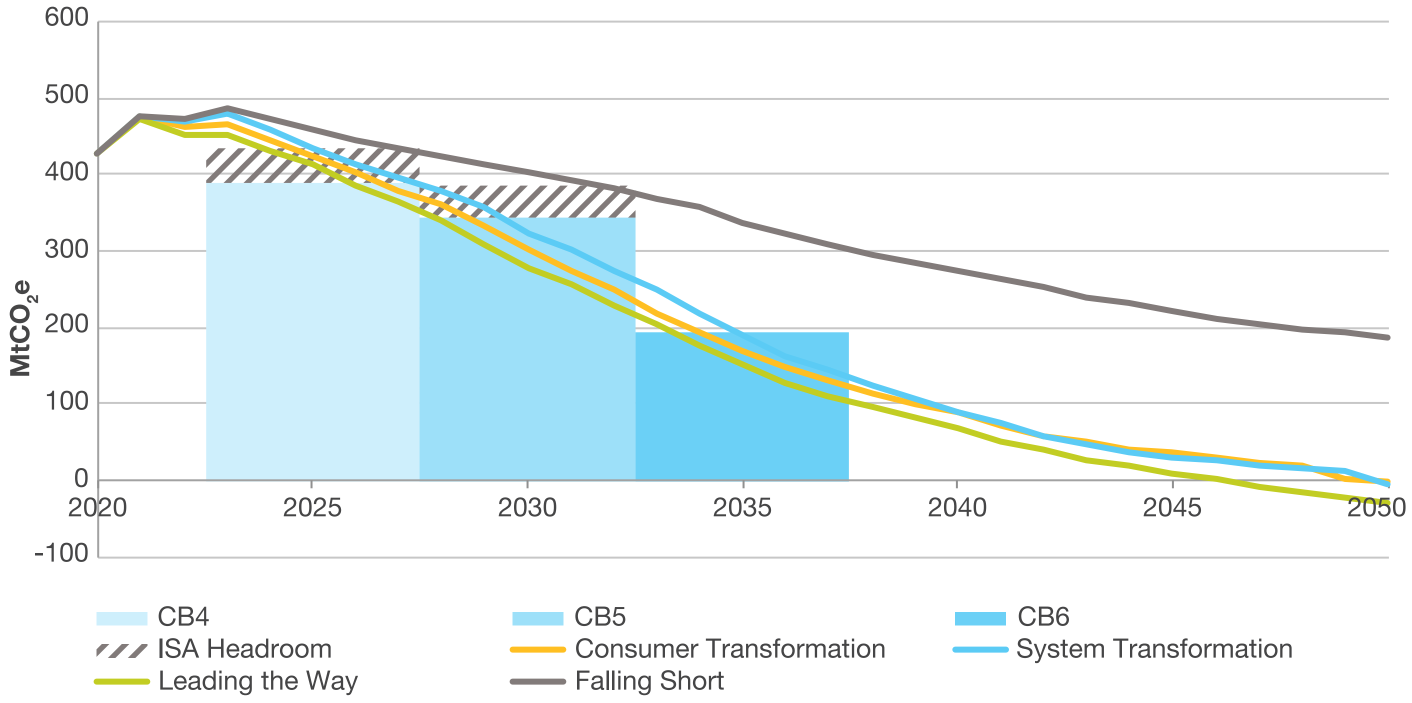
FES 2022 / Net Zero 49

Summary

Leading the Way, System Transformation and Consumer Transformation all meet Net Zero by 2050 (Figure NZ.08). Leading the Way reaches Net Zero by 2047 and achieves annual net emissions of -30 Mt by 2050, a removal of 30 Mt of GHG emissions from the atmosphere annually. To put this into context, total UK emissions in 2020 were 426 $MtCO_2e$; (including international aviation and shipping emissions), in the same year the UK power sector emitted 50 $MtCO_2e$ whilst surface transport emitted 91 $MtCO_2e$. System Transformation and Consumer Transformation also meet Net Zero by 2050 but achieve lower net negative emissions (i.e. they meet the target with less emissions to spare) of -3.7 $MtCO_2e$ and -0.4 $MtCO_2e$ respectively.

Into the 2030s and then on to 2050 all three scenarios which meet Net Zero also meet all carbon budgets (4th, 5th and 6th) when international aviation and shipping are included. This is a change from FES 2021 where System Transformation narrowly missed the 6th carbon budget and reflects the need to ensure there is urgent decarbonisation action in all Net Zero scenarios. Falling Short has substantially higher emissions than Net Zero, at 186 $MtCO_2e$ by 2050, having diverged from the trajectory to meet Net Zero around 2025. However even for Falling Short, the net emission reduction by 2050 is higher than in FES 2021, and results in an almost 80% reduction from 1990 levels. This was the UK's emission target prior to Net Zero being legislated in 2019 and highlights how decarbonisation ambition has progressed in recent years.

Figure NZ.08: Total net greenhouse gas emissions (including carbon budgets)



International aviation and shipping

Previous carbon budgets did not directly account for international aviation and shipping emissions; instead allowing them headroom. For the sixth carbon budget, these emissions have been formally included.

FES 2022 / Net Zero 50

Scenario breakdown

Figure NZ.09 shows decarbonisation by sector for each scenario out to 2050. Although System Transformation and Consumer Transformation both reach Net Zero by 2050, they get there in different ways. System Transformation uses more hydrogen, including for heating, as well as BECCS for hydrogen production. Consumer Transformation mainly electrifies demand and has more negative emissions from BECCS for power. There are also different levels of societal change, with Consumer Transformation assuming higher levels, although it is required to some extent in both scenarios.

Leading the Way, which gets to Net Zero soonest, combines electrification and hydrogen to decarbonise demand, and sees hydrogen produced mainly from electrolysis with only a small contribution from methane reformation combined with CCUS unlike System Transformation (see here for more information on these technologies). It also assumes some DACCS, as well as the highest levels of societal change.

Falling Short has the slowest credible level of decarbonisation. Based on current policy the power sector still reaches Net Zero but not until 2046, much later than the other scenarios. This is partly due to some continued reliance on unbated gas generation, and the slowest deployment of BECCS for the power sector. Road transport decarbonises almost to zero by 2050 but again is slower than other scenarios with the ban on the sale of new petrol/diesel cars not happening until 2040. Out to 2050, residential and industrial heat as well as non-energy sectors decarbonise significantly less than in the other scenarios.

Electrolysis

The process of using electricity to split water into hydrogen and oxygen.

Methane Reformation

A method for producing hydrogen, ammonia, or other useful products from hydrocarbon fuels such as natural gas.

FES 2022 / Net Zero 51

What we've found

Figure NZ.09: GHG emissions by sector Consumer Transformation

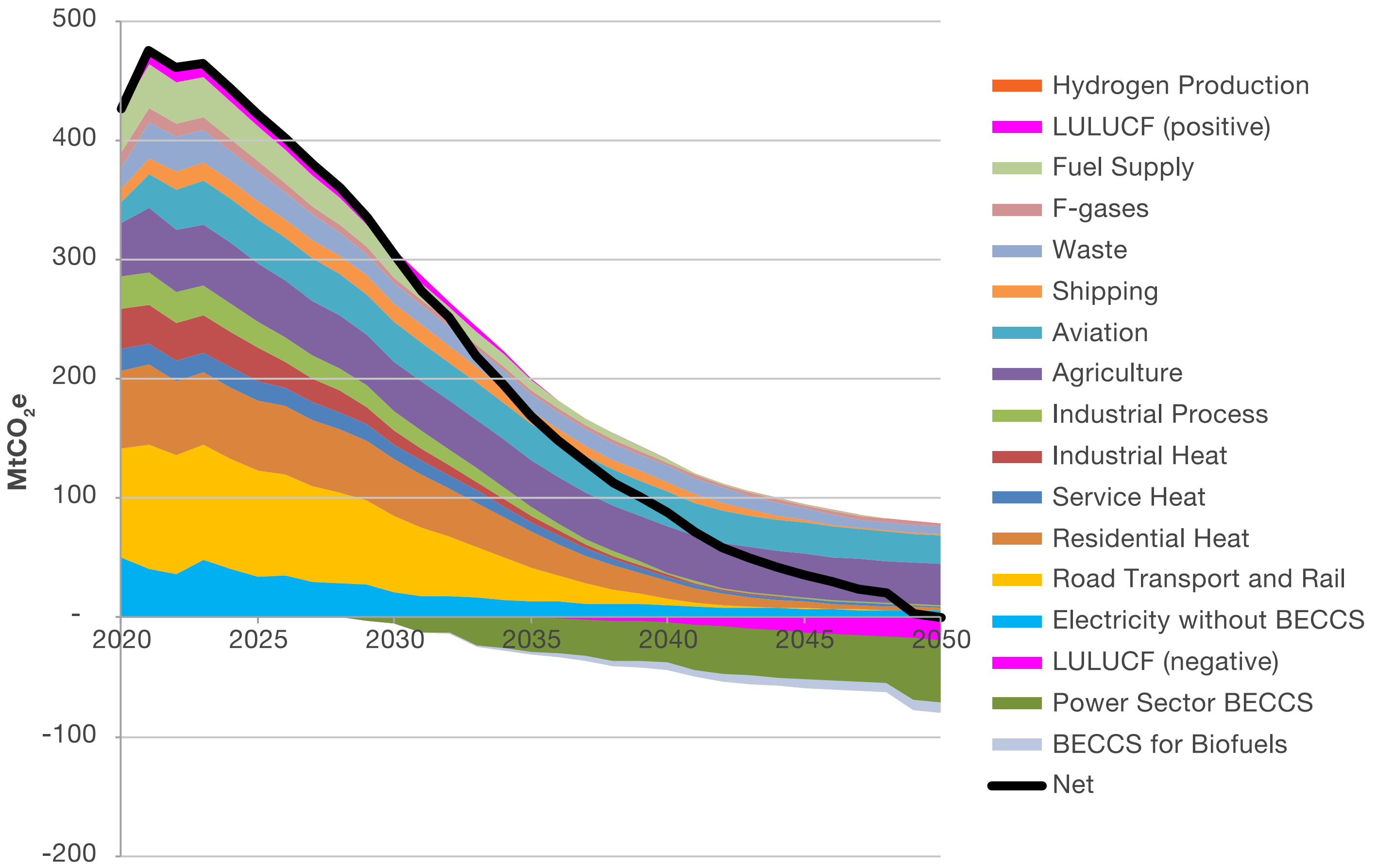
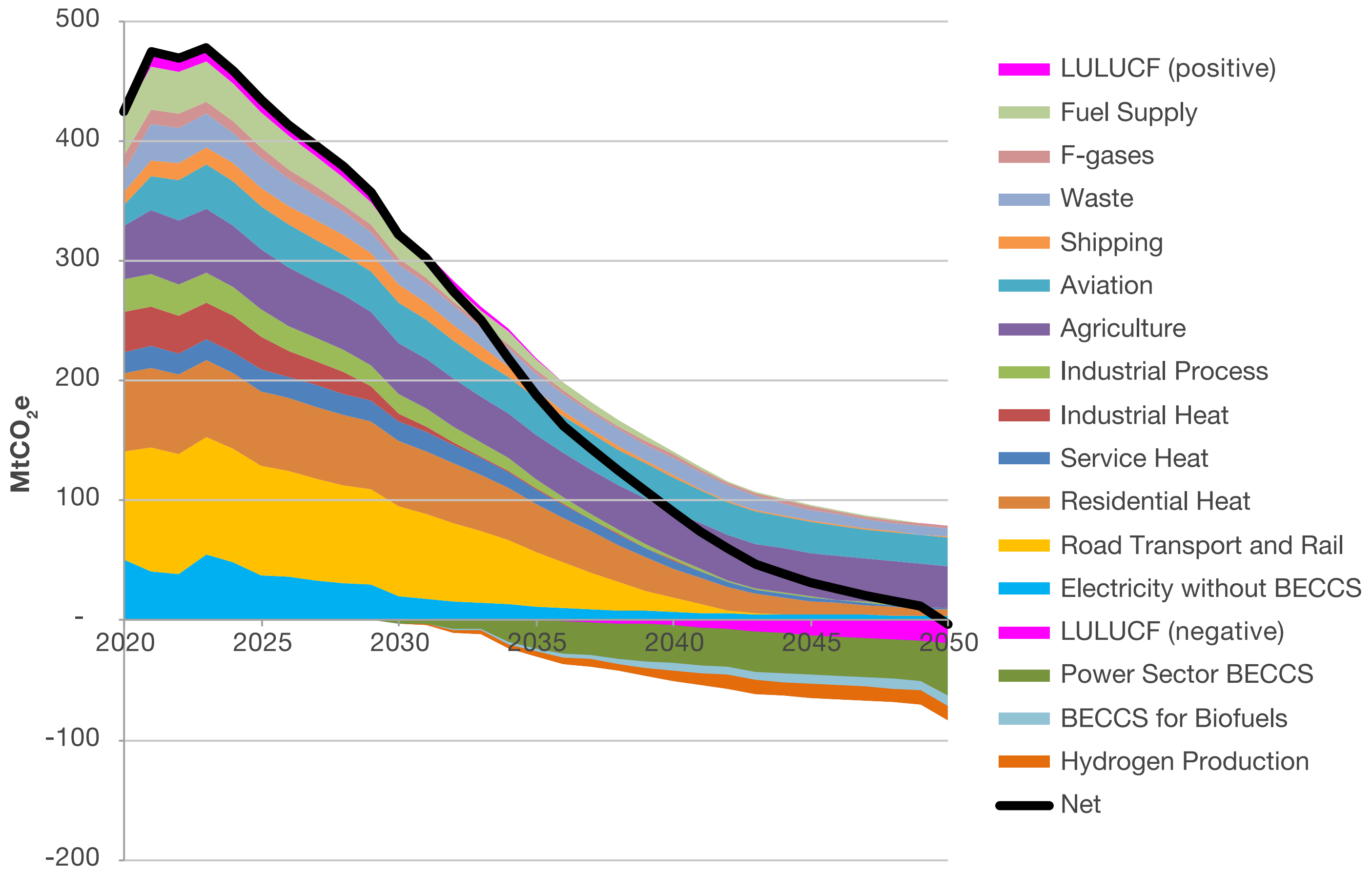


Figure NZ.09: GHG emissions by sector System Transformation



FES 2022 / Net Zero 52

What we've found

Figure NZ.09: GHG emissions by sector Leading the Way

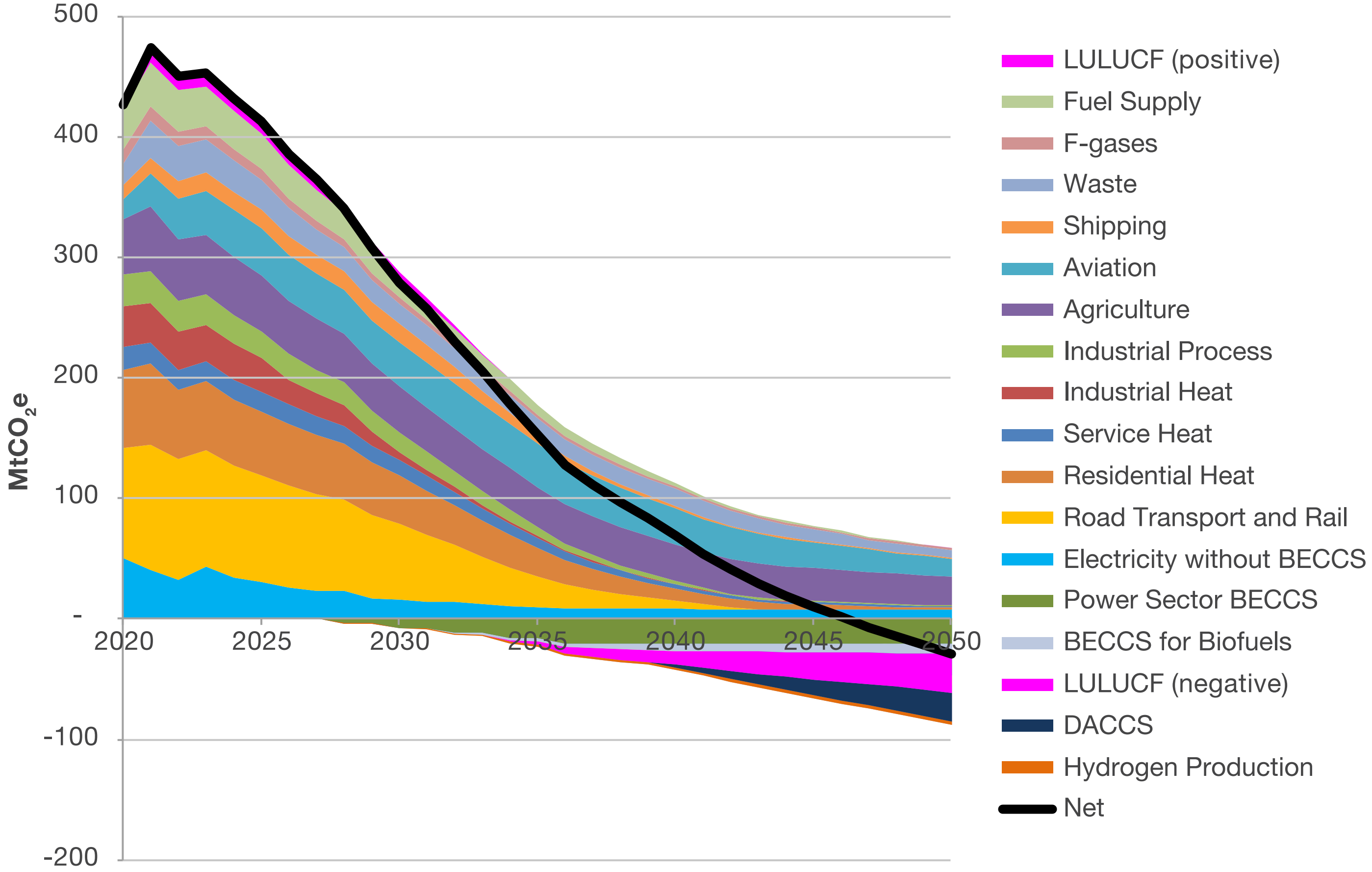
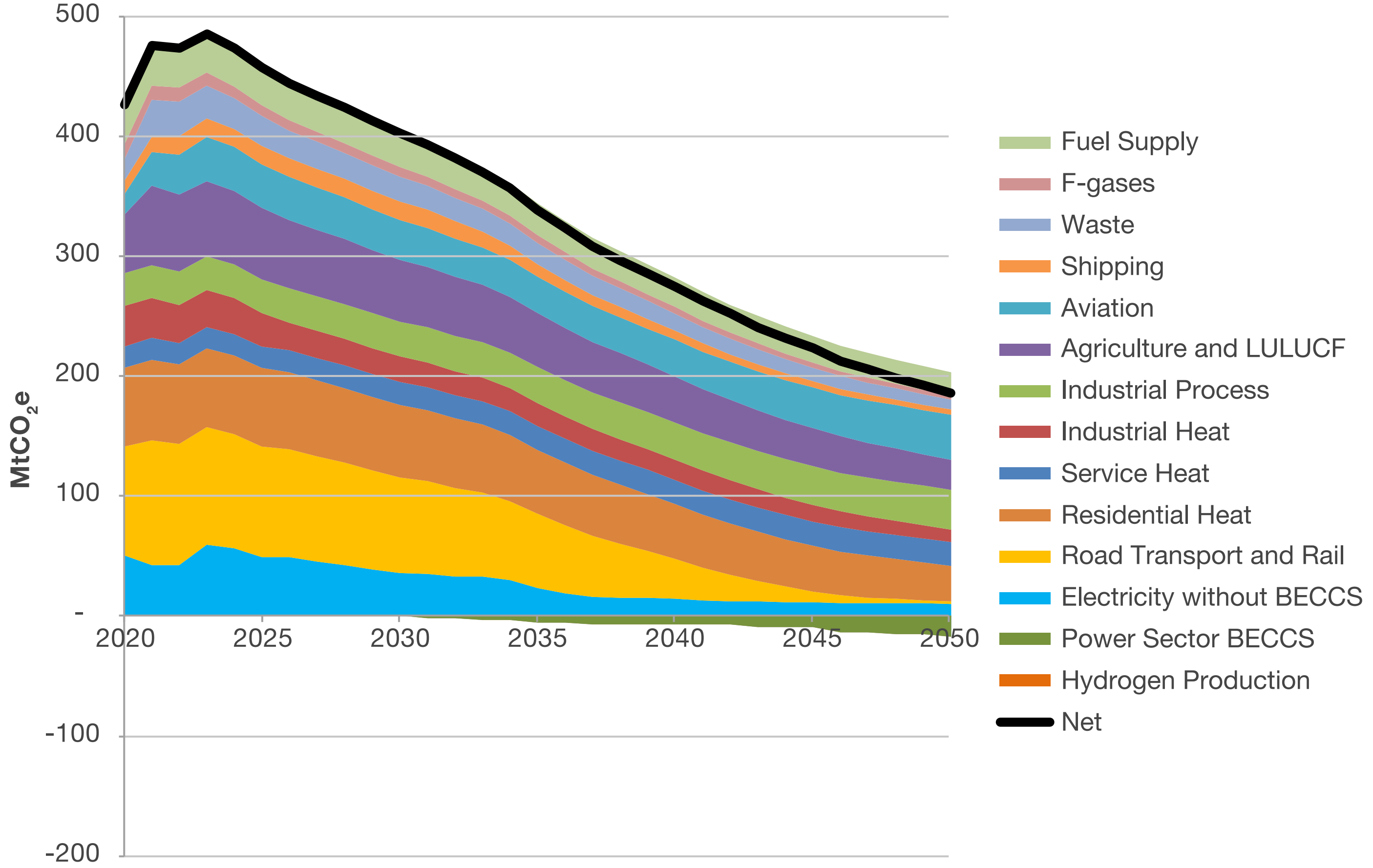


Figure NZ.09: GHG emissions by sector Falling Short



FES 2022 / Net Zero 53

What we've found

By 2035 all scenarios excluding Falling Short have Net Zero power sectors broadly aligned to the Government target to decarbonise the power sector by 2035.

Leading the Way and Consumer Transformation achieve this in 2033 followed by System Transformation in 2034. By 2035 the power sector in each of these three scenarios is producing between 9 and 14 $MtCO_2e$ before BECCS is factored in and they are then reliant on the negative emissions from BECCS to get to Net Zero.

For these three scenarios all other sectors have begun to decarbonise by 2035 at the latest, although to varying extents. The ban on the sale of new petrol/diesel cars by 2030 (even though it is not fully reached until 2035 in System Transformation) and an ongoing roll-out of low carbon heating technologies leads to significant decarbonisation in road transport and residential heat by 2035, although further decarbonisation is still needed out to 2050. While it has still made significant inroads by 2035, residential heating decarbonisation in System Transformation does lag slightly behind Leading the Way and Consumer Transformation as the hydrogen boiler roll-out in this scenario must wait for the development of a hydrogen network.

Across all Net Zero scenarios, many of the most difficult sectors to decarbonise are those not directly modelled by FES. They mostly relate to non-energy emissions such as agriculture, shipping and aviation, waste and land use. Here, most technical options for reducing emissions are at an early stage and face considerable challenges. The CCC's 6th carbon budget pathways reduced emissions using methods including technical innovation (e.g. development of low-carbon fuels), policy decisions (e.g. increased tree planting and peatland restoration) and further changes to individuals' behaviours (e.g. reduction in meat and dairy consumption, reduction in food waste and reduction in flights compared to business as usual).

The assumptions on emission reductions in those sectors not directly modelled by FES are detailed here. For Leading the Way these assumptions are based on more ambitious yet still credible assumptions from the CCC and assume higher levels of societal change. These represent an increased ambition on the assumptions for System Transformation and Consumer Transformation.

For Consumer Transformation and System Transformation, emissions from non-energy sectors reduce by around 80% from 2021 to 2050 with around 50 Mt remaining. The quicker and increased decarbonisation in Leading the Way is partly due to a slightly earlier transition to decarbonised domestic heat. However, most additional emission reductions in this scenario are from land use changes (see overleaf), leaving only 17 Mt of net emissions from non-energy sectors remaining by 2050, mainly across the agriculture, aviation and waste sectors.

For these emissions to reduce as modelled in Consumer Transformation and System Transformation, extensive policy support will be required to facilitate the innovation and lifestyle changes needed to decarbonise these difficult to change non-energy sectors. All of us will need to make changes to our lifestyle. Achieving the non-energy emission reductions under Leading the Way will require a doubling of these efforts. Despite this support, many of the non-energy sectors do not reach zero emissions by 2050 in any scenario, even in Leading the Way with its additional changes. It will need negative emissions in other sectors, using technologies which extract CO_2 from the atmosphere such as BECCS and DACCS, in addition to changes to land use, such as increased forestation.

FES 2022 / Net Zero 54

Negative emissions

Table 2: Negative emissions ($MtCO_2e$)

	2035			2050		
	CT	ST	LW	CT	ST	LW
BECCS for power	28	23	17	52	44	21
BECCS for hydrogen	0	5	2	0	12	3
BECCS for bioenergy	3	3	3	8	8	8
DACCS	0	0	0	0	0	24
LULUCF	0	0	3	19	19	32
Total	**31**	**31**	**25**	**79**	**83**	**88**

Table 2 shows the negative emissions for each Net Zero scenario in 2035 and 2050 while Figure NZ.10 shows the pathway of negative emissions from 2020 to 2050. In 2035 most negative emissions are due to BECCS for power while total negative emissions increase as we approach 2050 and more sectors contribute. By 2050, Leading the Way has the greatest negative emissions.

Table 2 highlights the importance of BECCS, which is responsible for the significant proportions of negative emissions across all scenarios in both 2035 and 2050. However, there are important considerations around the scale of deployment of bioenergy. These are discussed in more detail in the dedicated Bioenergy section and include the sustainability of feedstocks, land use trade-offs, and how carbon is captured and accounted for.

Due to these considerations, less BECCS was deployed in Leading the Way than the other two Net Zero scenarios, with more negative emissions coming from Land Use, Land Use-Change and Forestry (LULUCF), which reflects the greater societal change and faster decarbonisation in this scenario. Despite this, Leading the Way still relies on BECCS, mainly for the power sector, for over 30% of its negative emissions by 2050. LULUCF provides most of the remaining negative emissions with DACCS also making a material contribution.

The UK Government, CCC and IPCC all see BECCS playing a role in future energy systems, and it is included in our FES analysis, although we assume, on average, lower negative emissions from BECCS than the CCC. Under the Net Zero scenarios in FES, reliance on BECCS poses a potential risk to meeting Net Zero if associated issues are not managed and limit its deployment. In this case further use of DACCS and LULUCF, or greater societal change to reduce emissions in the first instance, would need to be considered. We do not expect deployment of BECCS to be limited; however, we will continue to review the latest evidence relating to bioenergy and update our scenarios accordingly.

FES 2022 / Net Zero 55

What we've found

LULUCF

LULUCF represents the emissions from Land Use, Land Use-Change and Forestry. Negative emissions from LULUCF are typically due to one, or a combination of:

- Forests and better forest management
- Restoring and managing peatlands and wetlands
- Enhancing the storage of carbon in the soil

DACCS could remove emissions but is an emerging technology which will require significant demonstration and scale-up before large-scale commercial use. It also has relatively high energy use. However, the Government has announced a £70 million innovation programme for DACCS and other negative emission technologies, and there is potential for use of waste heat to lower energy demand. So, we assume DACCS is available, but only in Leading the Way where it contributes 24 $MtCO_2e$, in line with the Net Zero Strategy.

Consumer Transformation and System Transformation have fewer negative emissions than Leading the Way by 2050 but with close to 80% of the total provided by BECCS in both cases. BECCS for power provides the greatest share in both scenarios with slightly less in System Transformation although its assumptions around hydrogen mean BECCS for hydrogen also makes a significant contribution. LULUCF makes the same contribution to negative emissions in both scenarios, although less than in Leading the Way. Falling Short only has negative emissions from BECCS for power and even then at a lower level than the Net Zero scenarios. There are also negative emissions within the LULUCF sector in Falling Short (i.e. negative emissions from trees), however the sector has net positive emissions and so is not shown.

FES 2022 / Net Zero 56

What we've found

Figure NZ.10: Negative emissions (Consumer Transformation)

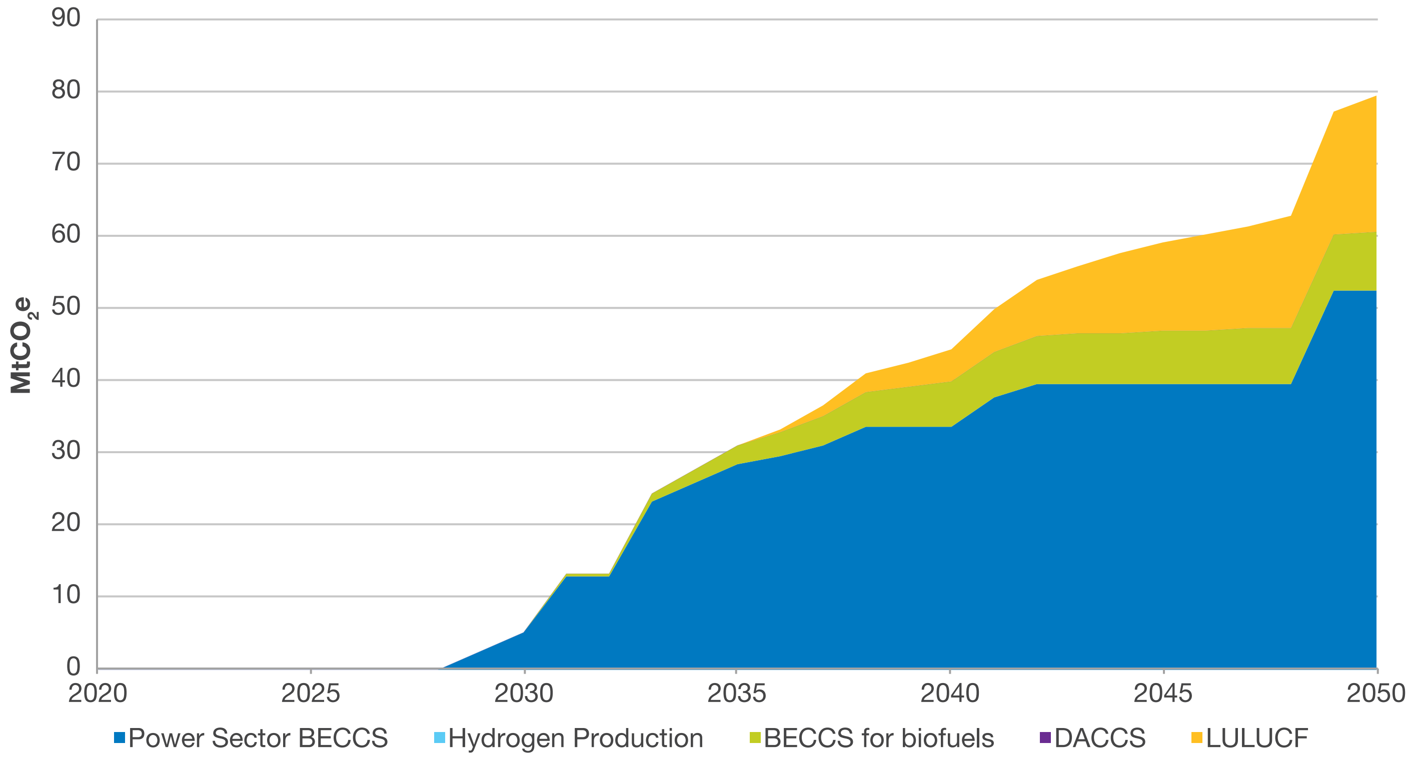
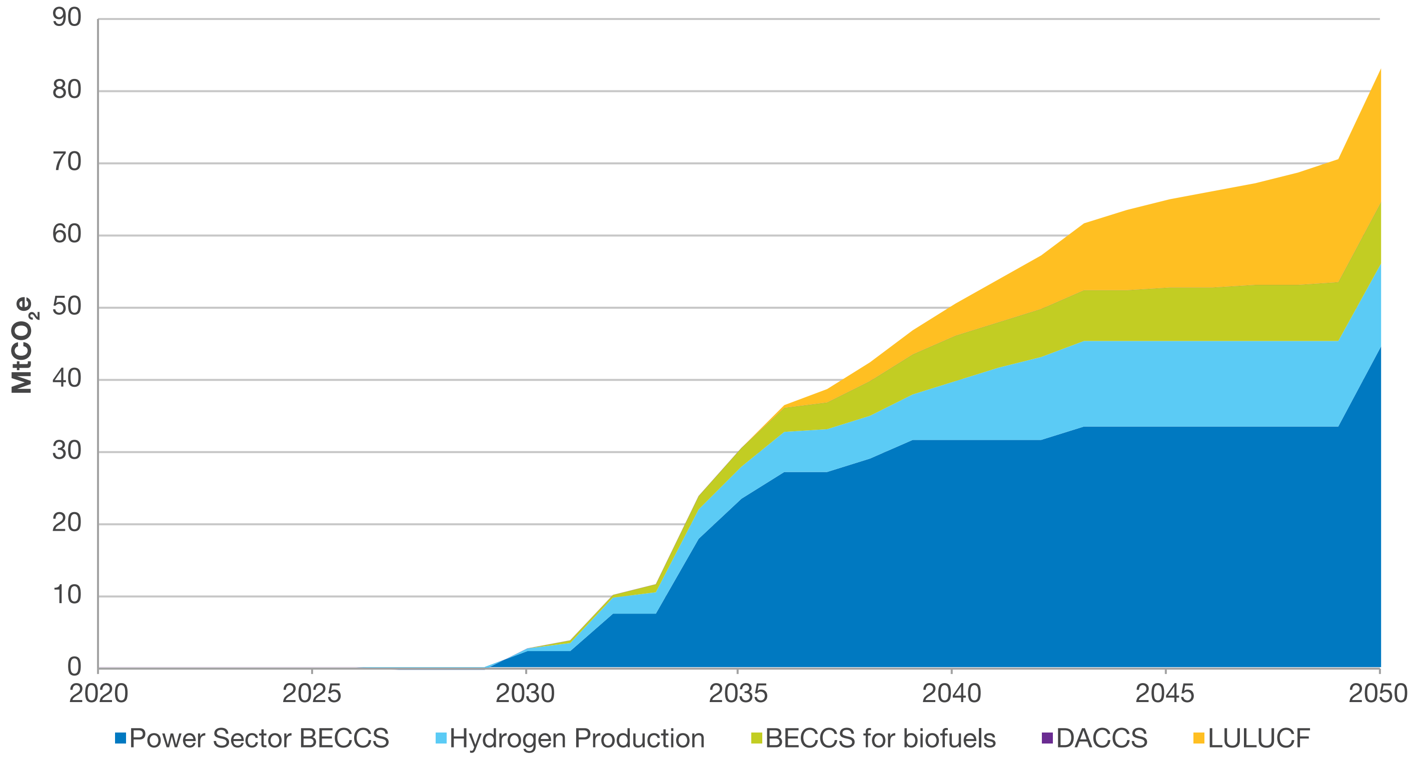


Figure NZ.10: Negative emissions (System Transformation)



What we've found

Figure NZ.10: Negative emissions (Leading the Way)

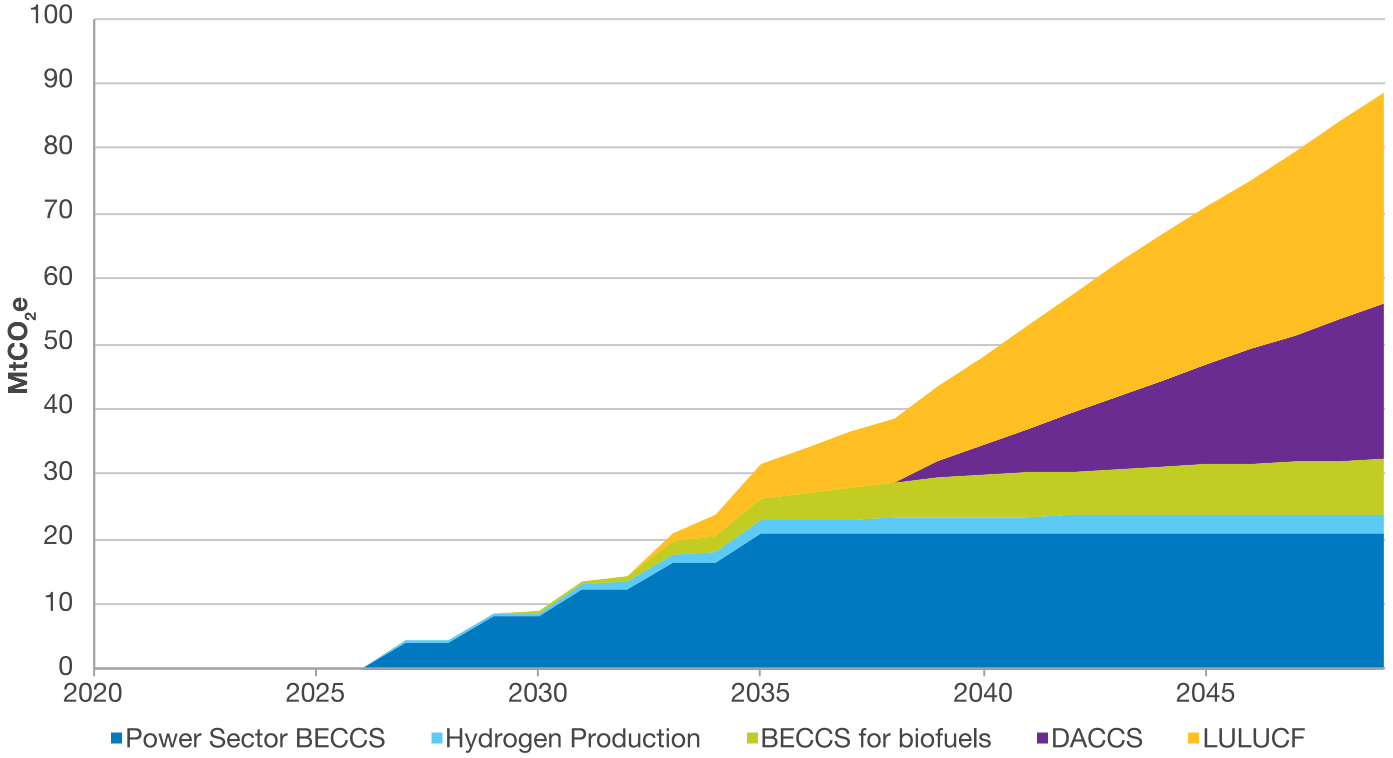
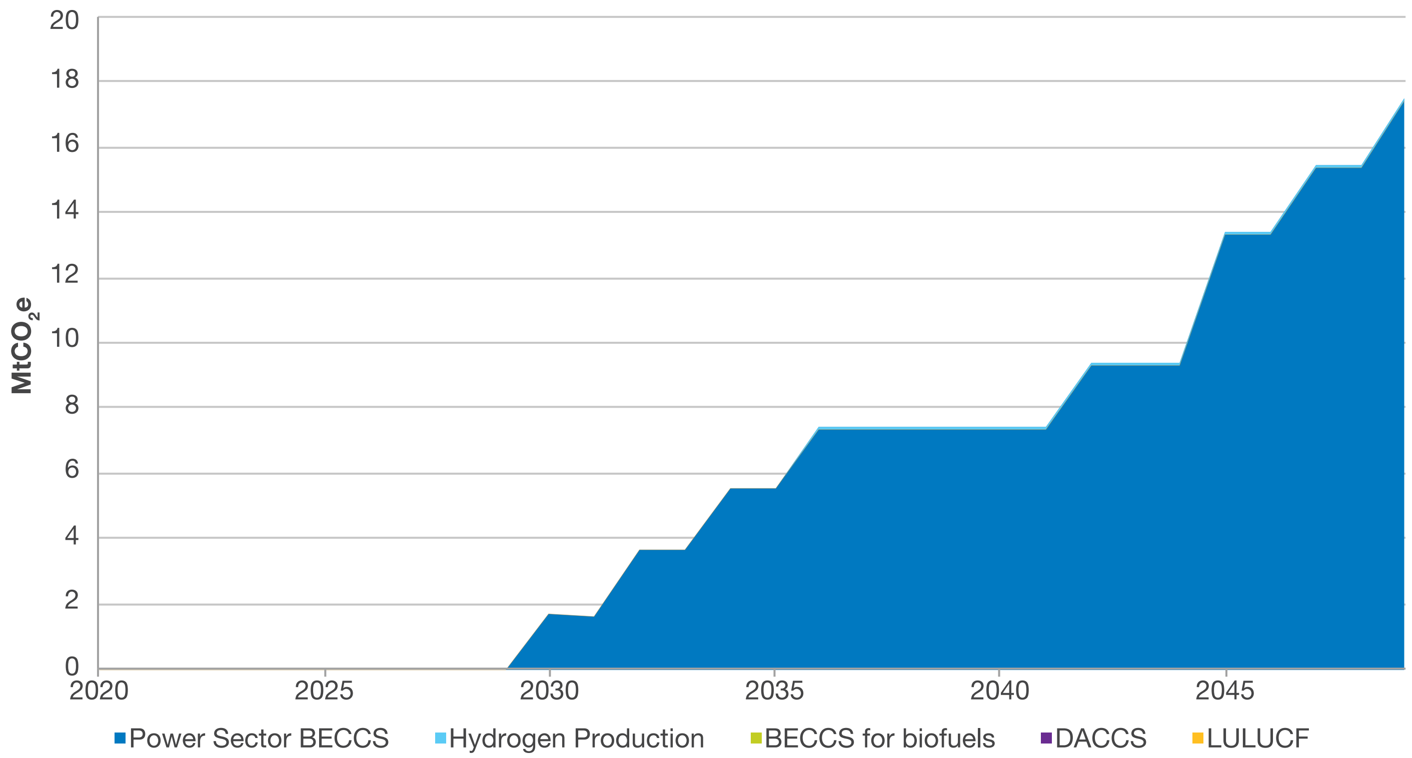


Figure NZ.10: Negative emissions (Falling Short)



FES 2022 / Net Zero 58

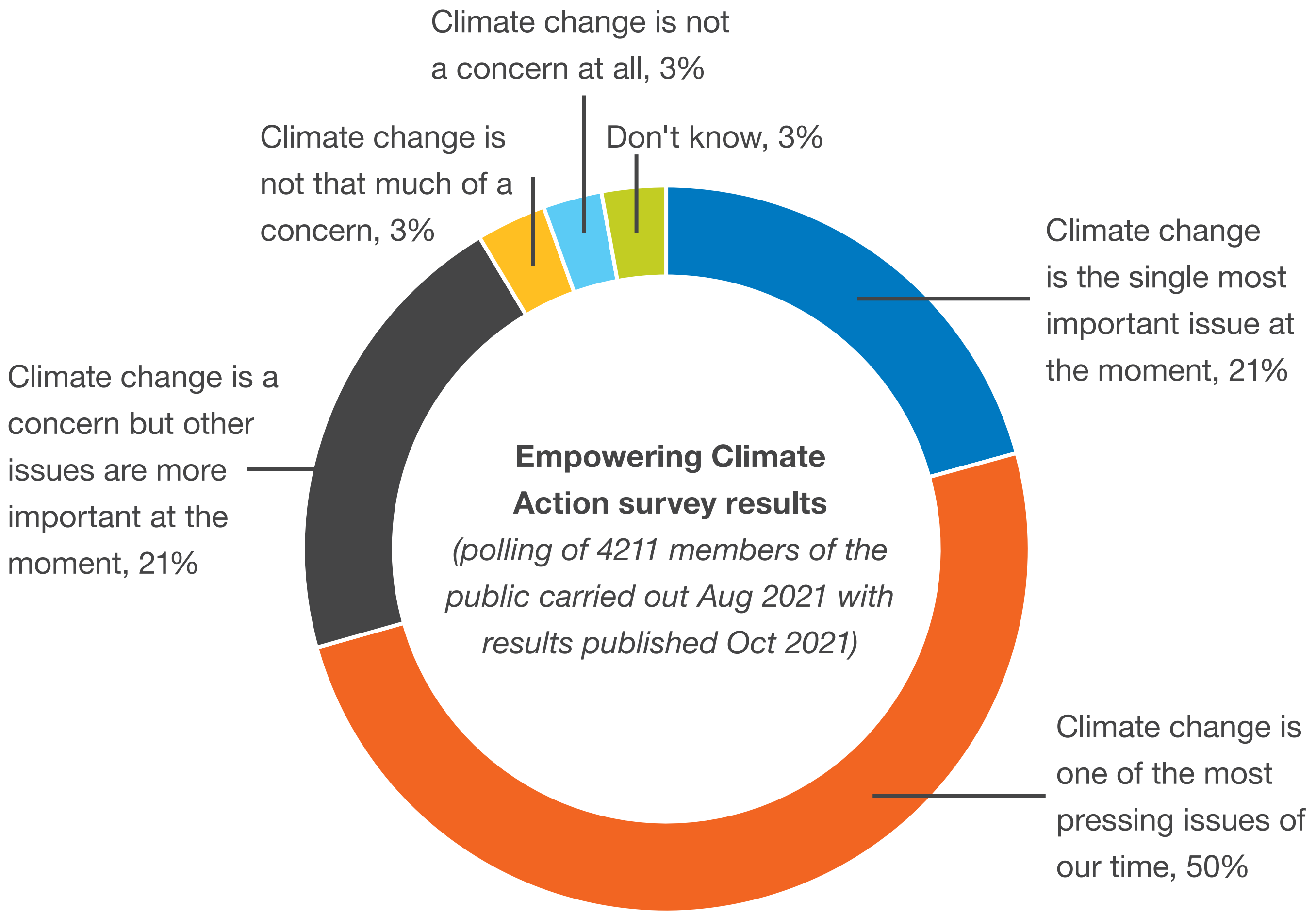
The energy consumer

To date, decarbonisation has largely happened in the background for consumers as most changes have impacted how energy is produced rather than how it is consumed. Where consumers have made changes, for example switching to energy efficient lighting, these were relatively easy policy decisions which had minimal impact on the consumer experience or use of energy. From now on, a more conscious effort will be required from consumers to achieve Net Zero, with at least moderate levels of societal change required for all three scenarios that reach Net Zero by 2050 (see Key Message 2). Change doesn't have to be negative, and many aspects of a lower carbon way of living will be beneficial to individuals, businesses, communities as well as biodiversity.

It is also vital that any transitions are fair, enabling and incentivising those who can engage without penalising those who can't. By better understanding the different barriers, opportunities and perspectives of consumers across the country, they can be engaged and supported through the energy transition. As part of our Empowering Climate Action (ECA) report, published in October 2021, National Grid ESO polled 4,211 members of the public and held 12 focus groups to better understand the public view on the UK's climate agenda and how they can get involved. The report identifies six archetypes, or 'segments', in the British population and recommends how each should be engaged. This work was undertaken before the cost-of-living crisis fully took effect, but it is felt that the results are still broadly valid. We will continue to engage with consumers to better understand their views on the energy transition and how they might be changing.

We found that the majority of the British public is concerned about climate change (Figure NZ.11) with 71% saying it is one of the single most important issues of our time, and only 9% not listing it as an issue of concern.

Figure NZ.11: Poll result to the question "How serious do you consider the issue of climate change to be?"



What we've found

We also asked consumers about technologies in their homes. Figure NZ.12 shows several which are seen in FES as being important for enabling Net Zero, alongside the percentage of respondents to the survey which owned them, and the range of ownership levels needed by 2035 under the Net Zero scenarios. Some, such as smart appliances, are required to support digital solutions for shifting demand to meet supply, whilst others such as heat pumps and Electric Vehicles are needed to decarbonise sectors like heat and transport.

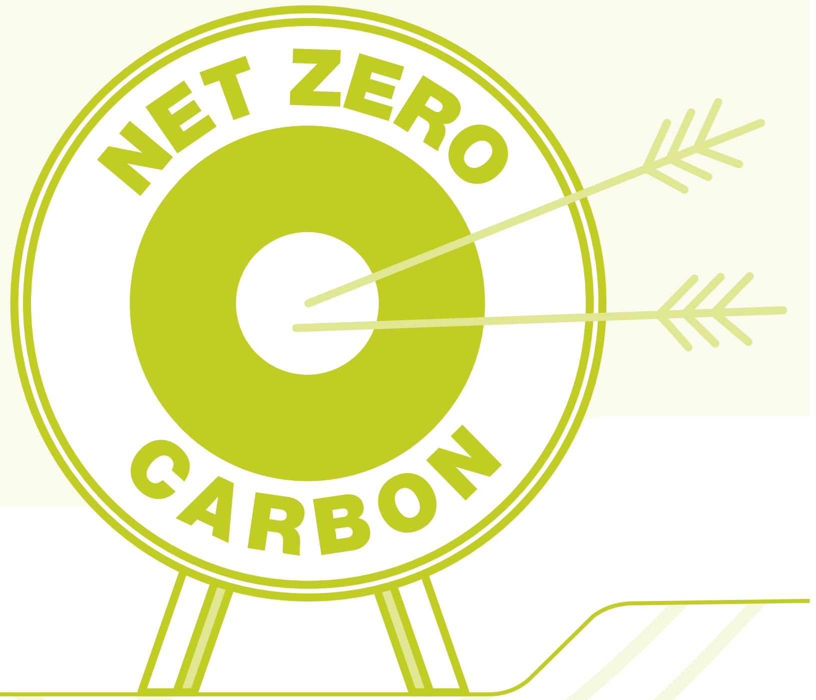
In almost all cases a significant increase in uptake of these technologies is needed by consumers, with a doubling or even trebling needed in the next 13 years in some instances. Many of these technologies have constraints on their annual roll-out due to issues such as supply chain restrictions, lack of skills available or infrastructure requirements. So, if ownership of these Net Zero enabling technologies is to reach the levels needed by 2035, increased deployment needs to start now.

Respondents were also asked whether they were likely over the next five years to purchase the technologies shown in Figures NZ.12 and Figure NZ.13 which they didn't own, with the majority stating that they were not likely to in the short term (Figure NZ.13).[7] This represents a potential barrier to deployment.

But it's not just increased adoption of these technologies which is needed, consumers need to be enabled to change the way they use energy to maximise the benefits of these technologies. For example, charging EVs when electricity supply is high and price is low, or combining heat pumps with thermal storage, enabled by smart devices. This will also require consumers to adopt smart tariffs.

For this to happen, it is vital that consumers are informed about the changes they can make and why they are important, and then supported through the transition. One method which is gaining increasing attention is "**positive tipping points**". Creating positive tipping points involves small, targeted interventions which trigger larger, more accelerated changes. For example, in the early part of the last decade, subsidies for small-scale renewable energy, coupled with reducing technology costs, led to a rapid increase in deployment of solar PV, resulting in 13 times over the capacity predicted by FES in 2011 for the year 2020. For more detail on the role of consumers in the energy transition and supporting policy see **The Energy Consumer section**.

We will build on our Empowering Climate Action analysis through an innovation project to create a set of industry standard consumer archetypes to identify where different types of consumer are across the energy networks and how they might behave with respect to Net Zero and their energy consumption. We will use these in our modelling process for developing FES and enabling them to take the required actions in support of demand side flexibility.



7 Respondents were asked a different set of questions for electric vehicles and so EV's were not included in Figure NZ.13

FES 2022 / Net Zero 60

What we've found

Figure NZ.12: Household ownership – current and by 2035 in FES[8]

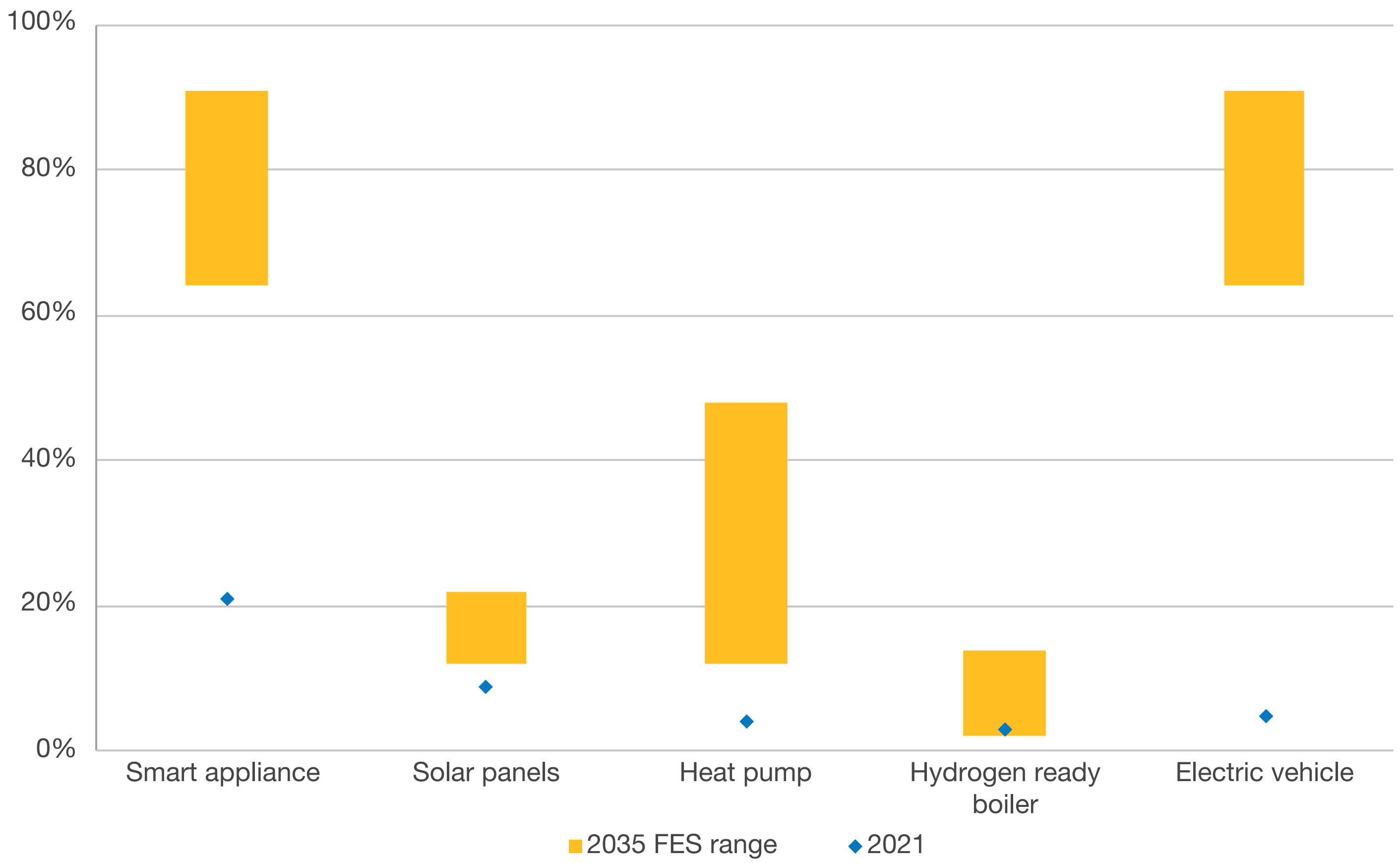
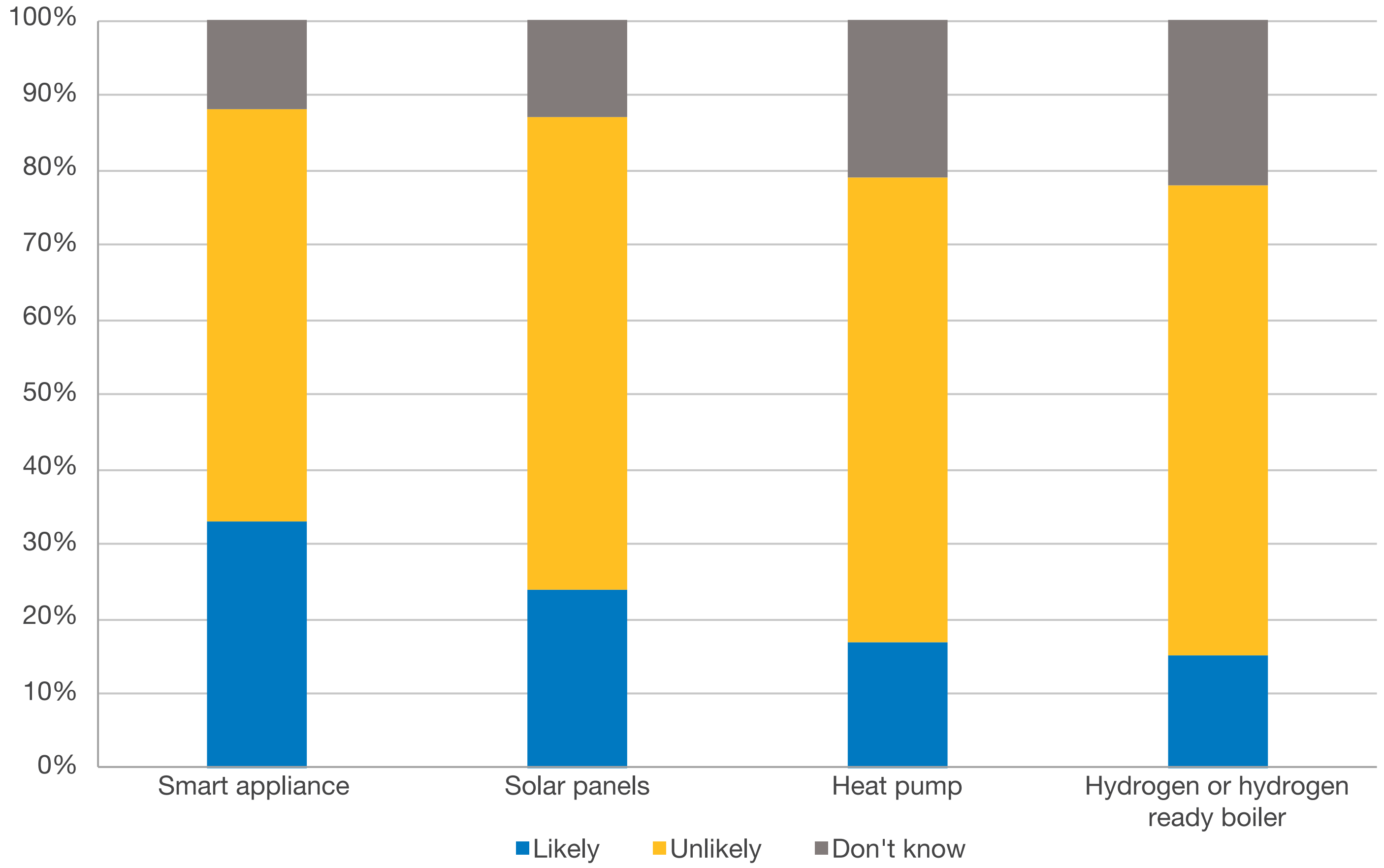


Figure NZ.13: Likelihood of households to purchase technologies in next five years



Based on findings from our Empowering Climate Action research which polled 4,211 members of the public (weighted to nationally representative proportions).

8 Figure NZ.12 assumptions: 2.16kW domestic solar PV systems, the survey response only included EV's as a first car. FES assumes the trigger point for residential consumers moving to dynamic tariffs is getting an EV, therefore we've also assumed by this point households will have a smart meter, devices and appliances. Hydrogen ready boilers in 2021 were compared to the range of hydrogen boilers in 2035 in FES.

FES 2022 / Net Zero 61

What we've found

The energy system

Reaching Net Zero requires a fundamental transformation of our energy system to become more digitalised, smarter and flexible with significant infrastructure investment needed (see Key Message 4). Transforming our energy system to one capable of meeting the Net Zero challenge will need the following activities and tools:

- Energy needs to be used efficiently across all sectors: transport, heating, appliances and processes. Residential heat demand is reduced by up to 107 TWh by 2050 in our scenarios from using more thermally-efficient building fabrics alone. Reducing the initial demand for energy makes decarbonisation easier.
- We need to use low or zero carbon energy sources (renewable electricity, hydrogen, bioresources, nuclear) or ensure that Carbon Capture and Storage (CCS) technology is used wherever fossil fuels are burned. By 2035 unabated fossil fuels are only providing between 0.4 and 1.8% of our electricity supply across our Net Zero scenarios and is used only to ensure Security of Supply.
- Carbon Capture Usage and Storage (CCUS) of emissions, either from the atmosphere or at source, will be needed. CCUS can be fitted to industrial processes when there are no alternatives to fossil fuels. Leading the Way and System Transformation both deploy two industrial CCUS clusters by 2026.
- Although all sectors can reduce emissions, not all will reach zero emissions by 2050. Negative emissions in some sectors will be required to offset remaining emissions in others.
- Financial and policy tools which attribute a cost to the carbon impact of processes and products will play a big role. For example, the EU has announced its “Carbon Border Adjustment Mechanism", a carbon import tax to be fully implemented by 2026 to avoid carbon leakage. In our Net Zero scenarios, we apply a carbon cost to the use of natural gas to encourage consumers to use lower carbon alternatives. This also means payments are made to those industries storing carbon, making bio-gasification for the production of hydrogen financially attractive in a world with high hydrogen demand such as System Transformation. This contributes to 33 TWh of hydrogen production in this way by 2050 under System Transformation.
- Policy, market and regulation decisions on Net Zero must take the whole system into account and happen quickly to maximise benefits. The UK energy system is complex and interconnected and, if support is given to one area, it must consider the impacts right across markets, infrastructure, and consumers. For example, as EVs are rolled out, there must be adequate support to ensure charging can be shifted to minimise demand on networks during peak demand periods.

Our scenarios incorporate all these different elements in different ways and the range in results illustrates there is still a lot of uncertainty about how to decarbonise, proving there is no single solution for Net Zero. Nevertheless, according to our scenarios, many of these measures need to be implemented at scale before the end of this decade if we are to be on track to reach Net Zero. For more detail on how the system may transform and the implications of energy choices on the system see our The Energy System section.

FES 2022 / Net Zero 62

The Energy Consumer

Introduction

The choices and actions of consumers are going to have a big impact on how we meet the UK's Net Zero targets. Consumers being willing and enabled to engage with the energy system is crucial to unlocking flexible supply and demand and achieving Net Zero in the most cost-effective way between today and 2050.

The extent to which consumers are willing to change their behaviour and lifestyle to enable the Net Zero transition has a high level of uncertainty. We explore this using our 'level of societal change' axis on our scenario framework, with consumer engagement ranging from Falling Short where consumers are relatively unwilling to adjust their behaviour, through to Leading the Way with a high level of societal change and consumers who actively engage and provide high levels of demand side flexibility. The total cost of the energy system, which is ultimately met by consumers, can be minimised by effectively encouraging consumers to make choices that benefit themselves and the wider energy system. This can be achieved through changing how energy markets operate, incentivising flexibility and investing in innovation and digitalisation.

To reach Net Zero, drastic change is needed across a range of sectors that will all impact the consumer experience. This includes changes in technology, lifestyle and consumption. Some of these areas require policy support from government, changes to the way energy markets operate and offers from suppliers and third parties to make this transition as easy as possible for consumers including smart meters and Time of Use Tariffs (ToUTs).

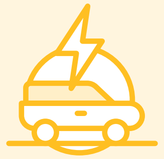
What do we mean by consumers?

We are all energy consumers, in our homes, workplaces and cars; energy is what our modern society runs on and is a basic need for everyone.

Today consumers use a lot of fossil fuels: petrol and diesel for cars, heating oil and gas for heating homes and businesses, and oil, gas and solid fuels in industry. This is already starting to change, and the energy used by consumers and the consumer experience will look very different in 2050.

In the The Energy Consumer we break energy consumption down into four sections:

Residential
Home heating and electrical appliances



Transport
Cars, HGV's, rail, aviation and shipping

Industrial
Heavy industry such as steel and cement production and light manufacturing such as food and textiles

Commercial
Shops, office, data centres

FES 2022 / The Energy Consumer / Introduction 64

Introduction

The energy transition could also have a positive impact on consumer bills and the cost of living. For example, energy efficiency improvements for appliances, homes and businesses can help reduce energy costs substantially, while heat pumps are three times as efficient as gas boilers, and electric vehicles are much more efficient than petrol or diesel vehicles.

This increase in efficiency can lead to reduced costs to consumers, although some of these efficiency savings may be offset by the current higher cost of electricity per unit of energy compared to fossil fuels.

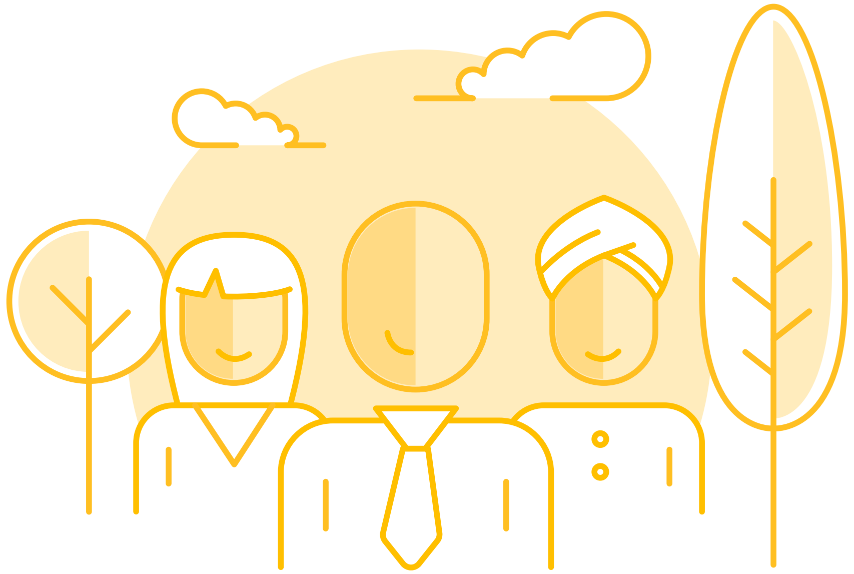
One major barrier for consumers is up-front costs. Low carbon technologies often still have higher capital costs than their fossil fuel equivalents, meaning that even when they are cheaper to run, they can be difficult for consumers to initially afford. Industry and government need to work on technological and policy solutions to help reduce costs and provide additional support to those on the lowest incomes.

Residential
Home heating and electrical appliances

Transport
Cars, HGV's, rail, aviation and shipping

Industrial
Heavy industry such as steel and cement production and light manufacturing such as food and textiles

Commercial
Shops, office, data centres



FES 2022 / The Energy Consumer / Introduction 65

Introduction

Key insights

Energy consumers across the residential, transport, industrial and commercial sectors need to be enabled to make changes in how they interact with the energy system. Changes in consumption behaviour, smart technology take-up, markets and policy will all be needed to ensure that the energy needs of consumers are met in a way that is clean, secure, affordable and fair.

- A **decision on the use of hydrogen** for residential and commercial heat needs to be made by the Government's 2026 deadline to give more certainty to consumers on the most appropriate low carbon heating technologies for their homes and businesses.
- Electrification of existing fossil fuel energy demand, particularly for heat and transport, and growth in electricity demand in new sectors, will increase annual and peak electricity demands. This will require **strategic investment** in electricity generation and energy network infrastructure to meet this demand.
- Appropriate policy support needs to be put in place to support consumers to improve **energy efficiency** of their homes and businesses. This will help reduce energy bills via lower annual and peak energy demands. Policy support will also be crucial to overcoming infrastructure challenges that currently present barriers to uptake of low carbon technologies such as heat pumps.
- **Smart technology** and demand side flexibility can help mitigate the increase in peak demands from electrification, optimise the whole energy system and thereby reduce consumer energy costs. This will involve the adoption of smart meters and Time of Use Tariffs (ToUTs) by residential consumers, smart charging of Electric Vehicles (EV) and increased industrial and commercial participation in Demand Side Response (DSR).
- All types of energy consumer need to be **enabled to engage** in the whole energy system of the future. Appropriate market signals need to be put in place to incentivise flexibility from consumers that is unlocked by digitalisation and smart technology.

FES 2022 / The Energy Consumer / Introduction 66

Introduction

What does this look like for consumers?



Use less energy	Use green energy	Change when or how they use energy
Consumers will need to stop using petrol or diesel cars and use a zero emission vehicle, take public transport, or walk or cycle.		Residential consumers will need to start engaging with Time of Use Tariffs and forms of smart control and automation of energy consumption that can shift electricity demand from times of low renewable generation to times with abundant renewable electricity supply.
Many consumers will need new insulation to improve the energy efficiency of their homes and reduce their energy costs.	Residential consumers will need to change their heating system away from fossil fuels to new technologies such as heat pumps or hydrogen boilers.	Industrial and commercial consumers will need to engage with aggregators and suppliers to provide higher levels of Demand Side Response to the energy system in response to price signals.
Businesses will need to improve energy efficiency and adopt low carbon heating systems.	Industry will need to switch away from fossil fuels to alternatives such as hydrogen or use Carbon Capture and Storage (CCS) technology to drastically reduce their emissions.	Some industrial consumers may need to re-locate in some scenarios to areas with hydrogen or Carbon Capture, Usage and Storage (CCUS) technology available to enable them to decarbonise.
	The freight industry will need to adopt electric, or hydrogen powered, Heavy Goods Vehicles (HGVs).	

We assume consumers are more engaged in our scenarios with higher levels of societal change, particularly in Leading the Way. They respond to price signals from the energy system, and automation optimises energy use for residential consumers in the background. It can manage consumer energy demand, shifting the time they charge their Electric Vehicle or feeding energy back to the system using Vehicle-to-Grid (V2G). It could also manage thermal storage in the home, adjusting when their heat pump runs or staggering the use of electrical appliances in response to price signals. Commercial and industrial consumers will also be increasingly engaged in DSR technology, able to adjust energy DSR to electricity market signals.

This type of behaviour will require changes to electricity markets, tariffs and signals offered to consumers, and the adoption of technology such as smart meters.

FES 2022 / The Energy Consumer / Introduction 67

Introduction

Figure EC.01: Annual end consumer energy demand by sector[1]

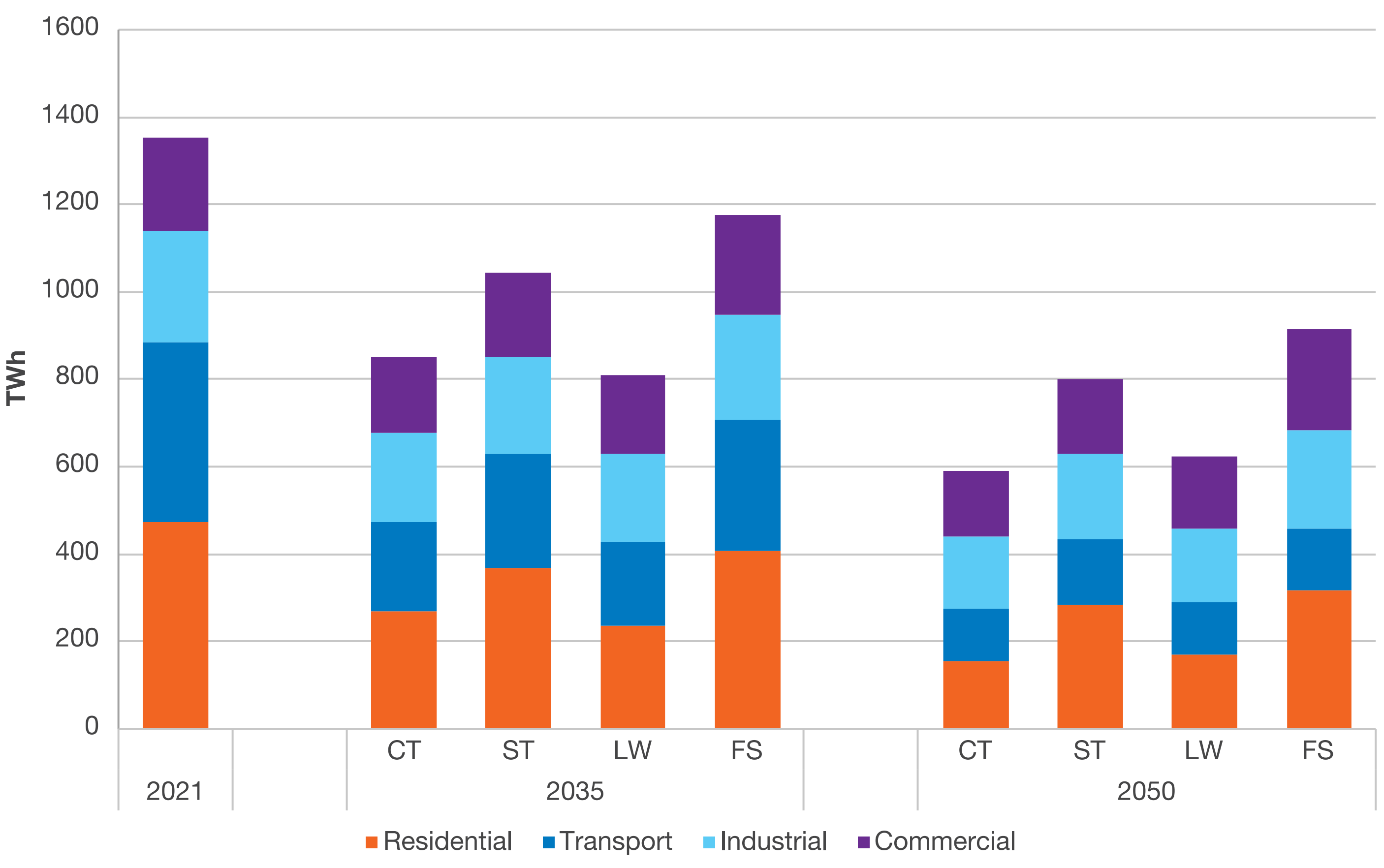
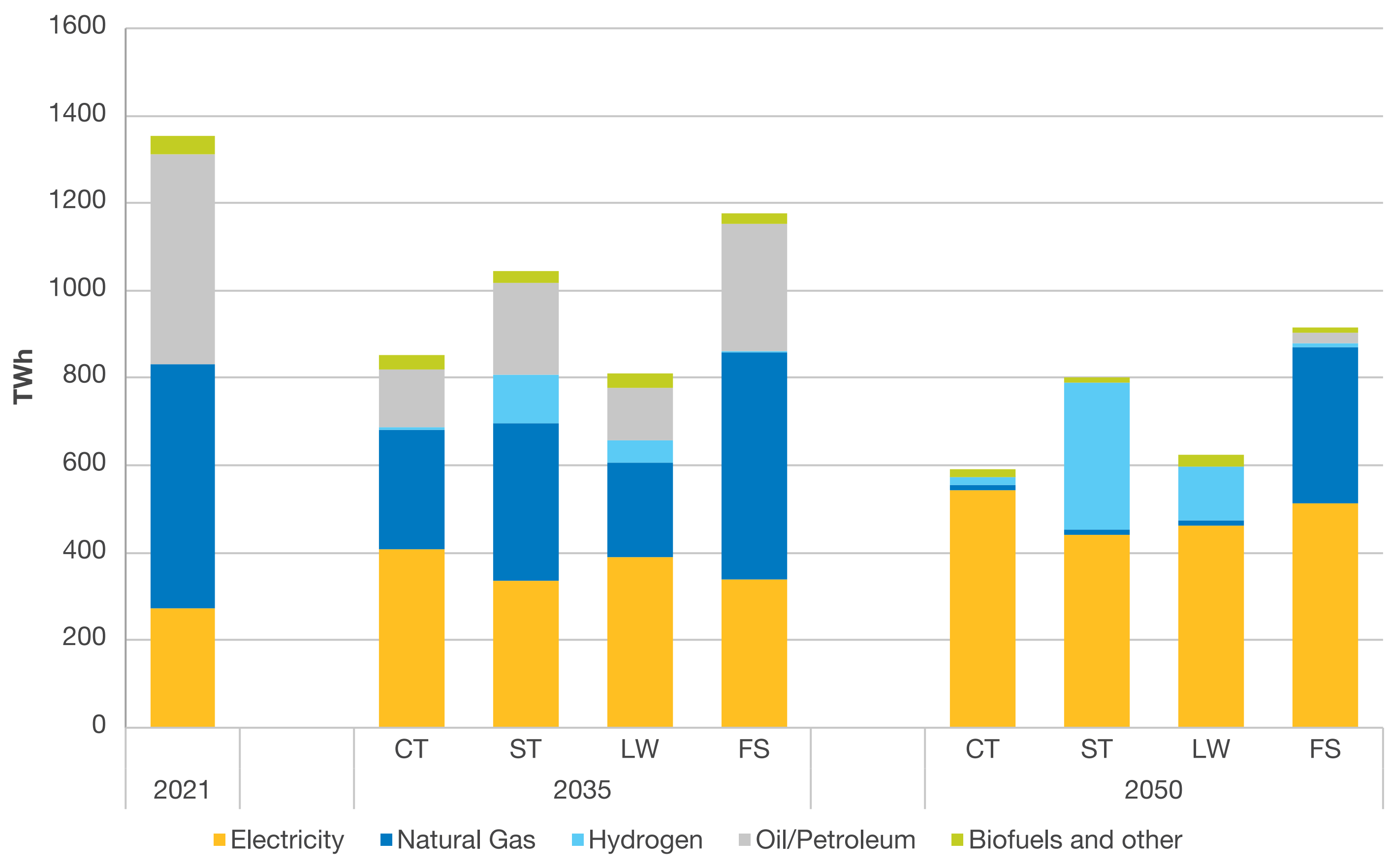


Figure EC.02: Annual end consumer energy demand by fuel



1 The energy demand figures stated here show the amount of energy consumed by the end user in each sector. They do not include how much primary energy may be required to meet this demand. Because of losses and energy conversion efficiency, this will always be larger than the demand from end consumers. The 2021 data is primarily made up of our modelled data for natural gas and electricity. However, some 2020 demand data from ECUK was used in order to provide a complete, whole energy system view of end consumer demand.

FES 2022 / The Energy Consumer / Introduction 68

Introduction

Total consumer demand: how does overall consumer demand change between today and 2050?

We see total energy demand (total height of the bars) fall significantly in all scenarios. This is across all sectors but is most pronounced for transport and heat. This is due to significant efficiency improvements through the switch to EVs and electric heat pumps, which can deliver much more output for the same level of energy input. Consumer adoption of different types of technology will also be affected by government policy, for example on the use of hydrogen in residential heating, and this varies across the scenarios. The result, however, is significantly increased electricity demands (the yellow portion of the bars) in 2050 compared to today.

The Energy System chapter considers the implications of changing consumer energy demand.

We will need more electricity generation capacity and reinforced electricity networks to transport this electricity, as discussed in Electricity Supply. Natural gas demand declines sharply in the Net Zero scenarios, discussed in Natural Gas Supply. The future demand for hydrogen and associated production, transmission and distribution requirements are covered in the Hydrogen section. And supply of and demand for bioresources is covered in the Bioenergy section.

FES 2022 / The Energy Consumer / Introduction 69

Regional demand

We are improving our FES modelling year on year, with greater granularity and more detailed regional outputs, rather than just using a GB view. This year we are providing more clarity on possible pathways for whole system decarbonisation through regional insights.

We have enhanced our regional assumptions and modelling to allow us to more accurately represent aspects of the scenarios which vary due to local factors. The regionalisation of FES can be used to show how different parts of Great Britain might decarbonise in different ways and at different rates and so the options available for consumers to decarbonise will vary in different regions of the country. More detail is included in the sub-sections within this chapter.

Heat

Our new spatial heat modelling considers the most cost-effective decarbonisation solutions for heating for homes and businesses in different areas of the country, allowing us to explore the variation in low carbon heating technology deployment across the country.

Transport

We've changed how our road transport modelling works to better capture regional differences in mileage and EV take-up to inform our scenario outputs for energy usage for transport.

Industrial

Regionalisation of our industrial modelling is at an early stage, this year we present how the development of industrial clusters may affect the decarbonisation options for industry and we intend to continue to work on modelling this area with greater granularity.

FES 2022 / The Energy Consumer / Introduction 70

Policy timeline / key comparison chart

CT Consumer Transformation LW Leading the Way
ST System Transformation FS Falling Short Policy

This chart contains a selection of recent policy targets in relation to Net Zero and energy security and highlights how they compare to the different scenarios. Analysis for FES 2022 commenced before the publication of several key policy documents and does not signify that any individual targets cannot be met across the range of scenarios.

		2021	By 2025	By 2030	By 2035	By 2040	By 2045	By 2050	Maximum potential by 2050
Transport	Sales of petrol and diesel cars and vans banned	1.6m petrol and diesel cars and vans sold		CT LW (Policy)	ST	FS			37m battery electric cars and vans FS
	Zero tailpipe emissions for all new cars	7% of cars sold			CT LW ST (Policy)	FS			Zero ICE cars still on the road CT ST LW
	Zero tailpipe emissions for all new HGVs	<1% of HGVs sold				CT LW ST (Policy)	FS		Zero ICE HGVs still on the road CT ST LW
Heating	600,000 heat pumps installed per year	Approximately 60,000	LW	CT (Policy)	ST	FS			1.1m per year CT
	4 in 5 homes not using natural gas boiler as primary heat source	1 in 5				LW	CT ST		100% CT ST LW
Natural Gas	Gas grid connection for new homes ends	>60%	CT LW (Policy)		ST				0% LW
Data centres	Additional demand for data centres exceeds 5 TWh	<0.5 TWh		CT LW	ST		FS		20 TWh LW
Industry	Annual industrial hydrogen demand over 10 TWh	<0.5 TWh		(Policy)	LW ST		CT		88 TWh (45 TWh target by 2035 narrowly missed in ST) ST
Hydrogen	4 hydrogen clusters	0		ST LW (Policy)					5 Clusters ST

FES 2022 / The Energy Consumer / Introduction 71

Residential

Key insights

- Policy gaps in support for **energy efficiency** and low carbon heating technologies (and associated supply chains) are the biggest barriers to decarbonising residential heating. Current policy commitments will not be enough to drive the technology shifts and consumer uptake for Net Zero.
- Reductions in the higher up-front **capital costs** for heat pumps are needed, as well as policy interventions to support uptake and allow the market to create new propositions for consumers.
- **Electrification of heat** could contribute to annual residential electricity demand increasing by 50% by 2035 and peak demand doubling by 2050, requiring more electricity generation and network capacity to support this.
- Demand for hydrogen for heating in System Transformation could need up to four fifths of today's residential gas demand for methane reforming by 2050, requiring **appropriate infrastructure and supply development**.
- Where hydrogen is primarily produced from electrolysis, our modelling indicates this is likely to be less cost-effective for use in home decarbonisation at scale compared to heat pumps without significant policy intervention to reduce costs. **Consumer Transformation has no residential end user demand for hydrogen.**
- Consumer engagement with **smart appliances and thermal storage** will be important to help mitigate the increase in peak residential electricity demand from electrification of heat.
- Consumers in some parts of the country may have more choices available to them for decarbonising their heating, due to factors such as **proximity of infrastructure**. Urban areas, for example, are more likely to be connected to district heating and hydrogen when compared to rural areas. This will influence how technologies are rolled out or supported.
- Hydrogen for residential heating in System Transformation and Leading the Way is developed initially around **hydrogen clusters** and then rolled out more widely as the hydrogen network is built out.

What is residential demand?

Residential demand includes energy used in the home for heating, cooking, lighting and appliances, but does not include transport, even for Electric Vehicles (EVs) charged at home, which is covered in the Transport section.

FES 2022 / The Energy Consumer / Residential 73

Key insights

Figure EC.R.01: Total residential energy demand for heat and appliances (excluding EV charging)

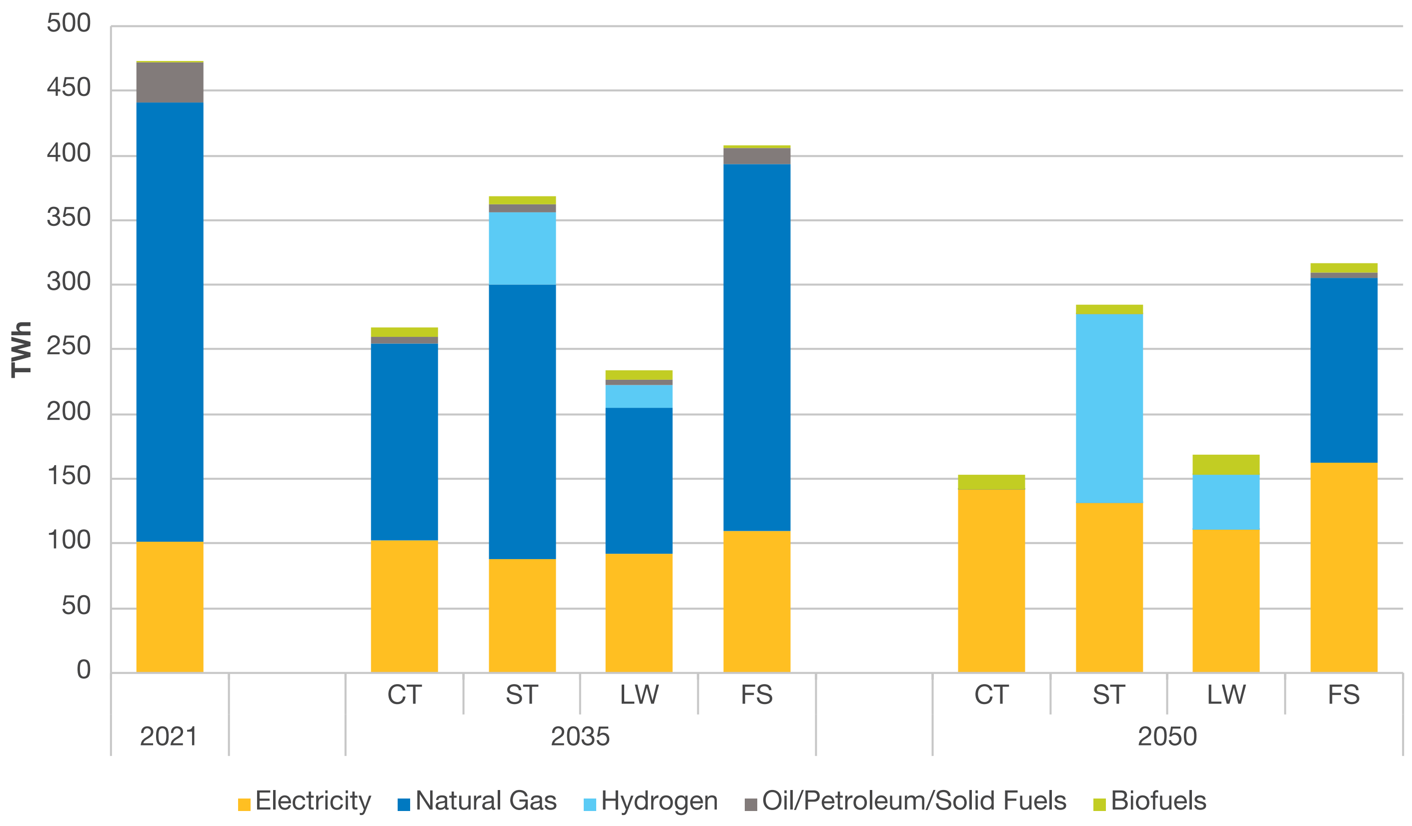
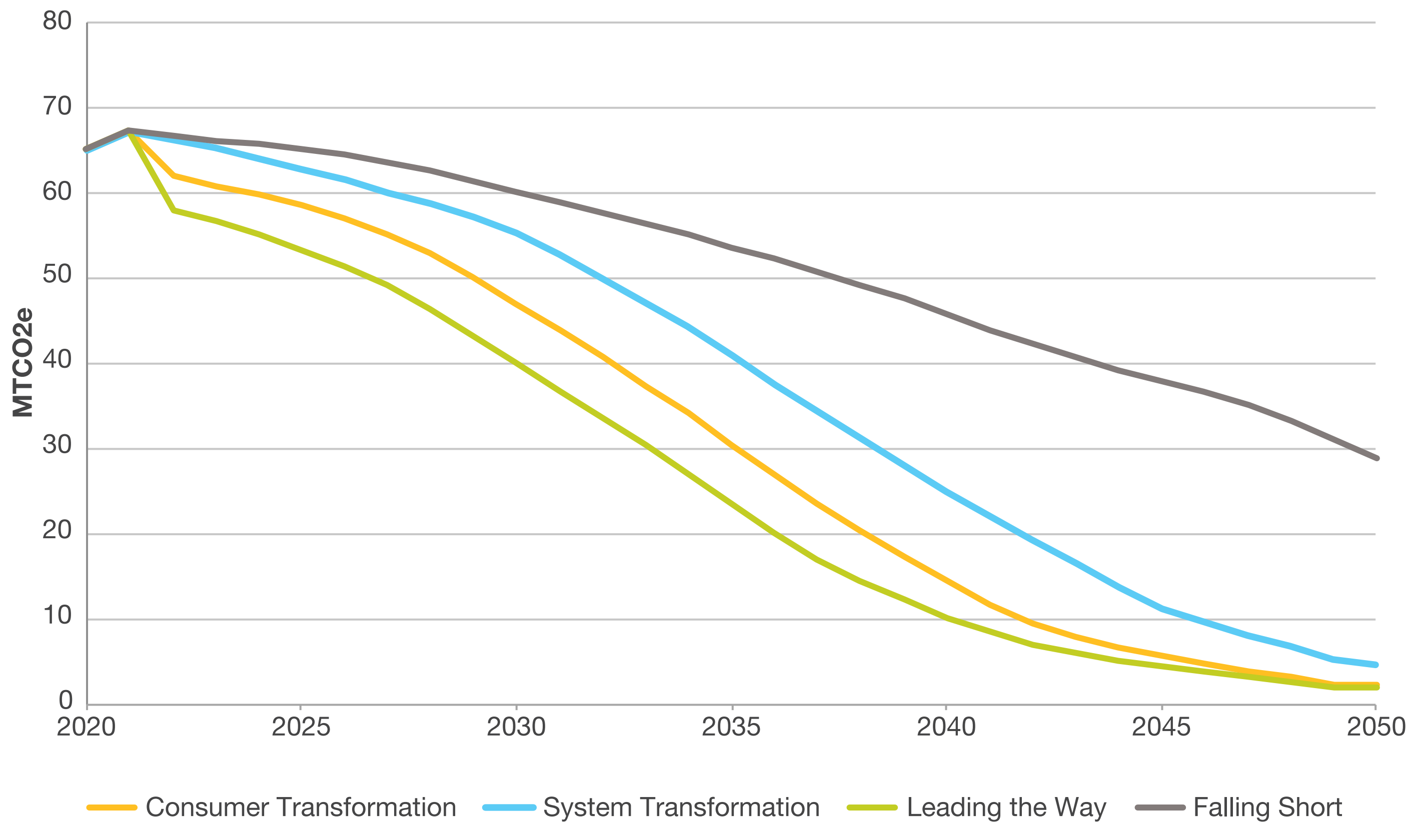


Figure EC.R.02: Emissions from the residential sector



FES 2022 / The Energy Consumer / Residential 74

Where are we now?

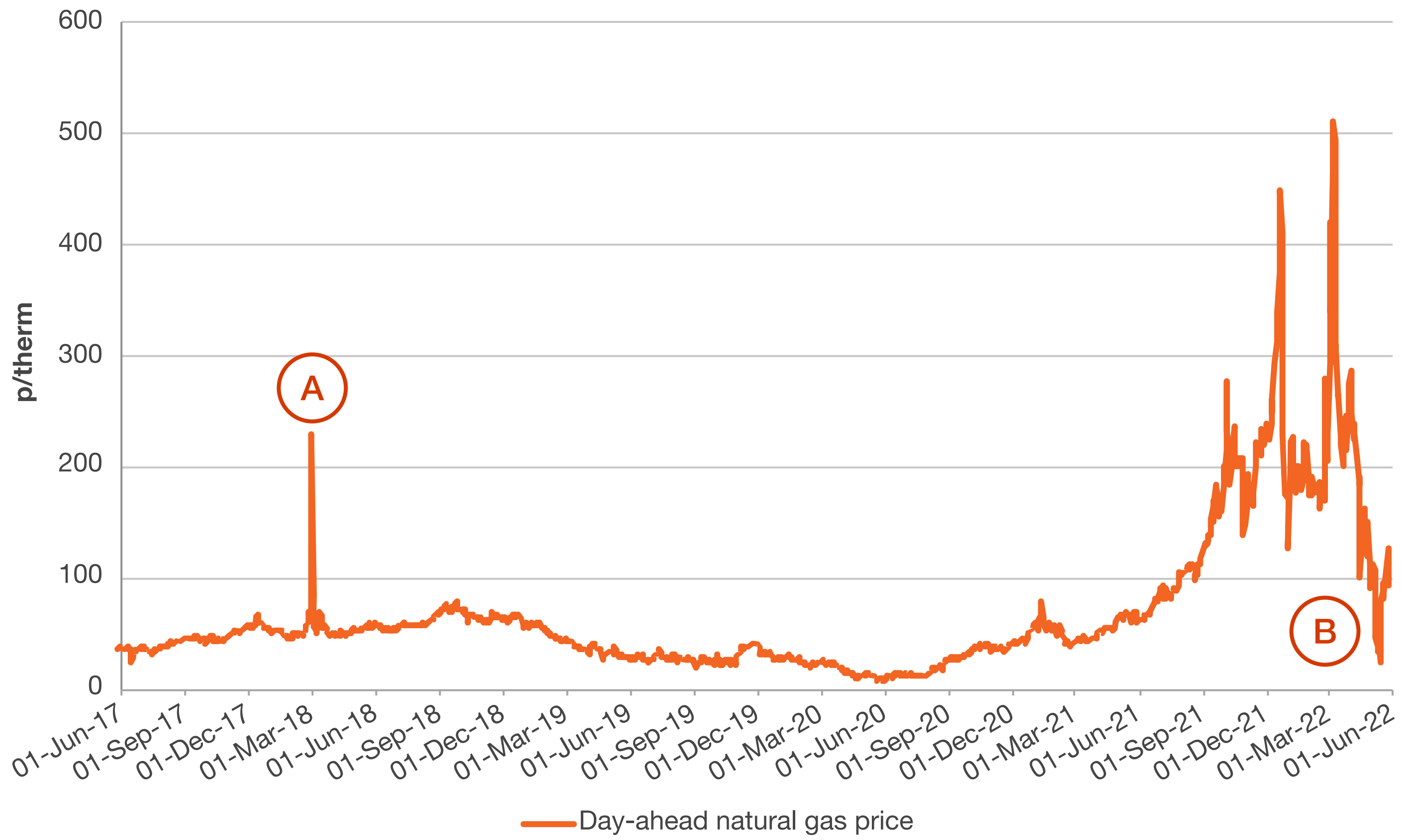
Current residential energy demand is dominated by natural gas, primarily for heating and hot water for homes.

In 2020, residential energy demand was approximately 450 TWh, with space and water heating making up 79%. The biggest impact on decarbonising the residential sector will come from the move away from natural gas to heat our homes. Use of solid fuels and oil in properties off the gas grid is a smaller share of total demand but is particularly challenging to decarbonise.

The past year has seen large increases in the cost of energy for domestic consumers, with the cheapest tariffs on the market now typically set by Ofgem's price cap rather than by cheaper fixed deals as in the past.
The price cap increased by 12% in October 2021, and a further 54% in April 2022, with a further rise expected in October 2022. This has been driven by sharp increases in wholesale gas prices from an average of around 50p/therm (1.7 p/kWh) across the previous five years, to fluctuations between 200-500p/therm (6-17 p/kWh) between January and April 2022 driven by the Russia/Ukraine crisis and wider market conditions.

This pressure on consumer bills places added emphasis on ensuring decarbonisation solutions are delivered in a way that is fair, just, and cost-effective for consumers. It is important to note that efforts to decarbonise can also support broader societal benefits, for example energy efficiency measures to reduce the energy consumption of homes helps reduce living costs for consumers. While both electricity and gas prices have increased, gas prices have risen most steeply. This has improved the competitiveness of heat pumps as a solution compared to gas boilers.

Figure EC.R.03: GB Day-ahead wholesale gas prices over the last five years



A: *Short term gas price spike during 2018s 'Beast from the East' weather event.*

B: *Day-ahead gas prices in GB fell sharply in April/May 2022 as high levels of LNG deliveries coincided with lower GB gas demand as we began to move into spring / summer. This has meant continued exports to Europe across our gas interconnectors. Lower prices reflect these short term circumstances but forward gas prices for winter 2022/23 remain high, above 200 p/therm.*

FES 2022 / The Energy Consumer / Residential 75

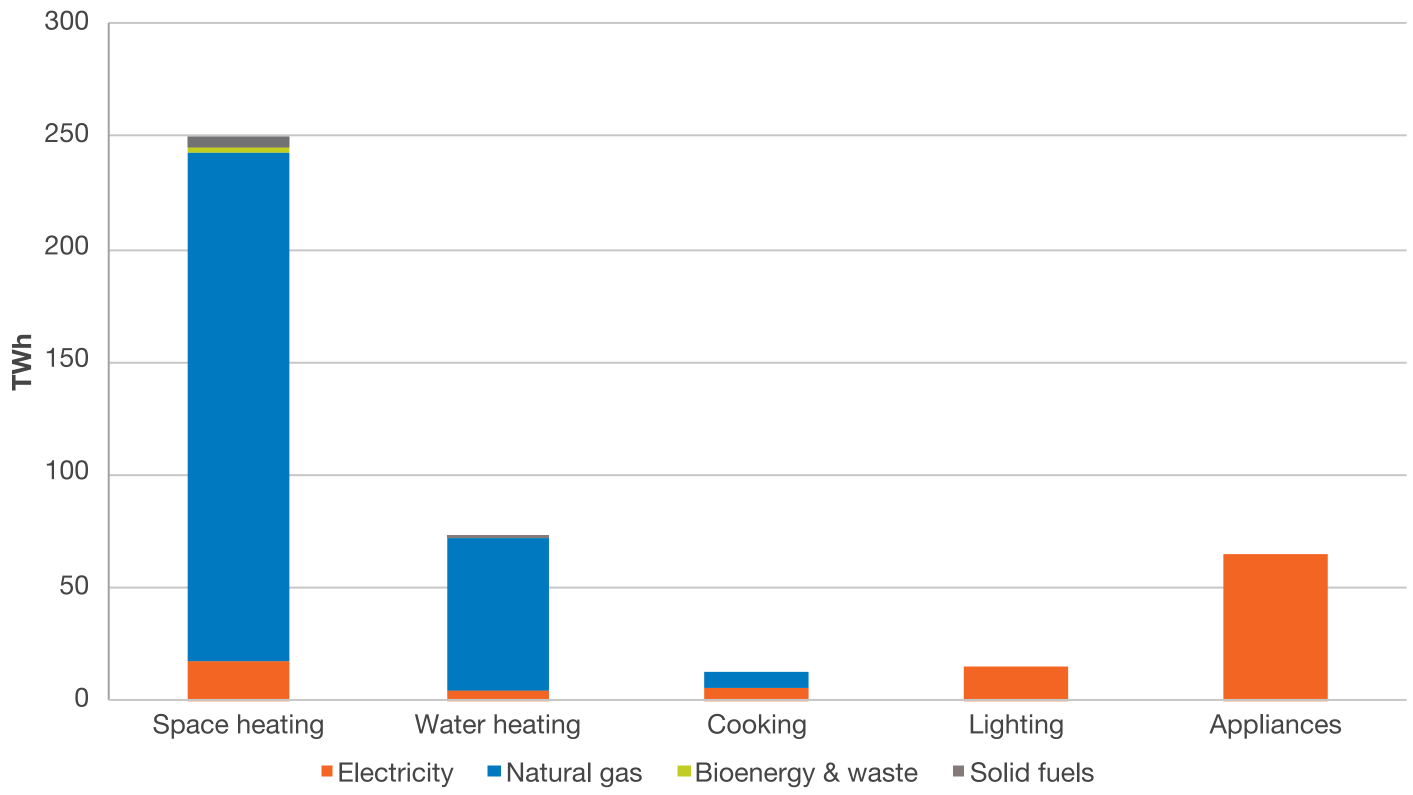
Where are we now?

For new homes, the Future Homes Standard will come into effect in 2025, ensuring new-build properties are more energy efficient. Most of the housing stock in 2050 will be made up of buildings that already exist today however, and these face different challenges. The publication of the Heat and Buildings Strategy and the Net Zero Strategy in 2021 and further policy in 2022 has clarified the future direction for the decarbonisation of heat, including the following policy announcements and targets:

- Grants for Air Source Heat Pumps (ASHPs) (£5,000) and Ground Source Heat Pumps (GSHPs) (£6,000) as part of the boiler upgrade scheme from 2022-2025, with a total commitment of £450M.
- Heat pumps should be no more expensive to buy and run than gas boilers by 2030. Innovation funding has been made available to support this goal.
- No gas boilers in new builds from 2025.
- New gas boilers to be hydrogen ready from 2025.
- Phase out the installation of natural gas boilers from 2035, including hydrogen-ready boilers in areas not converting to hydrogen.
- Annual heat pump installs of 600,000 by 2028, up from around 60,000 today.
- Upgrade homes to EPC band C by 2030 where cost-effective and practical.
- A commitment on major strategic decisions for the role of hydrogen for residential heat by 2026.
- A commitment to rebalance the costs on energy bills away from electricity to incentivise electrification across the economy. These include costs for measures to support renewable energy and energy bill support for low-income households.
- Cutting VAT on the installation of energy-efficient materials in homes, such as solar panels, heat pumps and insulation, from 5% to zero.

There is still a need to fill further policy gaps and take further major decisions on home heating.

Figure EC.R.04: Residential energy use today[1]



Energy Performance Certificate

Energy Performance Certificates or EPCs give a property an energy efficiency rating from A (most efficient) to G (least efficient). They are required whenever a property is sold or rented.

1 Data for 2020 from: ECUK Energy Data Tables (Table U3) - gov.uk/government/statistics/energy-consumption-in-the-uk-2021

FES 2022 / The Energy Consumer / Residential 76

What we've found

Scenarios overview:

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- From the early 2020s to 2035 homes are retrofitted with measures including insulation, triple glazing and low carbon heating under government initiatives.
- Annual heat pump installations reach 600,000 by 2028, in line with the government target.
- Consumers are encouraged to turn their thermostats down by an average of 0.5°C to reduce overall energy demand year-on-year, as well as reducing the electricity system peak from electric heating demand.
- From 2025, all new build homes have heat pumps installed, in line with the Future Homes Standard.
- Consumers change their light bulbs to LEDs and invest in highly-efficient smart white goods appliances and technology.
- The sale of natural gas boilers is banned from 2035.

What does 2050 look like?

- Total residential demand in 2050 is 153 TWh.
- As this is our scenario with the highest levels of electrification, the use of Air Source and Ground Source Heat Pumps is widespread. This scenario has the highest number of heat pumps – including hybrids - reaching over 23 million installations in homes by 2050.
- Around 10 million homes have thermal storage. Consumers respond to Time of Use Tariffs to change their demand at times of peak supply or demand on the local and national electricity networks. Smart appliances turn on, off, up or down throughout the day.
- No hydrogen used for residential heating.
- District heat networks are used in some areas, with hot water piped to homes by centralised heat pumps.

FES 2022 / The Energy Consumer / Residential 77

What we've found

Scenarios overview:

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- Extensive retrofitting schemes are driven by government incentives from the mid-2020s to increase household thermal efficiency.
- Hydrogen-ready boilers and appliances like hobs and kettles are installed from 2025 in readiness for switching the natural gas network to hydrogen from 2030.
- New build homes include hydrogen-ready boilers and appliances from 2025.
- Consumers invest in high-efficiency appliances and LED light bulbs.

What does 2050 look like?

- Total residential demand in 2050 is 285 TWh.
- A national hydrogen network means 57% of homes use hydrogen boilers for heating.
- Up to 14 million consumers use electric or hybrid heat pumps.
- Most appliances are highly efficient, and some are smart – providing flexibility at times of peak supply or demand.

FES 2022 / The Energy Consumer / Residential 78

What we've found

Scenarios overview:

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- Annual heat pump installations reach 600,000 by 2024, well ahead of the government target.
- This scenario has high levels of residential thermal efficiency installations. Retrofitting takes places from the mid-2020s, helping to offset increases in electricity demand from earlier heat pump installations.
- Consumers turn their thermostats down by 1°C on average to reduce heating demand.
- The development of local hydrogen networks leads to an increase in hydrogen boiler and hybrid hydrogen heat pump installations from 2028.
- Smart appliances are 40% more efficient by 2032.
- The sale of natural gas boilers is banned by 2035.

What does 2050 look like?

- Total residential demand in 2050 is 169 TWh.
- 64% of households have heat pumps – including hybrids.
- Thermal storage is used at times of peak demand to avoid high energy prices, with units recharged during peak supply.
- 10% of homes have only hydrogen boilers, with a higher proportion in the Midlands and the South East.
- 1.5 million homes previously off the gas grid now use biofuels, including in hybrid systems with heat pumps.
- All appliances are smart and highly efficient, with many consumers investing in home energy management systems.

FES 2022 / The Energy Consumer / Residential 79

What we've found

Scenarios overview:

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- There is limited government policy to encourage consumer investment in thermal efficiency measures such as insulation or triple glazing.
- The 2025 Future Homes Standard is not met, but some new builds have heat pumps installed where it is seen to be cost effective.
- Little to no additional policies exist to encourage widespread purchasing of highly-efficient appliances like washing machines and computers, energy efficiency improvements are limited.

What does 2050 look like?

- Total residential demand in 2050 is 317 TWh.
- 40% of homes still use natural gas boilers.
- There are no hydrogen boiler systems as there is no hydrogen network.
- Some consumers install heat pumps, particularly post-2035, but takeup of insulation or thermal storage measures alongside this is limited.
- While some appliances are highly efficient, most are not smart and cannot provide flexibility at times of peak supply or demand.

FES 2022 / The Energy Consumer / Residential 80

Home heating

Figure EC.R.05: Total annual demand for heating homes

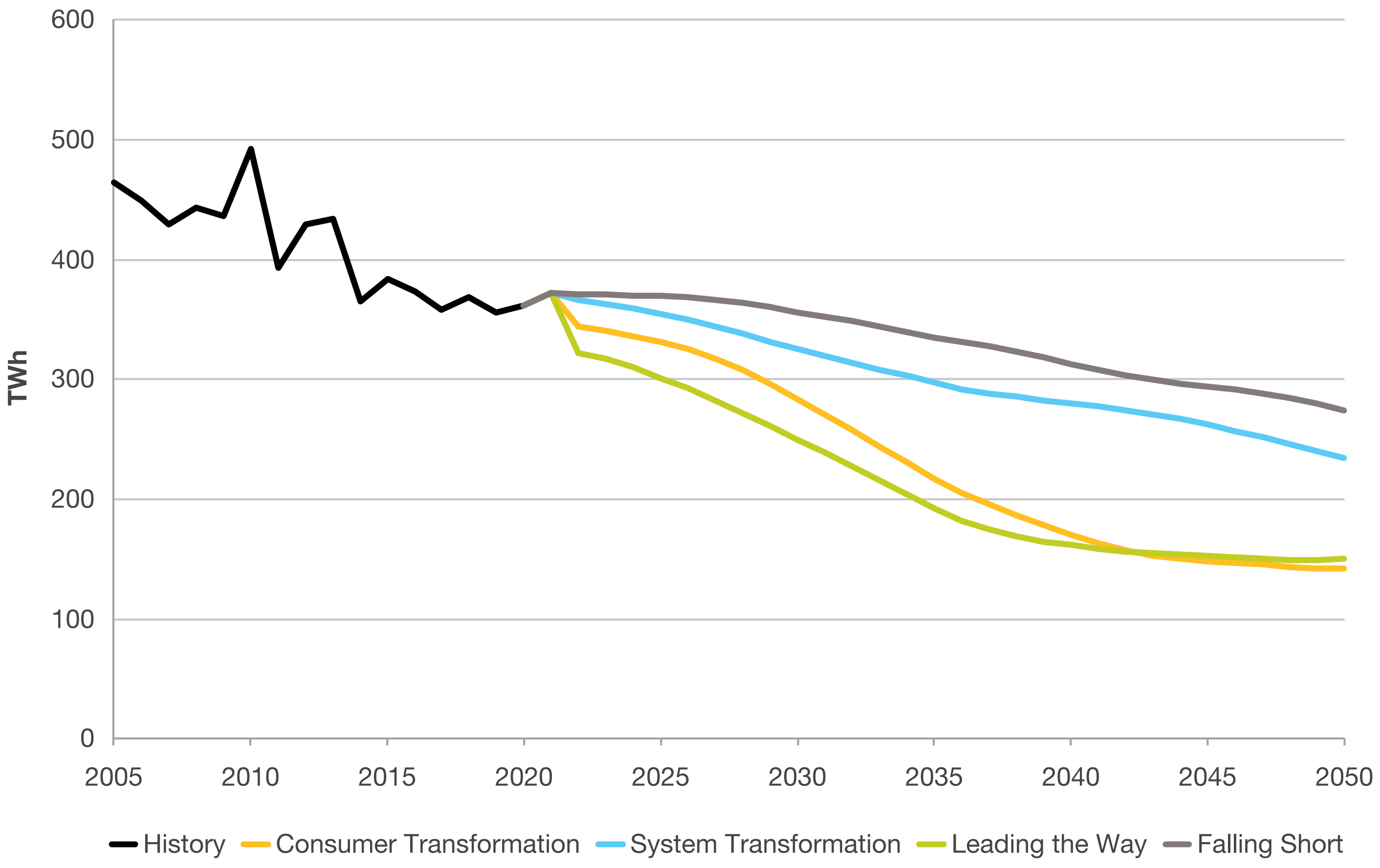
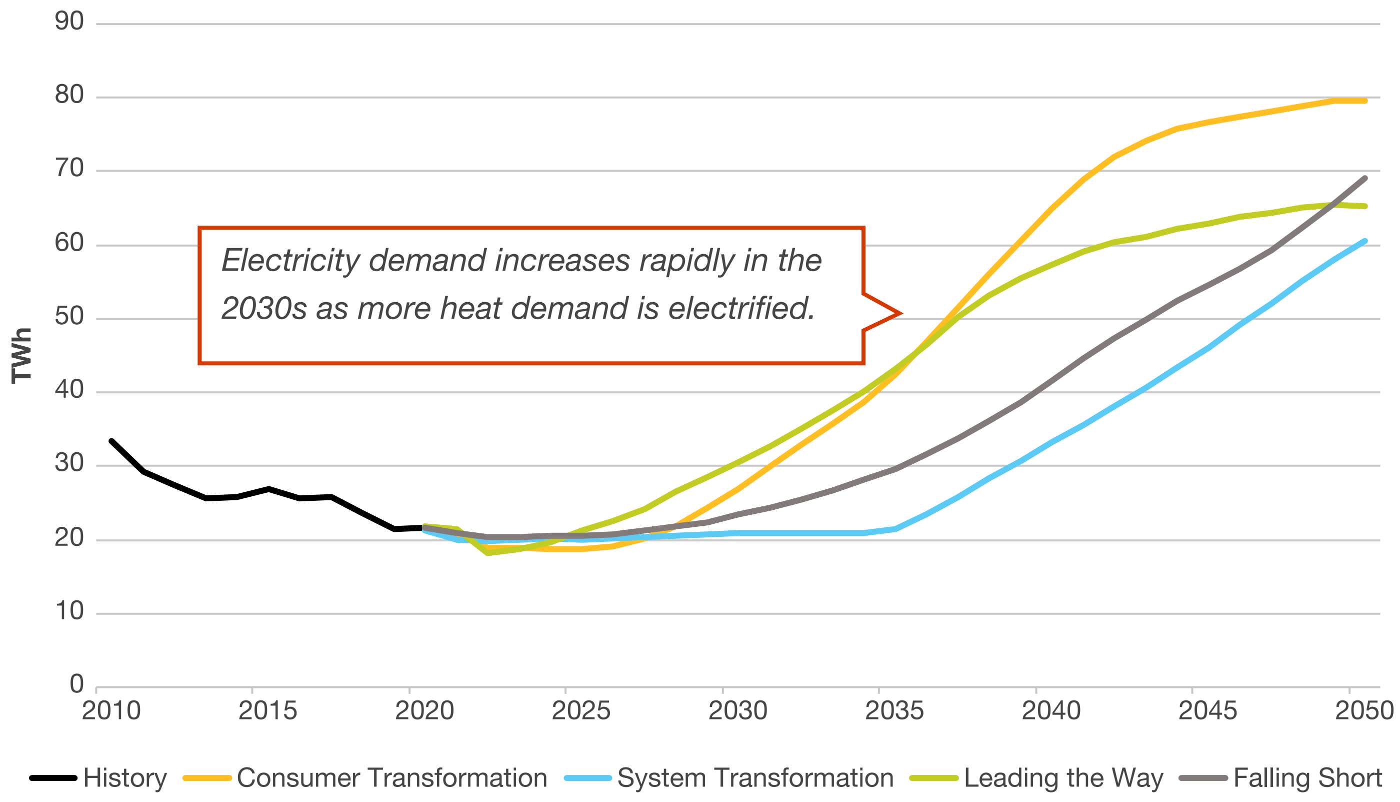


Figure EC.R.06: Electricity demand for heating



What we've found

Figure EC.R.07: Natural gas demand for heating

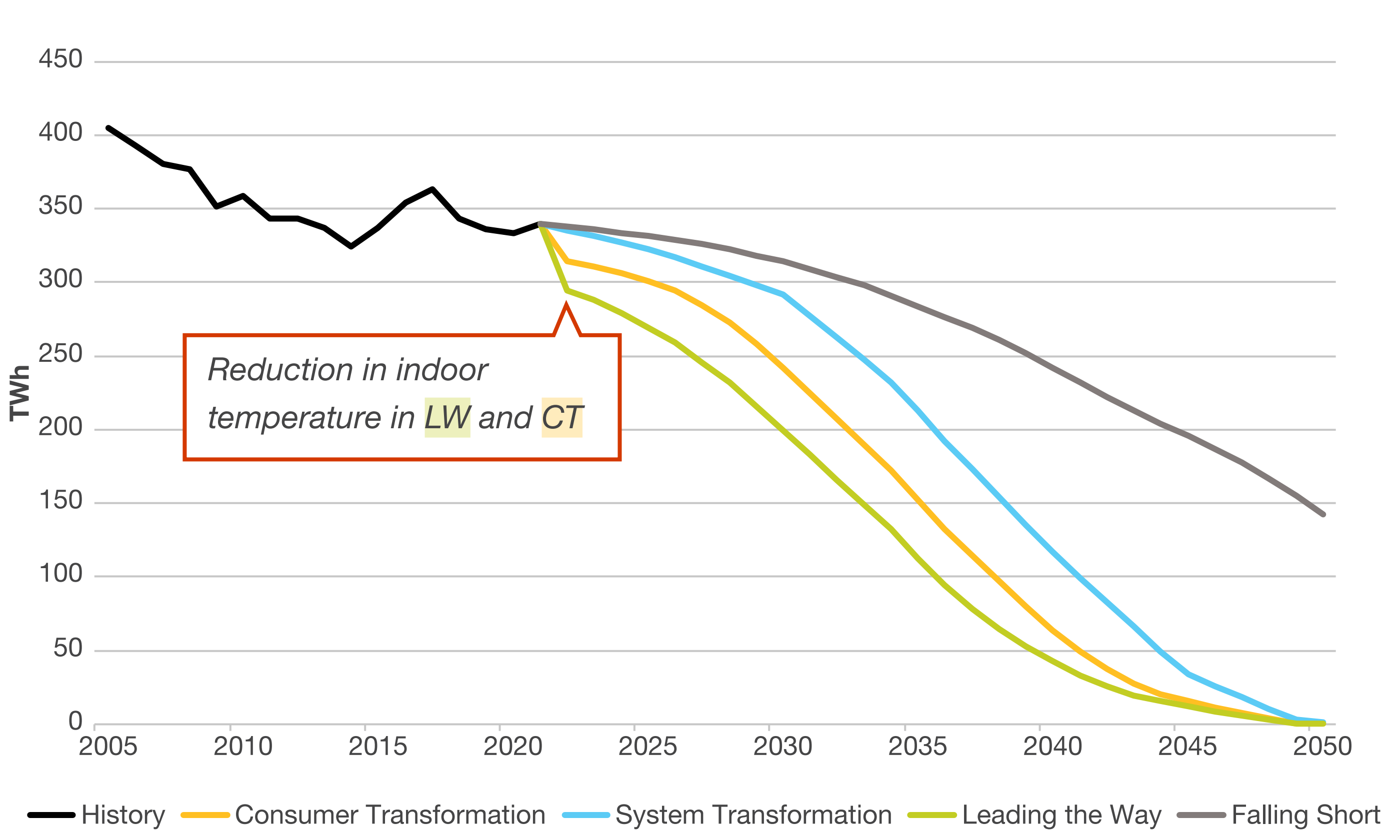
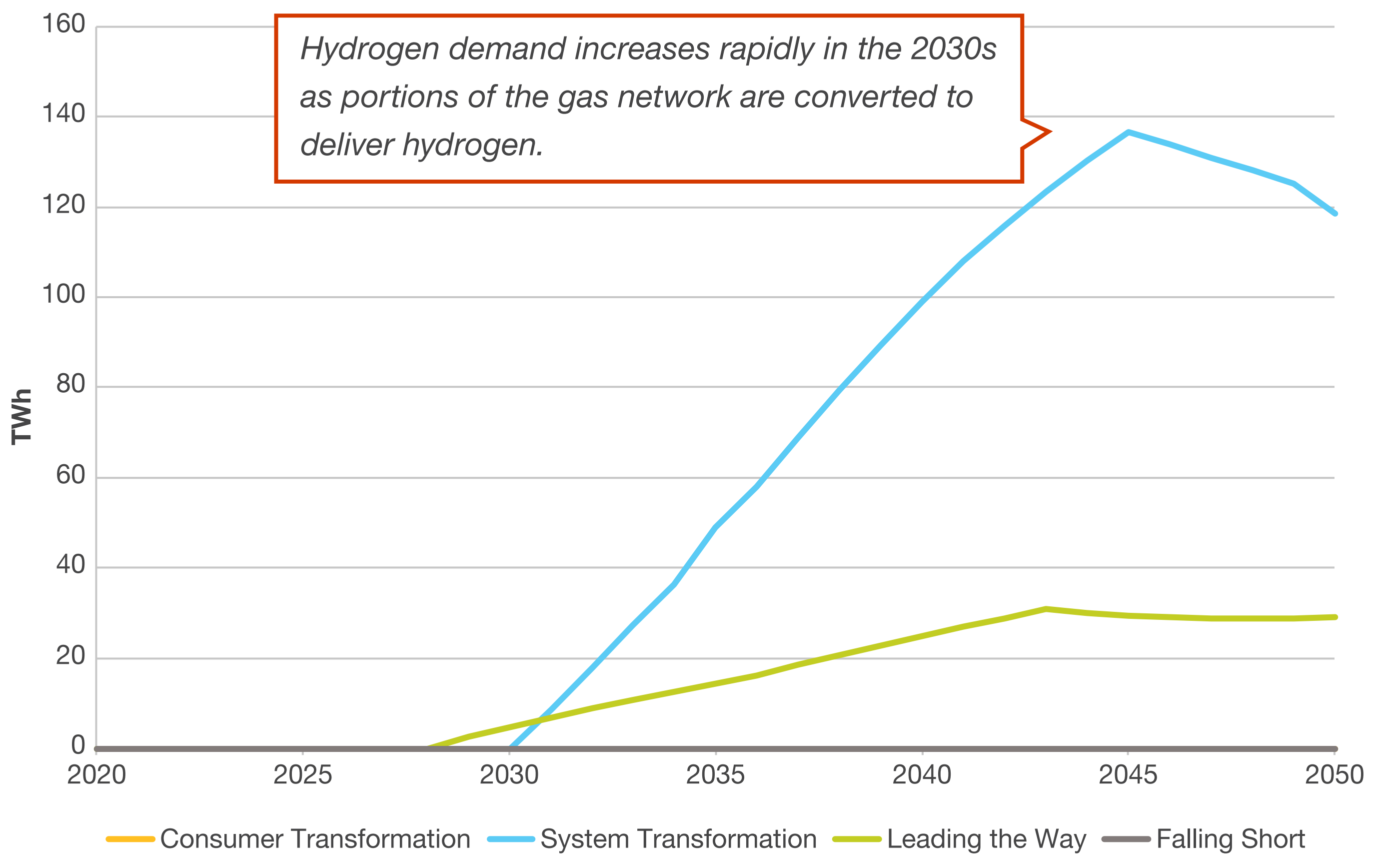


Figure EC.R.08: Hydrogen demand for heating



FES 2022 / The Energy Consumer / Residential 82

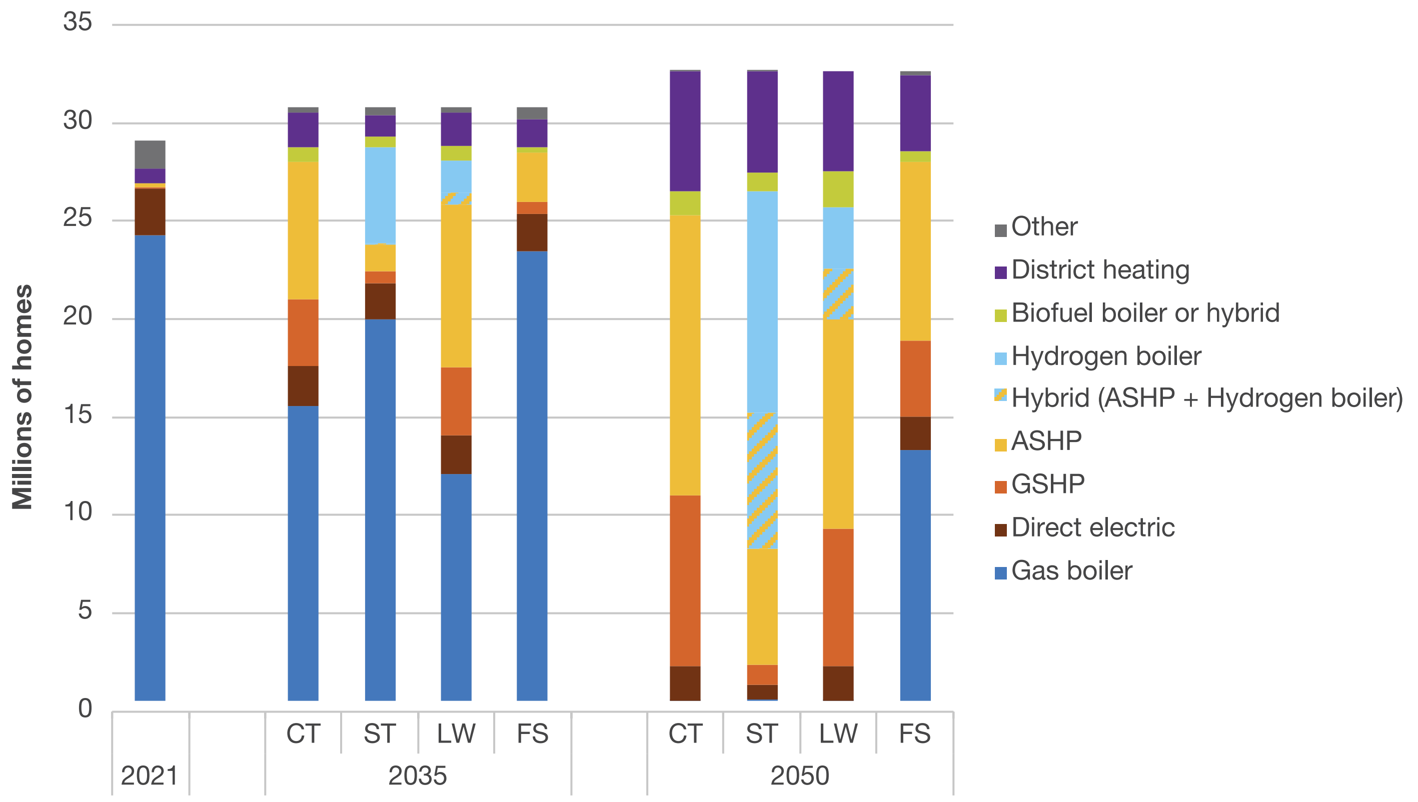
Heating technologies

Existing policy measures are not sufficient to drive the uptake of heat pumps and hydrogen boilers in the short and medium term needed to get the residential heating sector to Net Zero by 2050. A much longer, consistent period of policy incentives will be required to make heat pumps and hydrogen boilers more attractive for consumers compared to gas boilers.

Gas boilers still often have the cheapest lifetime cost for many building types when compared to low carbon technologies, primarily due to low capital costs and a well-established supply chain. Reductions in the higher up-front capital costs for heat pumps and, to a lesser extent, hydrogen boilers are needed, as well as policy interventions to support uptake and allow the market to create new propositions.

This could include scrappage schemes for gas and oil boilers, greater incentives for low carbon technologies, rebalancing energy bill levies away from electricity to encourage electrification or changes to gas and electricity taxation. Any additional policy measures need to carefully consider the impact on all consumers, especially the vulnerable, and particularly in light of recent energy price rises.

Figure EC.R.09: Home heating technology mix today, in 2035 and in 2050

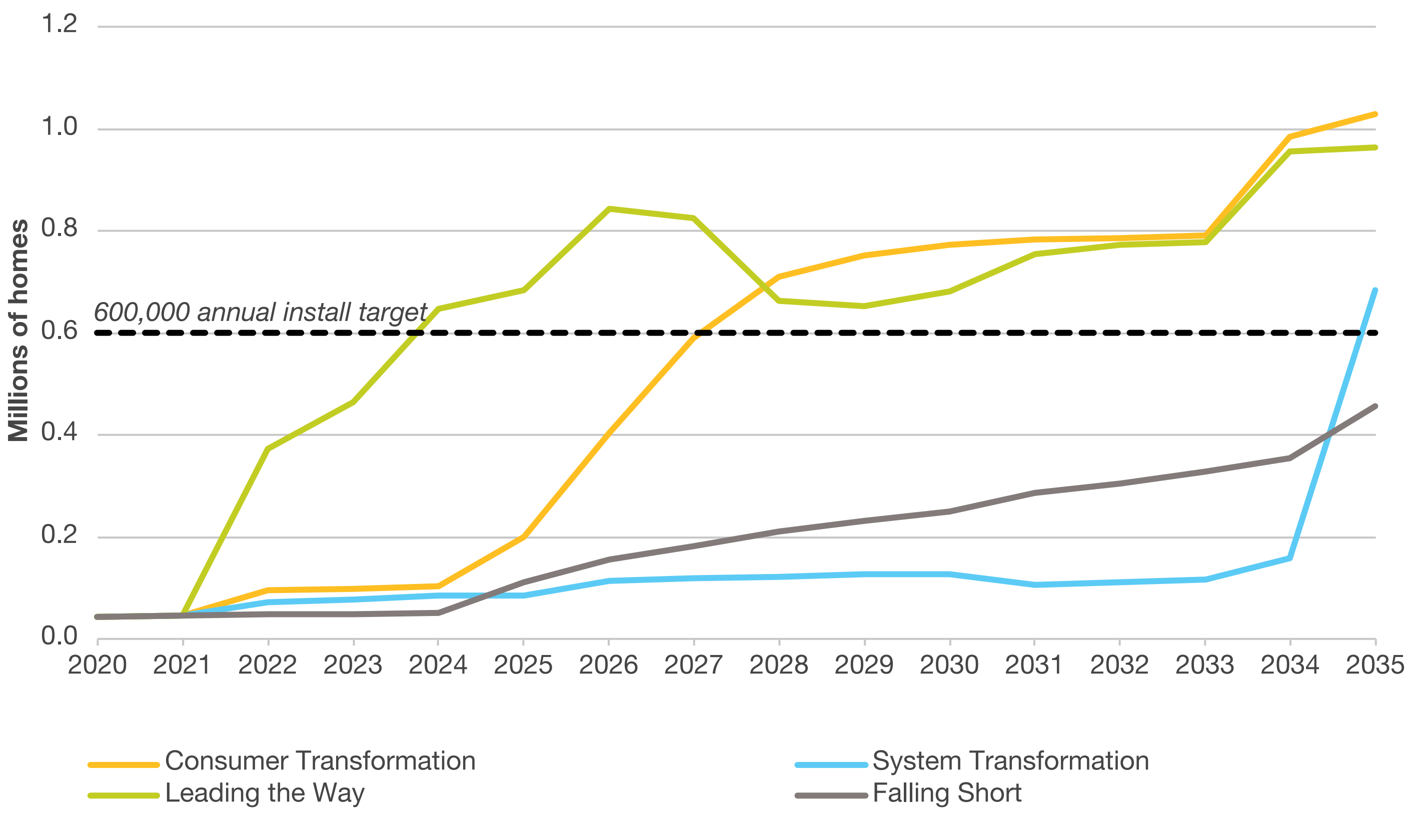


FES 2022 / The Energy Consumer / Residential 83

Heat pumps

Electrification of heat will be a major component of residential decarbonisation. Government targets for 600,000 annual heat pump installations by 2028, up from around 60,000 today, will be very challenging under current policy, with current incentives insufficient to drive take-up as rapidly as required. This target is met in Leading the Way and Consumer Transformation but missed by some distance in System Transformation and Falling Short.

Figure EC.R.10: Annual heat pump installations[2]



A combination of efficiency improvements for heat pumps, gas price rises and new government support for heat pumps means heat pumps could become competitive versus gas boilers over their lifetime for some consumers. However, up-front costs remain a barrier, despite government support. The £450m fund for grants towards heat pump capital costs until 2025 will only support 90,000 installations, with no indication of support available beyond. For the government's target of installing 600,000 heat pumps per year by 2028 to remain on track, an average of over 90,000 per year will need to be installed for the next three years. Further measures will be needed along with cost reductions for heat pumps delivered by industry.

The majority of heat pump installations are Air Source Heat Pumps, with Ground Source Heat Pumps making up a much smaller share. GSHPs are more expensive to install as they require a ground loop or borehole, but are typically more efficient than ASHPs. Costs can be reduced in community schemes with shared ground loop arrays where multiple heat pumps use the same boreholes and thermal storage. These can also take advantage of local sources of waste heat to feed in to the network and improve efficiency.

In Leading the Way, heat pump installations accelerate rapidly through the 2020s, whereas in Consumer Transformation uptake increases more quickly from the mid-2020s. System Transformation doesn't hit the 2028 installation target, with greater emphasis on hydrogen-ready boiler installations and the conversion of the gas network to deliver hydrogen. In Falling Short, heat pump uptake starts to increase post-2030, with limited progress between now and then, as assumed sustained high electricity prices discourage electrification.

2 Includes ASHPs and hybrid systems with a heat pump and another heat source.

FES 2022 / The Energy Consumer / Residential 84

Hydrogen boilers

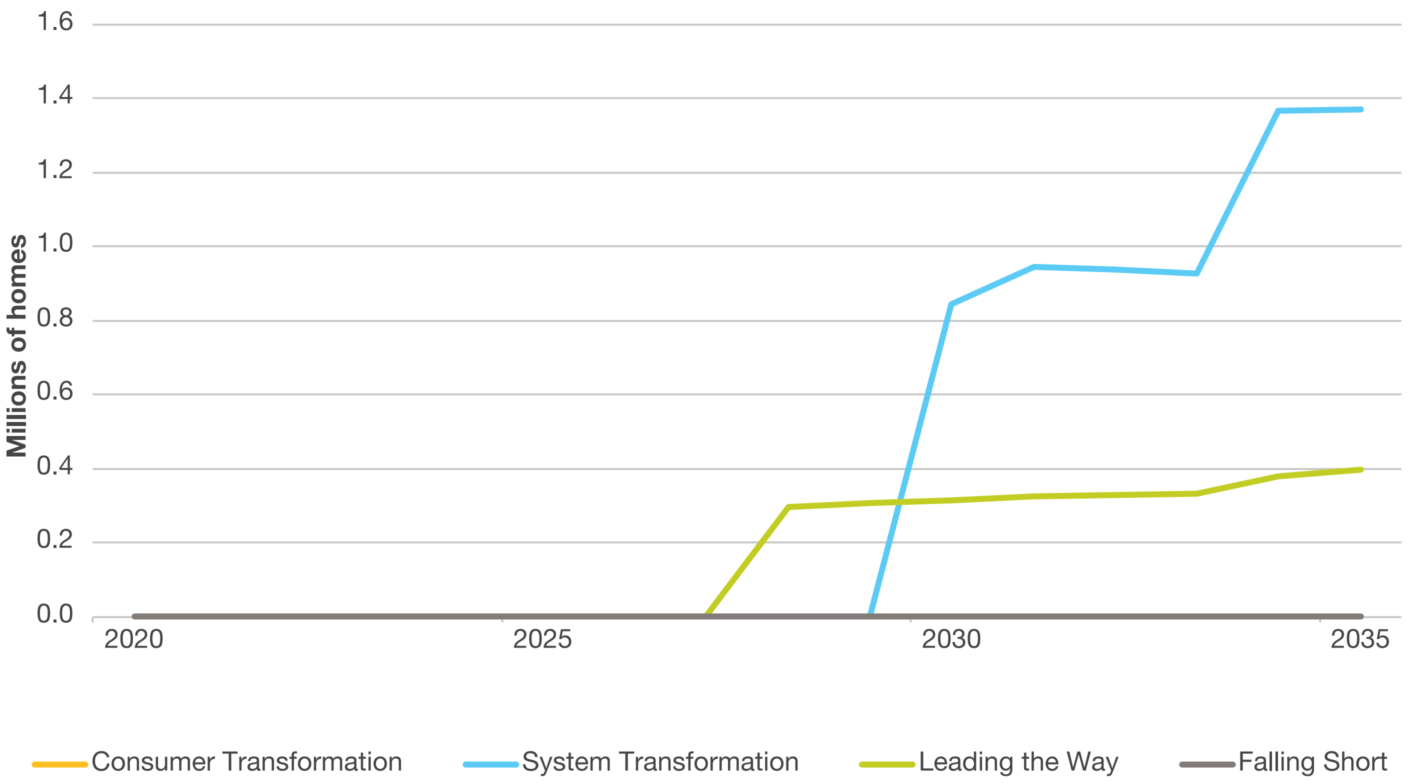
Hydrogen boiler take-up varies widely across scenarios. While every home will have a connection to the electricity network and can access electricity to run a heat pump, consumers will need to connect to a hydrogen network to adopt hydrogen boilers, and this will not be available to everyone. Hydrogen boiler uptake happens earliest in Leading the Way, by 2028, in areas around industrial clusters where hydrogen supply is likely to be available, with System Transformation seeing the first hydrogen boilers in 2030. Leading the Way has regional hubs where smaller hydrogen networks develop, but outside these, hydrogen is not available. The development of green hydrogen from electrolysis and blue hydrogen from methane reformation will affect the viability of hydrogen boilers.

System Transformation has widespread availability of hydrogen and a national hydrogen network from repurposing of the gas grid.

Hydrogen-ready boilers installed post-2025 can be converted to run on hydrogen where the local network switches from gas to hydrogen. This scenario requires a very high number of annual hydrogen boiler installations as parts of the gas network are switched over to deliver hydrogen. This is discussed in the Hydrogen section.

There are no hydrogen boilers in Consumer Transformation due to the lack of a widespread infrastructure for delivering hydrogen to homes. Hydrogen is prioritised for industrial clusters and other specific uses including shipping, aviation and electricity peaking power plants. In Falling Short, hydrogen use is minimal and limited to industry and transport rather than residential.

Figure EC.R.11: Annual hydrogen boiler installations[3]



3 Includes standalone hydrogen boilers and hydrogen boilers as part of hybrid ASHP / boiler systems.

Energy efficiency

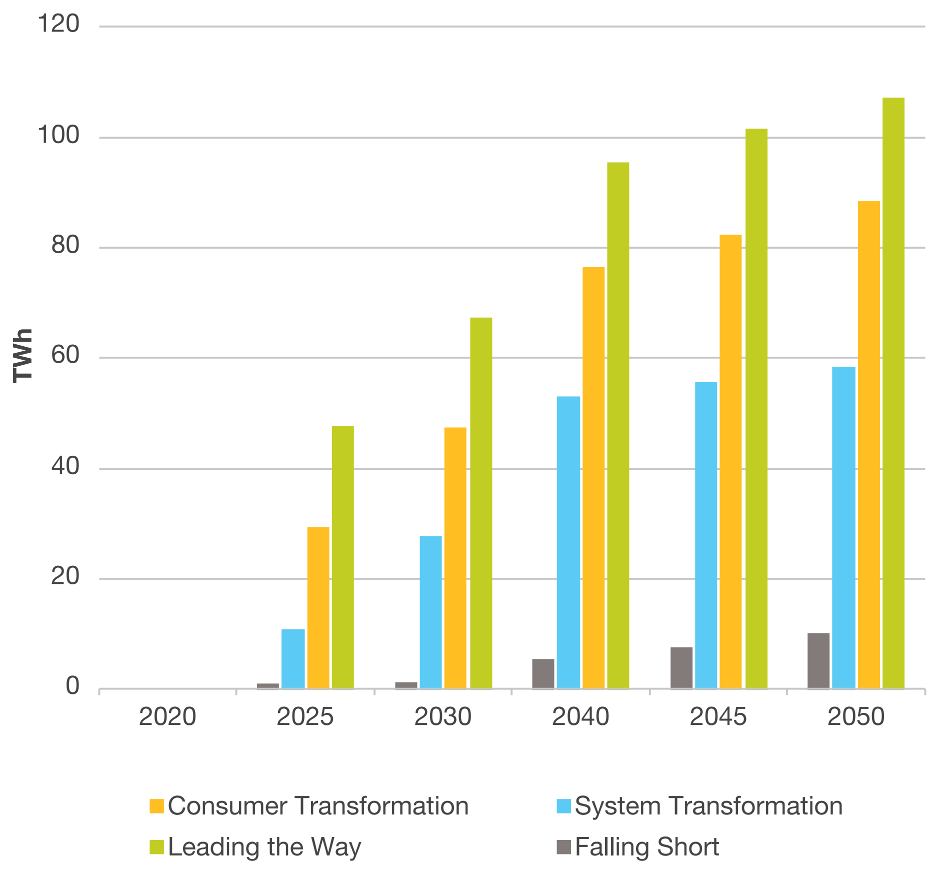
Adoption of thermal efficiency measures in homes – particularly from the early 2020s to mid-2030s and supported by a nationwide government policy to encourage extensive retrofitting – is key to achieving Net Zero emissions by 2050 in the residential sector.

We assume new build properties are more energy efficient from 2025 onwards, driven by the Future Homes Standard. For existing properties, we assume a programme of retrofit measures is brought forward in the Net Zero scenarios. This involves significant improvements to existing housing stock, bringing as many properties as possible up to EPC band C.[4] Retrofit measures will include wall, roof and sometimes floor insulation, and triple glazed windows, and will often be coordinated to take place simultaneously with upgrades to a low carbon heating system.

In scenarios with high levels of consumer engagement we assume consumers are willing to make changes to help reduce energy demand. On average this translates into consumers turning their thermostats down by 1°C in Leading the Way and 0.5°C in Consumer Transformation compared to today's indoor temperature levels, reducing energy demand for minimal change in comfort. These reductions in temperature can suppress heat demand by up to 13% and 7% respectively. These measures are less likely to affect internal comfort in these scenarios thanks to the higher levels of energy efficiency.

The assumed reductions in indoor temperatures in Consumer Transformation and Leading the Way are an average across all housing stock, and there will be some variation in this. For households in fuel poverty who have insulation measures applied to their home, this may allow them to afford to heat their home to a more comfortable temperature when previously it was underheated, leading to an increase in average temperature. This will be offset by some consumers who currently heat their homes to significantly higher temperatures than 21°C reducing their thermostats by more than the assumed 0.5-1°C. More energy efficient homes should have fewer draughts and cold surfaces in the home that make people feel colder at the same air temperature.

Figure EC.R.12: Annual savings in underlying heat demand from applying fabric insulation measures to existing homes, higher standards in new builds and consumer behavioural change



4 Current median EPC rating in England and Wales is band D.

What we've found

FES 2022 / The Energy Consumer / Residential 87

EPC

Energy Performance Certificates or EPCs give a property an energy efficiency rating from A (most efficient) to G (least efficient). They are required whenever a property is sold or rented.

Regional heat variation

The take-up of different technology types varies by region and by scenario.

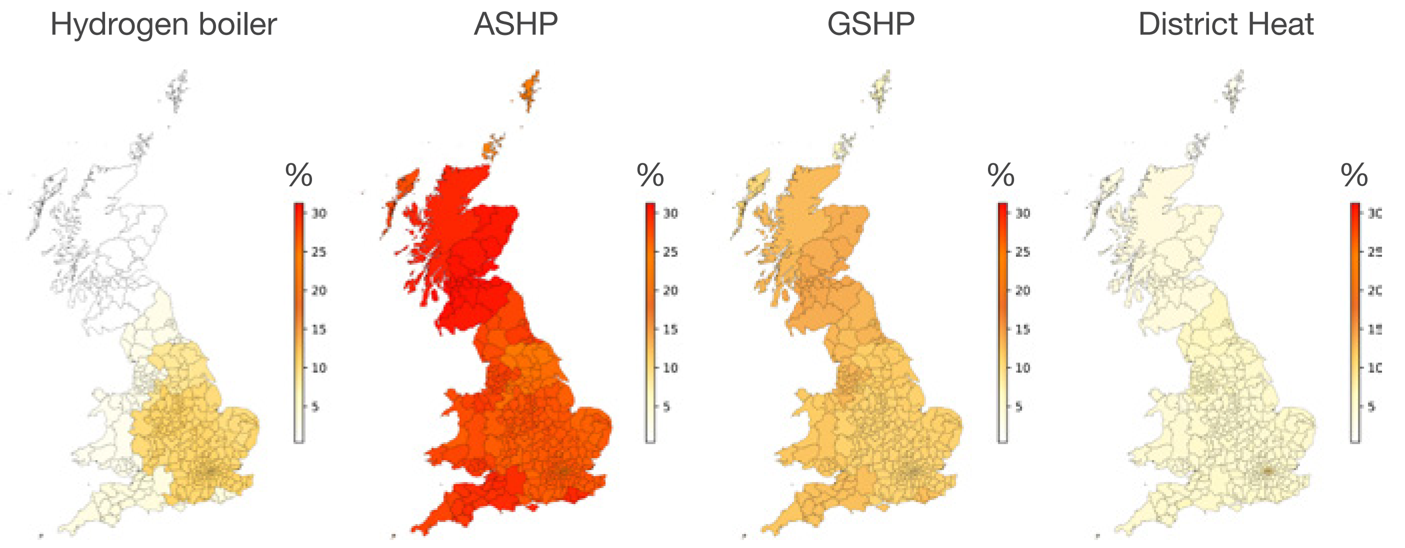
Areas closer to the current natural gas grid are likely to have higher concentrations of hydrogen boilers in a hydrogen dominated scenario, such as System Transformation. In this scenario properties in all Local Authorities would eventually be allowed to connect to a hydrogen network if within a certain distance of the existing gas grid due to a re-purposing of the grid to accommodate higher levels of hydrogen. The modelling assumes that the building has to be within 23 meters of the gas grid for hydrogen network connections. From 2025 new build homes are assumed to include hydrogen-ready boilers and appliances in readiness for switching the natural gas network to hydrogen from 2030 under this scenario.

In Leading the Way we assume that hydrogen production develops initially within clusters. The uptake of hydrogen boilers would therefore be focused in those areas where there is proximity to production as the associated costs of network upgrades to transport the hydrogen from further away become prohibitive. These clusters are based on cost-optimisation. Figure ECR.11 shows the deployment of different technologies in 2035.

Consumer Transformation sees a more uniform deployment of most technology types, but greater take-up of district heating in more urban areas.

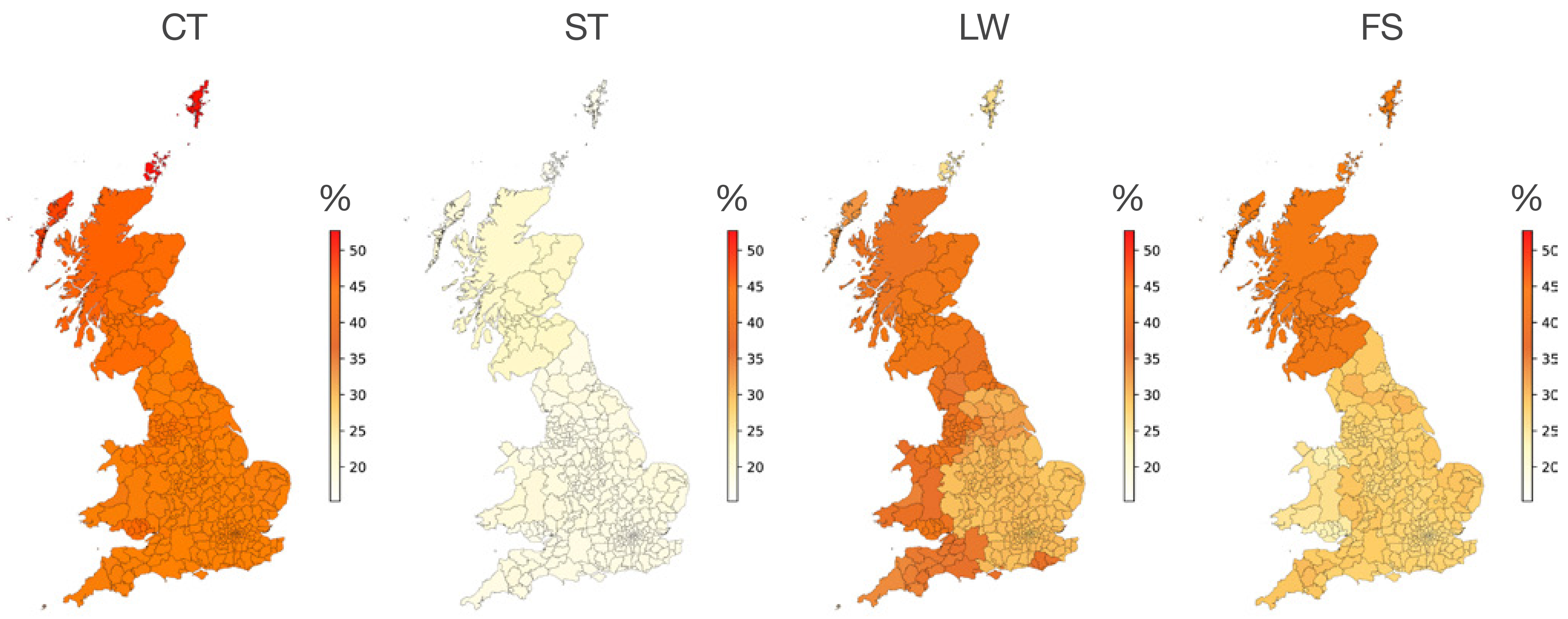
Here we have only shown some key snapshots of regional heating technology deployment. We publish a full detailed breakdown of our regional modelling outputs in our data portal **here**.

Figure EC.R.13: Technology deployment in Leading the Way in 2035



FES 2022 / The Energy Consumer / Residential 88

Figure EC.R.14: Heat pump take-up in 2050



FES 2022 / The Energy Consumer / Residential 89

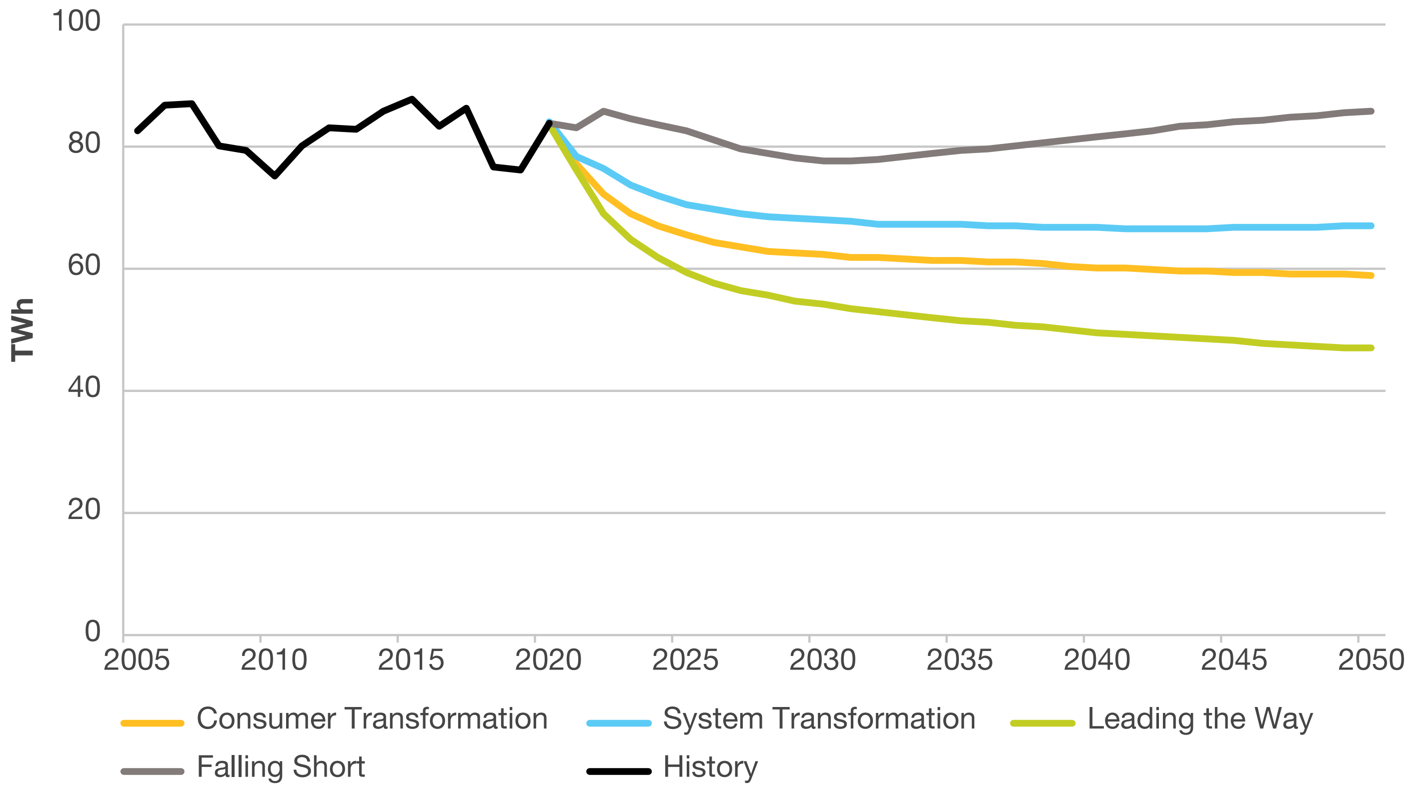
What we’ve found

Appliances

Demand from electrical appliances including white goods, lighting and computers reduces in all Net Zero scenarios compared to today.

This demand reduction is primarily driven by increased energy efficiency, and the ongoing switch from filament bulbs and halogens to LEDs as lighting is replaced. Falling Short has higher electricity demand as consumers aren’t as keen on purchasing more energy efficient or smart appliances or engaging with smart tariffs.

Figure EC.R.15: Annual residential electricity demand for appliances

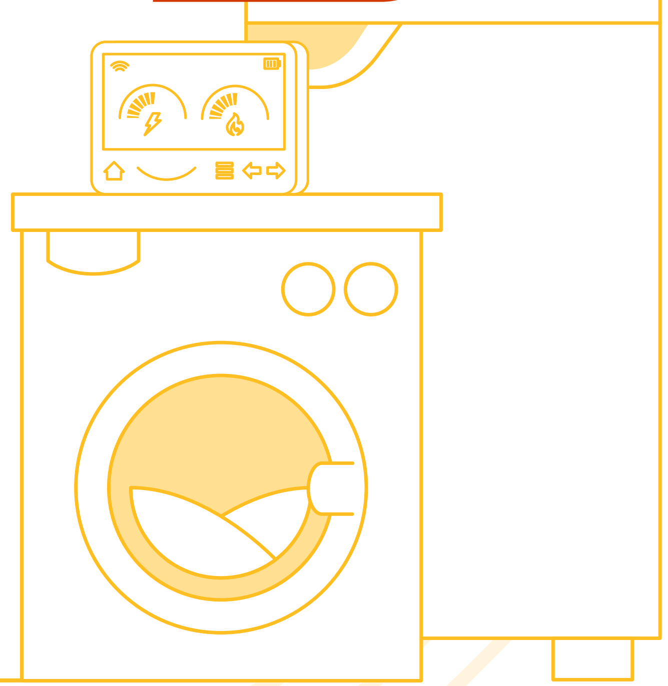


Consumer engagement with smart electricity tariffs and Demand Side Response is expected to grow. While smart appliances alone are unlikely to provide consumers with sufficient incentive to engage with Time of Use Tariffs, we assume major purchases such as Electric Vehicles and heat pumps will provide this impetus. In Leading the Way consumers adopt a smart tariff immediately with these purchases post-2026. In the other scenarios there is a time lag between purchase and smart tariff adoption that varies according to level of societal change. Once consumers do adopt a ToUT, this enables participation in load shifting from smart appliances.

Appliances are a relatively small component of DSR, but could still make an important contribution to DSR at peak; indeed recent years have seen aggregators start to make inroads into the domestic market. Other than EVs (which we discuss in the Transport section), we assume the only form of residential demand consumers are willing to shift away from at peak is white goods. Demand from these at peak is approximately 13% of peak residential electricity demand.

White goods

Large electrical household goods, including washing machines, dishwashers, tumble driers, fridges, freezers etc.

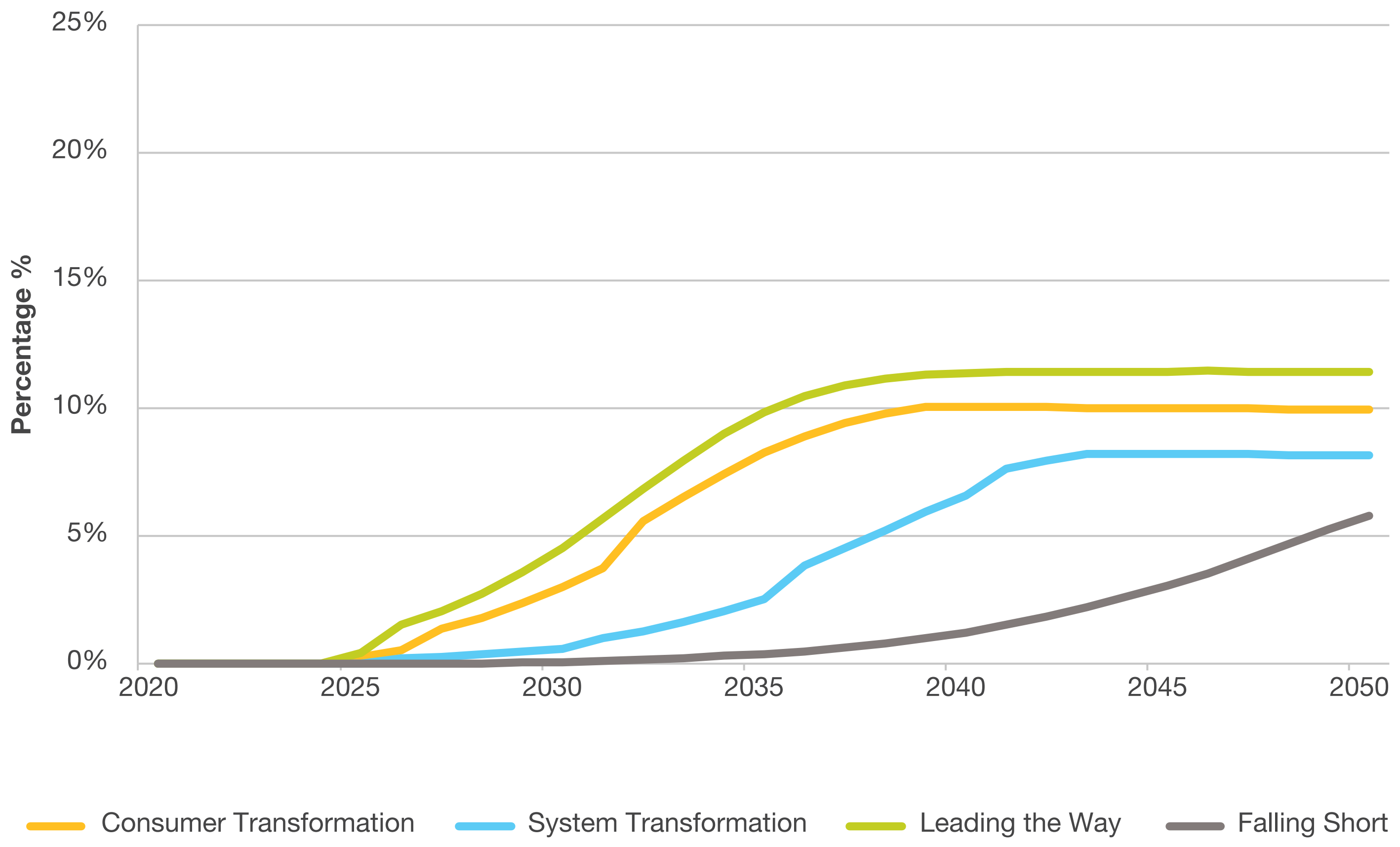


FES 2022 / The Energy Consumer / Residential 90

What we've found

In Consumer Transformation and Leading the Way, we assume high levels of DSR and consumer engagement with smart tariffs encouraged by high levels of electrification and appropriate policy and incentives. We therefore see earlier adoption of smart appliances in these more engaged scenarios. Policy must ensure barriers to entry for consumers are low, with appliances able to automatically respond to price signals. This requires appropriate standards and supply chains to provide this functionality. Incentives are also required for a suitable level of financial return. In Leading the Way, we see up to 11% of residential electricity demand at peak shifted by white goods, with engagement increasing rapidly through the late 2020s as consumers purchase smart appliances and adopt ToUTs.

Figure EC.R.16: Reduction in non-heat residential peak electricity demand from demand side response by white goods



FES 2022 / The Energy Consumer / Residential 91

Smart heating and thermal storage

The extent to which consumers embrace dynamic tariffs and thermal storage will have a significant impact on balancing the energy system.

The electrification of heat has the potential to significantly increase peak electricity demands, and so the adoption of smart controls, thermal storage and DSR for heating systems plays an important role in mitigating this increase and reducing the need for additional generation capacity and electricity network reinforcement.

Pricing incentives will encourage consumers to turn their use up, down, on or off and help manage the peaks and troughs in supply and demand. Energy suppliers have provided tariffs like Economy 7 since the 1970s, offering consumers cheaper electricity over a set seven-hour period overnight. More recently, some dynamic tariffs or Time of Use Tariffs incentivise consumers to increase or decrease their demand – turning on or off electrical appliances – depending on the levels of demand and renewable generation on the system.

In FES, we assume that the getting an EV or a heat pump acts as a trigger for consumers to change to a dynamic energy tariff as the increased domestic electricity demand incentivises them to pay more attention to their energy consumption. This happens immediately in Leading the Way and is increasingly staggered in the other scenarios according to their level of societal change. Thermal storage can then operate on a set schedule or based on forecast electricity prices, in order to store heat at times when electricity is cheap and then discharge at peak times.

Figures EC.R.17 and EC.R.18 show the aggregated profiles for operation of ASHPs and GSHPs respectively with thermal storage on the peak (coldest) day. Thermal storage typically charges up overnight, and discharges partially during the morning peak and again during the evening peak. At 6pm thermal storage discharge shaves 32% of ASHP demand and 25% of GSHP demand.

Hybrid heat pumps will also play a role in shifting electricity demand away from peak in System Transformation and Leading the Way, as the heating system switches to use hydrogen at peak times. District heating systems usually have a large thermal store to help manage supply and demand, and this will also play an important role in helping shift heat demand away from peak. More detail on the aggregate response from thermal storage and heating systems can be found in the Flexibility chapter.

Thermal storage

These can be hot water tanks or new forms of storage such as phase change materials and are sized to meet demand at peak times.

FES 2022 / The Energy Consumer / Residential 92

What we've found

Figure EC.R.17: Thermal storage operation with an Air Source Heat Pump on the peak day in Leading the Way

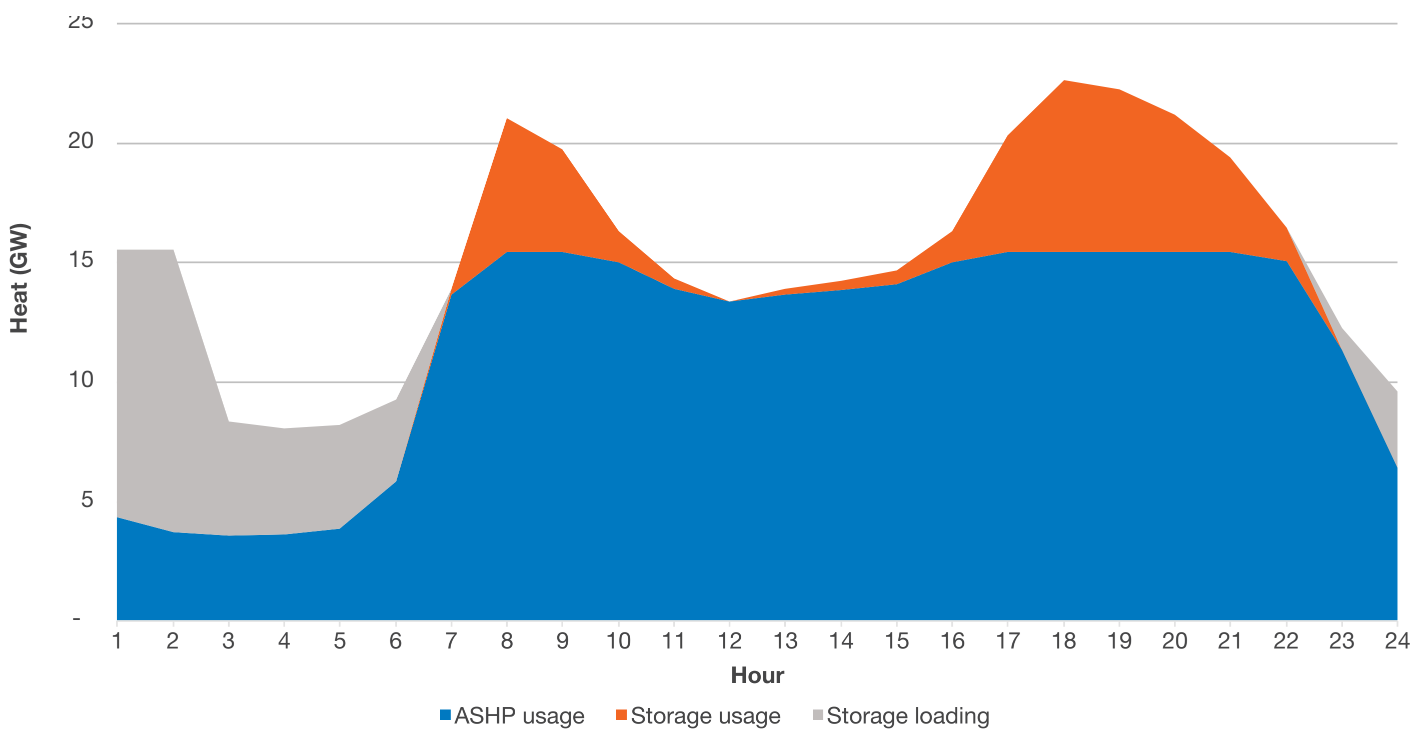
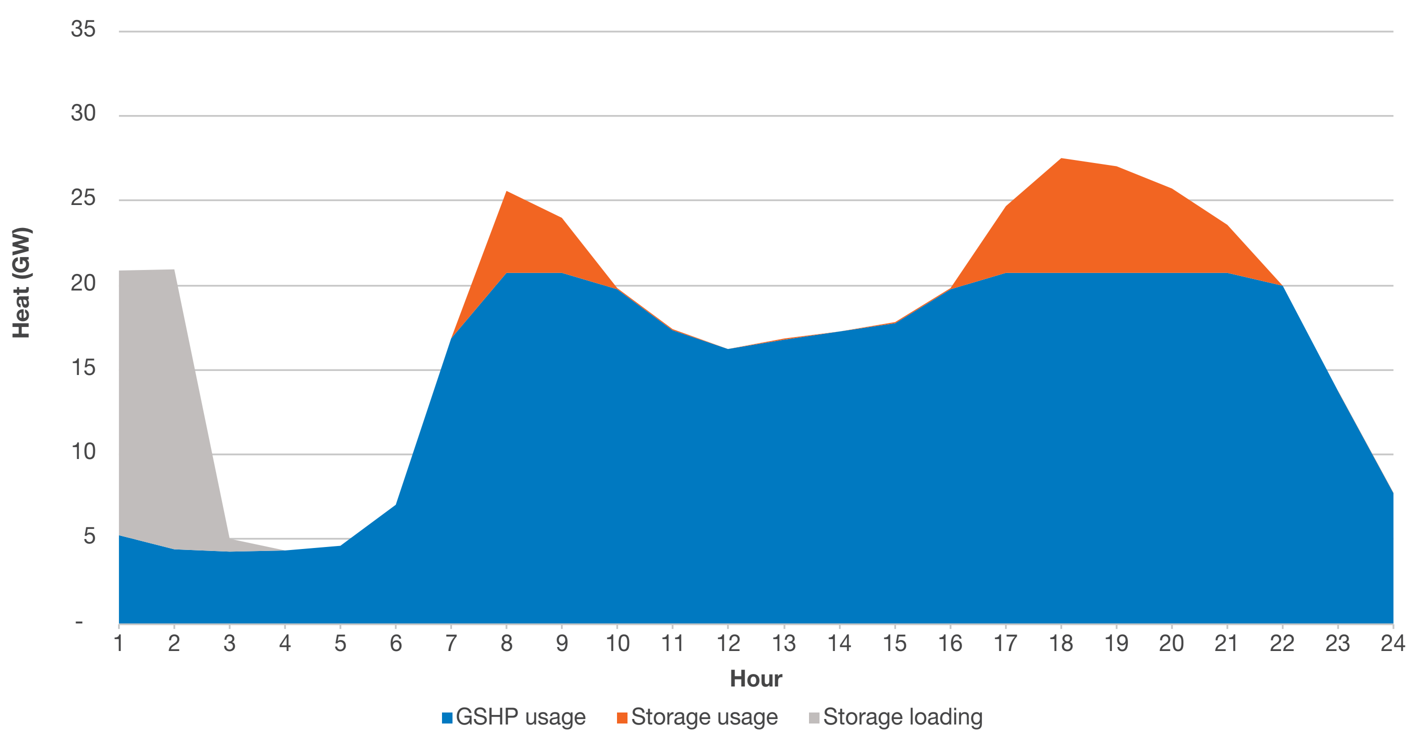


Figure EC.R.18: Thermal storage operation with a Ground Source Heat Pump operation on the peak day in Leading the Way



FES 2022 / The Energy Consumer / Residential 93

Other low carbon technologies

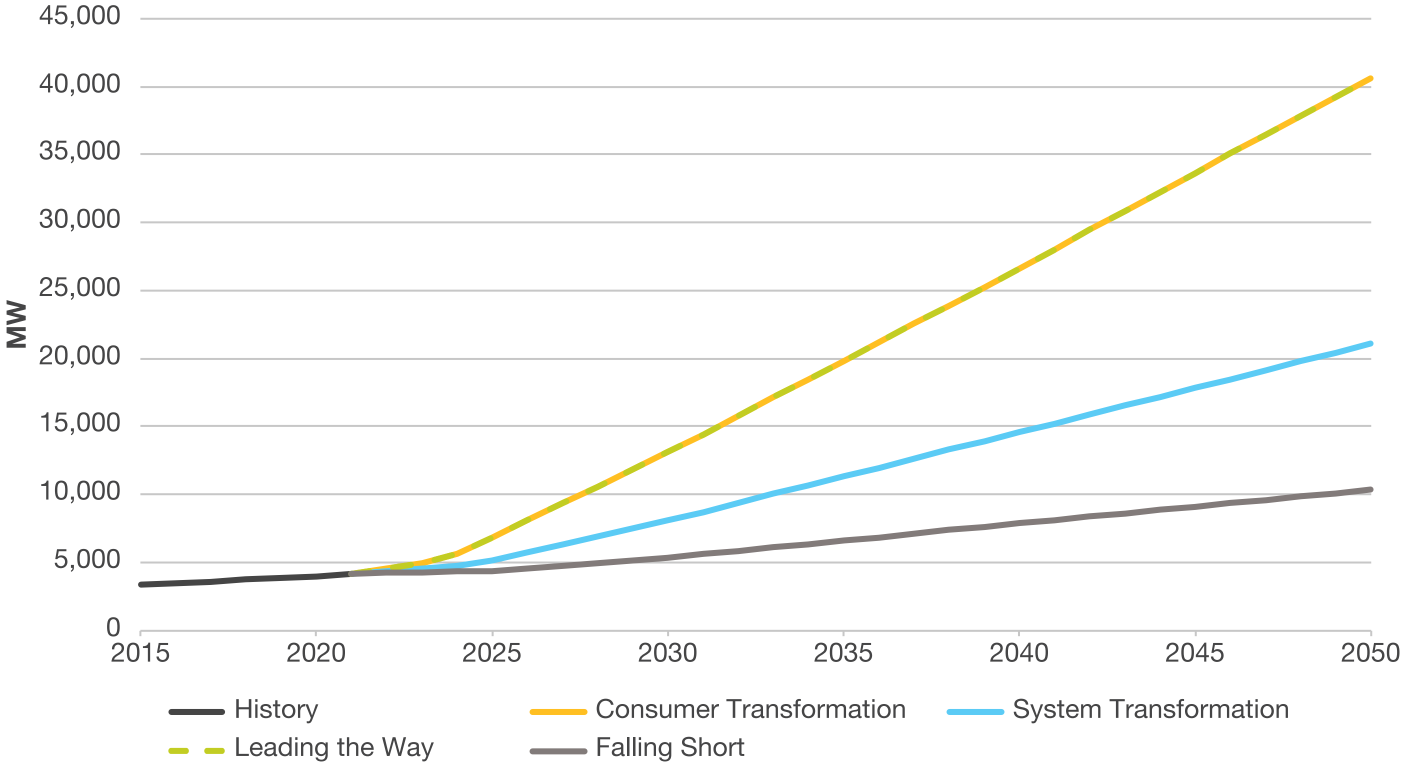
Consumer uptake of domestic generation and storage will change how they engage with the energy system.

Installation of domestic rooftop solar photovoltaic (PV) panels increased rapidly through the early 2010s, driven by the government Feed in Tariff (FiT) and capital cost reductions. In recent years growth has stalled, however continued falls in cost and rises in electricity prices are reducing payback periods, making it an increasingly attractive proposition.

Across our scenarios we expect consumers in scenarios with higher levels of societal change to have the highest appetite for local generation and storage. We expect solar PV installed capacity to increase gradually in all scenarios, and then increase more rapidly in the Net Zero scenarios from the mid-2020s, particularly in Consumer Transformation which sees a nearly 5-fold increase in domestic solar PV capacity by 2035.

We expect take-up of battery storage in homes to increase gradually through the 2020s and accelerate further through the 2030s in Consumer Transformation and Leading the Way. In these scenarios there is a greater share of highly engaged consumers who interact with the energy system. They will automate charging of their EV in response to price signals and feed power back to the system at peak times using V2G. They may have thermal storage to help shift the demand from their heat pump and will often generate their own power from solar PV and install battery storage to maximise self-consumption of this energy. These consumers are driven not only by the potential cost savings from using their own generated electricity and responding to changing Time of Use Tariffs, but also by the desire to be more self-sufficient.

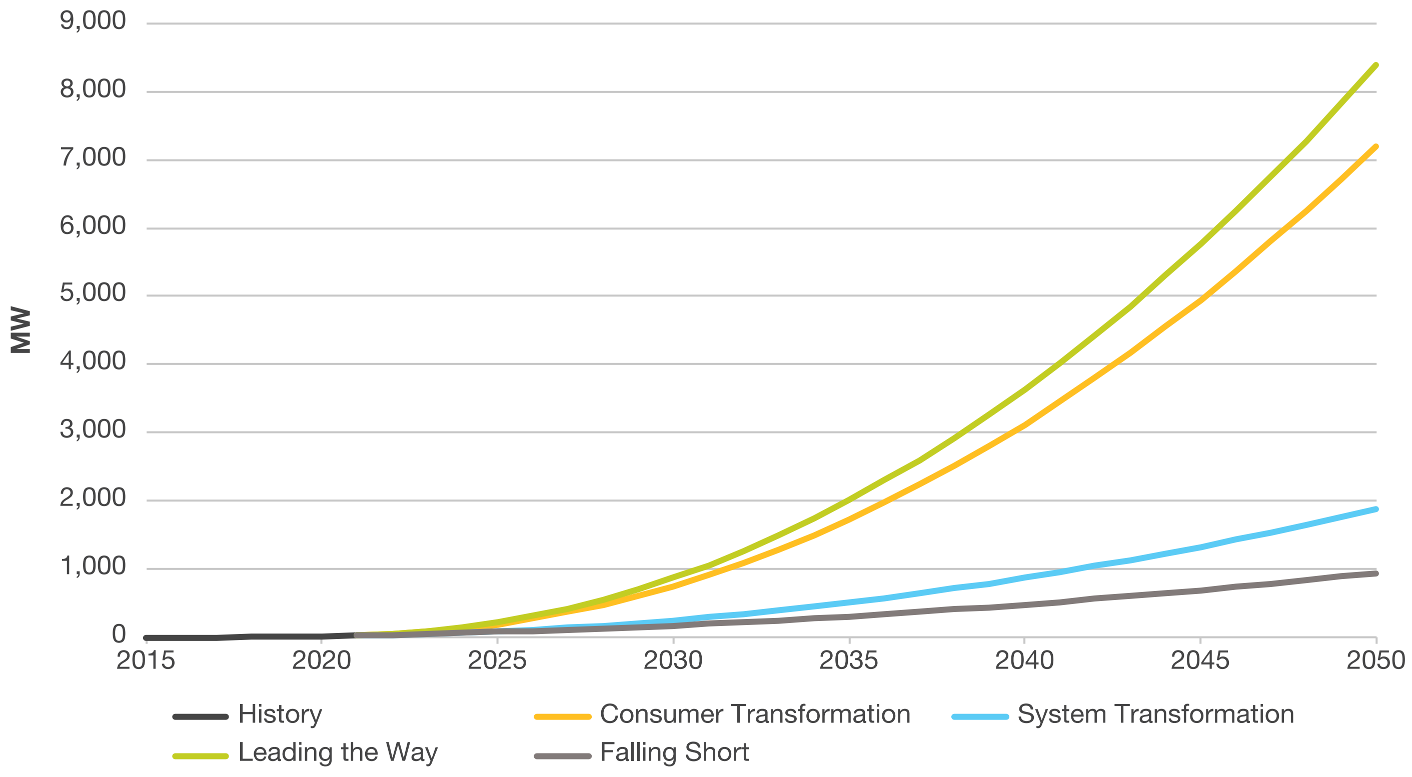
Figure EC.R.19: Domestic solar PV installed capacity



FES 2022 / The Energy Consumer / Residential 94

What we've found

Figure EC.R.20: Residential battery storage connection capacity



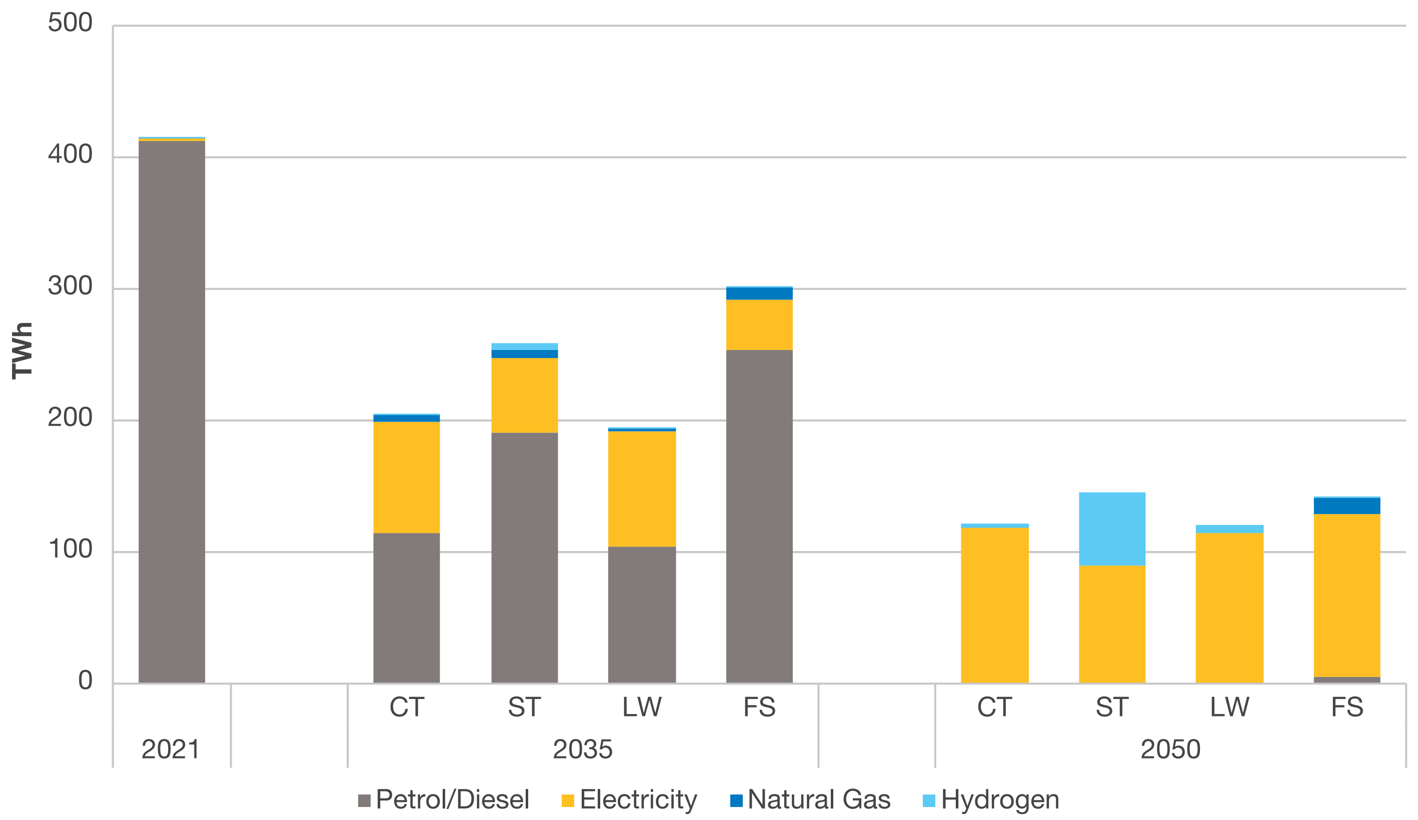
FES 2022 / The Energy Consumer / Residential 95

Transport

Key insights

- We expect adoption of **Battery Electric Vehicles** (BEVs) to be the most common way to decarbonise cars and vans, with the role of hydrogen being less certain and varying across scenarios.
- Electrification of transport leads to increased annual electricity demands in all scenarios, but lower overall energy demand as electricity displaces petrol and diesel. Electric Vehicles have much higher efficiency and travel further on one kWh of electricity than one kWh of petrol, so total energy demand reduces. **Overall transport demand is lowest in scenarios with the most electrification of transport**.
- Sales of electric cars are accelerating, but further action is needed to meet the Government's target for no new sales of petrol and diesel cars by 2030. While government and local leaders have announced measures to help increase uptake of lower emission vehicles, **challenges remain around consumer adoption**, such as up-front costs and the availability of charging infrastructure.
- All new Heavy Goods Vehicles are zero emission by 2040 in the Net Zero scenarios. Earlier dates are hit in our Net Zero scenarios for vehicles under 26 tonnes. Rapid uptake of zero carbon HGVs in the 2030s in line with government targets leads to significantly reduced energy demand for freight and **much lower emissions**. There is a high level of uncertainty in peak demands for HGVs, as it is unclear to what extent HGV charging will be able to avoid use of electricity at peak times.
- Enabling consumer engagement in **smart charging and Vehicle-to-Grid** technology, both for passenger electric cars and larger vehicles, will be crucial to minimise increases in peak demand and requirements for network reinforcement.

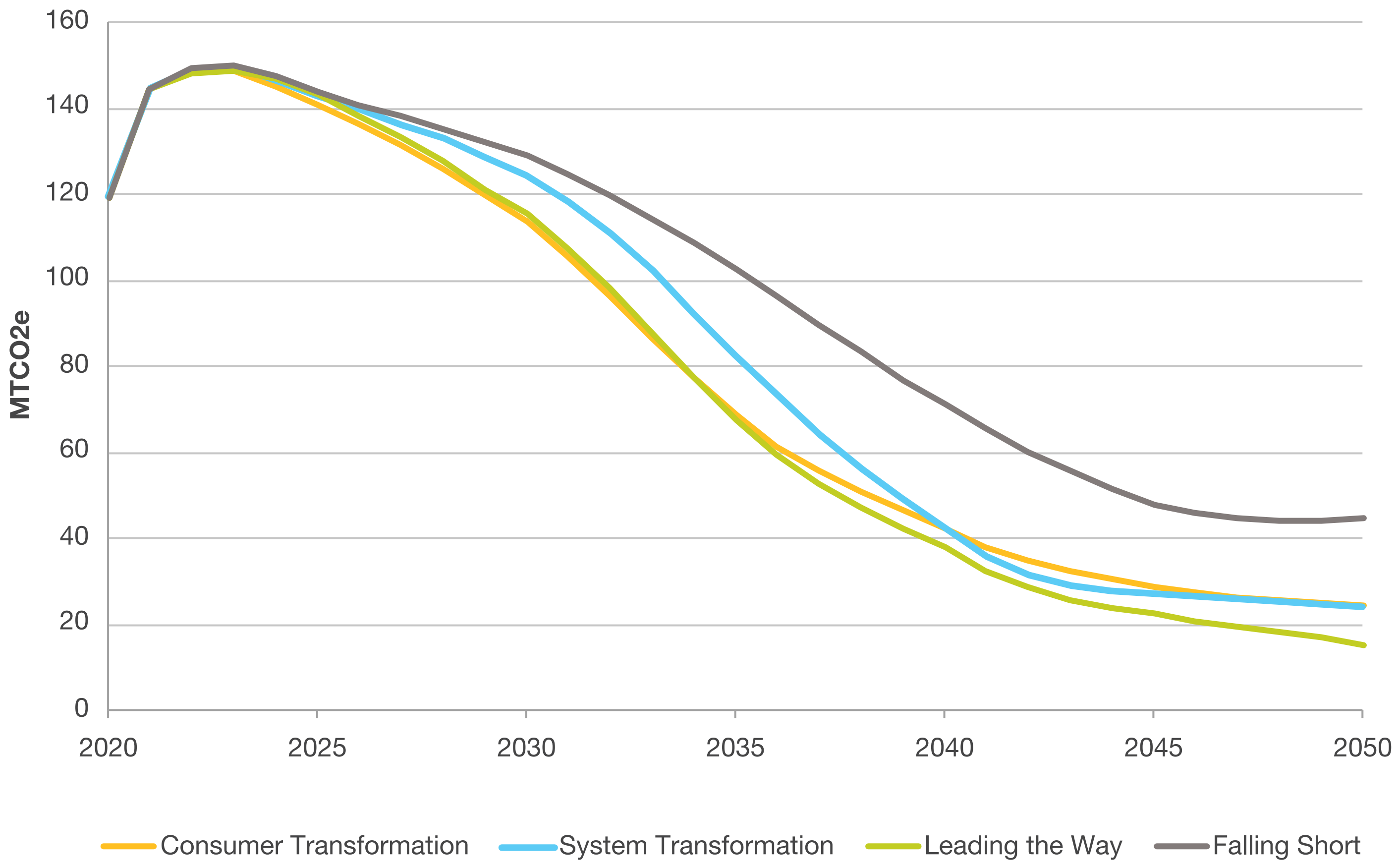
Figure EC.T.01: Total annual demand for road transport in 2035 and 2050



FES 2022 / The Energy Consumer / Transport 97

Key insights

Figure EC.T.02 Emissions from road transport, rail, aviation and shipping



What is transport demand?

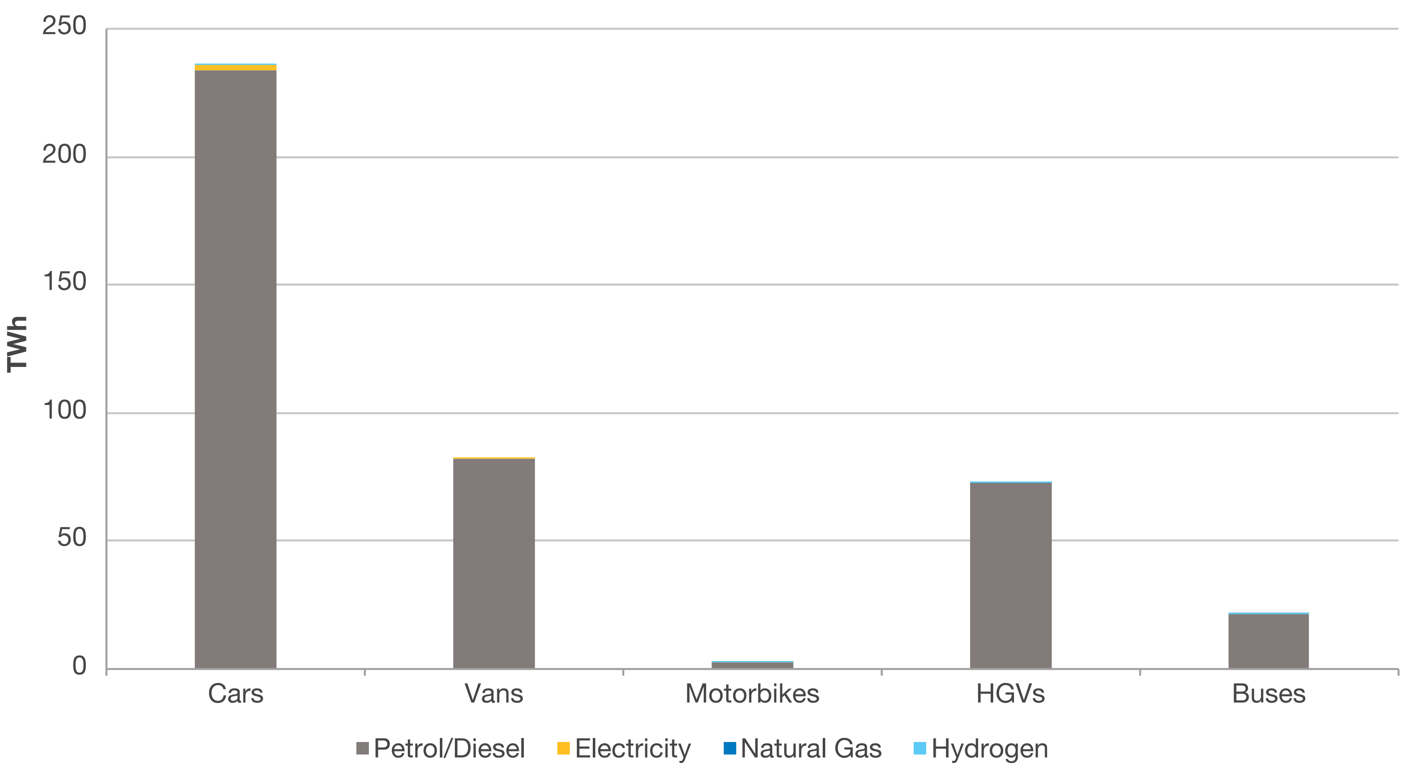
Transport demand covers all energy demand for transport including electricity, gas, hydrogen, and petrol and diesel for road transport, rail, aviation and shipping. This section focuses primarily on road transport, with greater detail on aviation and shipping in the Net Zero chapter.

FES 2022 / The Energy Consumer / Transport 98

Where are we now?

Energy demand for road and rail transport represented 31% of total end consumer energy demand in 2021, and 24% of emissions.[1] This was overwhelmingly met by oil in the form of petrol and diesel; this oil demand is higher than the total demand on the electricity system today.

Figure EC.T.03: Total annual energy demand for road transport in 2021



The government published its Transport Decarbonisation Plan in July 2021, setting out how they aim for the sector to decarbonise. This, together with the Net Zero Strategy and the previously announced ban on sales of new petrol and diesel car by 2030, gives a level of certainty in the near term for how different forms of transport can be decarbonised. The pathway is clearest for passenger cars, with electrification likely to be the dominant solution, but with more variation in the solutions for other forms of transport.

HGVs and vans make up a similar proportion of energy demand. The rise of online shopping and home delivery has led to increased use of vans for local deliveries. However, HGVs are still very important as they carry 90% of the UK's land-based freight.

In 2021 electric cars made up over 10% of new car sales, up from under 2% in 2019. Total car sales (across all types of passenger cars) have been lower in 2020 and 2021 than in 2019 (pre-pandemic), but despite this electric car sales are increasing. April 2021 to April 2022 saw BEV sales nearly double compared to the same period a year earlier.

Despite this rapid progress, only 2% of cars on the road are electric, and they use less than 1% of energy for road transport. It is clear that for the transport sector to reach Net Zero there is still a lot of change needed.

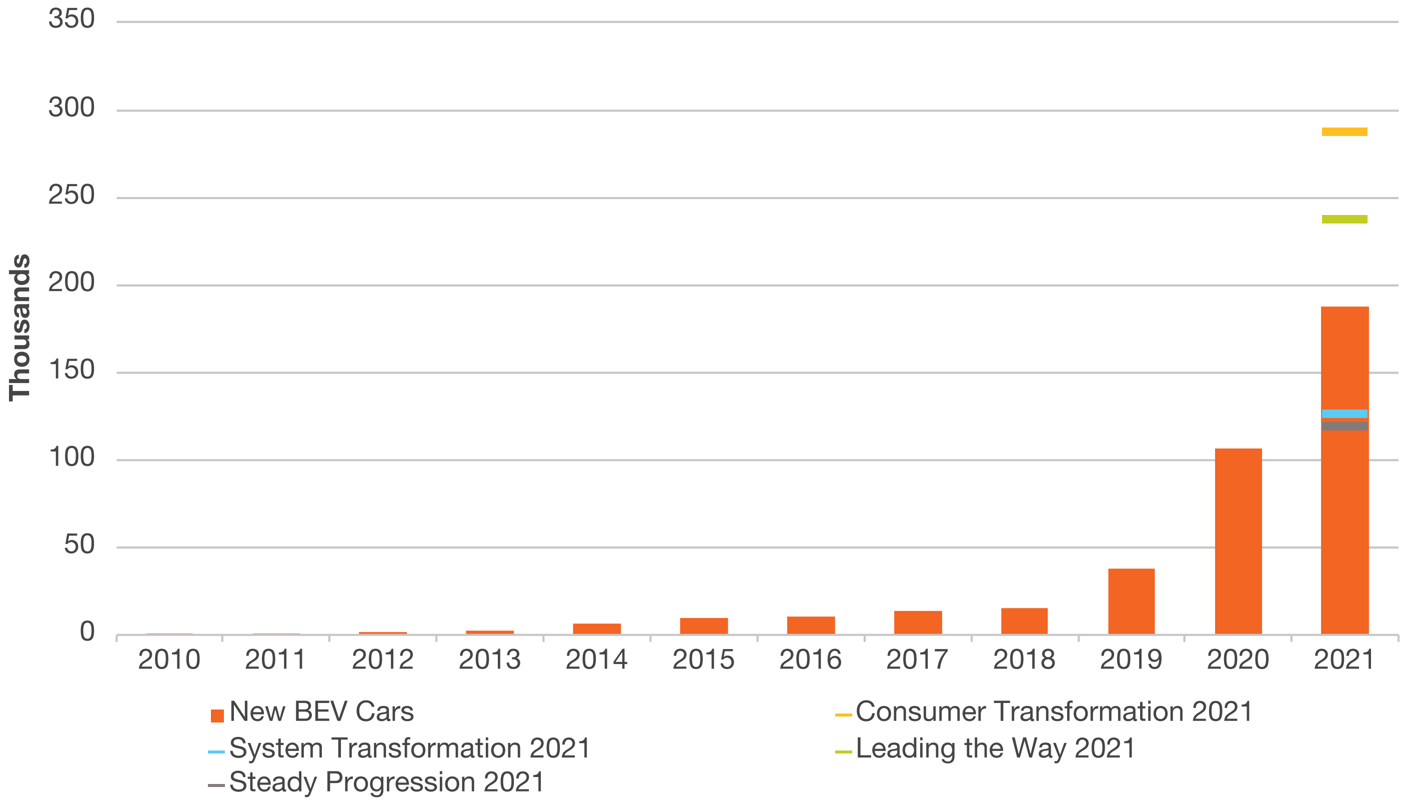
1 Excluding aviation and maritime.

FES 2022 / The Energy Consumer / Transport 99

Where are we now?

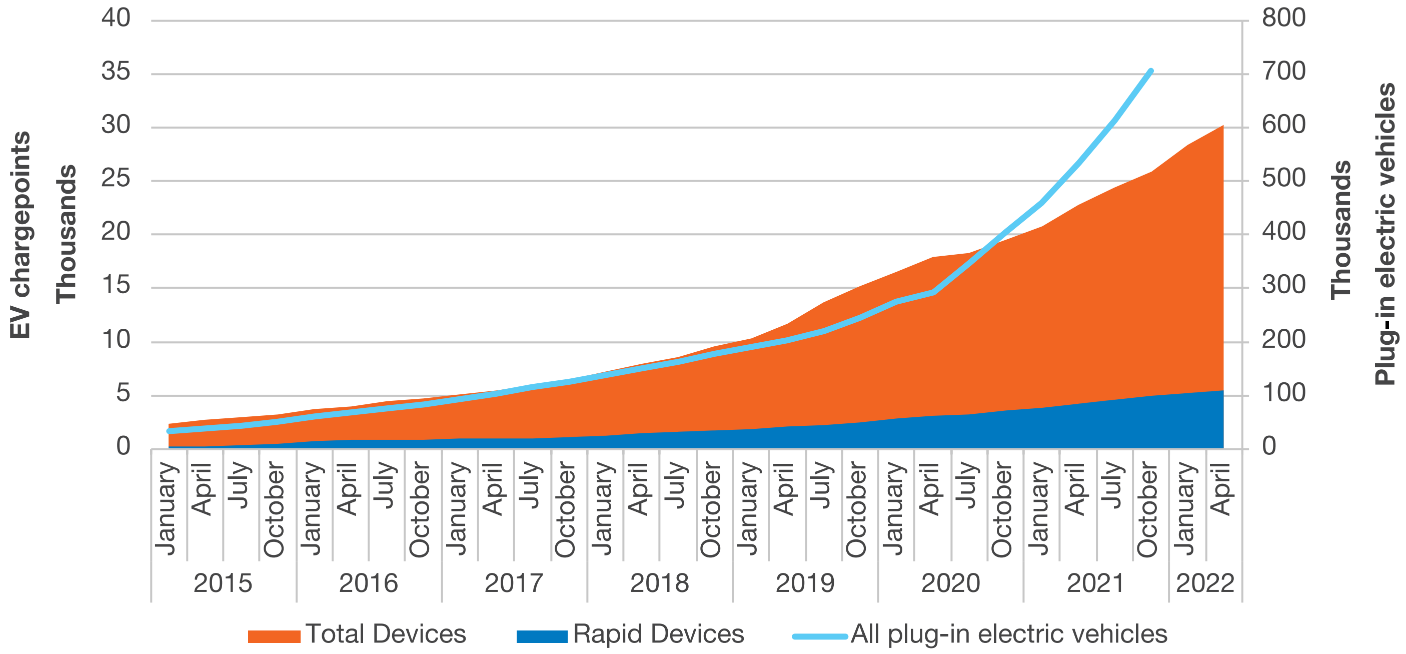
Sales of BEVs are currently above the projected sales for System Transformation in FES 2021, as shown in Figure EC.T.04, but are still not currently on track for the 2030 zero emission mandate, and sales will need to accelerate further.

Figure EC.T.04: Sales of BEVs against FES 2021 forecasts



Availability of public chargepoints is a reason often given by consumers who are reluctant to switch to an EV. This was only behind cost in terms of perceived barriers preventing consumers from switching to an EV[2], despite the ongoing roll-out of charging infrastructure. In March 2022 the Government published an EV infrastructure strategy, aiming for at least 300,000 public chargepoints to be installed by 2030, an 11-fold increase on today. However our scenarios indicate BEV numbers could be 12-32 times higher than today, and this target may not be sufficient. The locations of these chargepoints will also be important. We are exploring the implications this will have on regional demand variation and locational requirements on the electricity network.

Figure EC.T.05: EV public chargepoints installed across the UK



2 Empowering Climate Action, 2021. nationalgrideso.com/future-energy/our-net-zero-work/empowering-climate-action

Scenarios overview: road transport

Consumer Transformation

System Transformation

Leading the Way

Falling Short

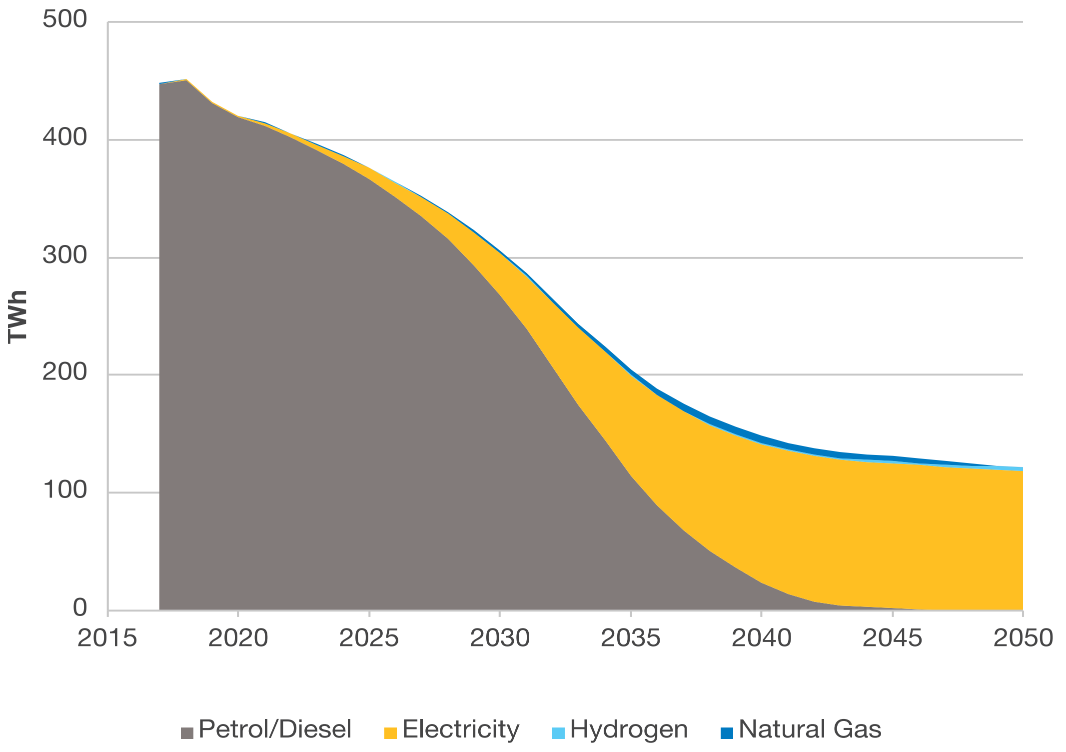
The route to 2050

- In the mid-2020s, higher levels of consumer engagement result in more people opting to use public transport where feasible.
- The 2030 petrol and diesel ban for cars and vans is met, followed by Plug-In Hybrid Vehicles (PHEV) from 2035.
- In the 2030s, uptake of battery electric lorries begins to increase and the 2040 target for all new HGVs to be zero emission is met. Some small growth in hydrogen HGVs post-2040.
- Smart charging of BEVs is widespread, and plays an increasingly important role as road transport is electrified.
- All buses sold are zero emission by 2030, and by 2035 for minibuses and coaches.

What does 2050 look like?

- Total demand for road transport in 2050 is 121 TWh. Most forms of road transport use electricity, with only small amounts of hydrogen.
- Hydrogen use in this scenario is limited, with some use for HGVs. These rely on regional refuelling infrastructure, since there is no national hydrogen network in this scenario.
- Most privately owned BEVs are used to support the grid with 68% of EV charging demand shifted away from peak and over 5m private EVs provide flexibility via Vehicle-to-Grid services.

Figure EC.T.06: Annual energy demand for road transport in Consumer Transformation



What we've found

Scenarios overview: road transport

Consumer Transformation

System Transformation

Leading the Way

Falling Short

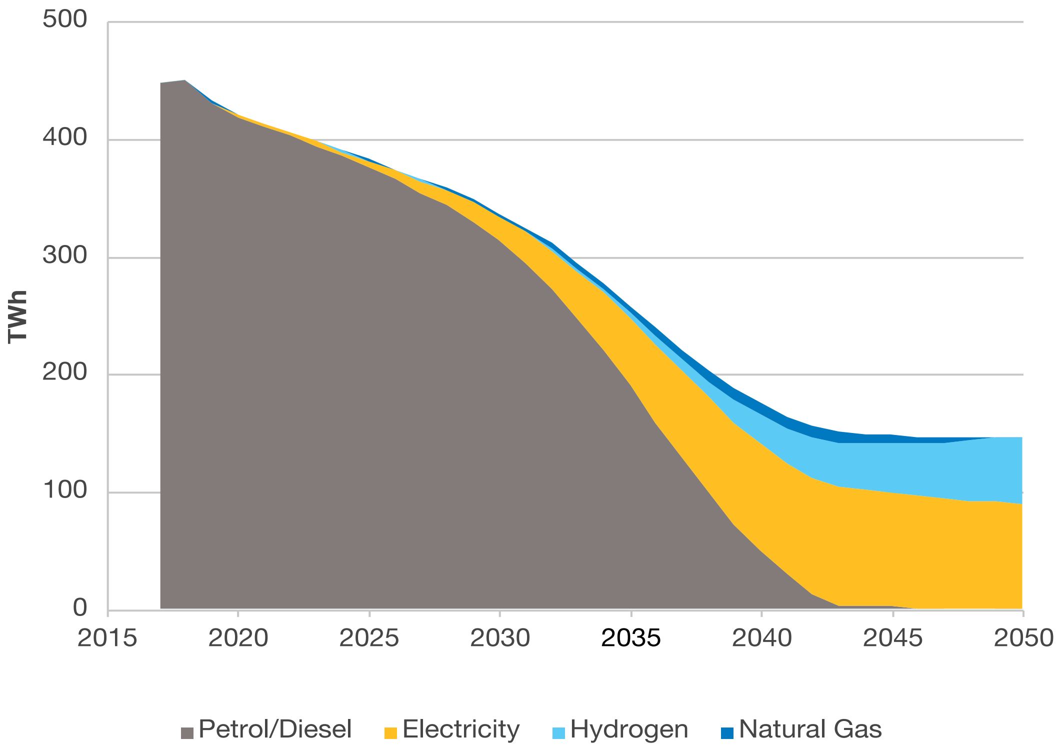
The route to 2050

- The ban on new petrol and diesel car sales is delayed until 2032. Sales of PHEVs are banned in 2035, along with new Internal Combustion Engine (ICE) van sales.
- From the mid-2030s, consumer uptake of Hydrogen Fuel Cell Vehicles (HFCVs) increases in line with the development of local and national hydrogen infrastructure.
- HGVs begin to decarbonise from the 2030s with the majority switching to hydrogen as a national refuelling network develops. The 2040 zero emission HGV target is met.
- All buses sold are zero emission by 2030, and by 2035 for minibuses and coaches.

What does 2050 look like?

- Total demand for road transport in 2050 is 146 TWh.
- This is our highest road transport demand, primarily due to the higher uptake of hydrogen vehicles – over 3 million in total - and the subsequent lower efficiencies that come with using hydrogen compared to electricity.
- Consumers are not as actively encouraged, either by local or national schemes, to ride share, walk or cycle.
- Up to 1m private EVs provide flexibility via Vehicle-to-Grid services, with over 50% of households using smart chargers at home or the office.

Figure EC.T.06: Annual energy demand for road transport in System Transformation



Scenarios overview: road transport

Consumer Transformation

System Transformation

Leading the Way

Falling Short

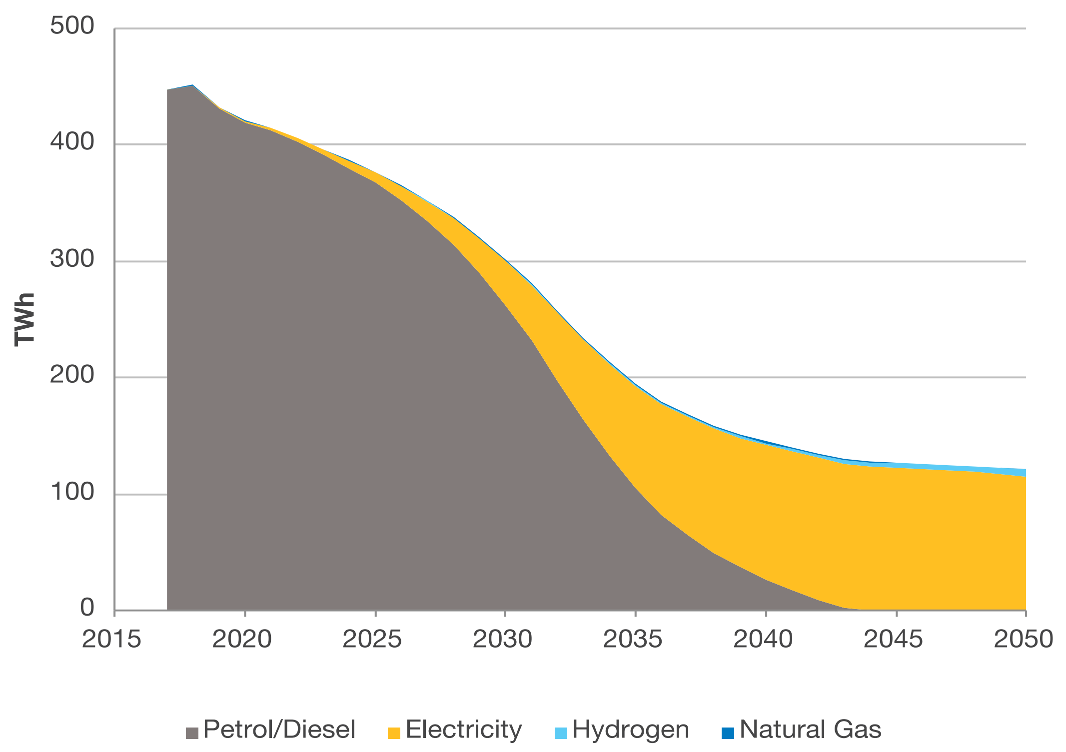
The route to 2050

- From the mid-2020s, consumers frequently use public transport or active travel such as walking or cycling instead of driving where possible.
- The petrol and diesel ban is effective for cars and vans in 2030. PHEV sales are banned from 2032.
- All buses sold are zero emission by 2028, and by 2032 for minibuses and coaches.
- Cars and vans are mainly electric, supported by the widespread national rollout of charging infrastructure, as well as smart charging devices at home.
- All HGVs are zero emission by 2040, primarily electrified, with limited uptake of hydrogen HGVs post-2040. The zero emission HGV target is met.

What does 2050 look like?

- Total demand for road transport in 2050 is 120 TWh.
- BEV cars on the road are lowest in this scenario, at around 25 million, as many consumers choose public transport, or use ride hailing apps for longer journeys.
- BEV cars smart charge at home or at the office, frequently paired with on-site solar PV and batteries to encourage self-consumption.

Figure EC.T.06: Annual energy demand for road transport in Leading the Way



FES 2022 / The Energy Consumer / Transport 103

Scenarios overview: road transport

Consumer Transformation

System Transformation

Leading the Way

Falling Short

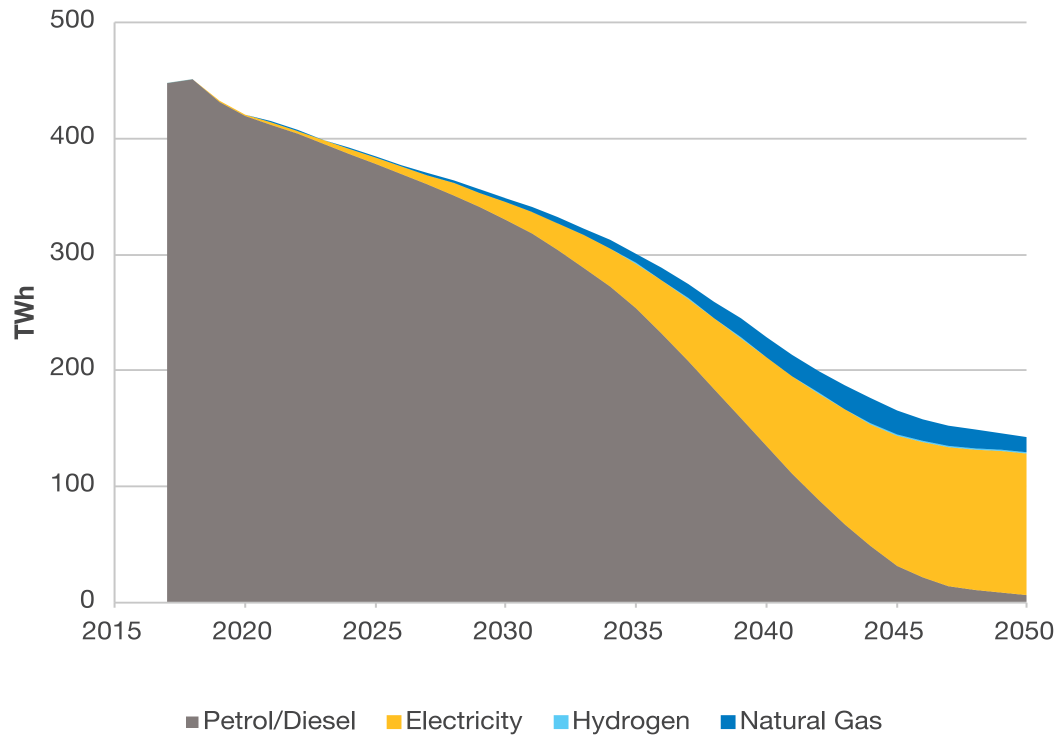
The route to 2050

- All HGVs lighter than 26 tonnes are zero emission by 2040, primarily through electrification.
- The petrol and diesel new car sales ban comes into place from 2035, with PHEVs and vans sales banned from 2040.
- By 2030 there are some Autonomous Vehicles (AVs) on the road. They increase in availability and popularity throughout this decade.
- All buses sold are zero emission by 2035, and by 2040 for minibuses and coaches.

What does 2050 look like?

- Total demand for road transport in 2050 is 140 TWh.
- This is the only scenario with petrol, diesel and natural gas demand for road transport by 2050, although with significant reductions due to the uptake of privately owned BEV and lower numbers of PHEV cars.
- However, there is a comparatively slower uptake in BEV and PHEV vans.
- There are around 38 million BEV and PHEV cars and vans on the road – the highest out of all scenarios.
- 5% of households take part V2G services, with over 50% using smart chargers at home or at the office.

Figure EC.T.06: Annual energy demand for road transport in Falling Short



Battery Electric Cars and vans

We expect EV uptake to continue accelerating through the 2020s and 2030s, particularly after the zero emission vehicle mandate for new car and van sales.

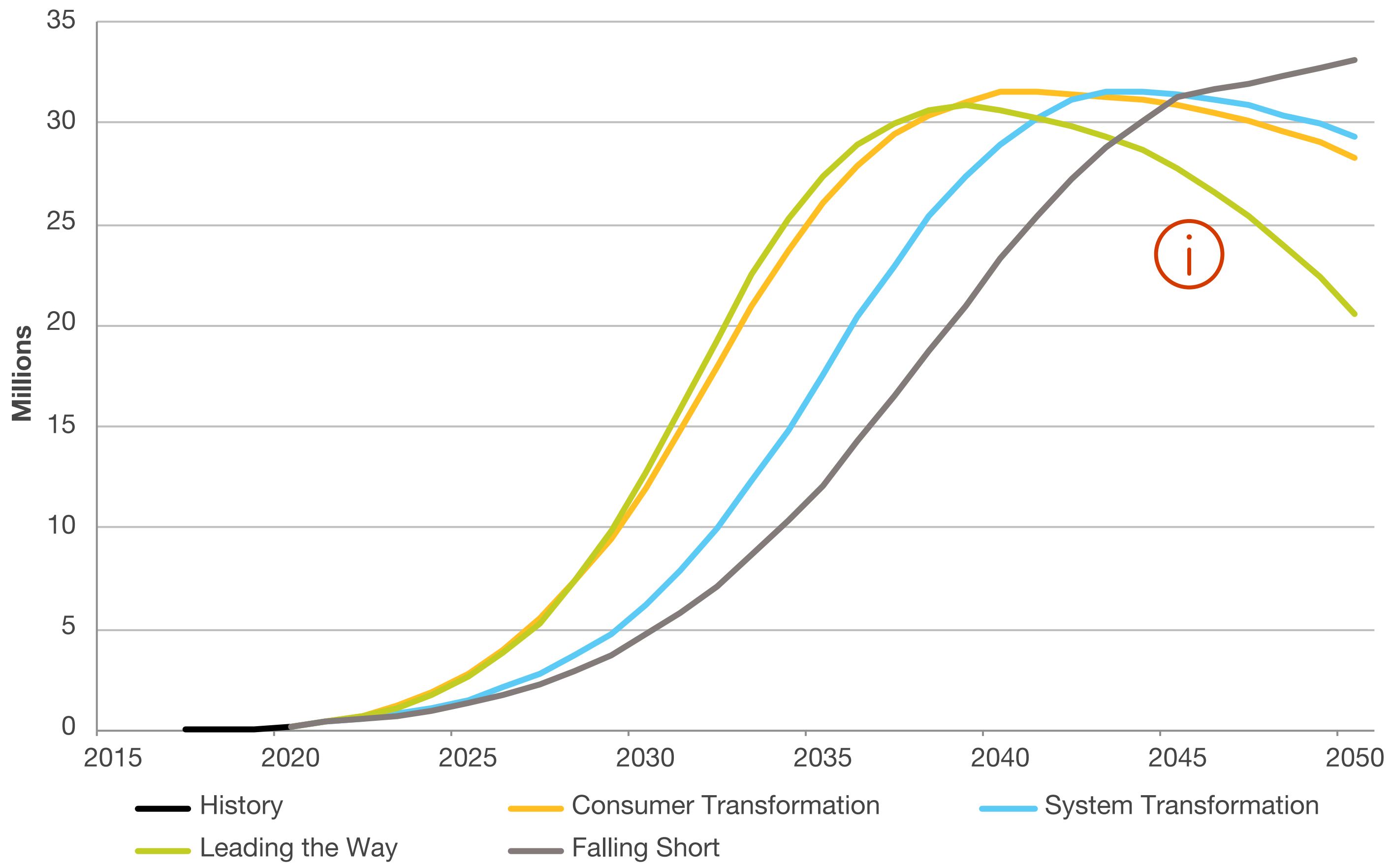
The 2030 target to ban sales of new petrol and diesel cars and vans is met in Consumer Transformation and Leading the Way.

The 2030 target is missed in Falling Short, and not met for cars until 2035 and for vans until 2040. System Transformation narrowly misses the 2030 date, despite being a Net Zero compliant scenario in 2050, with slower development of the EV market leading to some petrol and diesel car and van sales continuing into the early 2030s.

In our Net Zero scenarios, electric motorbike sales increase gradually through the 2020s and more rapidly in the 2030s, while this transition is more gradual in Falling Short, with uptake accelerating in the 2040s.

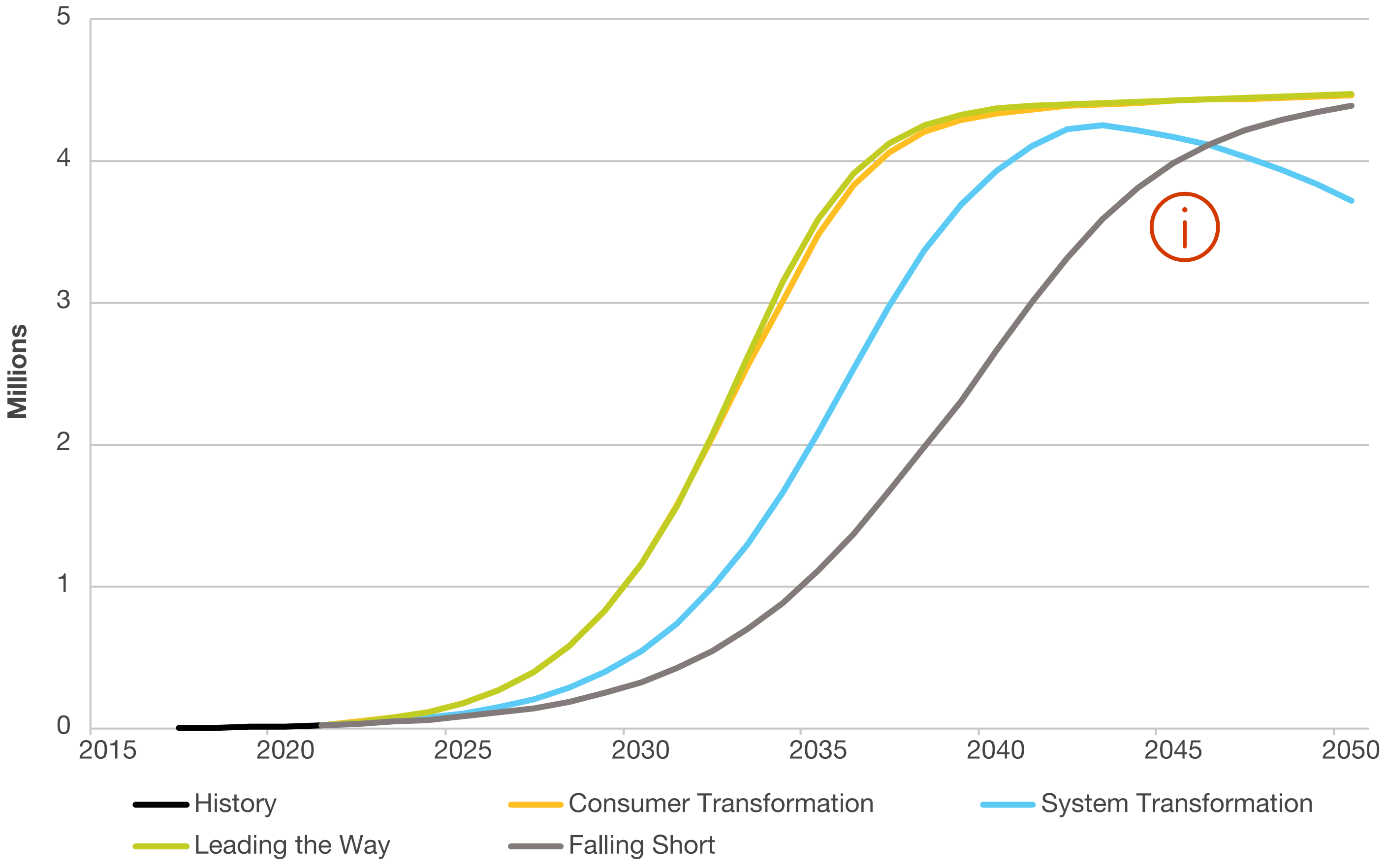
In the Net Zero scenarios we start to see the impact of Autonomous Vehicles post 2035, reducing total numbers of cars on the road as some consumers switch to mobility as a service solution and/or reduce the number of cars in their household. Fewer autonomous vehicles do greater annual mileage in this market.

Figure EC.T.07: Battery Electric Cars on the road



What we've found

Figure EC.T.08: Battery electric vans on the road



Post-2040 hydrogen vans displace some electric vans in System Transformation.

FES 2022 / The Energy Consumer / Transport 106

What we've found

HGVs

Decarbonising freight is challenging but there has been significant progress. Many companies are undertaking trials or even full commercial operation of part of their fleets with low carbon alternatives, typically hydrogen or battery electric solutions.

New policy commitments aim for all new HGVs under 26 tonnes to be zero emission by 2035 and all weights by 2040. These targets, and wider industry developments lead to faster uptake of zero emission HGVs than previously modelled in all our scenarios. Any HGV solution needs to be compatible with solutions for cross-border freight, as international freight vehicles typically travel continuously from the UK to Europe and vice versa. This is a crucial part of the global supply chain that includes the UK.

Battery electric | Hydrogen | Natural Gas/biogas | Pantograph

How does it work?	Challenges	Infrastructure needs	Potential for use for international freight	Inclusion in FES
Large batteries included in HGVs, charged up at destination or at rapid charging sites en route	Potential impact on peak demands. Requires downtime off the road to charge. This could limit the potential benefits for use of AVs to save costs. Large added weight for batteries limiting total payload	Rapid charging stations. HGV hubs for drivers to sleep and recharge batteries	Requires rapid charging hubs in GB and Europe. Longest distance journeys may be limited by battery size and weight requirements	Rapid uptake from the 2030s, particularly for vehicles <26tonnes

FES 2022 / The Energy Consumer / Transport 107

What we've found

How does it work?	Challenges	Infrastructure needs	Potential for use for international freight	Inclusion in FES
Vehicle powered by a hydrogen fuel cell, refuel at dedicated hydrogen refuelling stations	Requires availability of pure hydrogen nationwide (and potentially beyond the UK). Lower efficiency of engines leading to higher total energy consumption	Hydrogen transported to hydrogen refuelling stations in a hydrogen network or via road deliveries	Requires hydrogen refuelling infrastructure in GB and Europe. Most suitable for long haul journeys	High take-up in ST, some use in CT and LW in regions with greater H_2 availability. We are monitoring developments in hydrogen ICE vehicles as an alternative to hydrogen fuel cells, but currently do not include these due to lack of type approval and nitrogen oxide emissions

FES 2022 / The Energy Consumer / Transport 108

What we’ve found

Battery electric | Hydrogen | **Natural Gas/biogas** | Pantograph

How does it work?	Challenges	Infrastructure needs	Potential for use for international freight	Inclusion in FES
Vehicle powered by ICE running on methane or biomethane	Availability of refuelling infrastructure. Tailpipe emissions higher than for BEV or H_2 vehicles. Limited availability of bioresources	Dedicated Compressed Natural Gas (CNG) or biogas refuelling stations	Required CNG or biogas refuelling stations in GB and Europe. Suitable for long haul journeys	Low levels in Net Zero scenarios that disappear by 2050. Used by some end users as a bridging fuel to hydrogen. Some take-up in Falling Short for heaviest HGVs from the 2030s

FES 2022 / The Energy Consumer / Transport 109

What we’ve found

Battery electric | Hydrogen | Natural Gas/biogas | **Pantograph**

How does it work?	Challenges	Infrastructure needs	Potential for use for international freight	Inclusion in FES
These electric powered HGVs draw power from overhead cables suspended over motorways and major roads. They typically have a small battery or motor for the last section of journeys on minor roads	New disruptive infrastructure works needed for overhead catenaries on major roads and motorways	Overhead catenaries required across a large proportion of the major road network. Significant investment in suspended cable infrastructure	Cross-border infrastructure compatibility for pantograph vehicles may be a challenge even if pantograph HGVs are in use in GB and in Europe unless there is early cooperation on development of standards	We are working with stakeholders to understand pantograph HGVs more fully. We will consider including this technology in future FES analysis. We expect lower annual electricity demand (by approximately 5% over BEVs) and different impacts on system peak

FES 2022 / The Energy Consumer / Transport 110

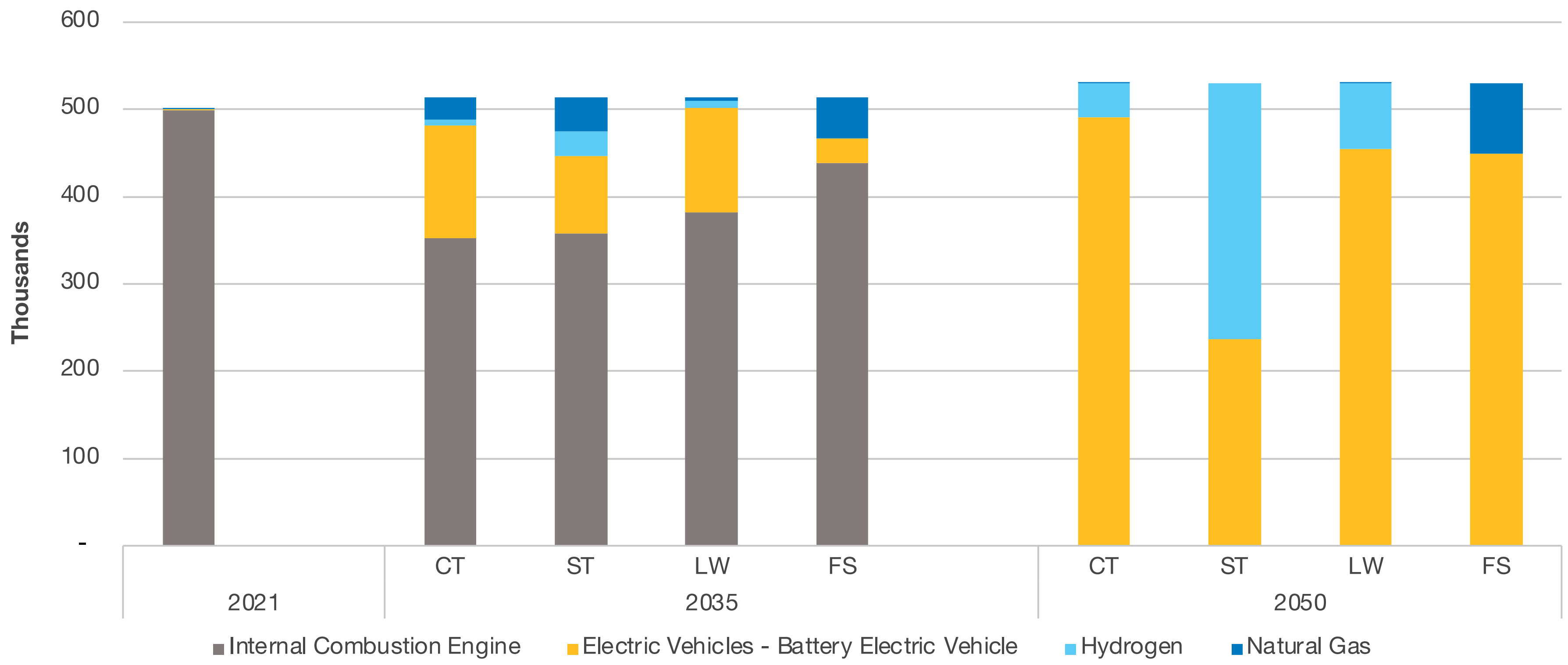
HGVs

We split HGVs into two main categories: above and below 26 tonnes. In all scenarios, battery electric becomes the most widespread technology for vehicles under 26 tonnes. In vehicles over this threshold we see greater uncertainty, as the technical challenges for these are greater.

In Consumer Transformation and Leading the Way, battery electric HGVs dominate this heavy-duty market, with a limited role for hydrogen-fuelled HGVs, while in System Transformation hydrogen vehicles make up nearly all heavy-duty freight. In Falling Short, Compressed Natural Gas, Liquefied Natural Gas (LNG) and biogas are typically used where electrification is not sufficient, primarily as a bridging technology, as it takes longer to encourage the market to switch to zero emission HGVs.

The first year that all buses sold are zero emission is between 2028 and 2035 across the scenarios. Minibuses and coaches, however, see a later date as they face greater challenges with more variety of journey types and operation. While the Net Zero scenarios see no ICE sales by 2035, Falling Short doesn't achieve this until 2040.

Figure EC.T.09: HGVs on the road by fuel type



What we've found

Figure EC.T.10: Battery electric HGVs on the road

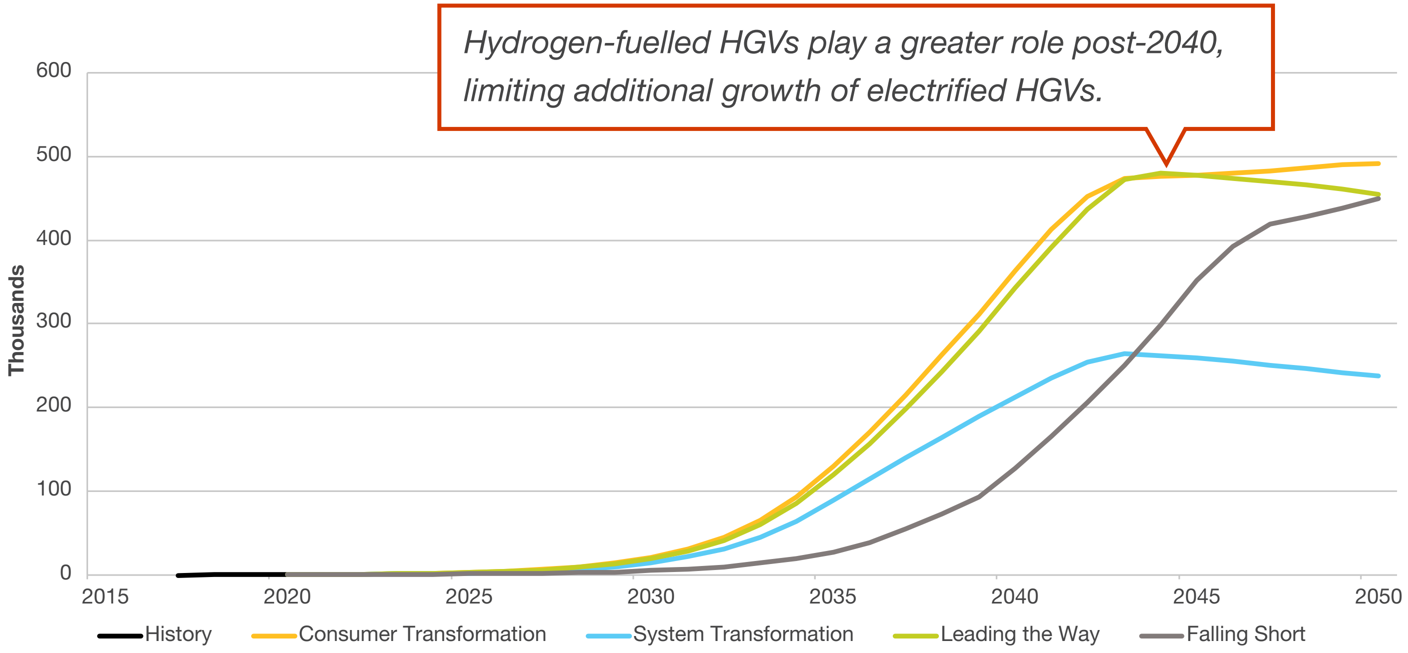
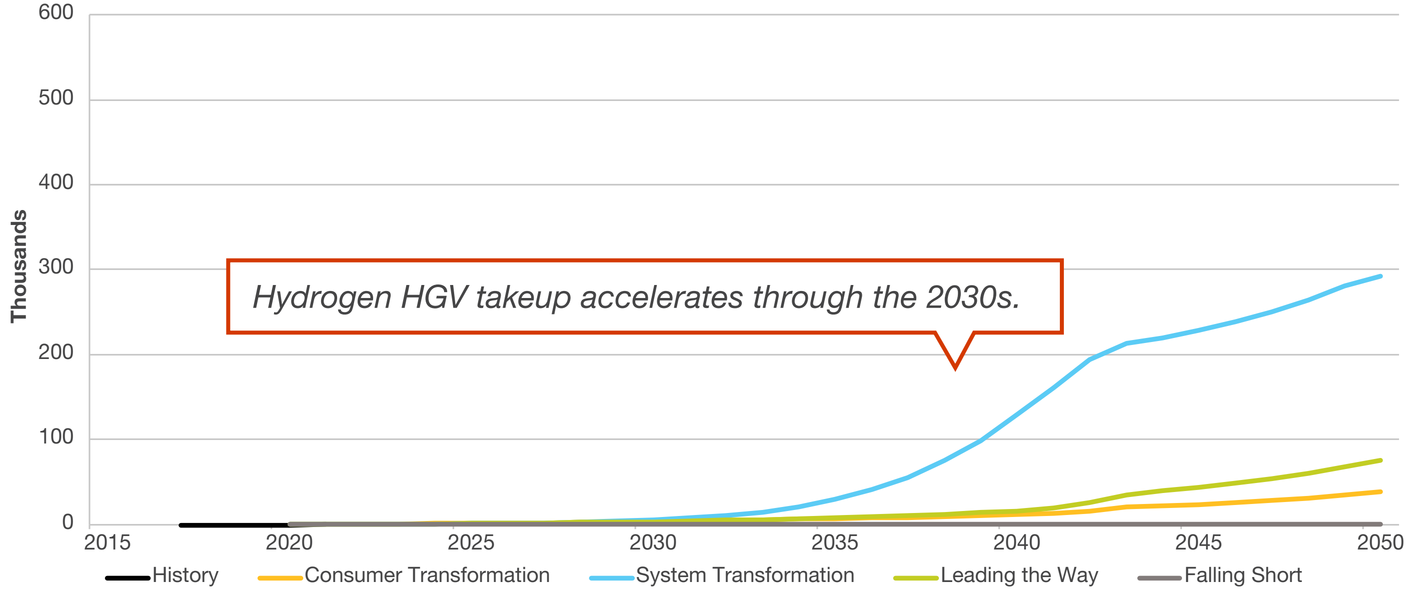
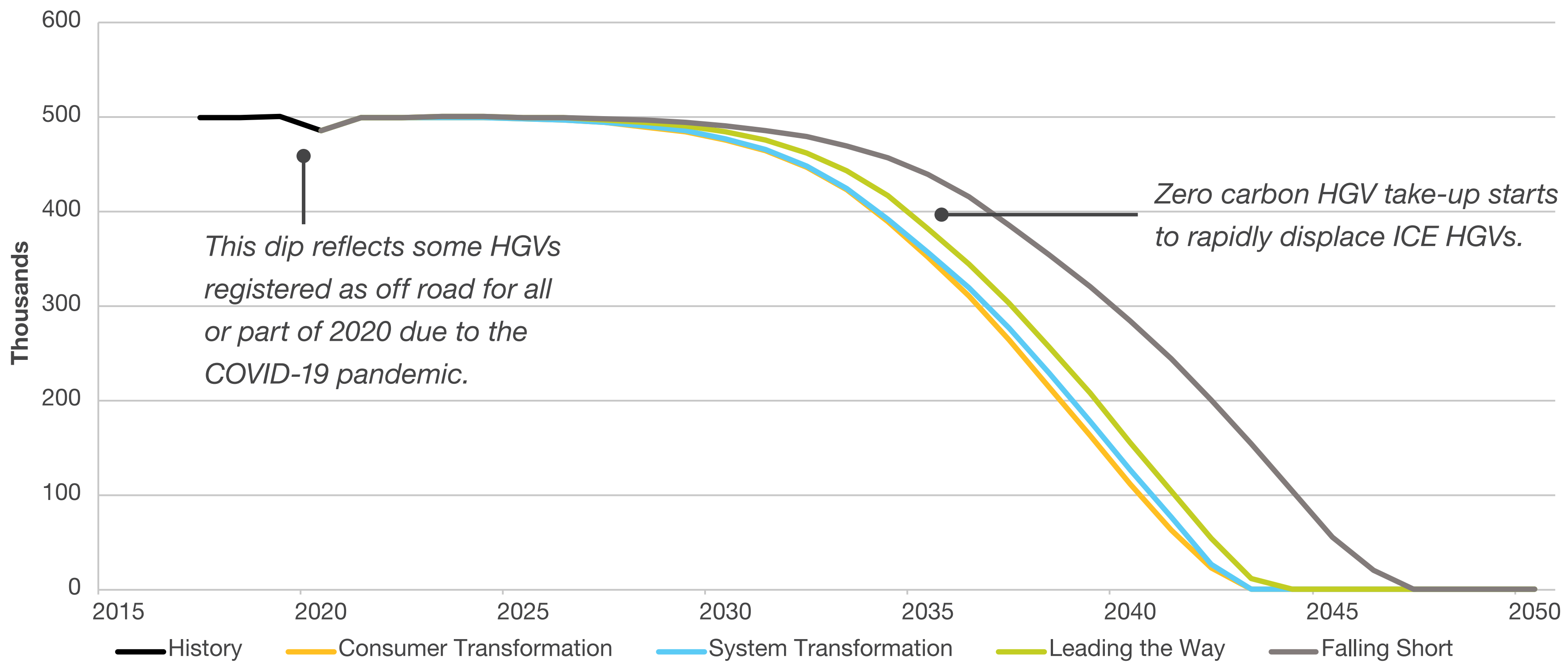


Figure EC.T.11: Hydrogen HGVs on the road



FES 2022 / The Energy Consumer / Transport 112

Figure EC.T.12: ICE HGVs on the road



FES 2022 / The Energy Consumer / Transport 113

What we've found

How and where will zero carbon vehicles be refuelled?

Today's experience of refuelling at local petrol stations is likely to change in future. This will vary according to the type of vehicle and the fuel.

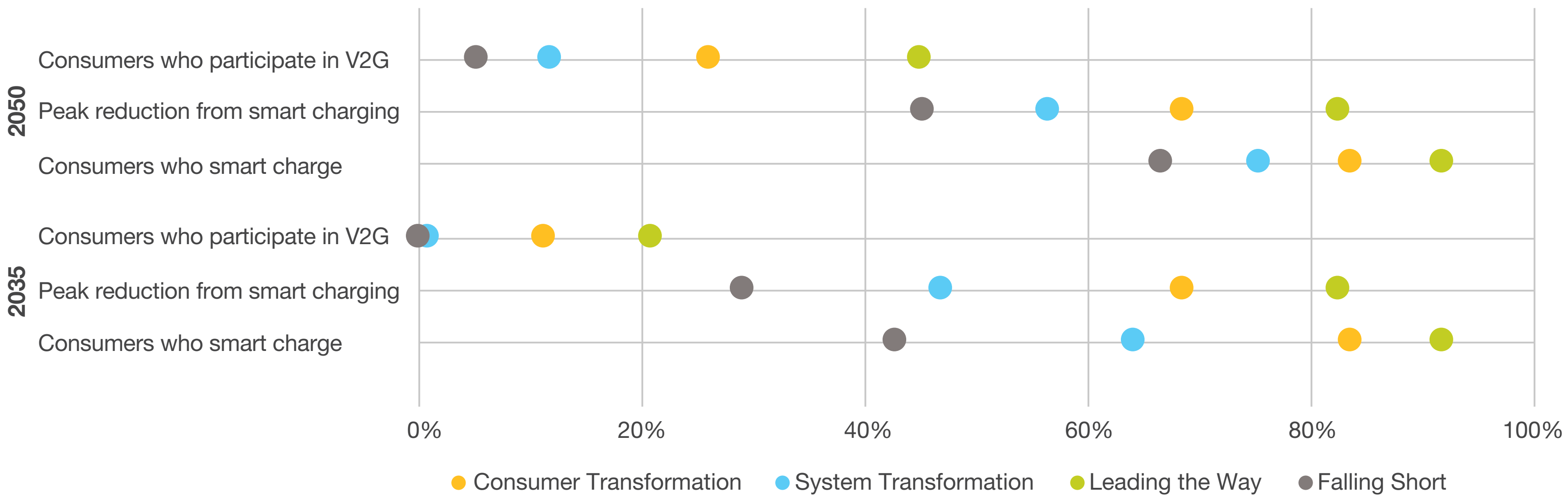
We expect electric cars to dominate the passenger vehicle market, but there is some growth in hydrogen fuel cell vehicles, and hydrogen plays a role for some HGVs in all Net Zero scenarios.

Electric Vehicles

There is variation across the scenarios in how Electric Vehicles are charged, reflecting the differences in infrastructure development and consumer preferences in each scenario. In all scenarios the majority of those who can charge at home do so where possible, however a range of options is needed to ensure solutions for all consumers.

Consumers are already, and will be increasingly, encouraged to engage with Time of Use Tariffs and automated vehicle charging to reduce their costs and shift electricity demand away from peak times and periods of low renewable output. We assume the purchase of an EV is a trigger point for consumers to increase engagement in the energy system and move towards smart charging.

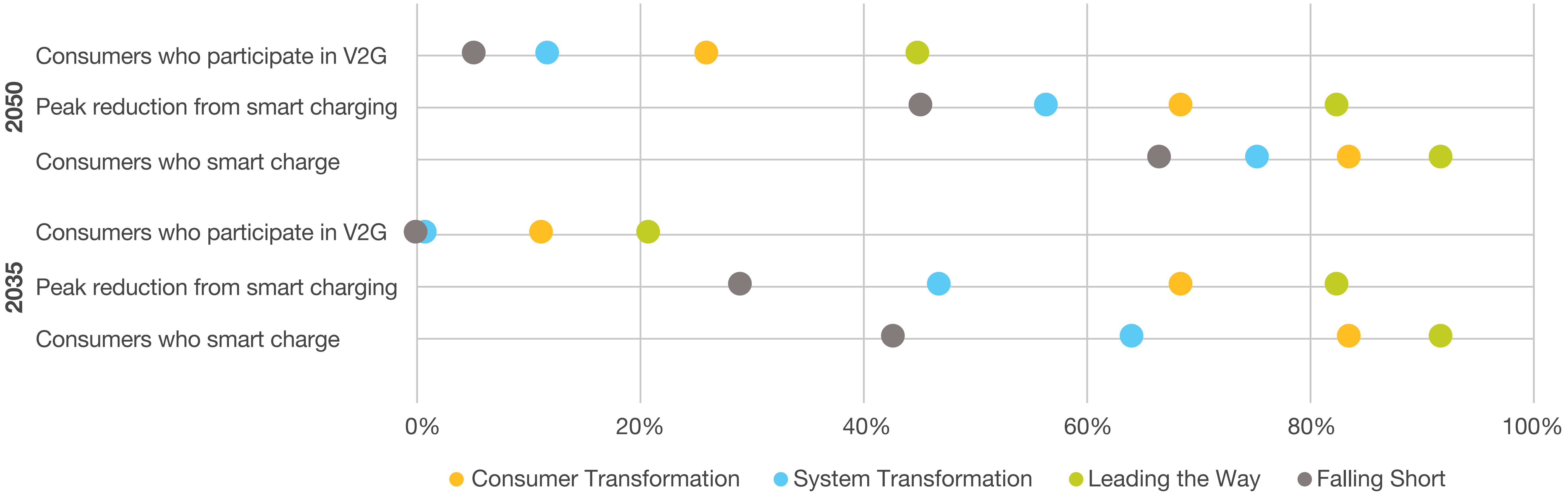
Figure EC.T.13: Consumer engagement in smart charging and V2G, and proportion of demand shifted at peak



FES 2022 / The Energy Consumer / Transport 114

What we've found

Figure EC.T.13: Consumer engagement in smart charging and V2G, and proportion of demand shifted at peak



FES 2022 / The Energy Consumer / Transport 115

What we've found

A smart charging system considers the best time to charge a vehicle based on current prices, forecasts of future prices, and renewable generation availability. It will enable consumers to participate in V2G or vehicle-to-home services where their car batteries send power back to the electricity grid, or the house at peak times, and charge up again later. This will require technology deployment of e.g. bi-directional charging, but also electricity market change so consumers are rewarded for participating in the energy system to optimise system costs for everyone. More detail on load shifting and response is in the Flexibility chapter.

Careful consideration is needed to ensure there is fair transition and affordable, equitable access to charging infrastructure in the shift to EVs. There is the potential for charging costs to be inequitable should different consumer segments face different costs due to use of different types of chargers, their accessibility and location. Consumers who can afford their own solar panels, battery and off-street parking may be able to charge cheaply at home, while those without could face higher costs charging away from home.
This highlights the potential role for policy and regulatory protection to support consumer fairness.

Types of charging

Residential charging (3-7 kW)

Typically for those with off-street parking who can install their own home charger and charge from their domestic electricity supply. This could also be via communal chargers in private car parks for blocks of flats or on-street parking close to homes that have an overnight domestic charging pattern.

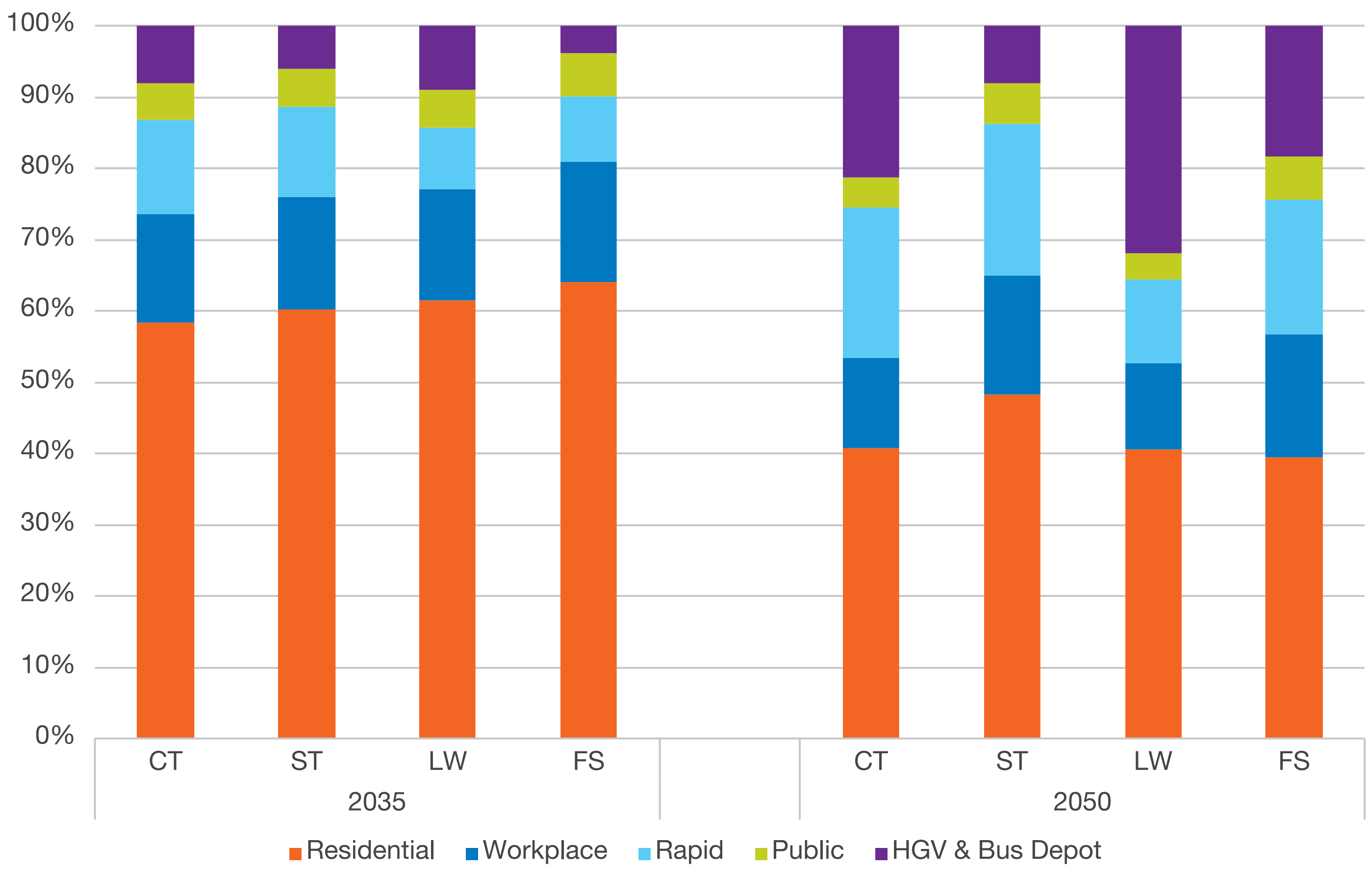
Workplace and destination charging (7-22 kW)

Using employer-provided EV chargers in workplace car parks, typically plugged in during the daytime, or charging in consumer locations such as retail parks, supermarkets and other commercial premises.

Rapid charging (50-150 kW)

High power chargers, typically 50 kW or greater, that can charge car batteries back to 80% or above in 20-40 minutes. Currently these are primarily found in motorway service stations, however there may be greater uptake of local rapid charging hubs.

Figure EC.T.14: Charging behaviour in 2035 and 2050, proportion of demand per chargepoint archetype



Refuelling with alternative fuels

Hydrogen and CNG refuelling stations will be needed for vehicles using these fuels. These could operate in a similar manner to petrol stations today. Refuelling can be done much more quickly than recharging an EV battery, particularly for the larger batteries needed for HGVs. This gives them an advantage in certain situations, but they will require suitable infrastructure.

In System Transformation, the conversion of the hydrogen network means there is widespread availability of hydrogen nationwide, which will enable greater take-up of hydrogen fuelled vehicles. Hydrogen vehicles require the hydrogen fuel to have a high level of purity. Green hydrogen produced from electrolysis meets this purity level, whereas blue hydrogen from methane reformation does not, and would need to be purified on site for use in transport. This means we may still see tankers used to move green hydrogen to refuelling stations around the country.

FES 2022 / The Energy Consumer / Transport 117

What we've found

Consumer Transformation:

Industry, regulators and local authorities work together to deliver innovative cost-effective solutions allowing the majority of those with adequate on-street parking to charge overnight. In addition, widespread 'near to home' rapid hubs are established.

System Transformation:

Majority of those without off-street parking charge at 'near to home' rapid hubs. This requires increased levels of consumer behaviour change, where chargers typically have higher levels of asset utilisation.

Leading the Way:

Widespread innovation and behaviour change allows the majority of those with on-street parking to charge overnight. This limits market for 'near to home' rapid charging.

Falling Short:

The majority of those without off-street parking charge via destination and workplace charging.

FES 2022 / The Energy Consumer / Transport 118

What we've found

Rail, aviation and shipping

Rail

Rail today is a mixture of electrified and diesel stock. Currently 40% of the UK's rail network is electrified. The Government's Transport Decarbonisation Strategy (2021) sets out a pathway for rail decarbonisation. It aims to deliver a programme of further electrification, together with the use of battery and hydrogen trains, to enable a zero carbon railway and an ambition for all diesel-only trains to be removed from the rail network by 2040.

Rail makes up a relatively small proportion (around 2%) of total energy demand for land-based transport; decarbonisation is nevertheless important. New rail lines and electrification programmes for existing infrastructure require high levels of capital investment and involve long lead times. To decarbonise by 2050, projects need to be planned and started well in advance.

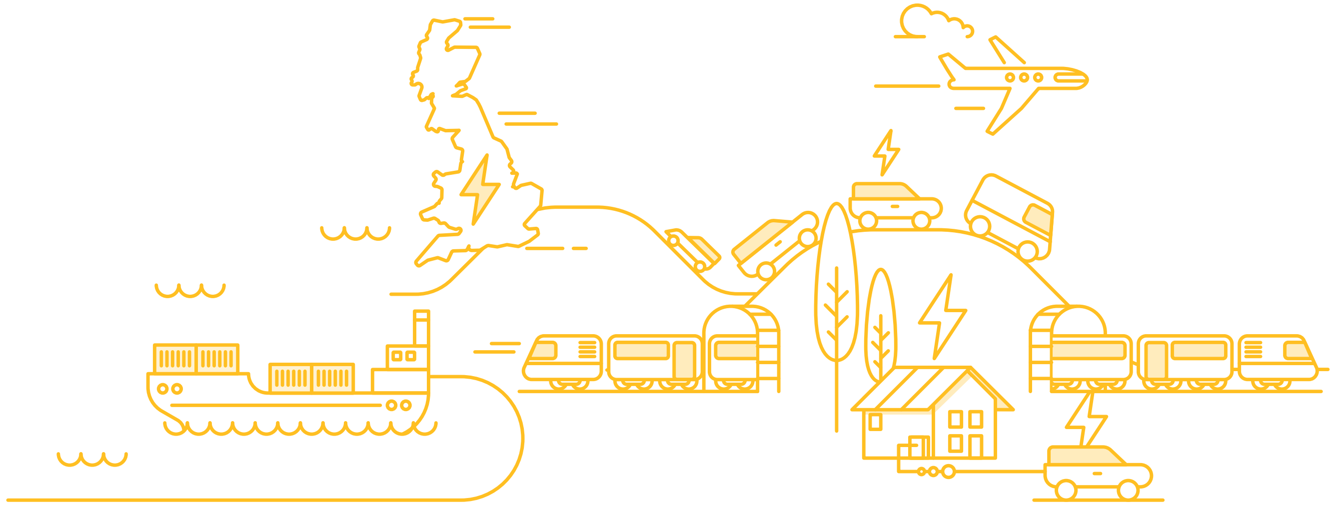
In Leading the Way, we see a higher willingness for consumer behaviour change. This means increased use of public transport, and shifts towards walking and cycling, which could contribute to further reducing energy demand and emissions.

Shipping

Decarbonisation of shipping is challenging. Some electrification of short haul shipping, ferries and boats is seen, as well as greater use of electricity from the grid when ships are docked in port rather than powering the ship from the engines. However, the dominant fuel is hydrogen. This is used directly in some cases or converted to ammonia as an alternative fuel. By 2035 we expect some progress, with significant take-up of alternative fuels, so that shipping achieves zero emissions between 2040 and 2050. More detail on this is in the Net Zero chapter.

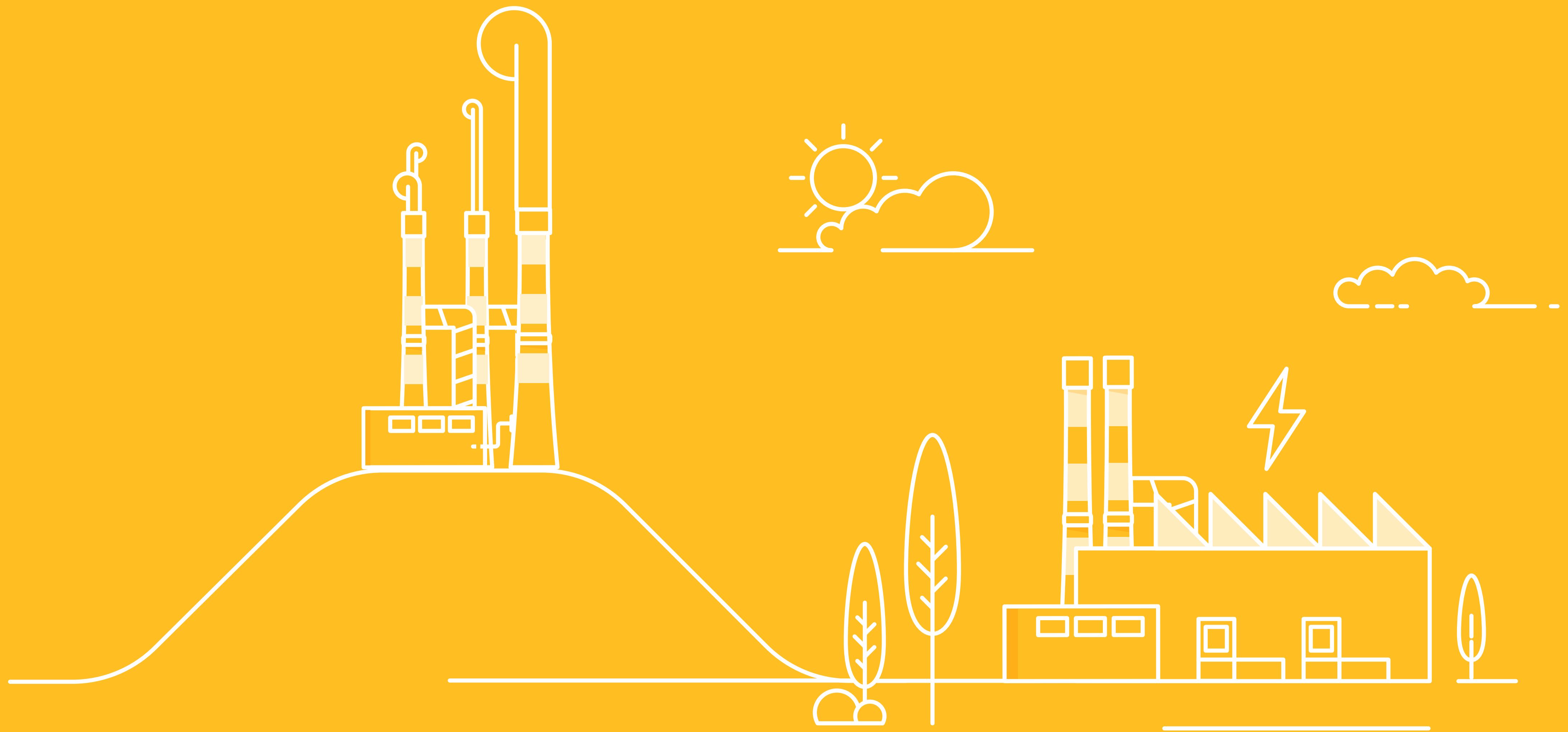
Aviation

Some progress is made on decarbonisation of aviation in the Net Zero scenarios using biofuels and synthetic jet fuels to displace kerosene. Aviation isn't fully decarbonised and is one of the main sources of residual emissions from the UK in 2050, which needs to be offset by negative emissions. More detail on this is in the Net Zero chapter.



FES 2022 / The Energy Consumer / Transport 119

Industrial



Key insights

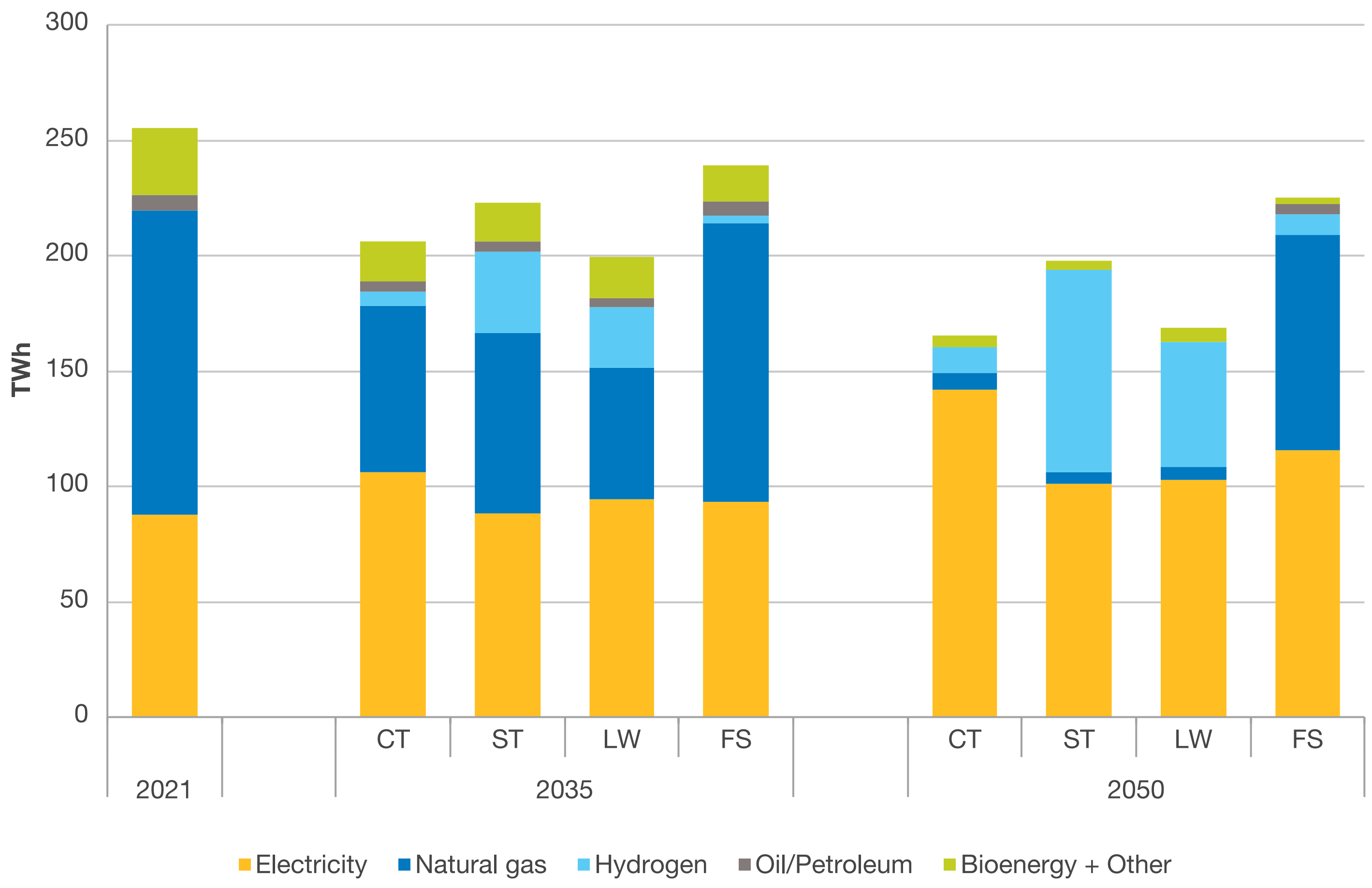
- We expect that the economic impact of the events in 2020 and 2021, together with current high energy prices, will lead to **suppressed electricity and gas demand** in the short term.
- Developments in the industrial sector suggest that electrification and fuel switching to hydrogen may take place **further and faster** than previously thought, with fuel switching expected to accelerate from the late 2020s onwards.
- **Industrial clusters** for Carbon Capture Usage and Storage and hydrogen could reduce whole system costs and the need for additional electricity and gas network investment. However, cluster locations must be carefully designed to maximise use of existing network infrastructure and avoid exacerbating system constraints. A shift towards more locational pricing, as explored in our Net Zero Market Reform work, could incentivise more efficient siting.
- **Industrial Demand Side Response** could shift up to 36% of peak industrial electricity demand away from peak demand periods or times of low renewable output with sufficient levels of consumer engagement.

What is industrial demand?

Industrial demand includes:

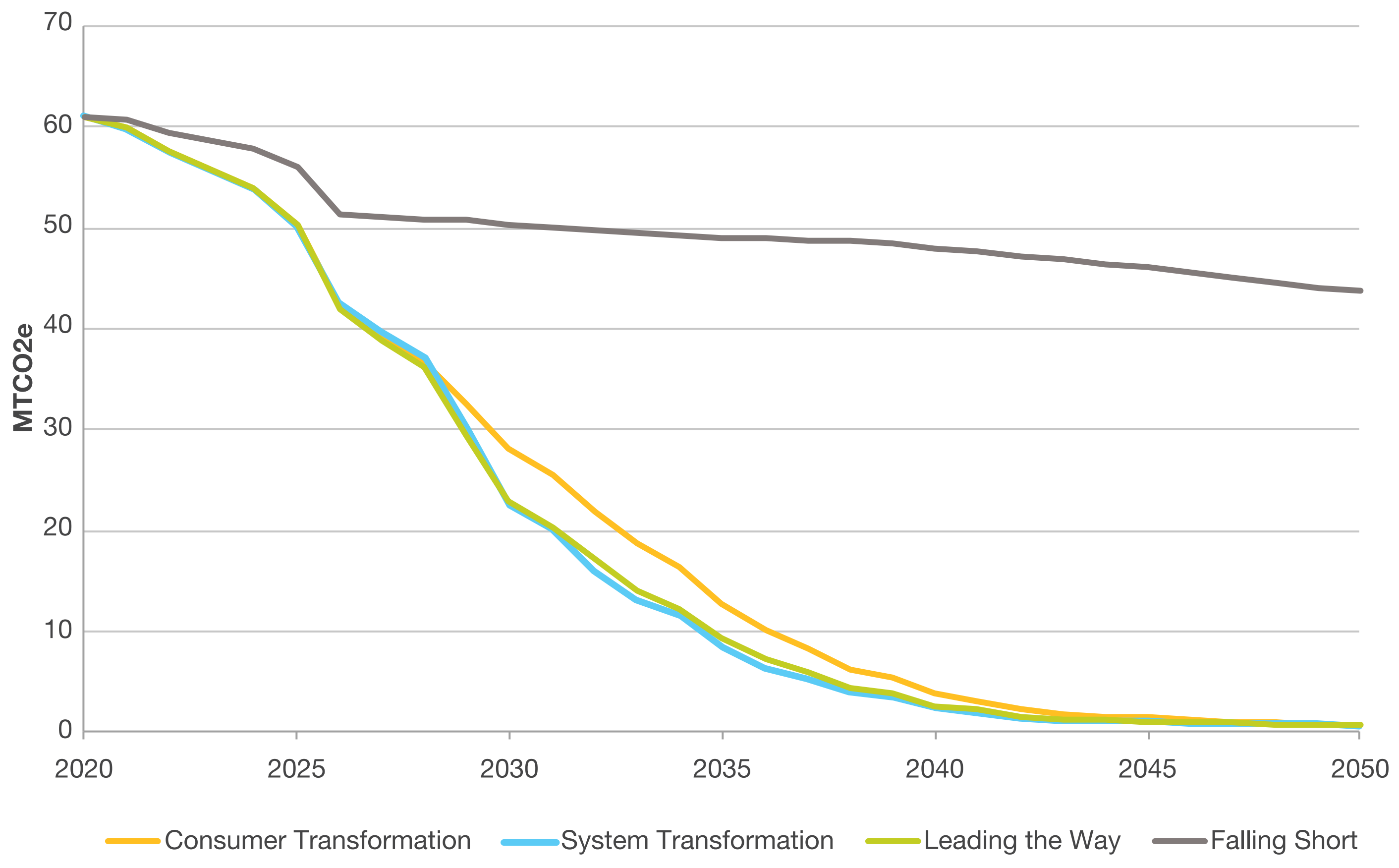
- Highly energy intensive industries producing things like steel, cement, and pharmaceuticals
- Manufacturing of:
  - Vehicles
  - Machinery
  - Food
  - Textiles
  - Furniture
  - Books and paper
  - Electronics
- Mining and quarrying

Figure EC.I.01: Annual industrial demand excluding electrolysis[1]



1 The 2021 data is primarily made up of our modelled data for natural gas and electricity. Some 2020 demand data from ECUK was used to provide a complete, whole energy system view of end consumer demand for these sectors. The chart reflects end user demand across the industrial sector.

Figure EC.I.02: Emissions from the industrial sector



FES 2022 / The Energy Consumer / Industrial 122

Where are we now?

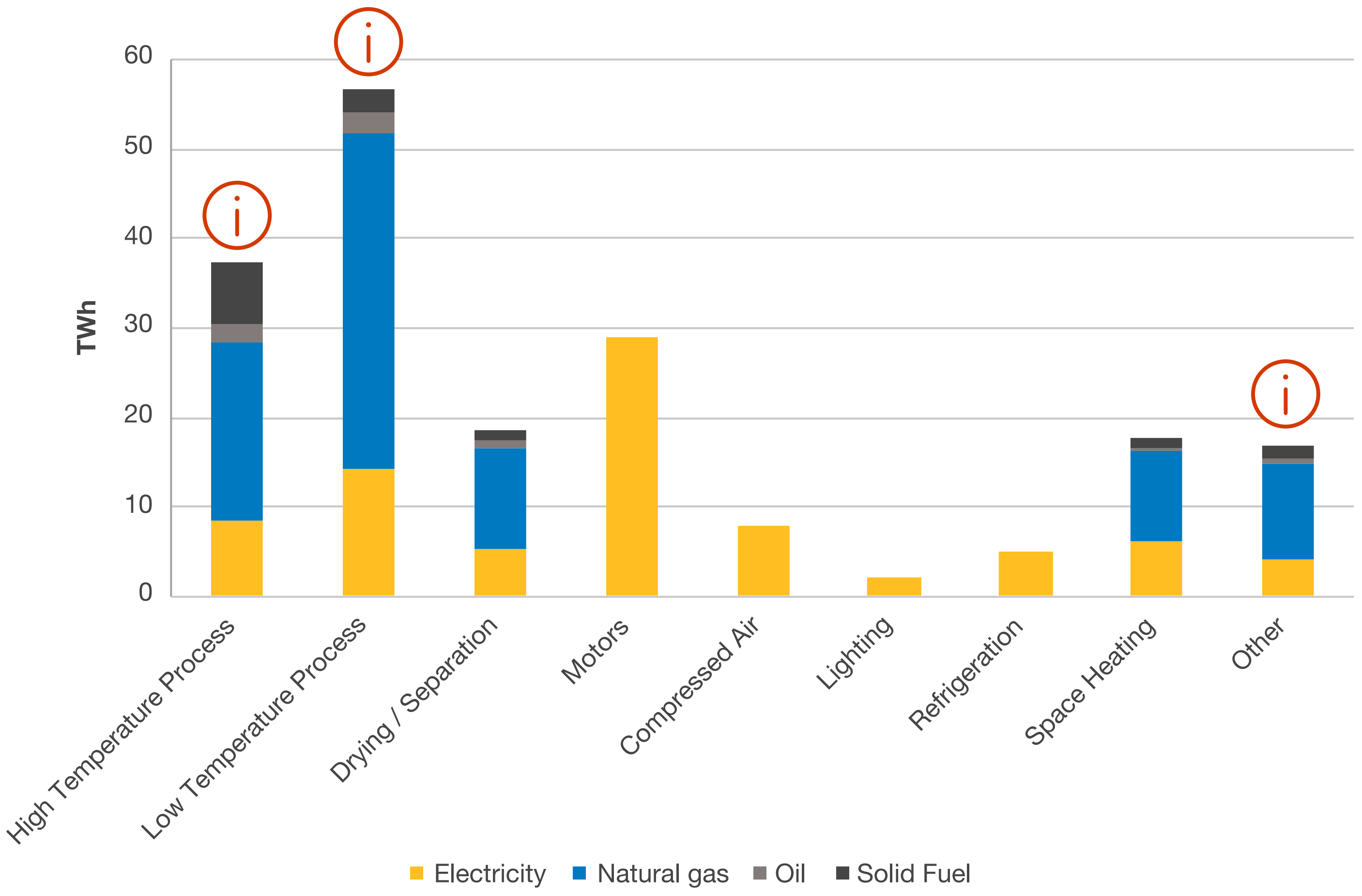
The industrial sector in 2020 represented 16% of GB energy demand and 13% of emissions.

Industry is spread around the country and often provides the backbone of local or regional economies. Some energy intensive industrial users are clustered together for historic reasons including resource availability and transportation links. High energy use and high reliance on fossil fuels mean the sector can be particularly difficult to decarbonise. Current high energy prices have also brought additional challenges and cost pressures to the sector.

Electricity today makes up 43% of industrial demand, with the remainder primarily met by fossil fuels (natural gas, oil, and solid fuels). Electrification is one avenue that will enable decarbonisation of some industrial demand as the electricity system decarbonises, however it will not be suitable for all end users. Whilst there is opportunity for further electrification of industry, other solutions are also needed to tackle industrial fossil fuel demand. Some sectors also use fossil fuels as feedstocks for their processes which will be particularly hard to displace and therefore require Carbon Capture Usage and Storage.

Industry and government have been working together to set out pathways for decarbonisation for different industrial subsectors while delivering broader benefits, such as opportunities for green industrial regeneration across different parts of the country. In April 2021 the government published an Industrial Decarbonisation Strategy setting out a roadmap for industry to get to Net Zero. This has been followed up with further policy papers including the Net Zero Strategy, Hydrogen Strategy and Heat and Buildings Strategy, all of which have an impact on decarbonisation routes for the industrial sector. This has included plans and funding for the development of existing industrial clusters that will benefit from shared clean energy infrastructure.

Figure EC.I.03: Industrial demand in 2020 by fuel and subsector[2]



High temperature processes: *These are for production of iron, steel and other metallic or mineral products. They have high demand for natural gas, oil and solid fuels and represent some of the most challenging areas to decarbonise by 2050, some requiring CCUS.*

Low temperature processes: *These have high fossil fuel use but are more easily electrified or converted to use hydrogen than high temperature processes.*

Other: *This comprises a diverse range of uses including manufacturing of chemicals, food products and paper.*

2 Data from 2020 ECUK Energy Data Tables (Tables U2 and U4) - gov.uk/government/statistics/energy-consumption-in-the-uk-2021

FES 2022 / The Energy Consumer / Industrial 123

What we've found

Scenarios overview: industrial

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- Strong carbon pricing in the 2030s encourages industrial consumers to switch away from unabated fossil fuels, primarily to use electricity where applicable.
- Hydrogen production develops within industrial clusters and limited numbers of industrial consumers switch to use it in the 2030s.
- Some industrial consumers outside of clusters who cannot electrify their demand begin to re-locate to clusters from the 2030s.
- Industrial consumers unable to electrify their processes have re-located to industrial clusters to use hydrogen or natural gas with CCUS.

What does 2050 look like?

- Total energy demand for the industrial sector is 166 TWh.
- 89% of demand is electrified, 8% met by hydrogen.
- Highly engaged users engage in Demand Side Response, shifting over 36% of peak electricity demand to other time periods.
- Industrial consumers unable to electrify their processes re-locate to industrial clusters to use hydrogen or natural gas with CCUS.
- Natural gas is used in limited amounts with CCUS in industrial clusters for very hard to decarbonise processes.

FES 2022 / The Energy Consumer / Industrial 124

What we've found

Scenarios overview: industrial

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- Hydrogen use grows in industrial clusters initially from the mid-2020s, before spreading out from these locations in the 2030s.
- Carbon pricing in the 2030s encourages more industrial consumers to switch away from unabated fossil fuels.
- The gas network is entirely repurposed to deliver hydrogen in the 2040s allowing widespread uptake of hydrogen by industry nationwide.

What does 2050 look like?

- Total energy demand for the industrial sector is 201 TWh.
- 45% of demand is electrified, 53% met by hydrogen.
- With limited electrification, there is a lower requirement for Demand Side Response and only around 16% of peak electricity demand is load shifted.
- There is widespread availability of hydrogen for industry via a national hydrogen network.
- Natural gas is used in limited amounts with CCUS in industrial clusters for very hard to decarbonise processes.

FES 2022 / The Energy Consumer / Industrial 125

What we've found

Scenarios overview: industrial

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- High gas prices and strong carbon pricing encourages industrial consumers to switch away from unabated fossil fuels towards electricity and hydrogen from the mid-2020s.
- These factors also incentivise industrial process efficiency improvements.
- Hydrogen production in industrial clusters ramps up rapidly in the 2020s, so industrial users in these sites wishing to switch fuels to use hydrogen aren't constrained by fuel availability.
- Availability of hydrogen remains limited by location, and so electrification remains the most common route for industrial decarbonisation.

What does 2050 look like?

- Total energy demand for the industrial sector is 169 TWh.
- 61% of demand is electrified, 37% met by hydrogen.
- Highly engaged users engage in Demand Side Response, shifting 23% of peak electricity demand to other time periods.
- Some consumers unable to electrify their processes and outside of hydrogen clusters have re-located to or near industrial clusters.
- Some limited use of natural gas with CCUS in industrial clusters for very hard to decarbonise processes.

FES 2022 / The Energy Consumer / Industrial 126

What we've found

Scenarios overview: industrial

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- There is very limited growth in fuel switching until the 2030s, when some industrial consumers start to switch fuels from gas to electricity.
- Industrial cluster development is slow, with limited levels of hydrogen production, and low levels of direct demand for the fuel from industry.

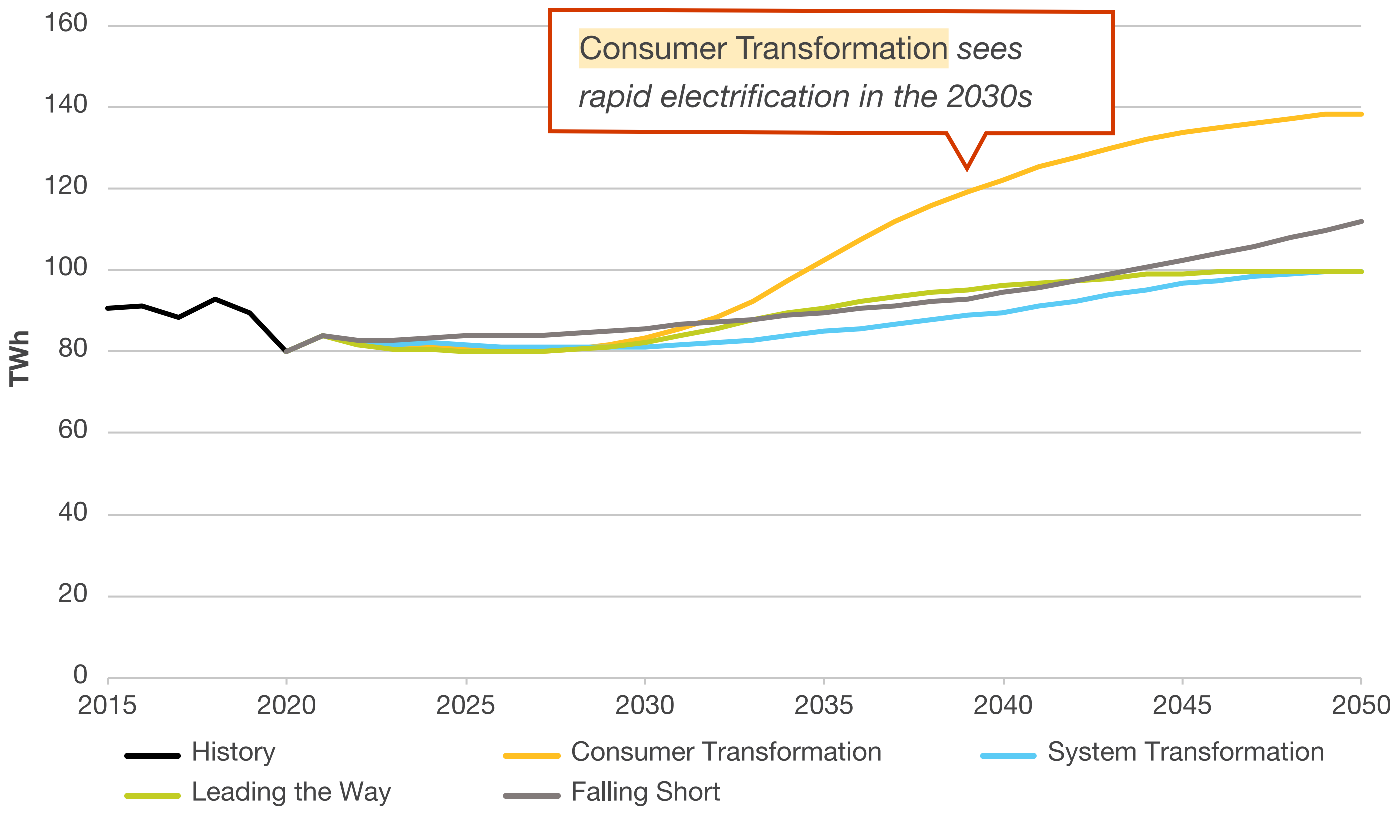
What does 2050 look like?

- Total energy demand for the industrial sector is 225 TWh.
- 59% of demand is electrified, 36% met by natural gas.
- Gas demand has fallen by only 35% since 2020.
- Relatively few consumers engage in Demand Side Response, shifting only 10% of peak electricity demand to other time periods.
- Some hydrogen used directly in industrial clusters.

FES 2022 / The Energy Consumer / Industrial 127

What we've found

Figure EC.I.04: Annual electricity demand for the industrial sector



What we've found

Figure EC.I.05: Annual natural gas demand for the industrial sector[3]

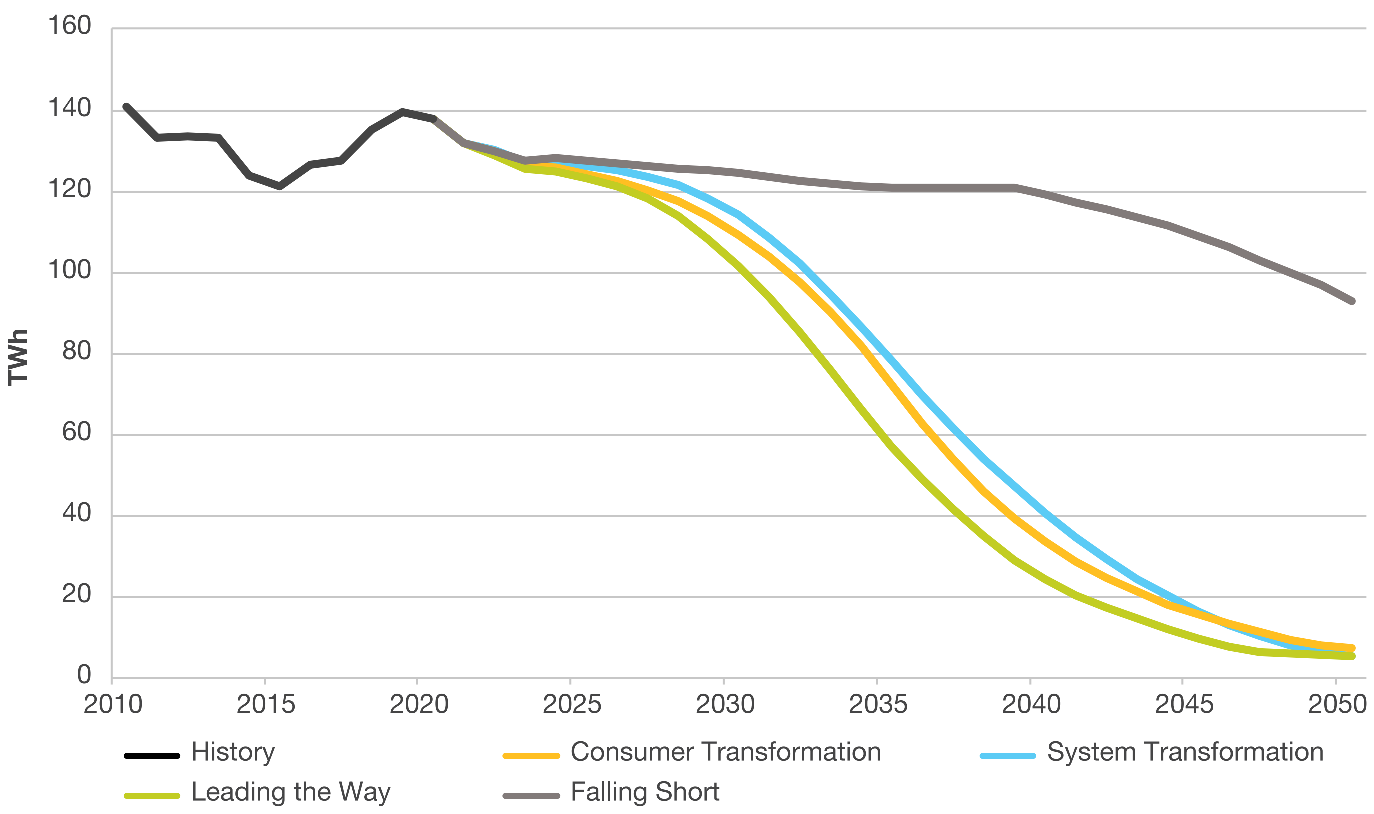
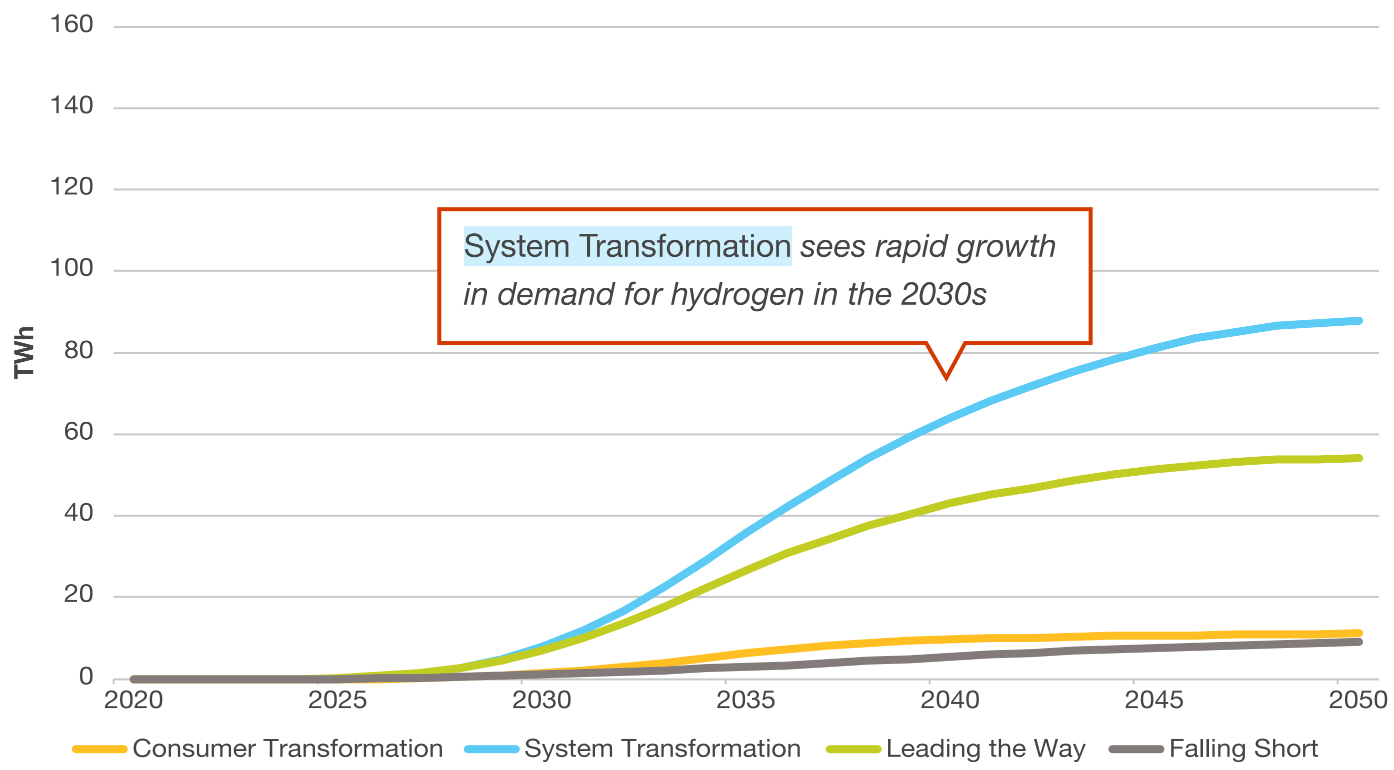


Figure EC.I.06: Annual hydrogen demand for the industrial sector[4]



3 Includes some demand met by hydrogen blended into the natural gas network in some scenarios.
4 Excludes use of hydrogen blended into the natural gas network.

FES 2022 / The Energy Consumer / Industrial 129

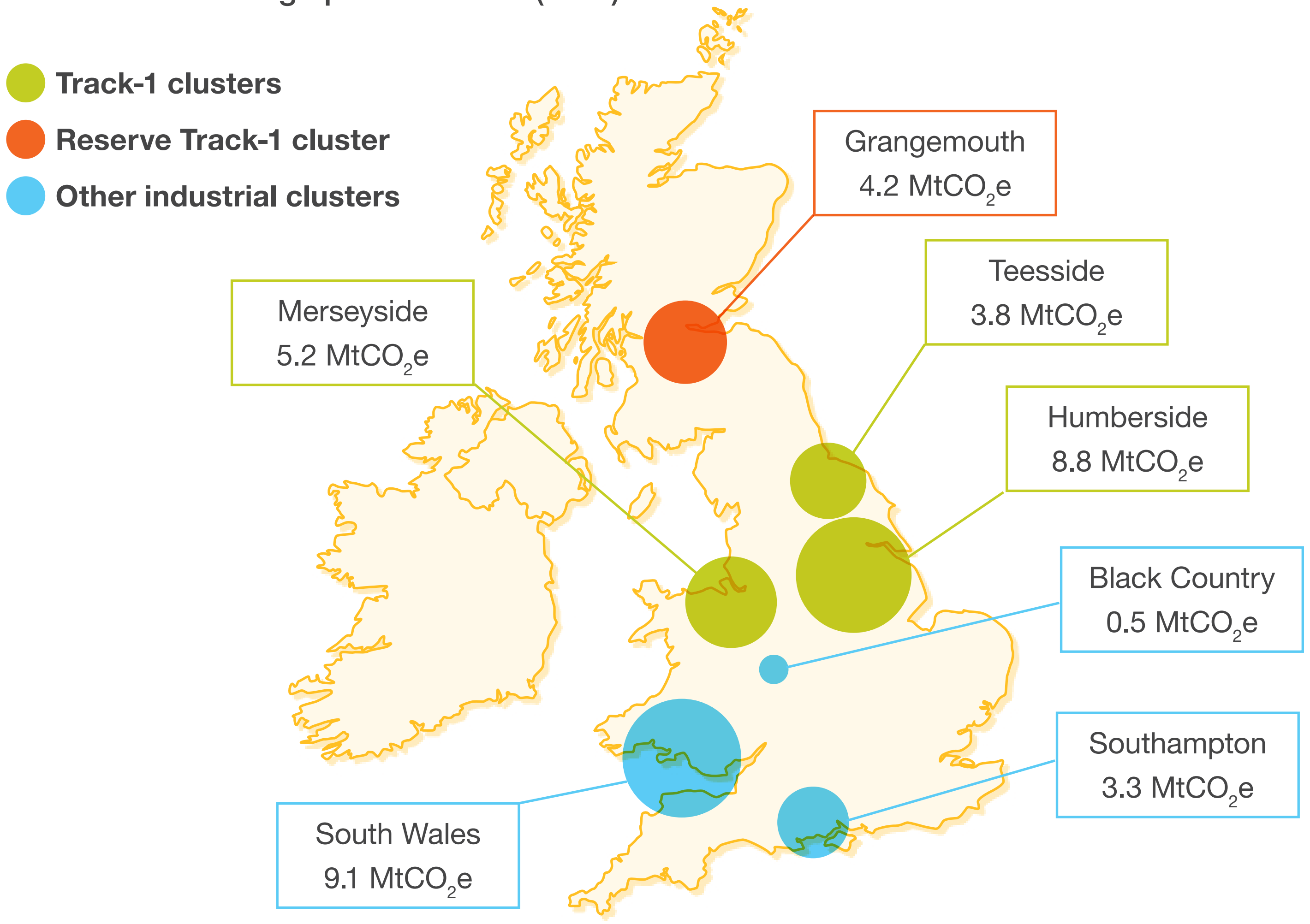
Industrial clusters

There are existing clusters of energy and emissions-intensive industry across the country; finding decarbonisation solutions for these areas will be crucial to meeting Net Zero.

The government has announced multi-million-pound funding streams for decarbonisation in industrial clusters and committed to two CCUS projects by the mid-2020s and four by 2030, subject to meeting contractual arrangements. A commitment has also been made to develop a Net Zero industrial cluster by 2040. The first two projects, HyNet around Merseyside in the Northwest and the East Coast Cluster encompassing Humberside and Teesside, have secured funding and aim to begin decarbonising industry from 2025, while the remaining clusters aim to begin decarbonisation from around 2030.

We expect hydrogen supply to be developed in these clusters, and that industries located there, which can use hydrogen as a fuel, will adopt technologies to use this as a source of energy. Industries will be able to test and embed decarbonisation strategies, including manufacturing of chemicals, iron and steel. This will help build the market for hydrogen within industry between now and 2030 and help stimulate the transition to hydrogen industry-wide.

Map of major UK industrial cluster emissions from large point sources (2019)[5]



5 Source: NAEI 2019 data, Government CCUS Investor Roadmap April 2022. Does not capture non-ETS (Emissions Trading Scheme) emissions in a cluster.

Industrial clusters

Industrial clusters are regions with energy and carbon intensive heavy industry located in proximity to one another, particularly manufacturing for chemicals, glass, steel, ceramics, and cement. Within these sites, strategic investment into hydrogen and CCUS infrastructure can help stimulate decarbonisation through exploiting economies of scale and sharing the costs of infrastructure investment across different types of users.

FES 2022 / The Energy Consumer / Industrial 131

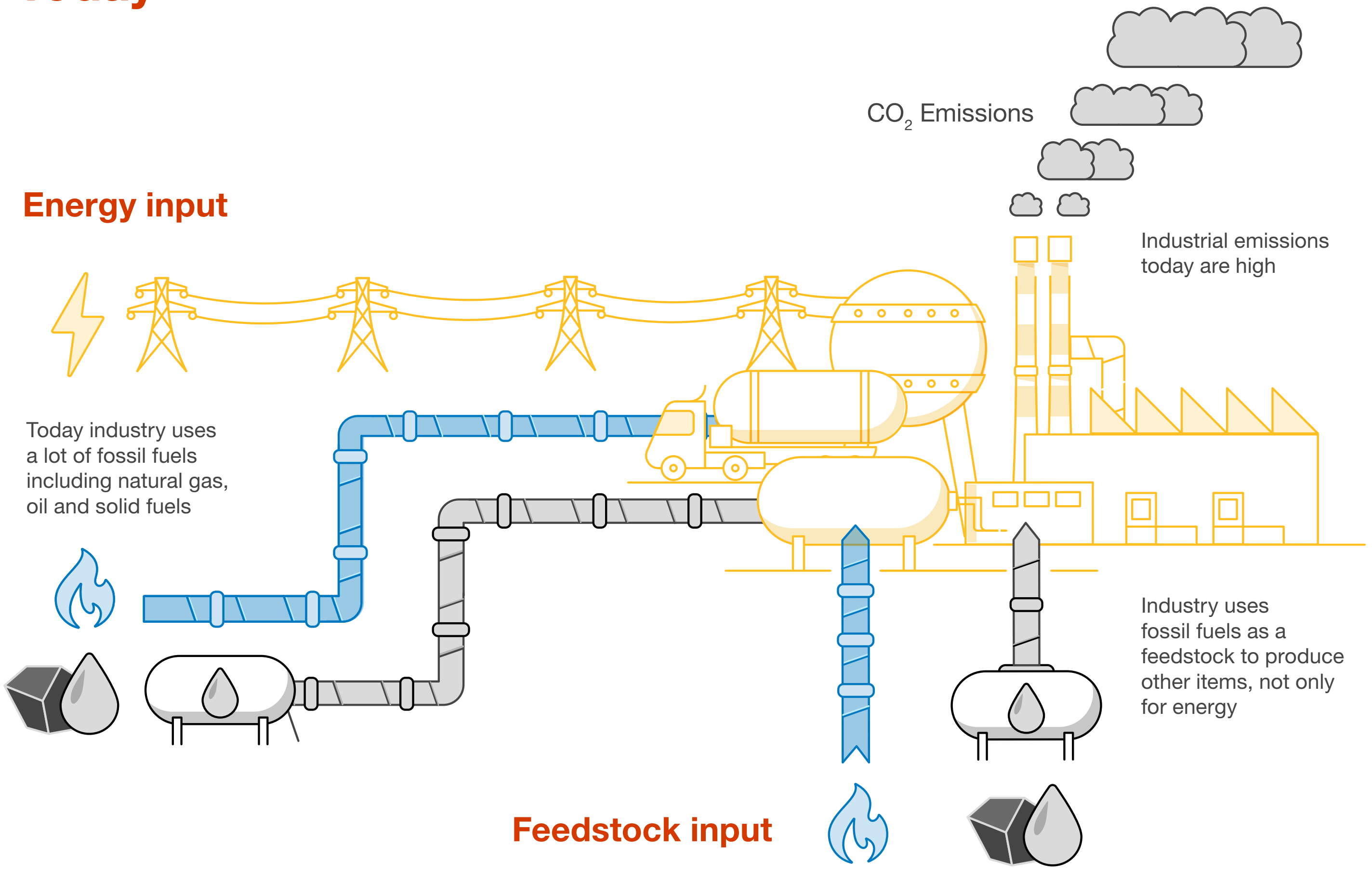
Industrial clusters

CCUS infrastructure based in the industrial cluster sites will enable the decarbonisation of industrial processes that are unable to switch away from fossil fuels or that use fossil fuels as a feedstock. This will be particularly important for areas such as chemicals and cement production. It will also enable the production of blue hydrogen within industrial clusters to supply hydrogen to the clusters.

Industrial sites located outside of clusters that are less energy-intensive such as the automotive or food production industries typically use natural gas for their industrial processes. If available, hydrogen is therefore a potential replacement to supply this industrial process heat, however in Consumer Transformation in particular, these sites would need to electrify their heat requirements.

We aim to improve our FES modelling in future by considering greater granularity of industrial and commercial demand and how this cluster-based development will impact regional development of decarbonisation.

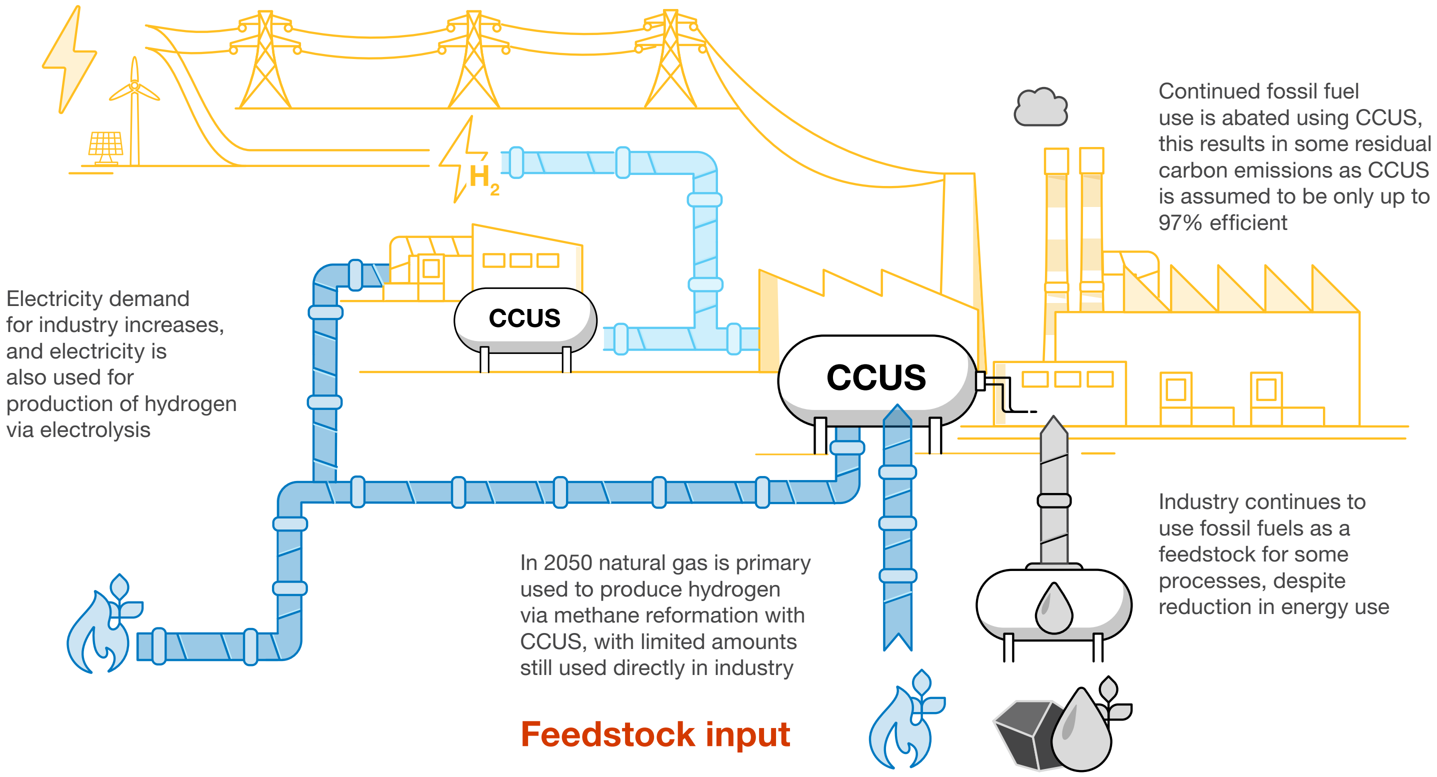
Today



FES 2022 / The Energy Consumer / Industrial 132

2050

Energy input



Electricity demand for industry increases, and electricity is also used for production of hydrogen via electrolysis

Continued fossil fuel use is abated using CCUS, this results in some residual carbon emissions as CCUS is assumed to be only up to 97% efficient

In 2050 natural gas is primary used to produce hydrogen via methane reformation with CCUS, with limited amounts still used directly in industry

Industry continues to use fossil fuels as a feedstock for some processes, despite reduction in energy use

Feedstock input

Blue hydrogen

Hydrogen made from methane reformation, using CCUS technology to capture and store up to 97% of carbon emissions from the process.

FES 2022 / The Energy Consumer / Industrial 133

Industrial fuel switching

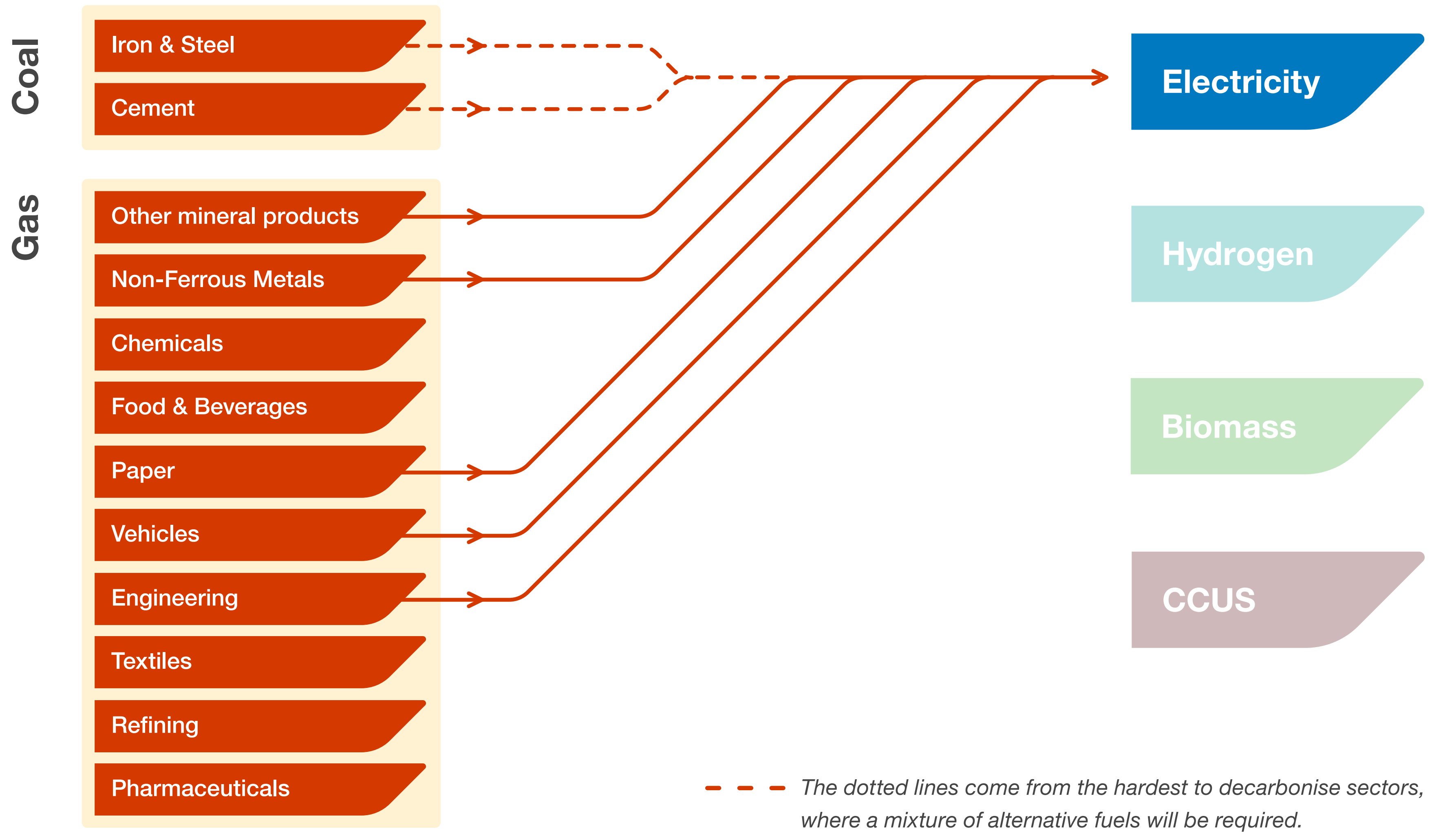
Investment in energy efficiency and fuel switching away from unabated fossil fuels towards electricity, hydrogen, or fossil fuels with CCUS is necessary to decarbonise industry.

Recent government policy announcements and strategies have led to more ambitious pathways for industrial decarbonisation. This has led to a faster transition away from natural gas for industry in our modelling compared to last year.

Policy supporting the development of industrial clusters indicates that these will provide locations for early decarbonisation between today and 2030, as discussed on the previous pages. We expect investment in hydrogen and CCUS projects to deliver anchor projects to help decarbonise industry. Fuel switching is then expected to ramp up in the 2030s as sources of hydrogen become more widely available and the electrification of energy intensive processes becomes more attractive driven by technology cost reductions and carbon taxes.

The two dominant solutions for fuel switching away from fossil fuels are electrification and hydrogen. Electrification is not suitable for every industry, while the use of hydrogen as a decarbonisation solution depends on its price and local availability. We expect hydrogen to be initially available in industrial clusters, but availability more widely varies across the scenarios.

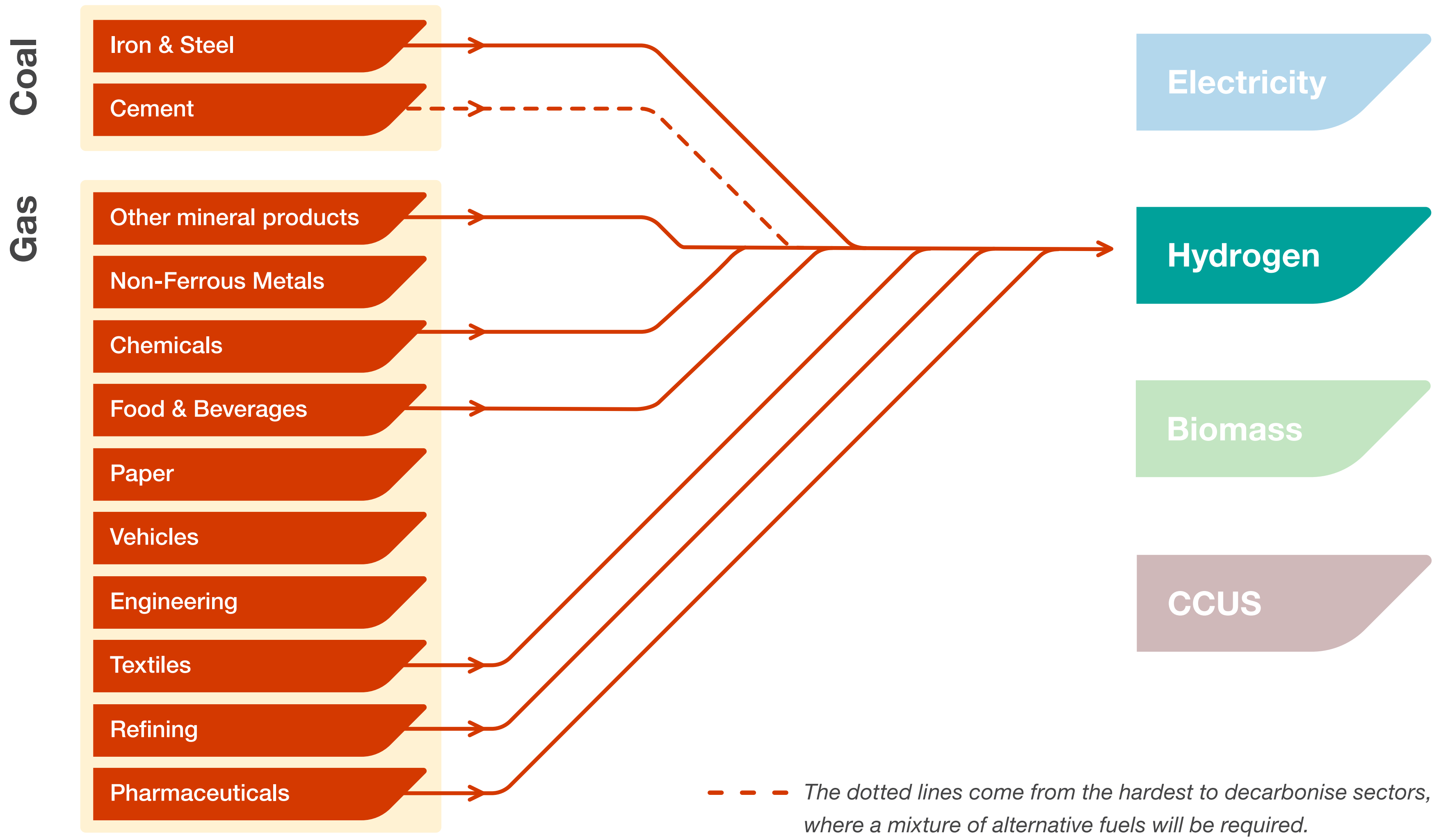
Figure EC.I.07: Industrial fuel switching options for decarbonisation[6]



6 The fuel switching options shown in this infographic are based on current technologies and may change in line with future innovation developments for the industrial sector.

What we've found

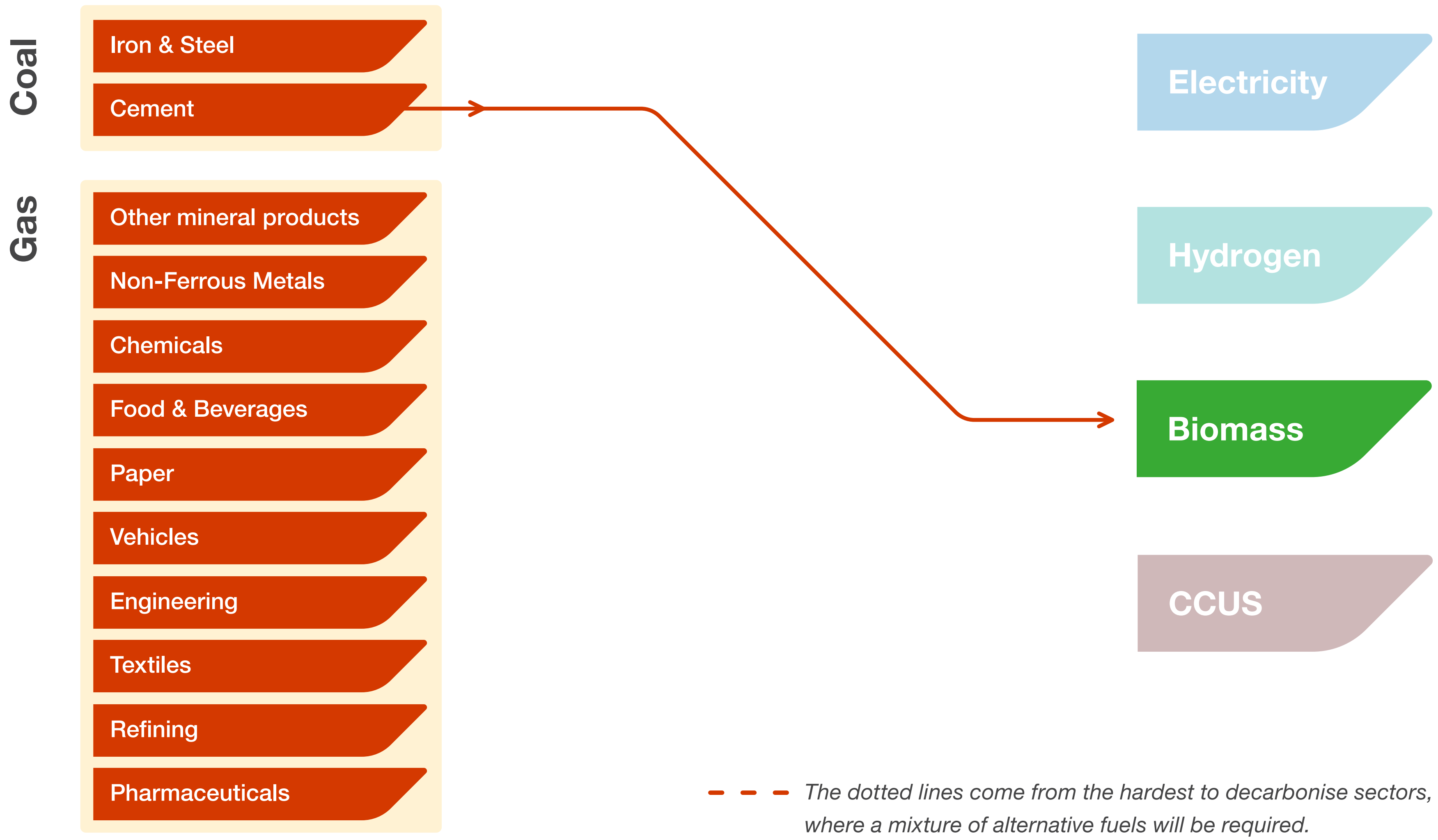
Figure EC.I.07: Industrial fuel switching options for decarbonisation



FES 2022 / The Energy Consumer / Industrial 135

What we've found

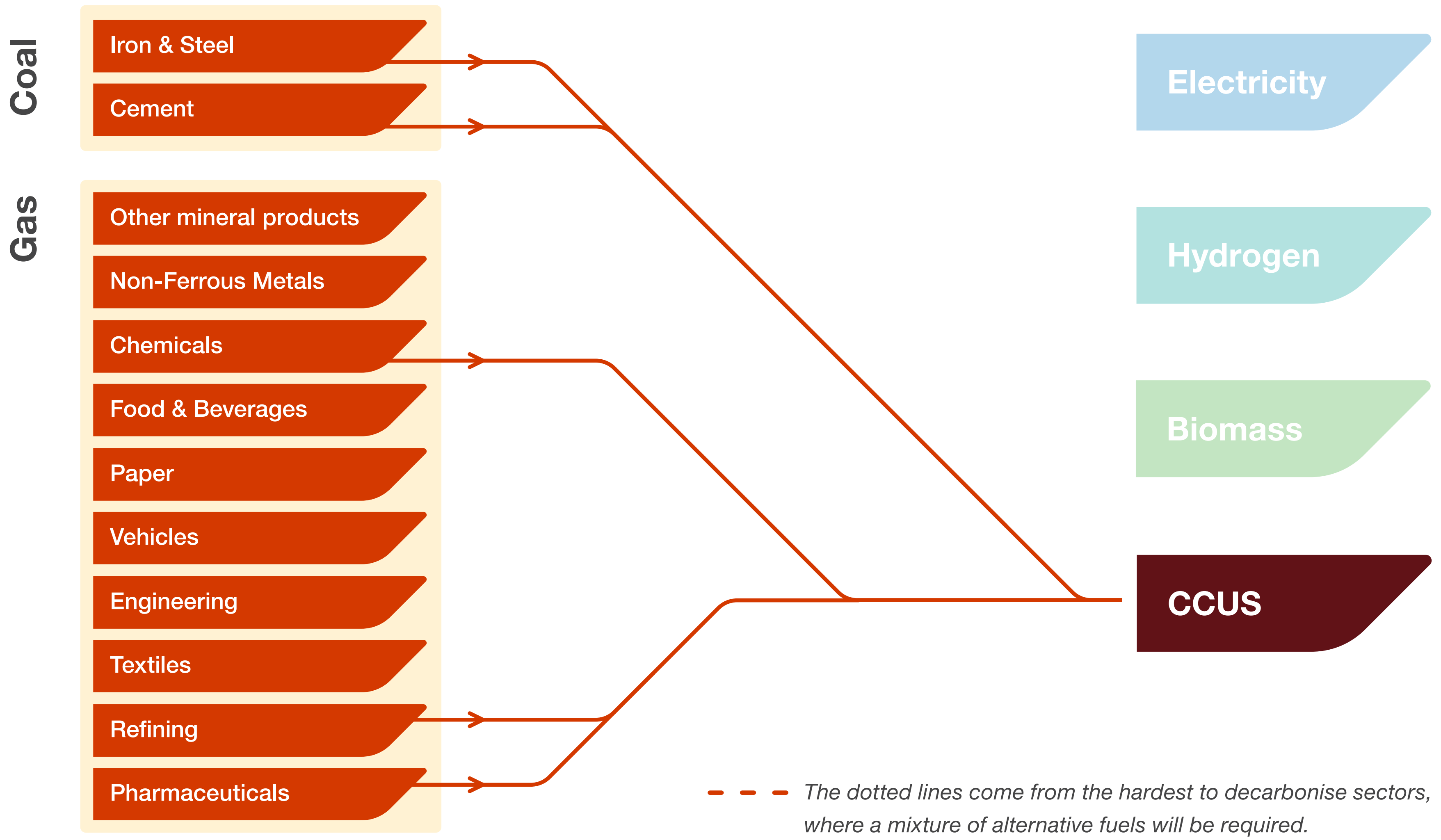
Figure EC.I.07: Industrial fuel switching options for decarbonisation



FES 2022 / The Energy Consumer / Industrial 136

What we've found

Figure EC.I.07: Industrial fuel switching options for decarbonisation



FES 2022 / The Energy Consumer / Industrial 137

What we've found

Consumer Transformation

In Consumer Transformation hydrogen availability is more limited; it is only available in industrial clusters, with no hydrogen distribution networks to allow use further afield. Electrification is a dominant decarbonisation solution, and businesses that want to use hydrogen need to relocate to clusters. The widespread electrification of industry leads to big increases in electricity demand for industry through the 2030s and 40s.

System Transformation

In System Transformation we assume that hydrogen demand growth starts in industrial clusters but spreads more rapidly through the rest of the country as broader hydrogen network infrastructure is developed beyond the clusters. Hydrogen is widely available and is the primary replacement for the natural gas and solid fuel used today, with electrification playing a more limited role.

Leading the Way

Leading the Way sees rapid developments for both uptake of hydrogen and electrification of industry, starting from the mid-2020s. The growth of hydrogen demand is focused on industrial cluster sites and nearby regions that can be supplied via local hydrogen distribution networks. It also sees rapid electrification and the highest level of process energy efficiency improvements to deliver the fastest pace of industrial decarbonisation.

Falling Short

In Falling Short, limited availability of hydrogen and less impetus behind decarbonisation means industrial processes see more limited progress, natural gas demand is only 35% lower than today, and electrification is the main route of choice for those who do choose to switch away from gas.

FES 2022 / The Energy Consumer / Industrial 138

What we've found

Industrial Demand Side Response

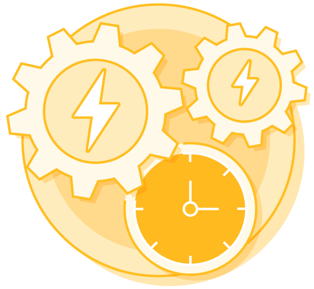
We estimate that currently around 6% of industrial peak electricity demand is shifted through Demand Side Response. In future we expect flexible demand to play a greater role in the industrial sector.

Changes to transmission network charging regimes have shifted the incentives for participation in this kind of activity, and we have seen 'triad avoidance' drop from over 2 GW of demand reduction at peak pre-2019 to around 1.3 GW today due to these reduced incentives.

Encouraging greater consumer participation will require appropriate market signals to be put in place to ensure it is worthwhile for these customers to participate in flexibility markets, and that they are compensated for the value they bring to the system through reduced peak demand requiring lower levels of future generation and associated network reinforcement. While some types of manufacturing such as steel or ceramics can require consistent high temperatures and energy demand to support them and have limited options to provide flexibility, some industrial users will be able to participate in flexibility markets.

Water pumping

The water industry uses a lot of electricity to pump water around the country, the timing of this demand may be able to be shifted.



Multi-stage production processes

Some industrial processes with more than one stage are not time critical and may be able to be staggered around times when energy is most expensive in between energy intensive production stages.

Infrequent processes

Some industrial processes occur less regularly and can be rescheduled around signals from the energy system.

Heating Ventilation and Cooling (HVAC) systems

Thermal storage can be used to shift heating loads for commercial systems. Air conditioning systems could respond to signals by adjusting their target temperature by 0.5-1 degrees, reducing demand.

Response from on-site battery storage or generation

Some large sites may have their own backup generation that could kick in and meet some of their demand at peak times.

FES 2022 / The Energy Consumer / Industrial 139

What we've found

Demand Side Response

Industrial Demand Side Response is currently a mixture of behind the meter generation offsetting demand (typically diesel generators), Combined Heat and Power (CHP) plants, batteries, and 'pure' Demand Side Response where the demand itself is shifted or postponed to another time. Response using behind the meter generation is typically more expensive to operate, and so these generators are where we have seen greater reduction in response. Current 'pure' Demand Side Response is around 1 GW, much of the response we see at peak.

Triad avoidance

A 'Triad' is one of the three highest peaks of electricity demand between November and February. These are half-hourly periods that normally occur between 4pm and 6pm on weekdays, when industrial demand coincides with increasing residential demand. Until recently, transmission network charges for industrial customers were based on their peak demand during triad periods, incentivising consumers to reduce their energy demand during these periods.

FES 2022 / The Energy Consumer / Industrial 140

What we've found

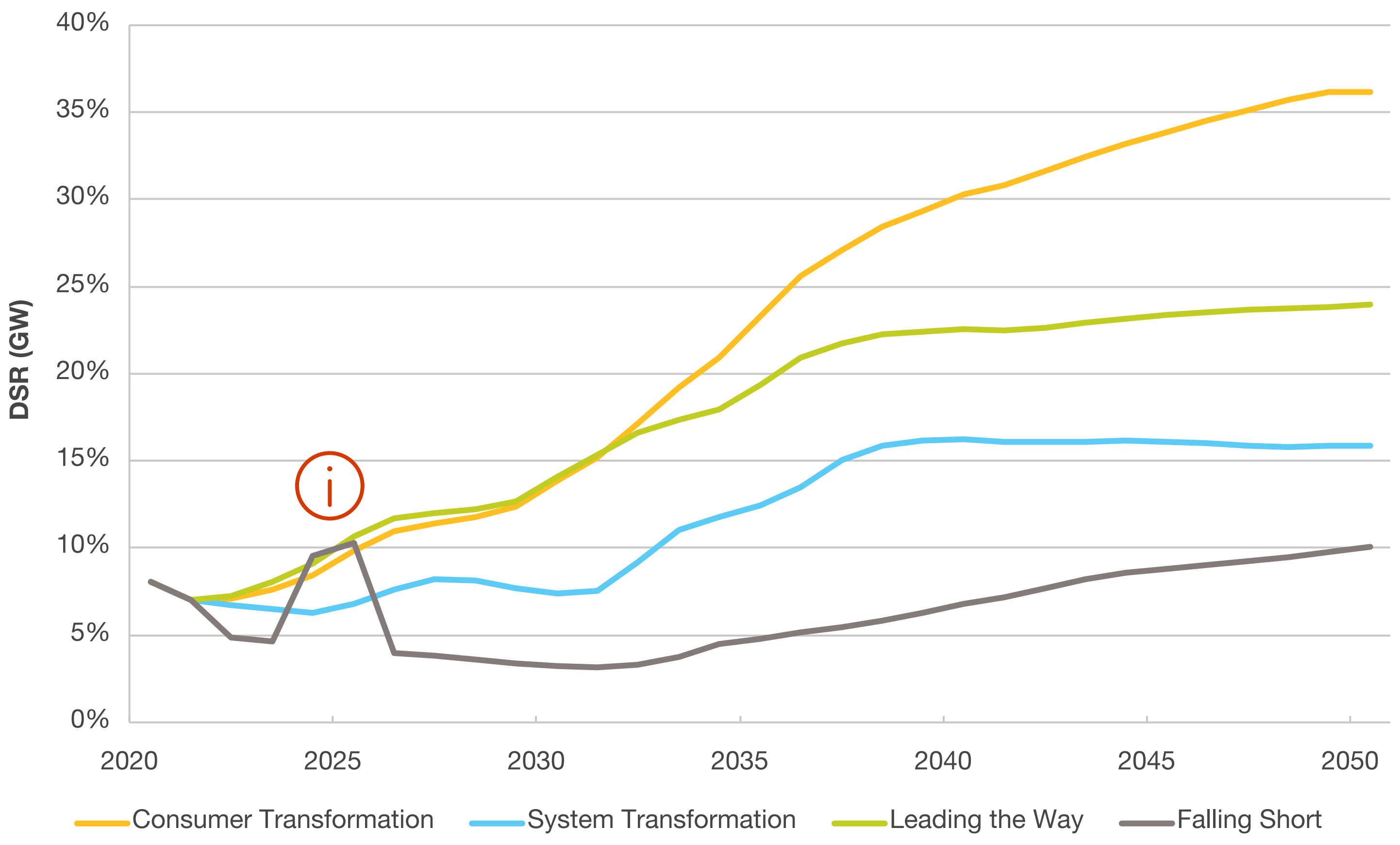
Different types of industrial demands have their own characteristics, with variations in the capacity of response they can provide, the notice period required for response and the duration they can respond for. The DSR levels shown in Figure EC.I.08 cover industrial processes in the areas detailed on the previous page.

There are several ways that industrial consumers could engage in DSR. These include engaging with smart tariffs and switching demand from times when energy prices are high to times when they are low and when renewable energy generation is abundant. Others may be through engagement with aggregators or direct participation in flexibility markets to provide dynamic response to price signals.

Consumer Transformation and Leading the Way see higher levels of electrification and higher levels of societal change; engagement by industrial consumers with these markets to help reduce peak demands will become increasingly important in these scenarios, particularly post-2030. More detail on Demand Side Response can be found in the **Flexibility chapter**.

The short-term increase in DSR in Falling Short in the 2020s is incentivised by higher prices and helps ensure Security of Supply is met. For more detail see the **Flexibility section**.

Figure EC.I.08: Percentage reduction in industrial demand at peak from DSR



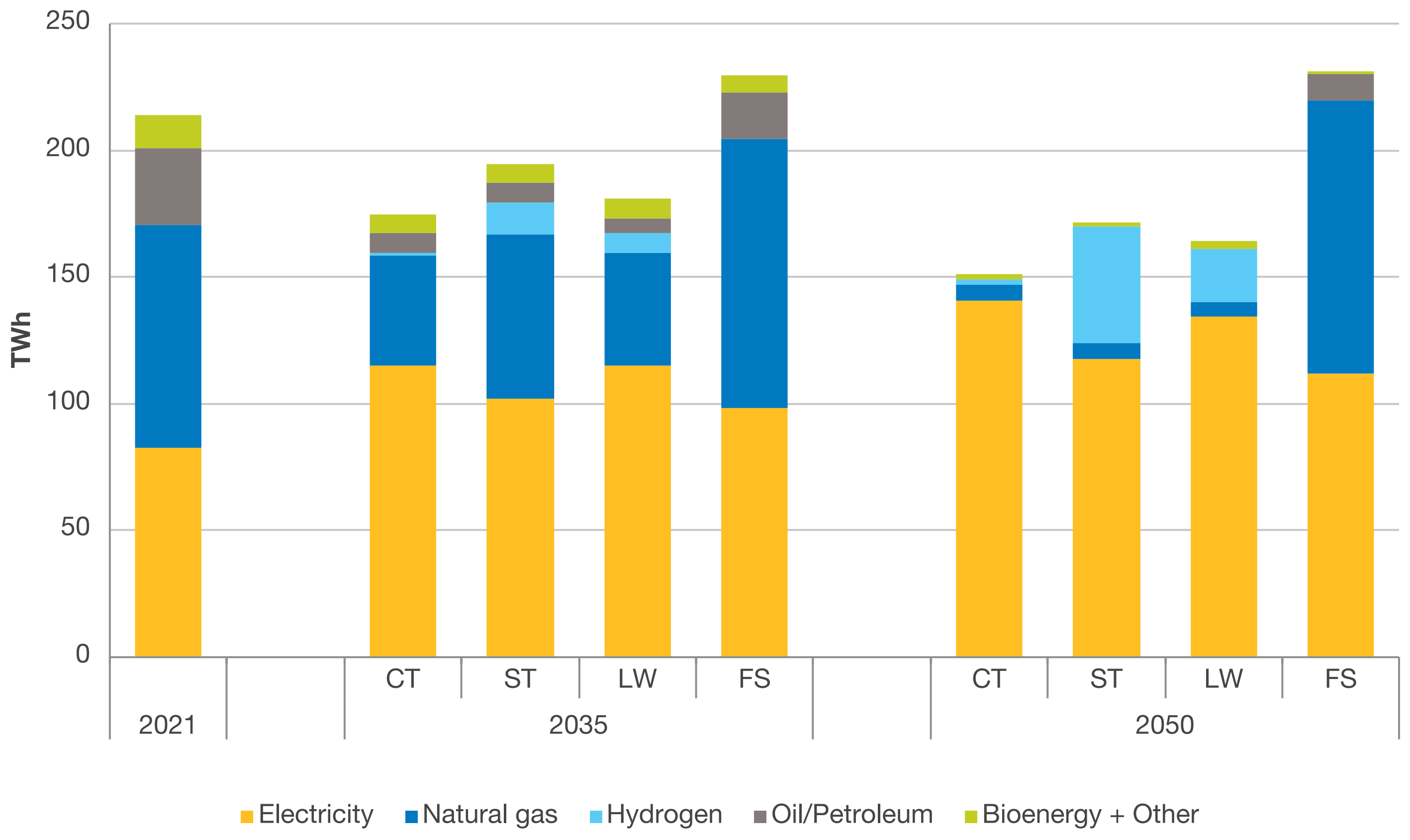
FES 2022 / The Energy Consumer / Industrial 141

Commercial

Key insights

- We expect that the economic impact of the events in 2020 and 2021, together with current high energy prices, to lead to **suppressed electricity and gas demand** in the short term.
- In the commercial sector, electrification is frequently **more cost-effective** than hydrogen for decarbonising heating, even in System Transformation.
- We expect high growth in energy demand in some sectors such as **commercial data centres.** This could represent up to 6% of GB electricity demand by 2030 from around 1% today, however there remains considerable uncertainty still in the range of the final energy demands for this sub-sector.
- In scenarios where hydrogen is used for commercial heating, this is likely to grow first around dedicated **hydrogen clusters** in the early 2030s.
- As for residential demand, it is possible that there won't be any hydrogen used for commercial heating as reflected in the Consumer Transformation scenario, with **hydrogen use prioritised for other sectors.**
- **Demand Side Response** from commercial premises, primarily from thermal storage, could shift up to 28% of electric heat pump demand away from peak in 2050.

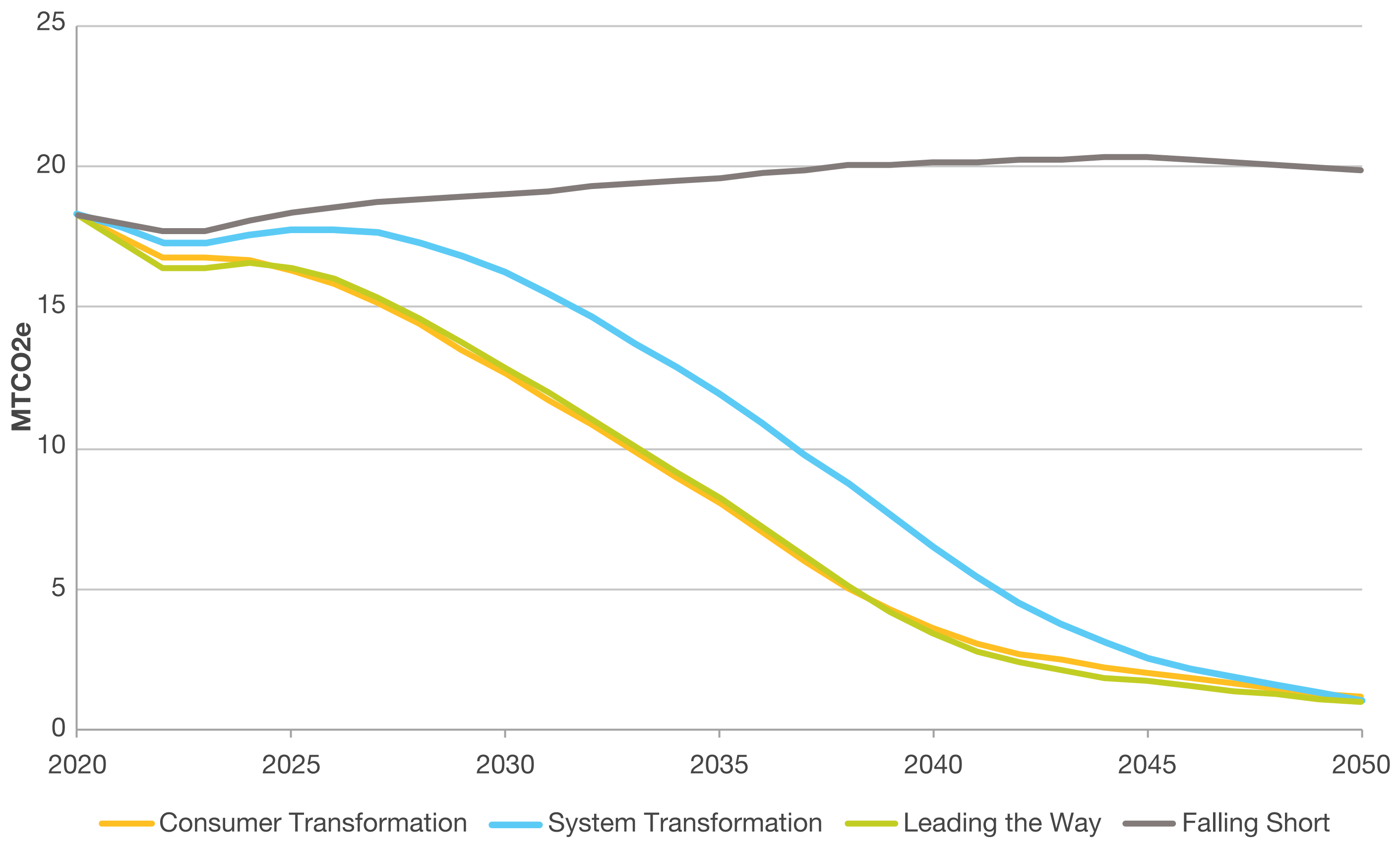
Figure EC.C.01: Annual commercial energy demand in 2035 and 2050[1]



1 The 2021 data is primarily made up of our modelled data for natural gas and electricity. Some 2020 demand data from ECUK was used to provide a complete, whole energy system view of end consumer demand for these sectors. The chart reflects end user demand across the commercial sector.

Key insights

Figure EC.C.02: Emissions from commercial heat



What is commercial demand?

The commercial sector encompasses a wide variety of different types of business and public and private sector operations. These include:

- Offices
- Retail: shops and shopping centres
- Education: schools and universities
- Hospitals and other healthcare services
- Military sites
- Hospitality: pubs, bars, and restaurants
- Public sector: national and local government buildings
- Community and the arts: museums, community centres
- Leisure: swimming pools, gyms
- Data centres

FES 2022 / The Energy Consumer / Commercial 144

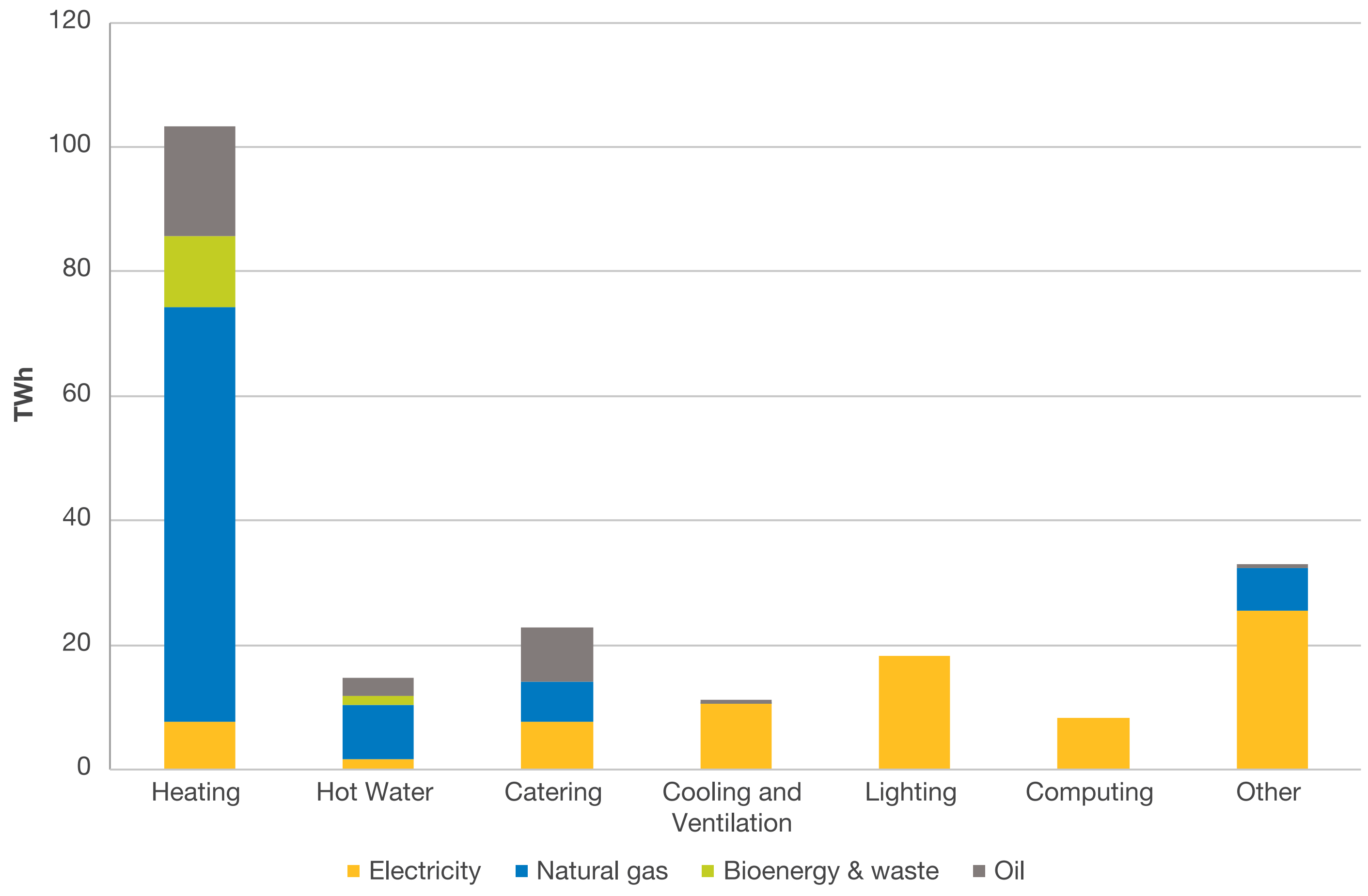
Where are we now?

The commercial sector in 2020 represented 16% of GB energy demand and 15% of emissions. The past two years have seen significant challenges in the sector. Energy demand in 2020 was heavily impacted by the pandemic, and energy price rises over the past year have put added pressure on businesses since then, particularly for Small and Medium Enterprises (SMEs).

Electricity today makes up 37% of commercial demand, with the remainder primarily met by fossil fuels (natural gas, oil, and solid fuels), as well as some contribution from bioenergy and waste for heating and hot water. Decarbonising the electricity system helps tackle the carbon emissions from the electrified portion of commercial demand, however where we use fossil fuels today alternative energy sources need to be found. Non-electricity demand is primarily used to supply heating and hot water in the commercial sector, often using gas boilers. Decarbonisation of this demand faces similar challenges to the residential heating sector. Electrification of heat is one potential solution, but will not be suitable for all uses, and other fuels will also have a role to play.

Recent policy papers affecting the sector include the Heat and Buildings Strategy, which set a target of a minimum efficiency standard of EPC band B for all privately rented commercial buildings by 2030 in England and Wales. Many commercial buildings are privately rented which places the onus on landlords to make energy efficiency and heating system improvements.

Figure EC.C.03: Commercial demand today by fuel and subsector[2]



2 Data from 2020 ECUK Energy Data Tables (Tables U2 and U5) - gov.uk/government/statistics/energy-consumption-in-the-uk-2021

FES 2022 / The Energy Consumer / Commercial 145

Where are we now?

Energy Performance Certificate

Energy Performance Certificates or EPCs give a property an energy efficiency rating from A (most efficient) to G (least efficient). They are required whenever a property is sold or rented.

FES 2022 / The Energy Consumer / Commercial 146

Scenarios overview: commercial

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- Heat and hot water are primarily electrified, with heating system changes increasing electricity demand.
- Uptake of energy efficiency measures increases through the 2020s helping suppress energy demand for heating and lighting.
- Electricity demand for data centres starts to increase after 2025 before flattening off in the 2040s.

What does 2050 look like?

- Total demand for the commercial sector is 158 TWh.
- Electricity meets 89% of commercial demand.
- Net additional annual electricity demand for data centres is 15 TWh.
- There is high participation in Demand Side Response primarily using thermal storage to shift heating demand away from peak times.

FES 2022 / The Energy Consumer / Commercial 147

Scenarios overview: commercial

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- Hydrogen use grows for commercial consumers from 2030 onwards, initially around hydrogen clusters in the Midlands and Wales, before spreading nationwide as the gas network is converted to deliver hydrogen.
- Electrification of heat also plays a role particularly from the 2030s.
- Additional electricity demand for data centres starts to increase in the late 2020s.

What does 2050 look like?

- Total demand for the commercial sector is 176 TWh.
- Hydrogen meets 27% of demand, primarily used for heating and hot water.
- Widespread use of hydrogen boilers and hybrid Air Source Heat Pump/hydrogen systems.
- Net additional annual electricity demand for data centres is 10 TWh.

FES 2022 / The Energy Consumer / Commercial 148

Scenarios overview: commercial

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- High energy prices incentivise uptake of energy efficiency measures through the 2020s helping suppress energy demand for heating and lighting.
- Rapid uptake of heat pumps through the 2020s and 2030s.
- Hydrogen for heat rolled out from 2028, starting from hydrogen clusters in the Midlands and South East of England.
- Electricity demand for data centres increases rapidly through the 2020s and 2030s.

What does 2050 look like?

- Total demand for the commercial sector is 170 TWh.
- Electrification is the dominant solution for heat, but hydrogen still meets 19% of heat demand, in a mixture of hydrogen boilers and hybrid heat pump / hydrogen boiler systems.
- Net additional annual electricity demand for data centres is 20 TWh.
- There is high participation in Demand Side Response primarily using thermal storage to shift heating demand away from peak times.

FES 2022 / The Energy Consumer / Commercial 149

Scenarios overview: commercial

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- Take-up of commercial heat pumps increases in the 2030s, starting to displace gas boilers in some areas.
- Total gas demand remains high out to 2050.
- Electricity demand for data centres increases gradually through the late 2020s, before plateauing in the 2030s.

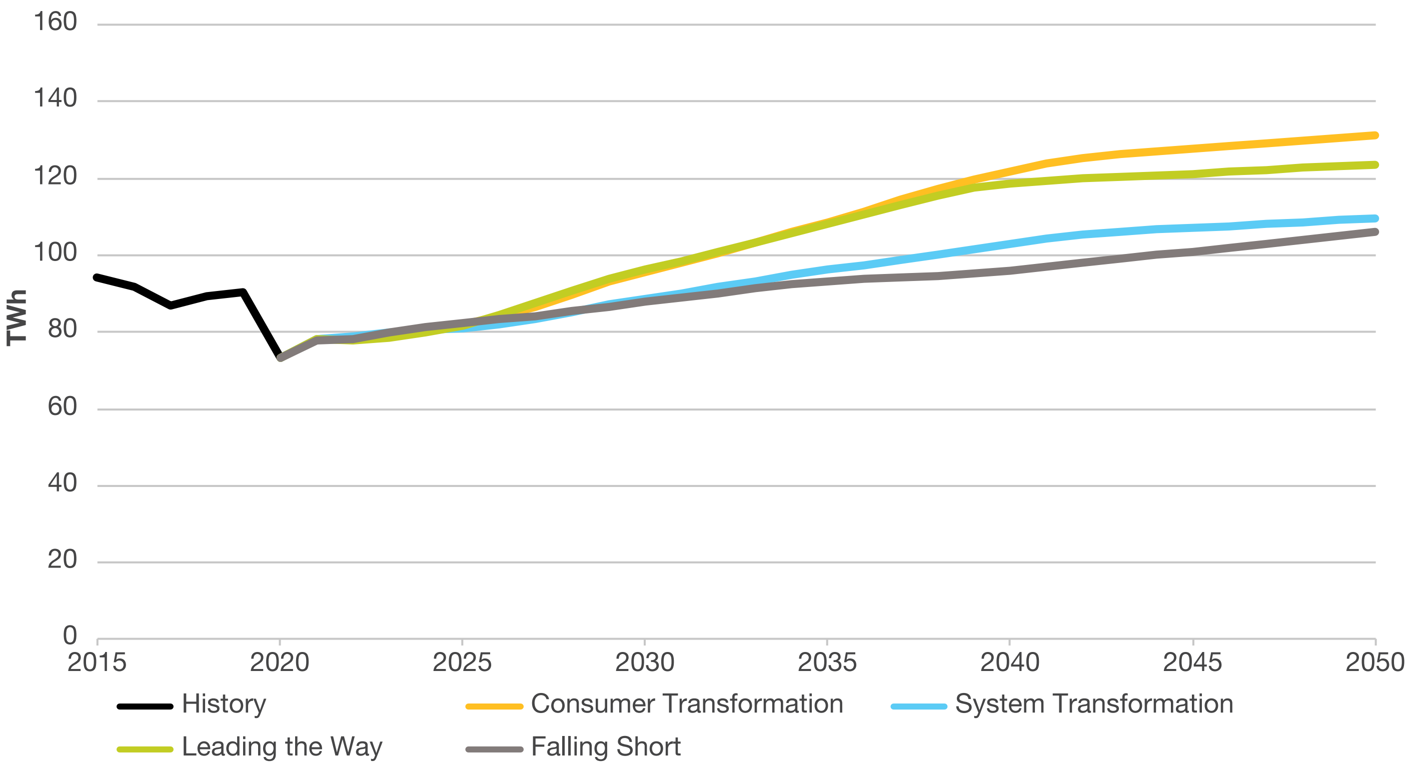
What does 2050 look like?

- Total demand for the commercial sector is 232 TWh.
- Natural gas meets 46% of energy demand, with only limited progress made in decarbonising heating.
- Net additional annual electricity demand for data centres is 5 TWh.

FES 2022 / The Energy Consumer / Commercial 150

What we’ve found

Figure EC.C.04: Annual electricity demand for the commercial sector



FES 2022 / The Energy Consumer / Commercial 151

What we've found

Figure EC.C.05: Annual natural gas demand for the commercial sector

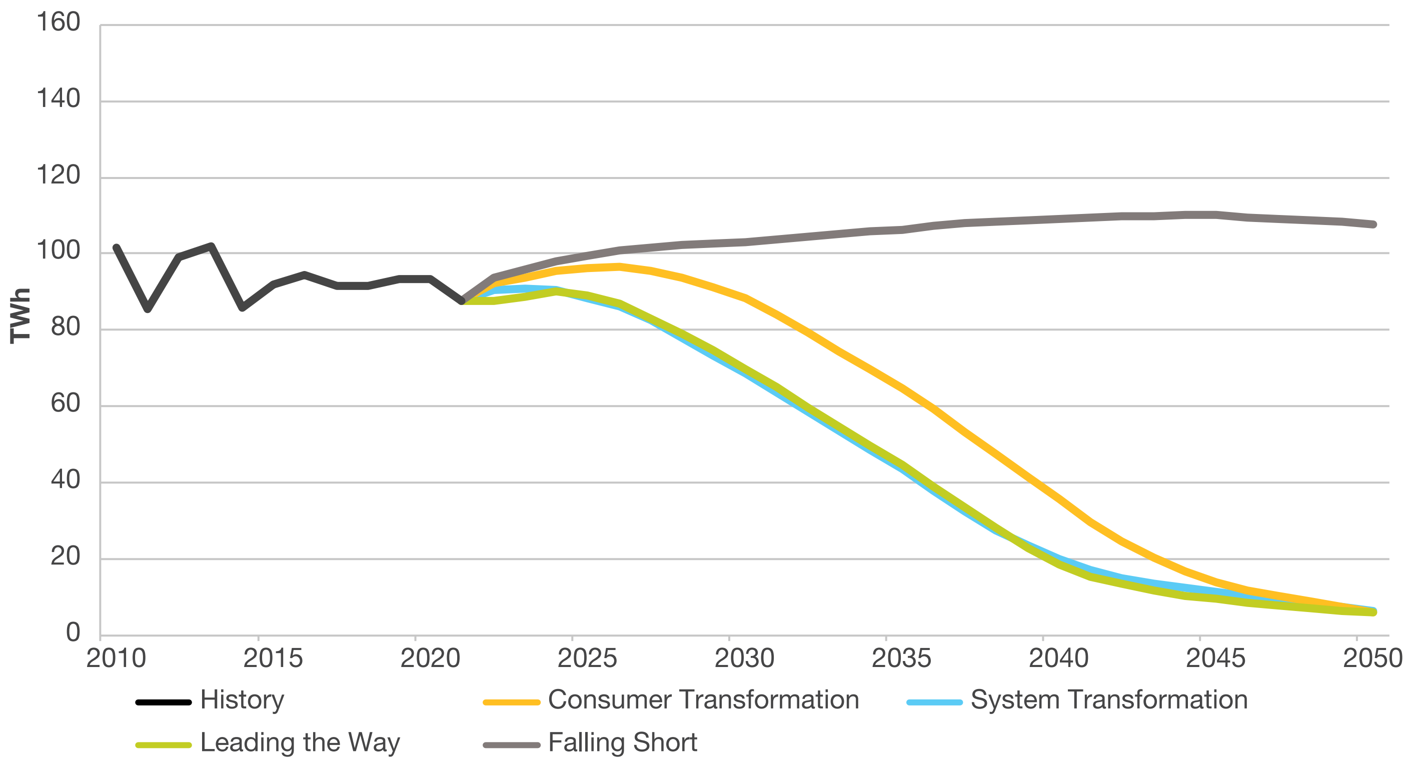
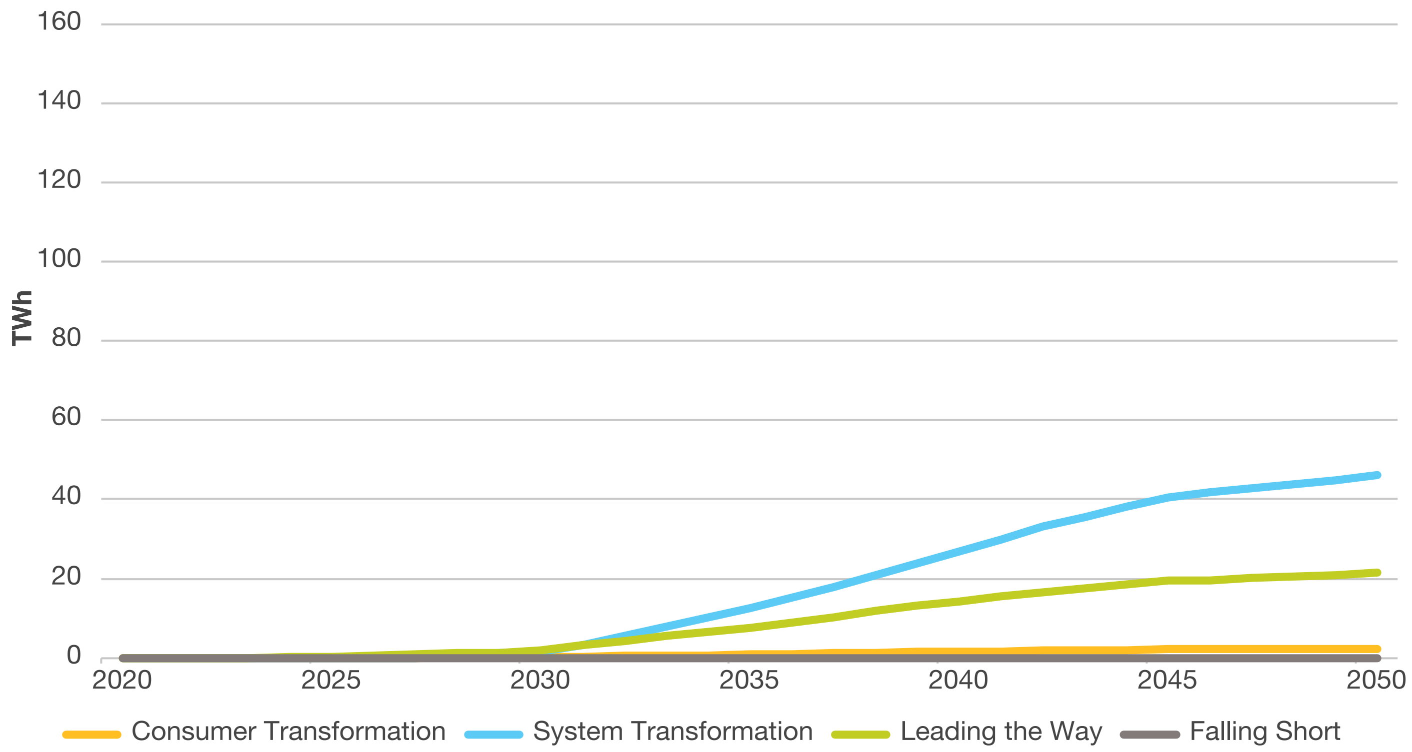


Figure EC.C.06: Annual hydrogen demand for the commercial sector



FES 2022 / The Energy Consumer / Commercial 152

What we've found

Data centres

We expect a high level of growth in data centre capacity in the coming years. Stakeholder engagement indicates there is a strong pipeline of new data centres seeking to connect to the electricity network, particularly in London and the South East.

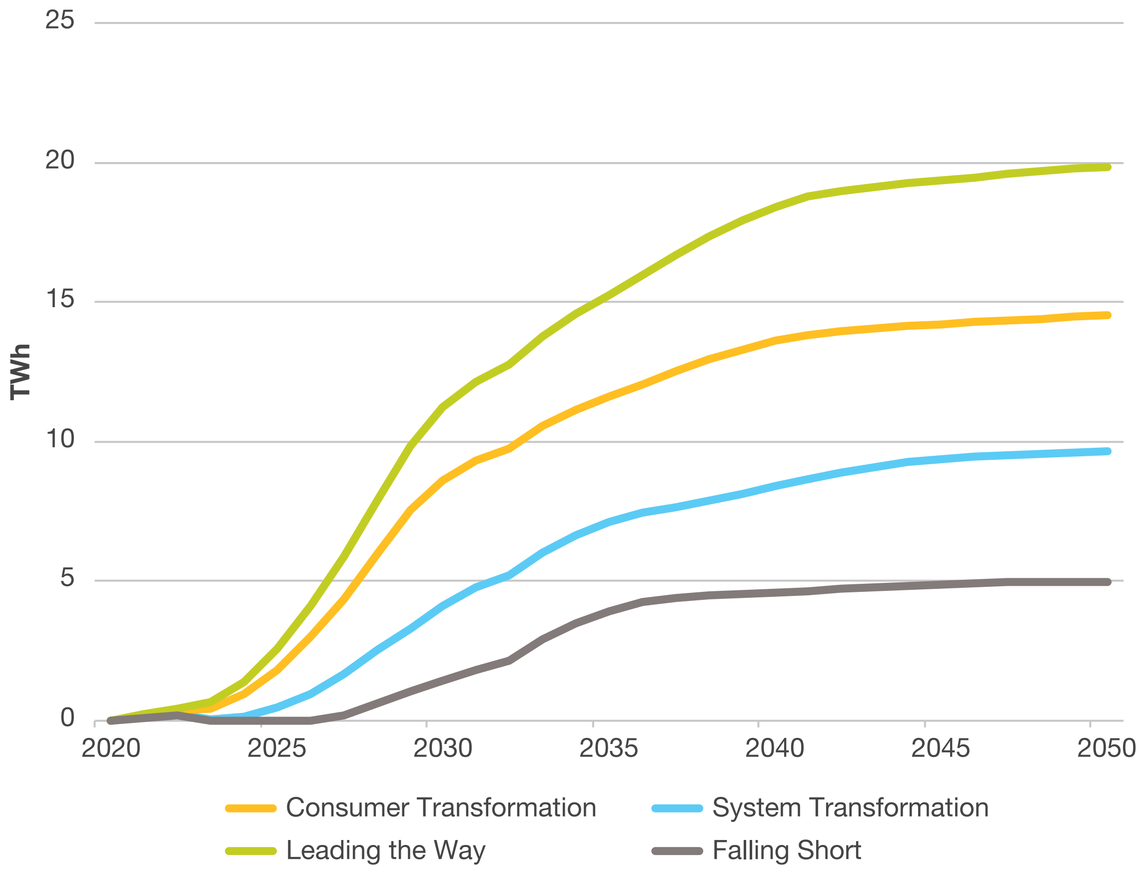
We have been refining our modelling of energy demand from data centres in this year's Future Energy Scenarios. You can find an introduction to data centres and our new modelling in our thought piece here.[3]

Data centres require electricity both to run the equipment – computers, servers, and electronics – but also for cooling. Up to 40% of electricity consumption is spent on keeping the facilities temperature controlled and optimised to prevent IT equipment overheating, with the rest used to power the equipment itself.

We forecast that annual data centre electricity consumption for commercial data centres could see a net increase of up to 20 TWh by 2050 in Leading the Way. This will be made up of an increase from 3.6 TWh of electricity demand for standalone data centres in 2020 to as much as 30 TWh by 2050 and a reduction in many business's on-site IT electricity demand due to companies outsourcing their existing computing power to these new data centres. This increase is equal to a quarter of today's electricity demand for the commercial sector, highlighting the impact of the rapid growth in demand on total electricity demand.

We will continue engaging with stakeholders in this area to refine our modelling of data centres and improve the spatial resolution of our analysis. New data centres will be connected at both transmission and distribution level, depending on the scale of the new facilities. Understanding the impact of data centres at a more granular level will be important for predicting how they will affect energy supply issues during peak times and the role they could play in a zero carbon electricity system.

Figure EC.C.07: Net additional annual electricity demand for data centres



3 nationalgrideso.com/document/246446/download

FES 2022 / The Energy Consumer / Commercial 153

Data centres

Data centres are physical facilities that organisations use to accommodate their computing applications and data. They range from private facilities that are owned and located within individual businesses, to large standalone commercial data centres offering services such as 'cloud' and 'managed' computing services. Data centres host core IT infrastructure that supports much of today's digital activity, and so are fundamental to our modern way of living. Our dependence on them is only set to increase as our consumption of data continues to grow. Every time we send an email, buy something online, save something to 'the cloud', or play online video games we are exchanging information with a data centre.

FES 2022 / The Energy Consumer / Commercial 154

What we've found

Heating in the commercial sector

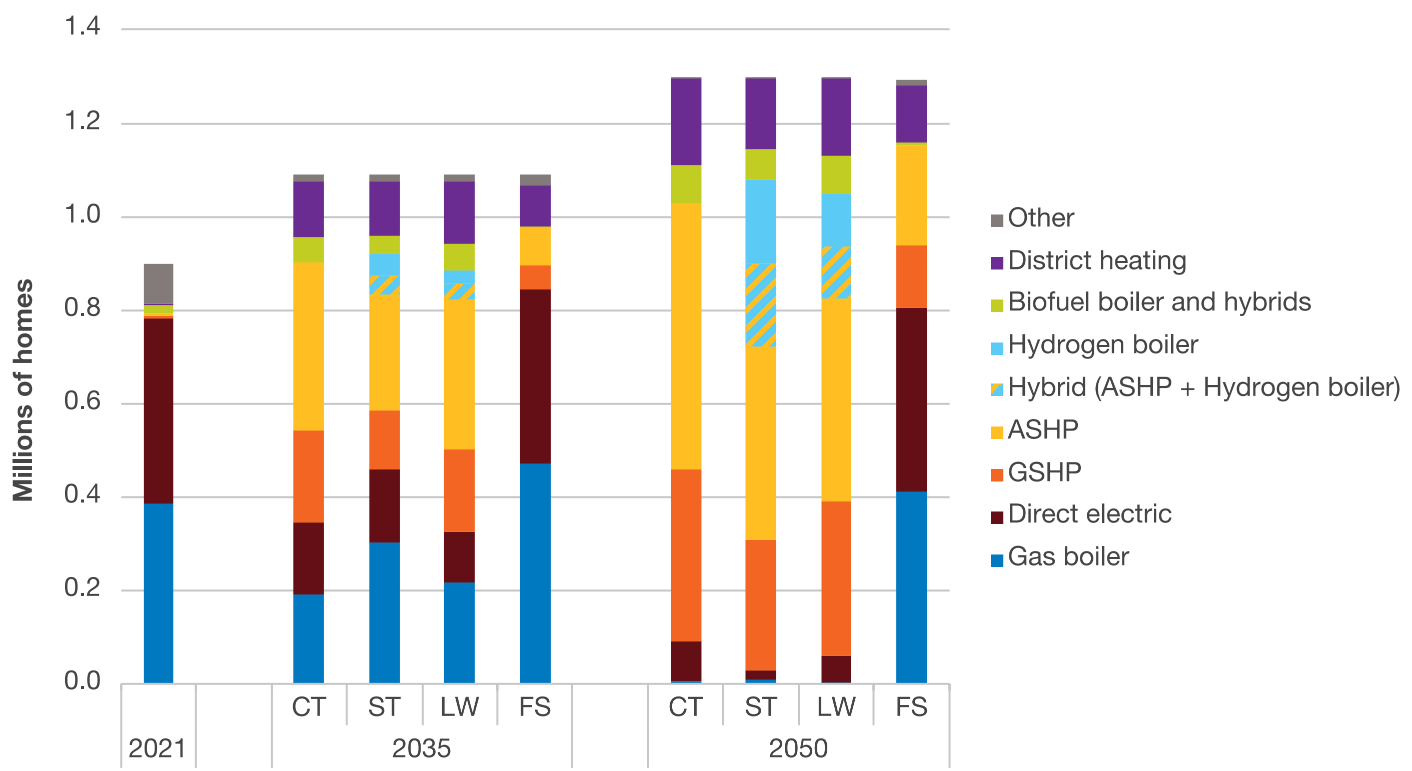
The dominant source of energy demand and emissions in the commercial sector is for heating and hot water, which is today largely met by natural gas. This means decarbonisation solutions follow similar patterns to residential heating and face similar challenges.

There are a range of low carbon technologies that can contribute to decarbonisation in this sector. The most appropriate technology for different consumers will be dependent on factors including cost, availability of infrastructure and building type.

Thermal energy efficiency is an important first step in tackling emissions for these demands. The heat and building strategy minimum efficiency standard of EPC band B for rented properties by 2030 sets a clear ambition for improvement in this sector but will require significant investment. Recent high energy costs have brought added salience to this issue and highlight the importance of energy efficiency and demand reduction as a cost saving measure and not only as a decarbonisation solution.

We expect heat pumps to be a widespread solution for commercial heat across the Net Zero scenarios; electrified heating and cooling is already common for many businesses and increasing uptake of these technologies would allow simple decarbonisation in many sectors.

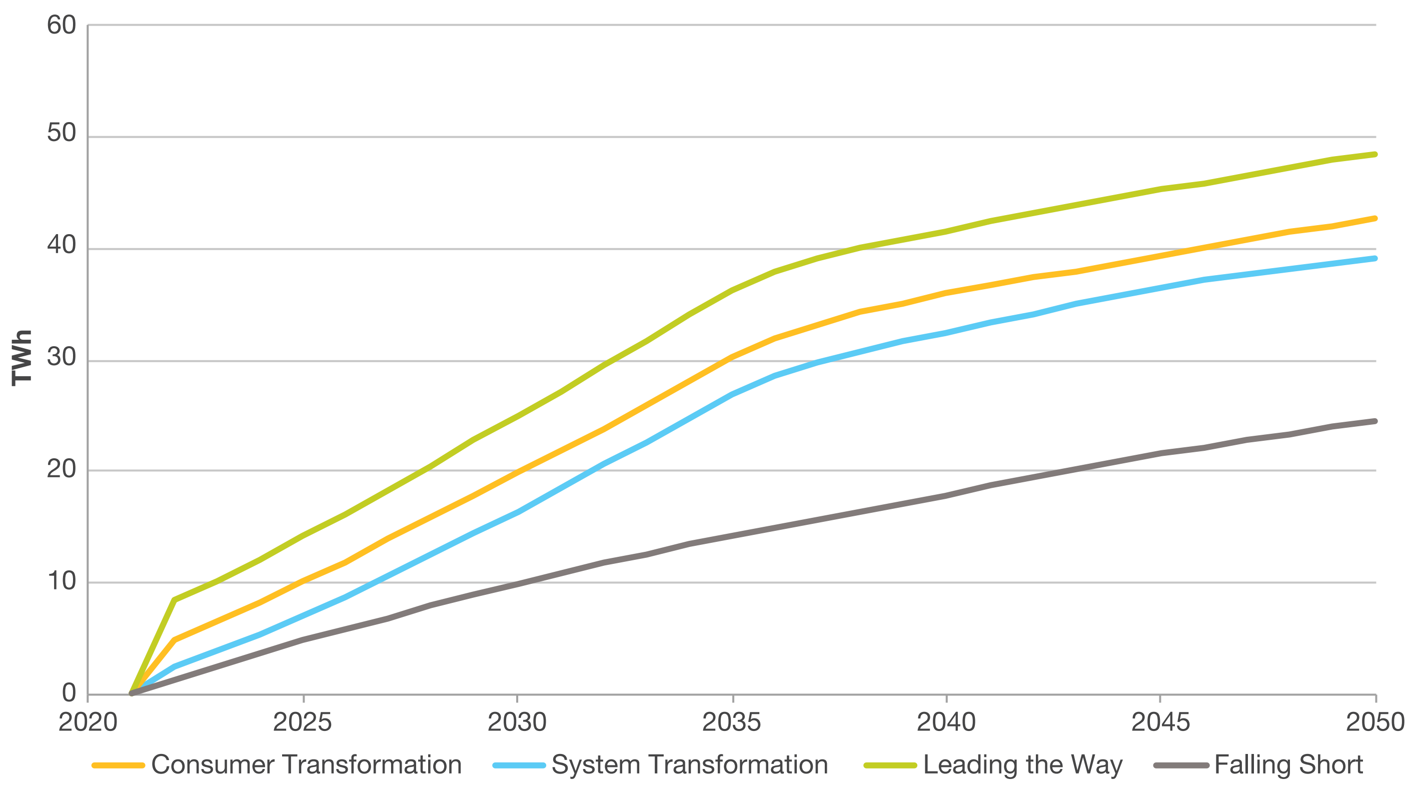
Figure EC.C.08: GB-wide commercial heating technology types by scenario



FES 2022 / The Energy Consumer / Commercial 155

What we've found

Figure EC.C.09: Annual savings in underlying heat demand from energy efficiency improvements in the commercial sector



FES 2022 / The Energy Consumer / Commercial 156

Regional deployment of heating technologies

Our spatial heat model allows us to model heating demands and decarbonisation solutions at high levels of granularity and explore regional insights.[4]

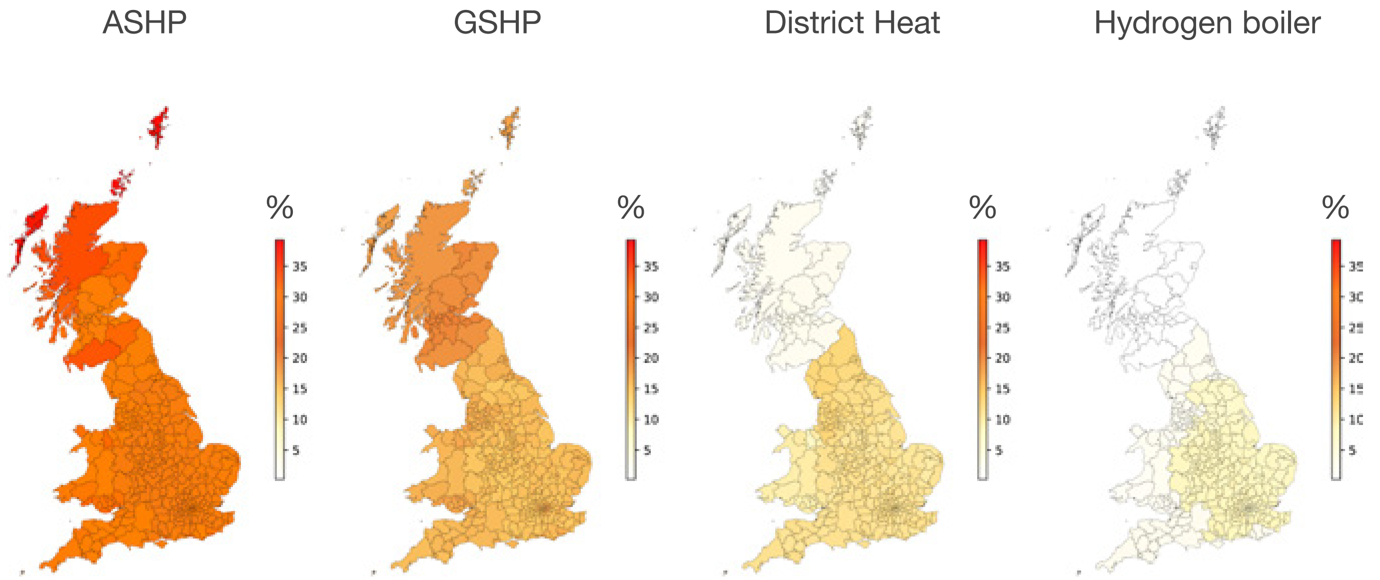
Hydrogen for heating availability depends on the development of hydrogen clusters across the country. We expect these to develop initially around industrial clusters as detailed in the industrial chapter. In Consumer Transformation and Falling Short there is no use of hydrogen for heat directly. In Consumer Transformation this leads to a fairly even spread of heat pump deployment across the country as the dominant decarbonisation solution, with hydrogen prioritised for uses other than heat.

System Transformation is likely to see the greatest uptake of hydrogen boilers as a direct replacement for natural gas boilers in use today. The gas network being converted to deliver hydrogen nationwide, leads to widespread use of hydrogen boilers, with hydrogen first available for heat in 2030 and hydrogen uptake growing around clusters.

In Leading the Way, hydrogen heating take-up develops primarily across the Midlands, East England and the South East, in some areas from as early as 2028, with air source and ground source heat pumps more dominant in other areas.

Falling Short sees more limited progress in decarbonising heat, both for residential and commercial customers. There is some uptake of heat pumps, but this is limited, particularly before 2030, and gas boilers continue to be in widespread use as the most cost-effective heating solution.

Figure EC.C.10: Regional deployment of commercial heating technologies, in Leading the Way in 2035



4 Additional regional data can be found here data.nationalgrideso.com/data-groups/future-energy-scenarios

What we've found

Demand Side Response

Historically large industrial and commercial consumers have participated in DSR in relation to 'triad avoidance', aiming to reduce the network charges they pay by minimising their demand at peak times in the winter. Demand Side Response in the commercial sector will become increasingly important in a Net Zero world.

Changes to transmission network charging regimes have shifted the incentives for participation in this kind of activity, and we have seen 'triad avoidance' drop from over 2 GW of demand reduction from industrial and commercial DSR at peak pre-2019 to around 1.3 GW today due to these reduced incentives.

In future we expect flexible demand to be increasingly important in the commercial sector. End users will be able to respond to market signals to vary some portions of their demand. This will require appropriate market signals to be put in place to encourage participation in these markets. Many commercial consumers are small businesses without the capacity to engage in the energy market themselves, so they will need an appropriate consumer proposition to allow them to participate with as few barriers as possible. This could involve the use of automation of response to signals and targeted campaigns from energy suppliers or aggregators to engage consumers.

There are several ways that commercial consumers could engage in DSR. This includes engaging with smart tariffs and switching demand from times when energy prices are high to times when they are low when renewable energy generation is abundant. Others may be through engagement with aggregators or direct participation in flexibility markets to provide dynamic response to price signals.

Forms of commercial demand suitable for engaging in Demand Side Response include:

Heating Ventilation and Cooling (HVAC) systems

Thermal storage can be used to shift heating loads for commercial systems. Air conditioning systems could respond to signals by increasing their target temperature by 0.5-1 degrees, reducing demand.

Refrigeration loads

Commercial fridges and freezers can be turned off for short periods with only minimal impact on the internal temperature.

Response from on-site battery storage or generation

Some large sites may have their own backup generation that could kick in and meet some of their demand at peak times.

FES 2022 / The Energy Consumer / Commercial 158

What we’ve found

Triad avoidance

A ‘Triad’ is one of the three highest peaks of electricity demand between November and February. These are half-hourly periods that normally occur between 4pm and 6pm on weekdays, when industrial demand coincides with increasing residential demand. Until recently transmission network charges for industrial customers were based on their peak demand during triad periods, incentivising consumers to reduce their energy demand during these periods.

Demand Side Response

Demand Side Response is currently a mixture of behind the meter generation offsetting demand (typically diesel generators today), Combined Heat and Power (CHP) plants, batteries, and ‘pure’ Demand Side Response where the demand itself is shifted or postponed to another time. Response using behind the meter generation is typically more expensive to operate, and so these generators are where we have seen greater reduction in response. In a Net Zero world diesel generators would be unable to continue operating and other forms of behind the meter generation would be required.

FES 2022 / The Energy Consumer / Commercial 159

What we've found

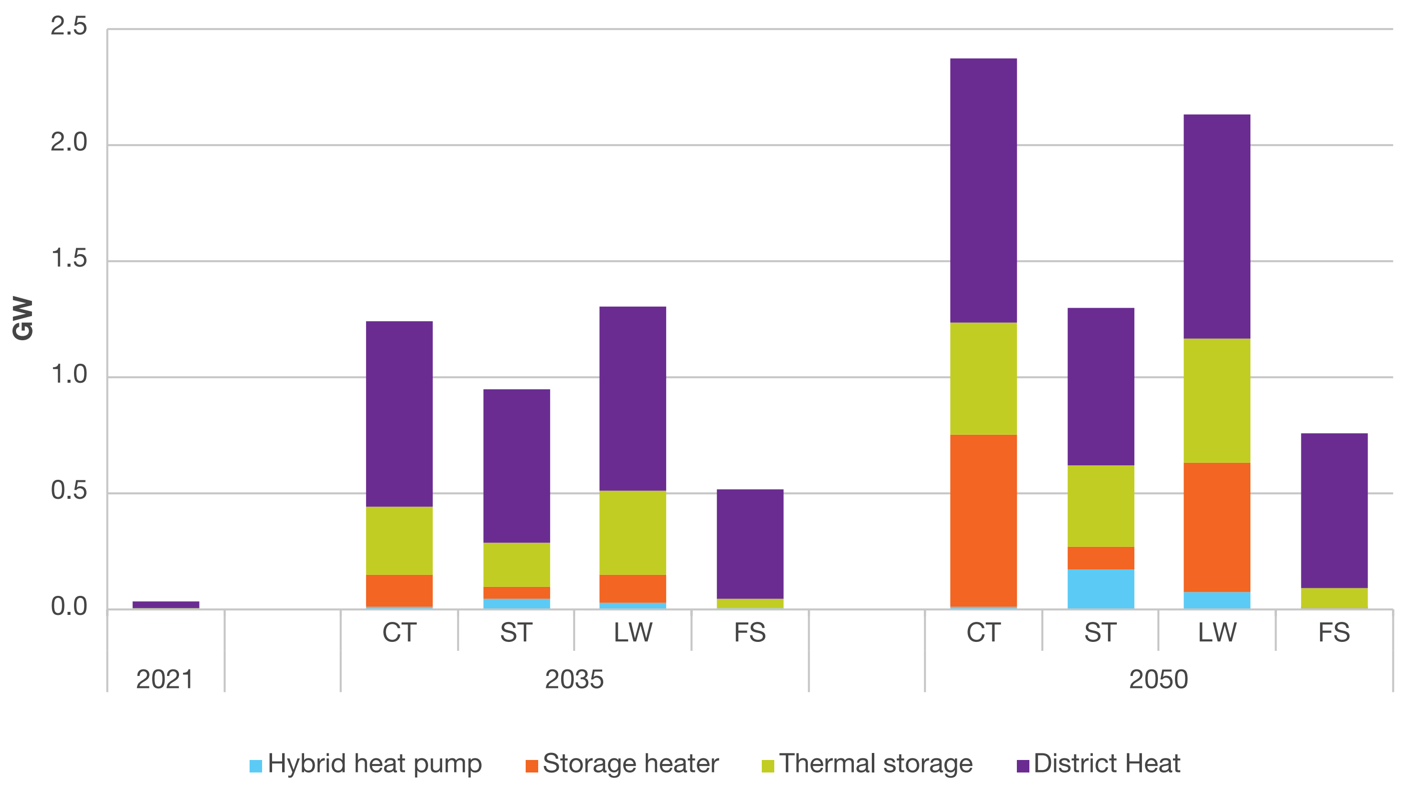
Commercial demands have their own characteristics, with variations in the capacity of response they can provide, the notice period required for response and the duration they can respond for.

Consumer Transformation and Leading the Way see higher levels of electrification and higher levels of societal change. Engagement by businesses in these markets to help reduce peak demands will become increasingly important in these scenarios, particularly post-2030. More detail on Demand Side Response can be found in the Flexibility chapter.

The large share of energy demand for heat and hot water represents the biggest opportunity for commercial load shifting. Electrification of some of this energy demand will lead to increased peak demands but also presents an opportunity to reduce costs to commercial consumers and stress on the electricity network by incentivising DSR.

This can be delivered using thermal storage alongside heat pumps or district heating, the use of load shifting in hybrid systems from electricity to hydrogen or biofuel, or the use of electric storage heaters.

Figure EC.C.11: Commercial heating peak shaving by technology



FES 2022 / The Energy Consumer / Commercial 160

The Energy System

nationalgridESO

Introduction

Transformation of the whole energy system is achievable, and can deliver energy that is clean, secure, affordable, and fair. This requires strategic and holistic development of the networks, markets and technologies required, in a coordinated and timely manner, to ensure we make the most of the abundant renewable energy we could use to meet energy demand.

This chapter explores the energy system: how it works today, how it needs to change and what the future might look like. There are four sections, one for each of the main ways we meet demand, which explore how this energy is produced:

- Bioenergy Supply
- Natural Gas Supply
- Hydrogen Supply
- Electricity Supply

In each scenario, we match annual supply and demand (shown by our energy flow diagrams). We also ensure that the energy system can meet peak demand in all scenarios in line with reliability standards (1-in-20 gas peak and Average Cold Spell (ACS) peak electricity demand), including Flexibility needs.

FES 2022 / The Energy System / Introduction 162

Introduction

Key insights

Consumers require energy that is clean, secure, affordable and fair. This is achievable but relies on urgent and strategic development of networks, markets and technologies to make the most of the abundant renewable energy available in GB.

We have already seen the GB energy system evolving as new technologies and innovations emerge, and the electricity system in particular has decarbonised rapidly. To reach Net Zero by 2050, the energy system will need to continue to evolve, while maintaining Security of Supply (SoS).

- Achieving Net Zero by 2050 across the whole economy will require **Greenhouse Gas Removal (GGR)** in some sectors to offset emissions from hard to abate sectors. The energy sector is well placed to deliver this through technologies such as Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS).
- Decarbonising sectors like transport, and potentially heat, will require significant electrification and electricity ultimately overtakes fossil fuels in all scenarios to become the biggest supplier of energy to end users. This means the **power sector must first be fully decarbonised.**
- Driven by the need to ensure this electricity is carbon free, affordable and sustainable, **renewables emerge as the dominant source of electricity generation for Britain** between now and 2050. By 2030, wind and solar generation will have risen to at least 66% in Falling Short (from 43% today) and by 2050, it will meet 70% to 84% of annual electricity demand.
- A range of **flexible technology is needed** to integrate this generation output from weather dependent renewables, ensure supply is reliable and minimise curtailment. Our scenarios demonstrate the importance of utilising low carbon technologies and fuels, especially hydrogen and CCUS, alongside electricity storage, interconnection and demand side flexibility, to deliver a balanced whole energy system.
- Across all scenarios, **strategic investment is required now** to develop this whole energy system and deliver clean, secure, affordable and fair energy for all consumers.

FES 2022 / The Energy System / Introduction 163

Introduction

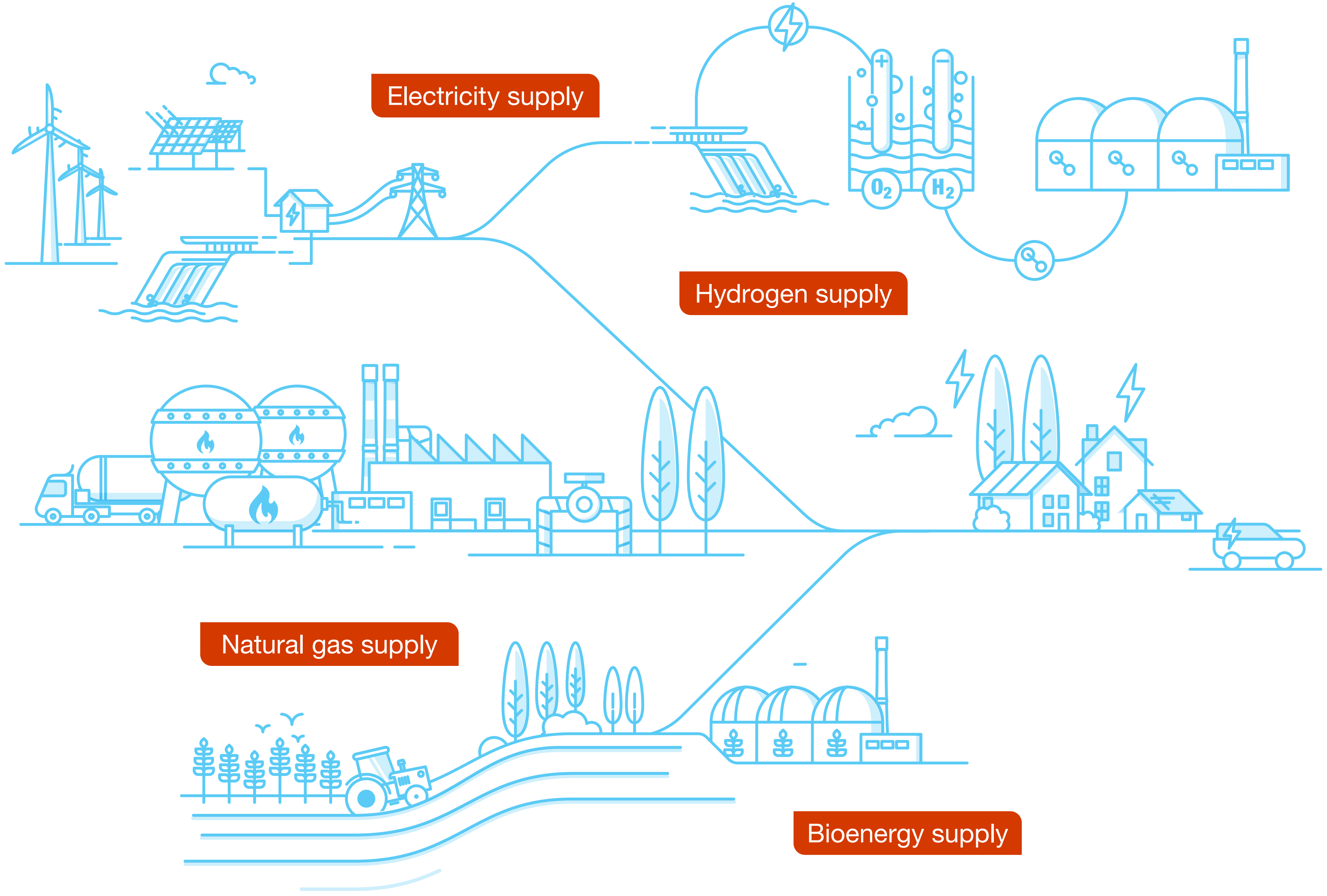
Whole system thinking helps decarbonisation and energy security

Here, we explain what we mean by the phrase 'whole energy system'.

The energy system of the future won't just be about getting energy from point A to point B in the right quantities. Each piece of the future energy system comes with new challenges and opportunities. On their own, these are difficult to solve but when thought of as a whole system, strengths in one area can offset challenges in another, or unlock new options entirely.

The energy flow diagrams illustrate how interconnected different energy uses are in a Net Zero world, such as where transport is electrified, biofuels are used for planes and hydrogen heats our homes and buildings. This whole energy system view, where all uses of energy are considered alongside each other, also creates an energy system which is as efficient as possible.

Learn more about what whole system means in FES for each of the main ways energy is supplied here.



Click label to jump to section.

FES 2022 / The Energy System / Introduction 164

Introduction

Electricity – more electricity from wind and solar is vital to help the UK meet its target for Net Zero by 2050. However, it won't always be available when we need it, which is why developing more sources of flexibility is important. Whole energy system thinking means considering how we can store this energy for use later or how we can change demand to maximise the use of renewable electricity across transmission and distribution networks as well as non-networked generation. One example is using Electric Vehicles (EVs) as mobile batteries, which can store electricity at times of peak supply and supplement supplies later at times of peak demand. More information on Vehicle-to-Grid (V2G) can be found in the Flexibility section.

Natural Gas – although a fossil fuel, natural gas continues to play an important role in the transition to a Net Zero energy system. Its use in power stations provides a flexible electricity source for times when renewable generation is not possible, and produces low carbon electricity when combined with CCUS technology. The network of natural gas pipes could also be part of a Net Zero system, by converting them to transport hydrogen around the country. Whole energy system thinking for natural gas means understanding its interactions with the electricity system, with hydrogen and with carbon transport and storage infrastructure.

Hydrogen – is a versatile source of energy, which can help across the whole energy system as it produces zero emissions when used. It can be used to store renewable electricity, and has potential use in sectors including transport, heating and industry. For this reason, it features in all our Net Zero scenarios. Whole system thinking includes ensuring locations for electrolysers are carefully considered to minimise network constraints and are convenient for the use of the hydrogen produced – as well as understanding the interaction of blue hydrogen production with the broader energy system.

Bioenergy – sustainable bioenergy is carbon neutral and flexible. It can be used as fuel for aviation, heating and transport, either as a liquid or a gas. Its use in power stations, when combined with CCUS, gives us an electricity source independent of weather which also provides negative emissions. It is important to prioritise the use of bioresources across the economy to maximise negative emissions and to focus on those areas which are hardest to decarbonise.

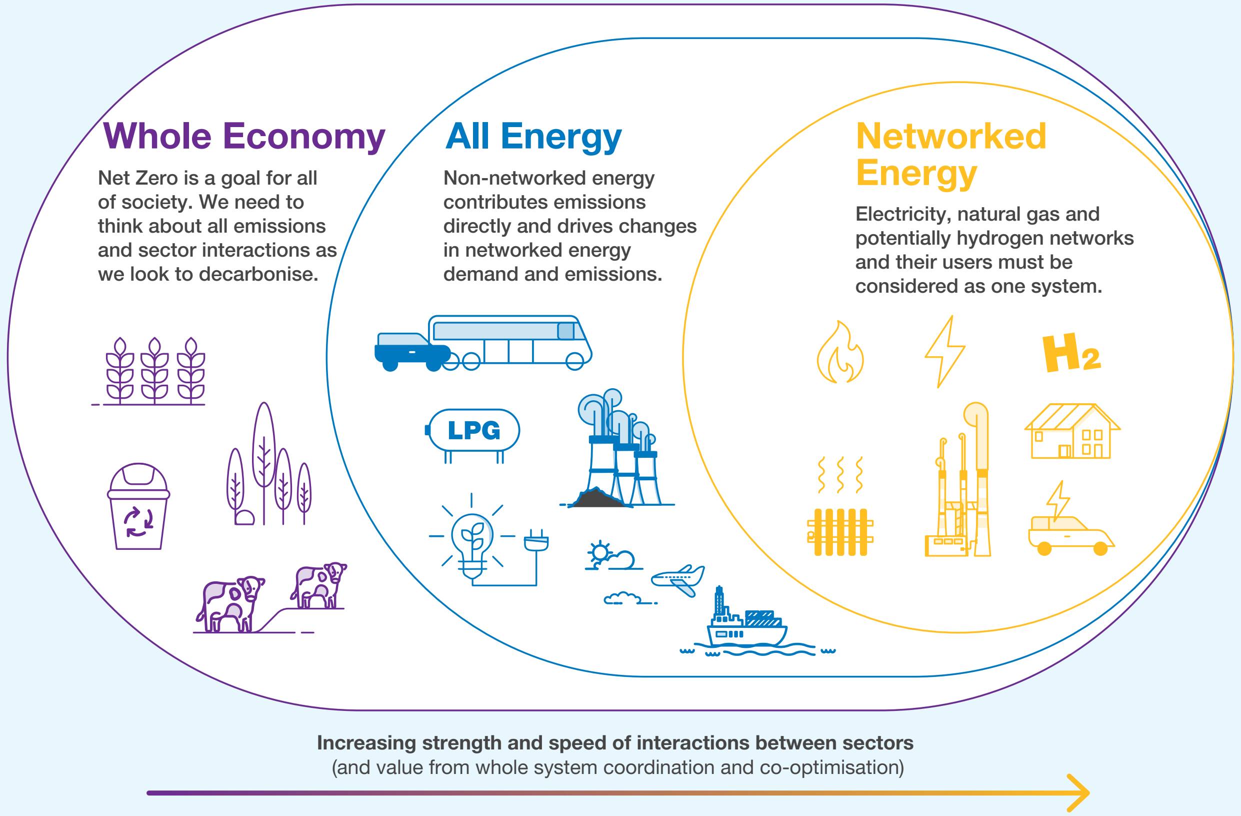
FES 2022 / The Energy System / Introduction 165

Introduction

Whole system thinking and coordination across energy networks provides greater efficiency and co-optimisation. However, whole system thinking should also be applied to the wider economy.

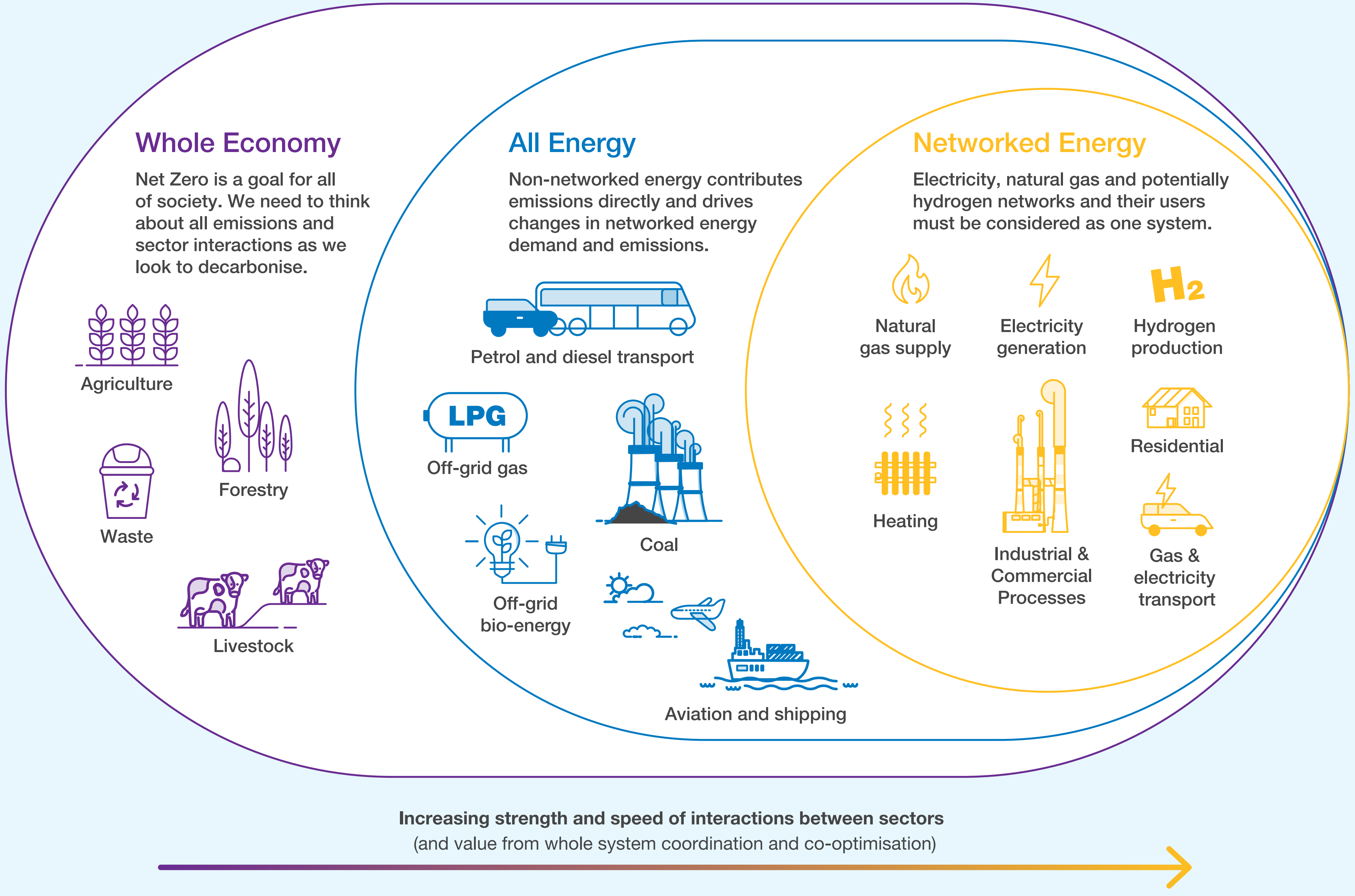
- **Networked energy –** This is energy transported from where it is produced to where it is consumed using transmission and distribution networks, such as electricity and gas, that interact closely with each other every day (e.g. gas-fired electricity generation).
- **All energy –** This includes areas where energy demand is met outside of the networked energy system such as by oil or petroleum-based products. This demand may potentially be met by the networked energy system in the future (e.g. as the transport sector decarbonises).
- **Whole economy –** This includes non-energy sectors which have an indirect interaction with energy decarbonisation. This is seen most clearly in the complex role of bioenergy and its implications for land use, but also includes how societal change impacts energy and emissions.

Whole system interactions for Net Zero



FES 2022 also considers energy use for aviation and shipping, as well as from non-energy sectors such as agriculture and Land Use, Land Use-Change and Forestry (LULUCF). For these sectors where we don't have deep expertise, or where we do not yet have strong stakeholder evidence, we use inputs from published analysis from the Climate Change Committee (CCC) and engagement with their experts.

FES 2022 / The Energy System / Introduction 166



FES 2022 / The Energy System / Introduction 167

Understanding the energy flow diagrams

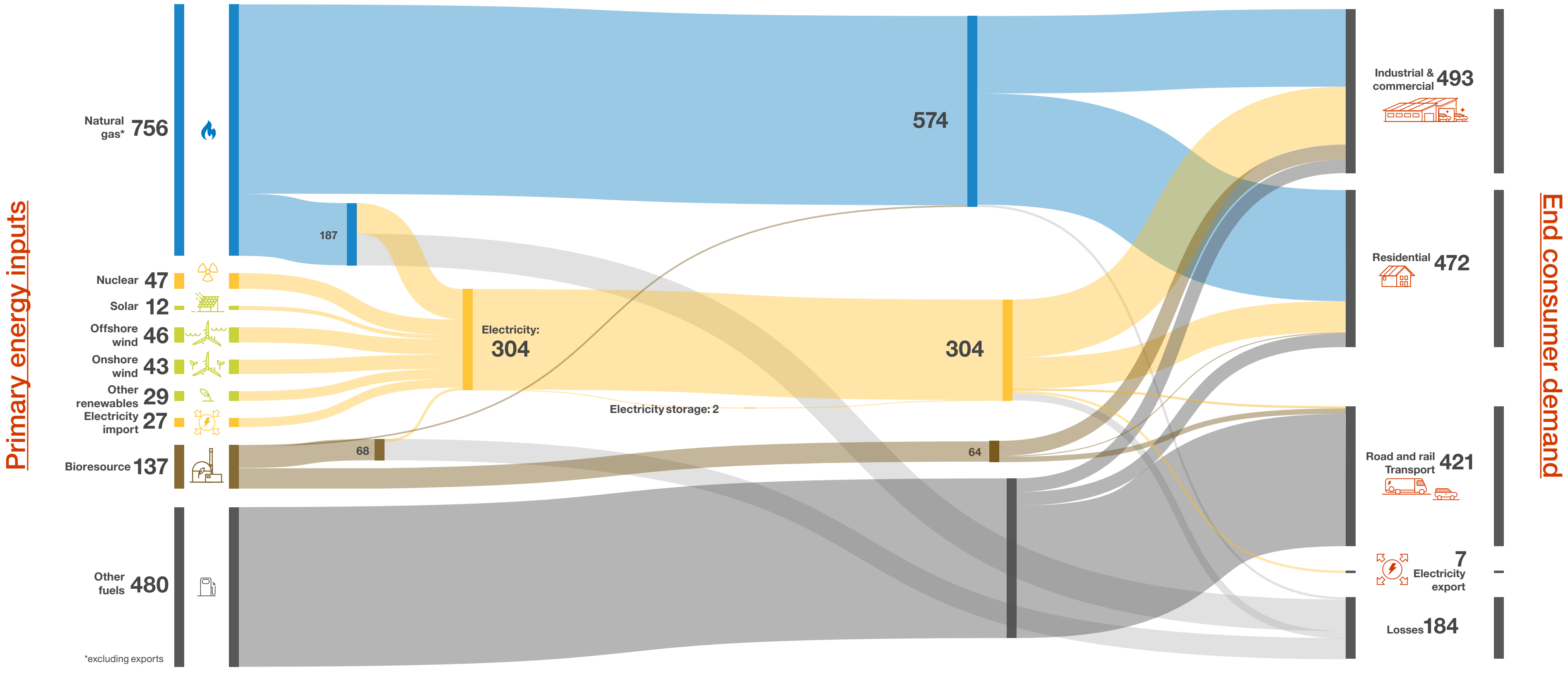
Energy flows in each scenario

These energy flow diagrams show how much energy is needed for a given year in each scenario, by end consumer (on the right-hand side) and where that energy comes from, by primary energy type (on the left-hand side). They also show levels of imported and exported energy for electricity and hydrogen.

These are useful for understanding total annual supply and demand, but it is also essential to understand how supply and demand profiles change through the year and how they are matched. This is explored in more detail in the Flexibility chapter.

You can learn more about how we create these diagrams and what they show here.

Energy Flows in 2020 (1577 TWh)



Energy transformation and losses

FES 2022 / The Energy System / Introduction 168

Understanding the energy flow diagrams

Primary energy inputs

The primary energy inputs we consider here are bioresources, natural gas, other fossil fuels, and renewable and nuclear electricity generation. It is possible to break some of these areas down in more detail; for example the natural gas we use comes from a range of different sources, but we have chosen the cut-off point to make the diagram as clear as possible. Sources of natural gas and the make-up of our total pool of bioresources are considered in more detail in the sub-chapters.

Energy transformation and losses

The diagram shows several points where energy is transformed between different fuels or forms of energy. This is often important for system reasons, for example using electricity to produce hydrogen allows electricity generated in the summer to be transformed into a form of energy that can be stored and used during the winter. The use of hydrogen to generate electricity then provides additional flexibility to the energy system.

These conversions are usually associated with some form of energy loss, as none of these processes are 100% efficient. For example, thermal electricity generation involves combustion of fuels such as gas, hydrogen or biomass to create heat to generate steam to drive a turbine, with energy losses at each step. Other conversion points within the diagram include electricity converted to hydrogen via electrolysis, methane reformation of natural gas or biomethane to produce hydrogen, and energy moving in and out of electricity or hydrogen storage. Technologies such as Carbon Capture and Storage (CCS) are not shown, although any changes this may have on the efficiency of a conversion process is included in our analysis.

Losses on the energy system at different stages of energy transformation or transportation are shown by the light grey lines that combine in the bottom right corner of the diagram. We also include electricity transmission and distribution losses and natural gas pipeline shrinkage.

FES 2022 / The Energy System / Introduction 169

Understanding the energy flow diagrams

End consumer demands

Our total end consumer demands are split by sector: Industrial & Commercial, residential, road and rail transport, and aviation and shipping. These include energy used for different purposes, for example for electricity used for lighting and appliances within the home, but also energy used to produce heat. This is a measure of the energy used by the sector, in terms of electricity, hydrogen, natural gas and bioresources, and not the input energy needed to meet these demands. This is particularly important when considering the effect of different heating technologies.

While Consumer Transformation and System Transformation have relatively similar heat demands, on the energy flow diagram these look markedly different in size. This is because System Transformation relies heavily on hydrogen boilers to produce heat – which are around 90% efficient – while Consumer Transformation primarily uses heat pumps. These have an equivalent efficiency of around 250%, as the electricity for heat pumps is used to run pumps and compressors that are able to extract additional energy from the air or the ground around the heat pump. This increases the difference for end user demand for electricity, gas and hydrogen between these scenarios. This is particularly apparent in the 'residential' end consumer demand section, which is dominated by heat.

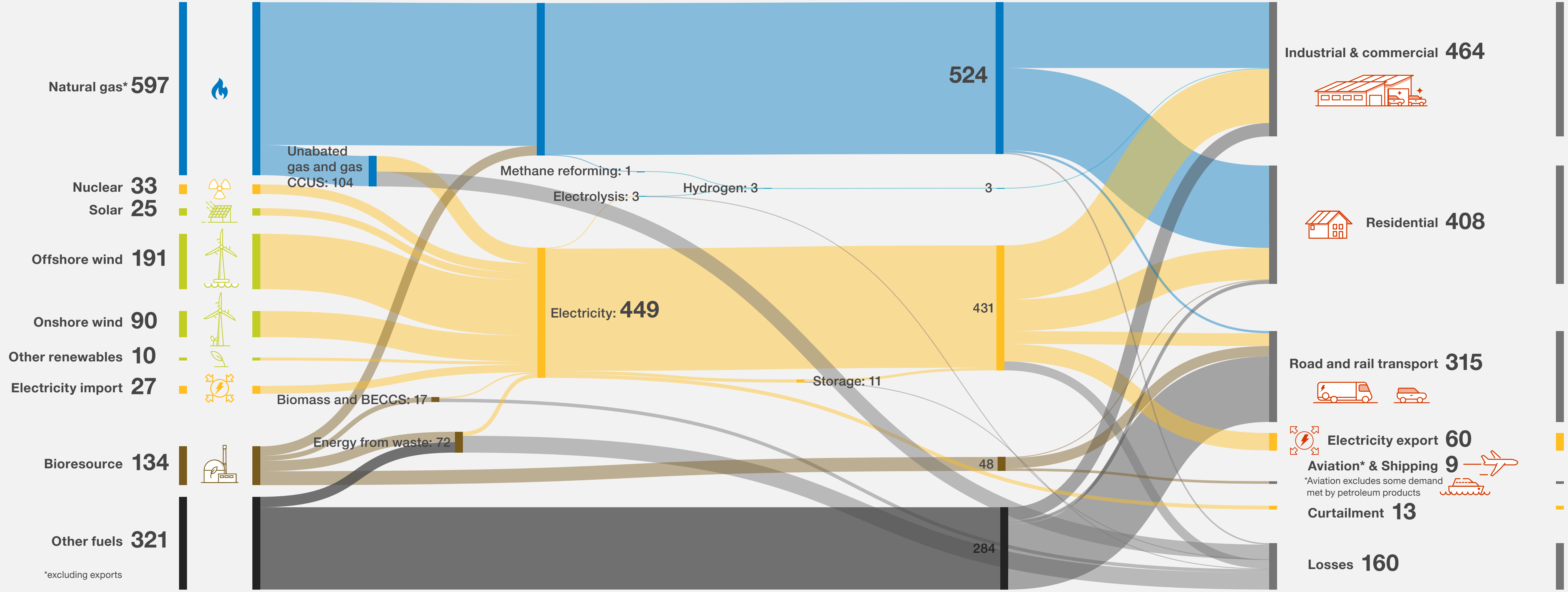
FES 2022 / The Energy System / Introduction 170

Energy flows in our scenarios 2035

For FES 2022, energy flow diagrams have been included for Falling Short and Leading the Way in **2035** to highlight the differences between the slowest and fastest decarbonising scenarios in relation to the target for no unabated natural gas in the power sector by this year.

Falling Short (1428 TWh)

- Minimal difference to today with continued reliance on both oil-based fuels as well as natural gas
- Main area of progress is in surface transport where increased electrification and use of biofuels reduces demand for oil-based products
- Significant increase in electricity generation from renewables but unabated gas-fired generation still contributes heavily
- Use of oil-based fuels in residential heating largely replaced by electric heat pumps

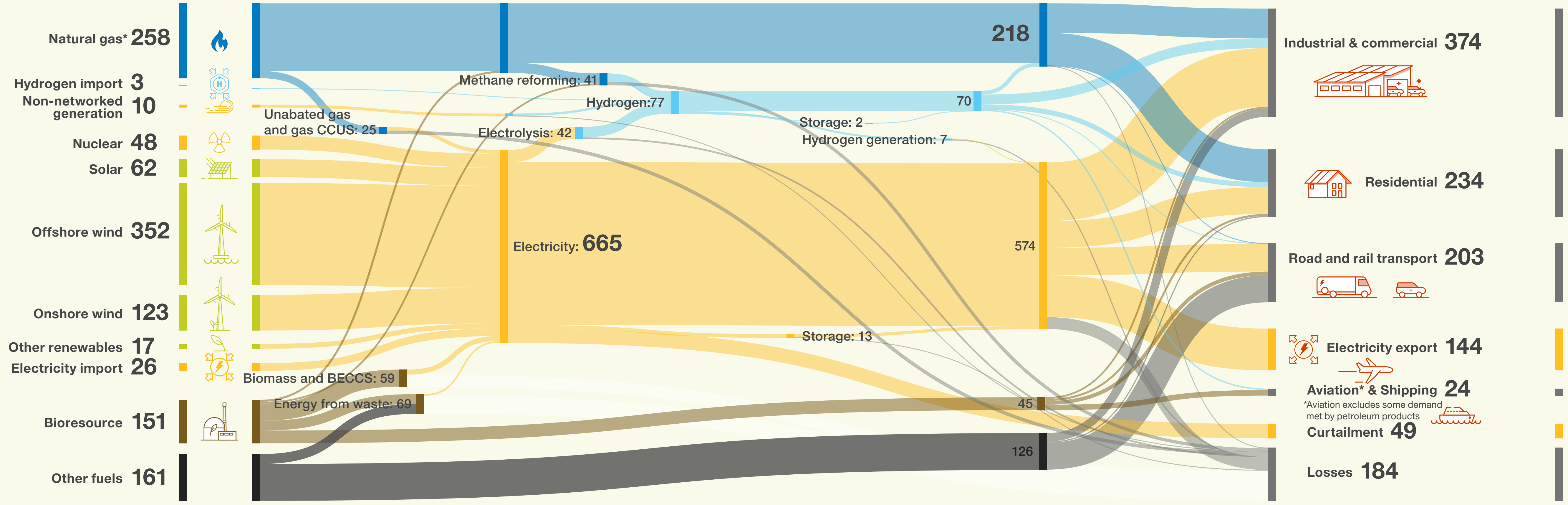


Energy flows in our scenarios 2035

For FES 2022, energy flow diagrams have been included for Falling Short and Leading the Way in **2035** to highlight the differences between the slowest and fastest decarbonising scenarios in relation to the target for no unabated natural gas in the power sector by this year.

Leading the Way (1211 TWh)

- Virtually no unabated natural gas used for electricity generation
- Half of energy demand for road and rail transport sector is met by electricity
- Significant hydrogen production has commenced from a broadly equal combination of electrolysis and methane reformation
- High levels of electricity curtailment already beginning to be seen (this reduces to almost nothing by 2050)



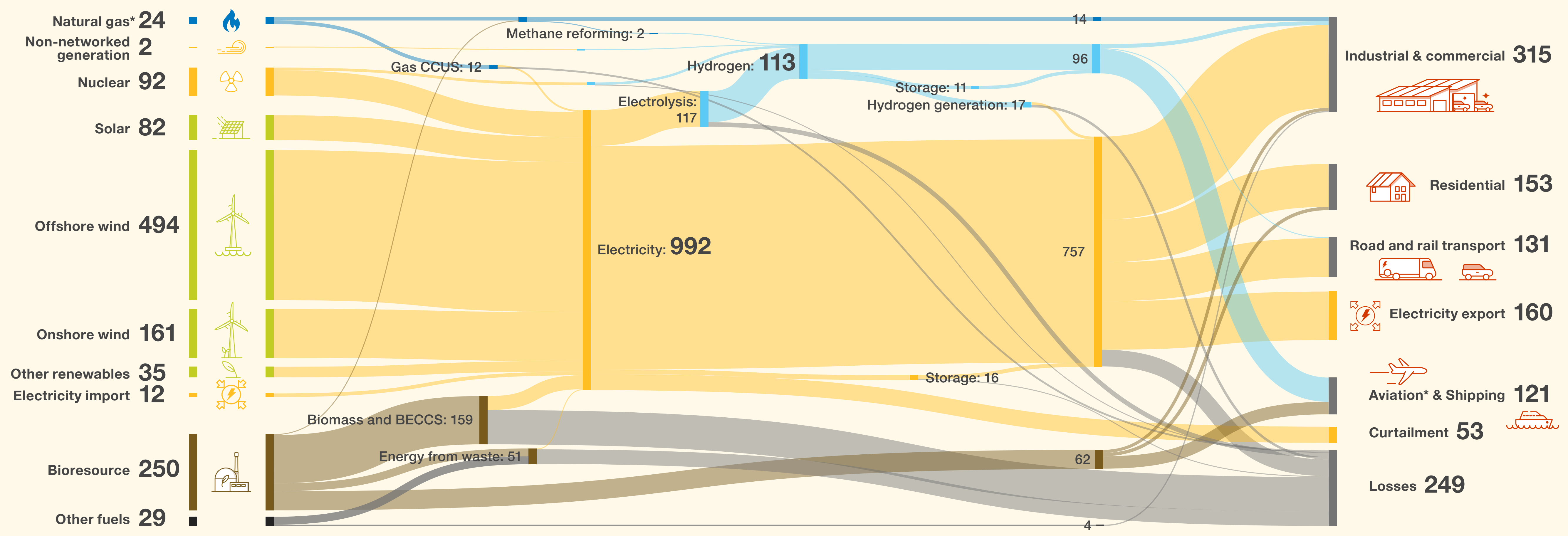
*excluding exports

FES 2022 / The Energy System / Introduction 172

Energy flows in our scenarios 2050

Consumer Transformation (1182 TWh)

- Home heating, transport and industry largely electrified
- High levels of energy efficiency combined with large-scale electrification lead to lowest end user energy demands across the scenarios
- Electricity generation capacity and output is highest in this scenario to meet high annual electricity demands
- High levels of renewable generation with low hydrogen production leads to highest levels of electricity curtailment across the scenarios



*excluding exports

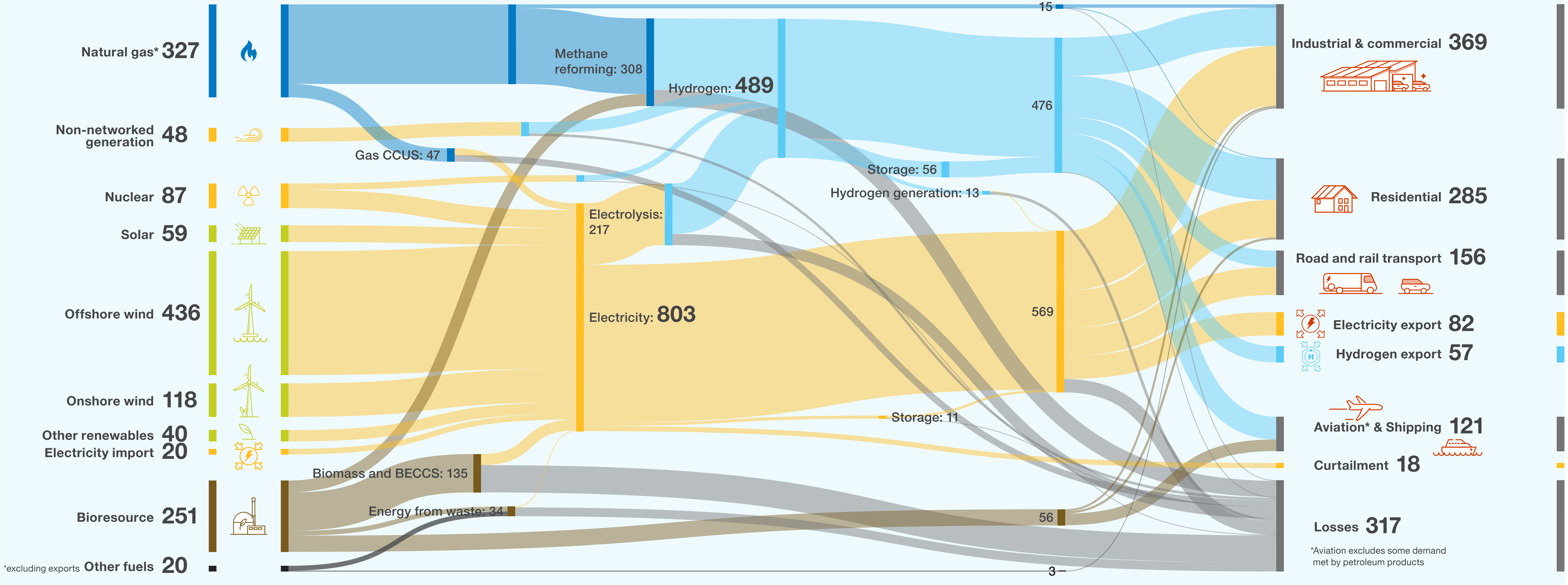
*Aviation excludes some demand met by petroleum products

FES 2022 / The Energy System / Introduction 173

Energy flows in our scenarios 2050

System Transformation (1406 TWh)

- Highest proportion of hydrogen across the scenarios with widespread use for home heating, industry and HGVs
- All hydrogen is produced in the UK from a combination of methane reformation and electrolysis
- High levels of hydrogen production enable an export market to form
- Joint highest level of bioresource use with Consumer Transformation - biomass used to produce both hydrogen and electricity

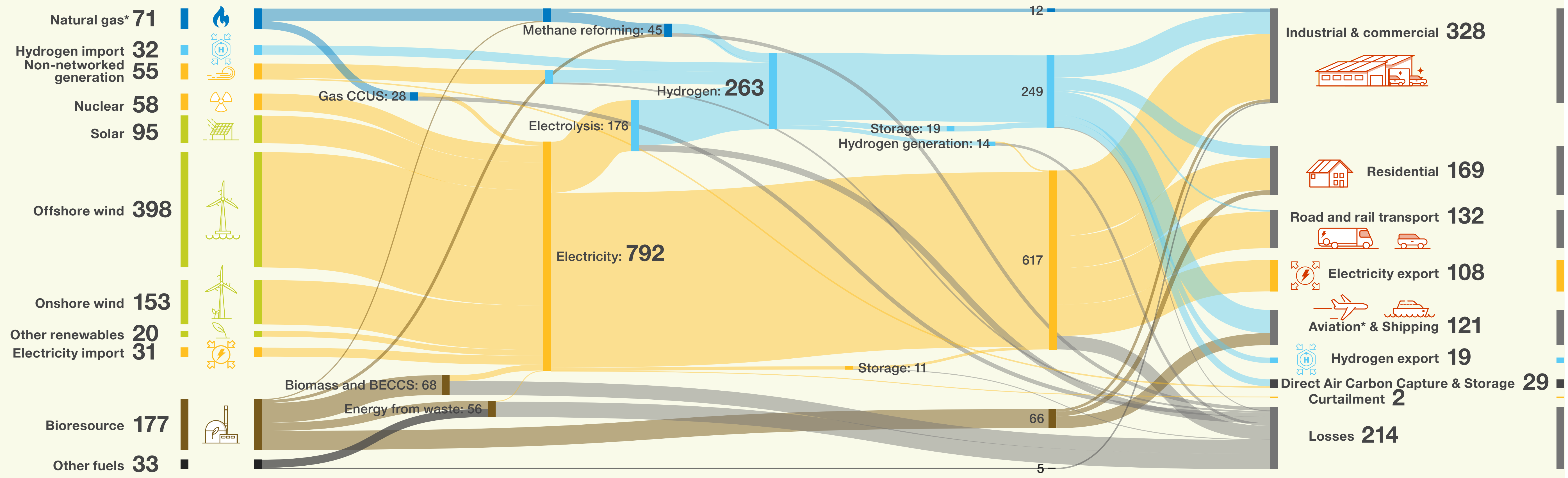


FES 2022 / The Energy System / Introduction 174

Energy flows in our scenarios 2050

Leading the Way (1123 TWh)

- Combination of hydrogen and electricity used in industry and to heat homes
- Imports and exports of hydrogen to provide maximum levels of system flexibility
- Lowest level of electricity curtailment across the scenarios
- Direct air carbon capture and storage (DACCS) used for negative emissions



*excluding exports

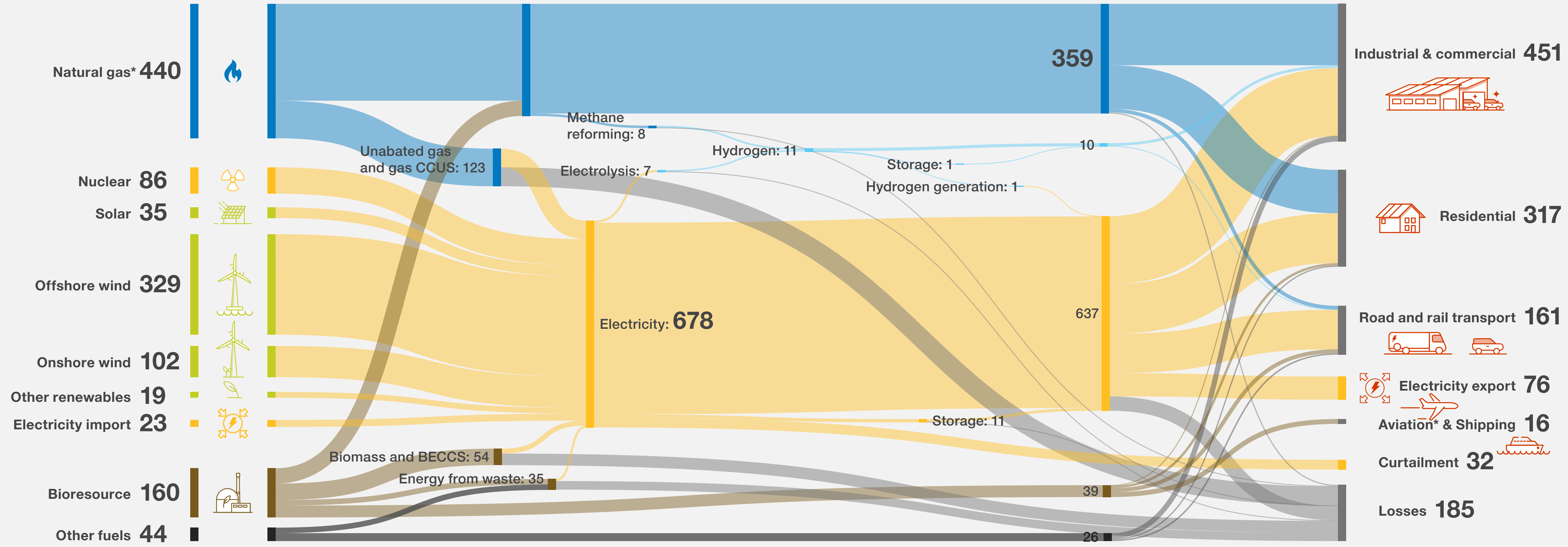
*Aviation excludes some demand met by petroleum products

FES 2022 / The Energy System / Introduction 175

Energy flows in our scenarios 2050

Falling Short (1237 TWh)

- Continued high usage of natural gas, particularly for domestic heating and industry
- Small private vehicles fully electrified (including some plug-in hybrids) whilst HGVs rely on fossil fuels
- Low use of hydrogen as production isn't decarbonised
- Highest total end-user energy demand due to minimal increase in energy efficiency measures and reliance on inefficient fossil fuels



*excluding exports

*Aviation excludes some demand met by petroleum products

FES 2022 / The Energy System / Introduction 176

Introduction

Policy timeline / key comparison chart

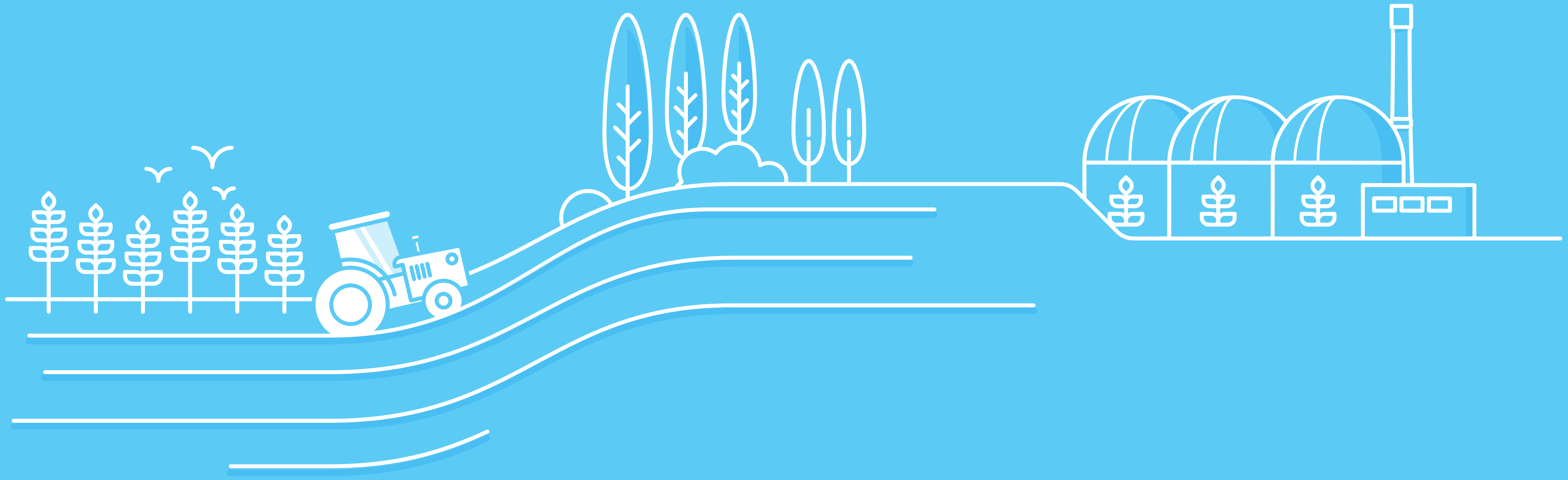
This chart contains a selection of recent policy targets in relation to Net Zero and energy security and highlights how they compare to the different scenarios. Analysis for FES 2022 commenced before the publication of several key policy documents and does not signify that any individual targets cannot be met across the range of scenarios.

CT Consumer Transformation LW Leading the Way
ST System Transformation FS Falling Short Policy

		2021	By 2025	By 2030	By 2035	By 2040	By 2045	By 2050	Maximum potential by 2050
Emissions	Meets 2050 Net Zero target	499 MtCO2e emissions						CT LW ST	Net Zero by 2047 LW
	Meets 5th carbon budget			CT LW ST	FS				
	Meets 6th carbon budget				CT LW ST				
Electricity Generation	50 GW of offshore wind	13 GW		LW	CT ST	FS			110 GW CT
	Up to 5 GW floating offshore wind	0 GW			CT LW ST	FS			25 GW CT
	Up to 70 GW of solar	13 GW				LW		CT	92 GW CT
	No unabated natural gas-fired generation capacity (subject to security of supply)	35 GW				LW	ST	CT	LW reaches this target in 2036 LW
	Up to 24 GW nuclear generation capacity	7.6 GW							15 GW CT
Hydrogen	10 GW low carbon hydrogen production capacity	<1 GW		LW	ST		CT		83 GW ST
	5 GW hydrogen production from electrolysis	<1 GW		LW	ST	CT			55 GW LW
	Up to 2 GW of low carbon hydrogen production capacity in operation or construction[1]	<1 GW		ST LW	CT				83 GW ST
	4 hydrogen clusters	0		ST LW					5 Clusters ST
Natural Gas	40% reduction in gas consumption			LW	CT	ST			96% reduction ST
Bioenergy	*Strategy expected this year – bioresource supply consistent with CCC Carbon Budget 6*								

1 FES scenarios on this chart represent operation rather than construction as well as a mix of blue and green hydrogen.

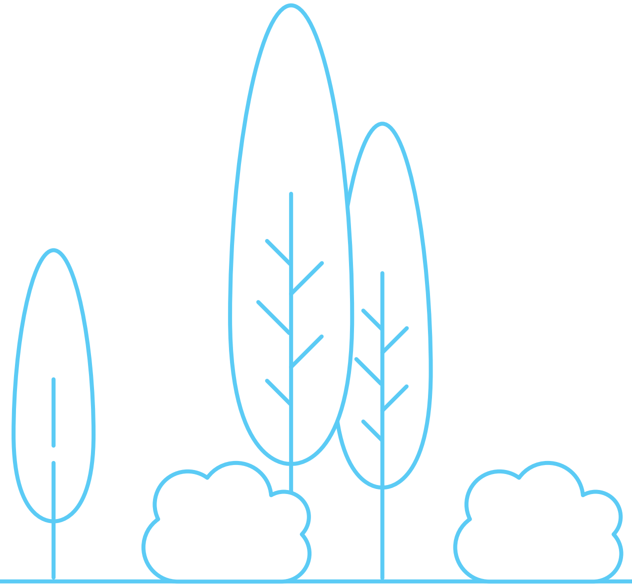
Bioenergy Supply



Key insights

Bioenergy has an important role today and one that changes in the future. Most of the required emissions reduction across the economy between now and 2050 comes from reducing demand and replacing fossil fuels with renewables or low carbon alternatives. However, negative emissions from Bioenergy with Carbon Capture and Storage (BECCS) and other Greenhouse Gas Removal (GGR) methods are still required to offset emissions from sectors of the economy which are 'hard to abate'. Reaching Net Zero by 2050 without BECCS would either require higher levels of lifestyle change (e.g. in relation to diet) or improvements in other GGR technologies to an extent that we consider challenging at this time.

- In 2050, BECCS for power generation accounts for between 50% and 66% of total bioresource demand in our Net Zero scenarios and provides between 24% and 66% (21 and 58 MtCO2e in Leading the Way and System Transformation respectively) of the **negative emissions** required to offset 'hard to abate' sectors. Sustainability and carbon accounting must be considered when deploying BECCS.
- In System Transformation and Consumer Transformation, around 43% of the demand for bioenergy is met by imports in 2050, but in Leading the Way, **only 3% of bioenergy is imported** in the form of biofuel with all other feedstock, including biomass, being sourced in Britain by 2050. Sustainability criteria will be easier to assess for domestic supply chains and reduced reliance on imports also strengthens energy security.
- Bioenergy plays a key role from a **whole energy system perspective** as it is used for BECCS in the power sector, for biomethane on the natural gas system and to produce hydrogen via biomass gasification. This is in addition to limited direct use in heating and transport.
- In Leading the Way, we assume a minimal amount of BECCS in order to offset emissions across the economy - and that all biomass feedstocks will be sourced domestically. More is applied in the other Net Zero scenarios with a greater contribution from imports. This is to reflect **varied stakeholder feedback** on the role of bioenergy in meeting Net Zero as well as uncertainty around policy post-2027.[1 2] FES modelling is done on the basis that all bioenergy feedstock meets the Government's criteria for sustainability.



1 The CCC makes clear recommendations for the UK government to increase domestic biomass supply, improve international governance over supply chains and ensure biomass is used in the most sustainable way - theccc.org.uk/wp-content/uploads/2018/11/Biomass-in-a-low-carbon-economy-CCC-2018.pdf and this is reflected in the government's 2021 Biomass Policy Statement - assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1031057/biomass-policy-statement.pdf

2 https://joint-research-centre.ec.europa.eu/welcome-jec-website/reference-regulatory-framework/renewable-energy-recast-2030-red-ii_en

FES 2022 / System View / Bioenergy supply 179

What is bioenergy and why do we assume it helps to reduce emissions in FES?

Bioenergy comes from bioresources. These include renewable, organic feedstock like wood, used cooking oil, agricultural waste and energy crops (like elephant grass). This can be used as solids (biomass), liquids (biofuel) or gas (biogas).

We use the Intergovernmental Panel on Climate Change (IPCC) international carbon accounting standards to determine the carbon footprint of energy crops. As they grow, energy crops absorb carbon which is released when they are burned to produce heat or power. So, bioenergy is considered to have no net carbon emissions in our scenarios. Capturing and storing the carbon emitted from burning biomass therefore results in negative emissions (for more information go to the Net Zero chapter). This helps achieve Net Zero by offsetting emissions from those sectors currently deemed unlikely to completely decarbonise, like agriculture and aviation.

We have assumed the bioenergy used in our Net Zero scenarios comes from sustainable sources; that the supply chain is transparent and that its emissions are accounted for, regardless of whether the bioresources are from the UK or outside.

There are emissions associated with the processing and transportation of bioenergy feedstock, but we assume these are accounted for as transport, industrial and AFOLU (Agriculture, Forestry and Land Use) emissions in their home countries or within international shipping and aviation emissions.

Bioenergy can also reduce emissions in the following areas:

- Avoiding emissions: by using the emissions from decomposing waste as a fuel rather than emitting it directly to the atmosphere (which would otherwise be the case), we can use it to displace fossil fuels.
- Providing negative emissions: under the Renewable Energy Directive (ii)[2], Anaerobic Digestion (AD) of some slurries and wastewater can be carbon negative (around -45gCO_2/MJ).
- Displacing artificial fertilisers: recycling the nutrients in bioresources avoids a normally very energy and carbon intensive manufacturing process.
- Reducing demand for industrial gases elsewhere: stored CO_2 from bioresources can be used to reduce CO_2 demand from the food and drink industry, which is normally met with a by-product of fertilizer manufacture. It can also be converted to gas such as methane or sustainable aviation fuel.

2 https://joint-research-centre.ec.europa.eu/welcome-jec-website/reference-regulatory-framework/renewable-energy-recast-2030-red-ii_en

Key insights

Figure ES.B.01: Total bioenergy demand in 2050 (TWh)

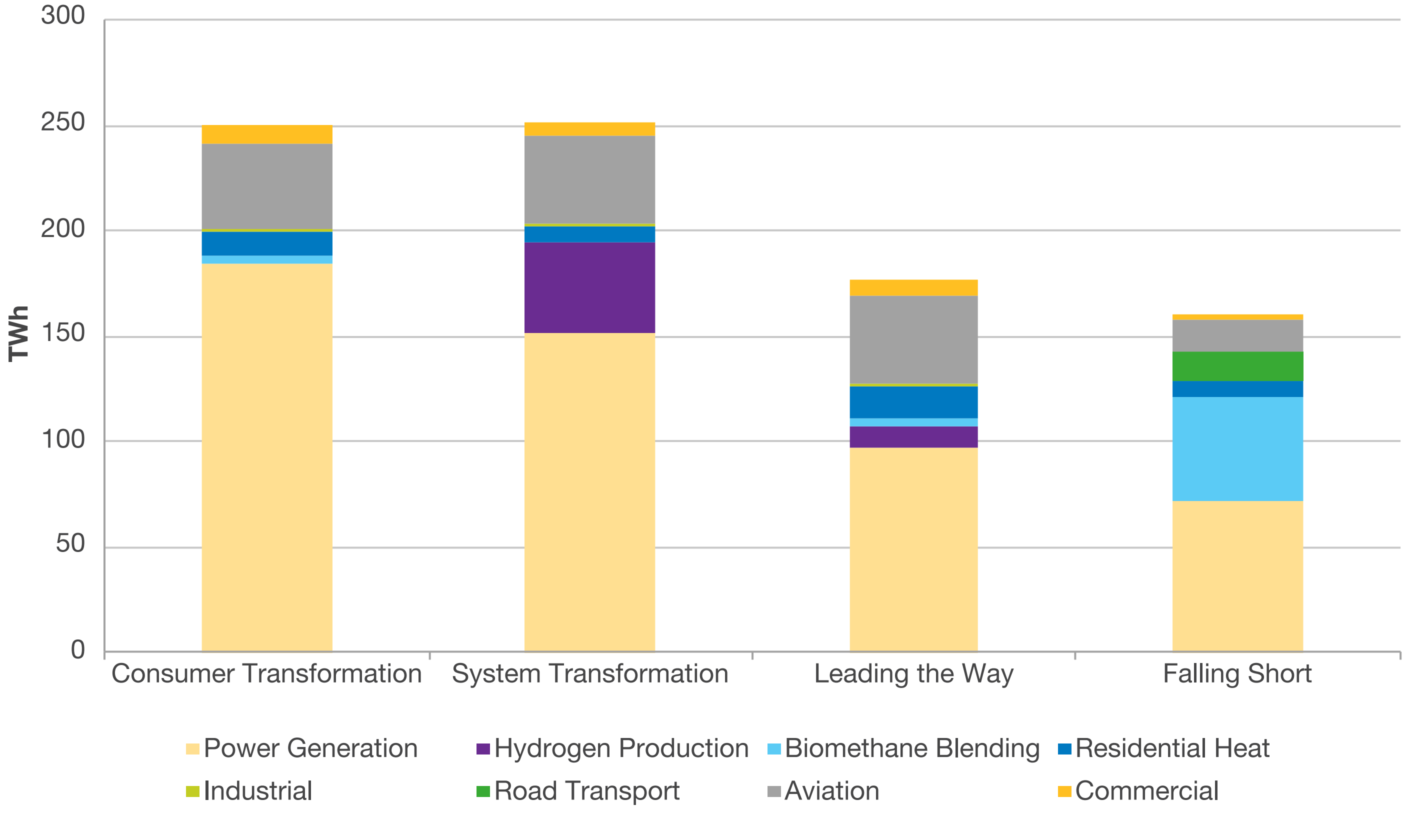
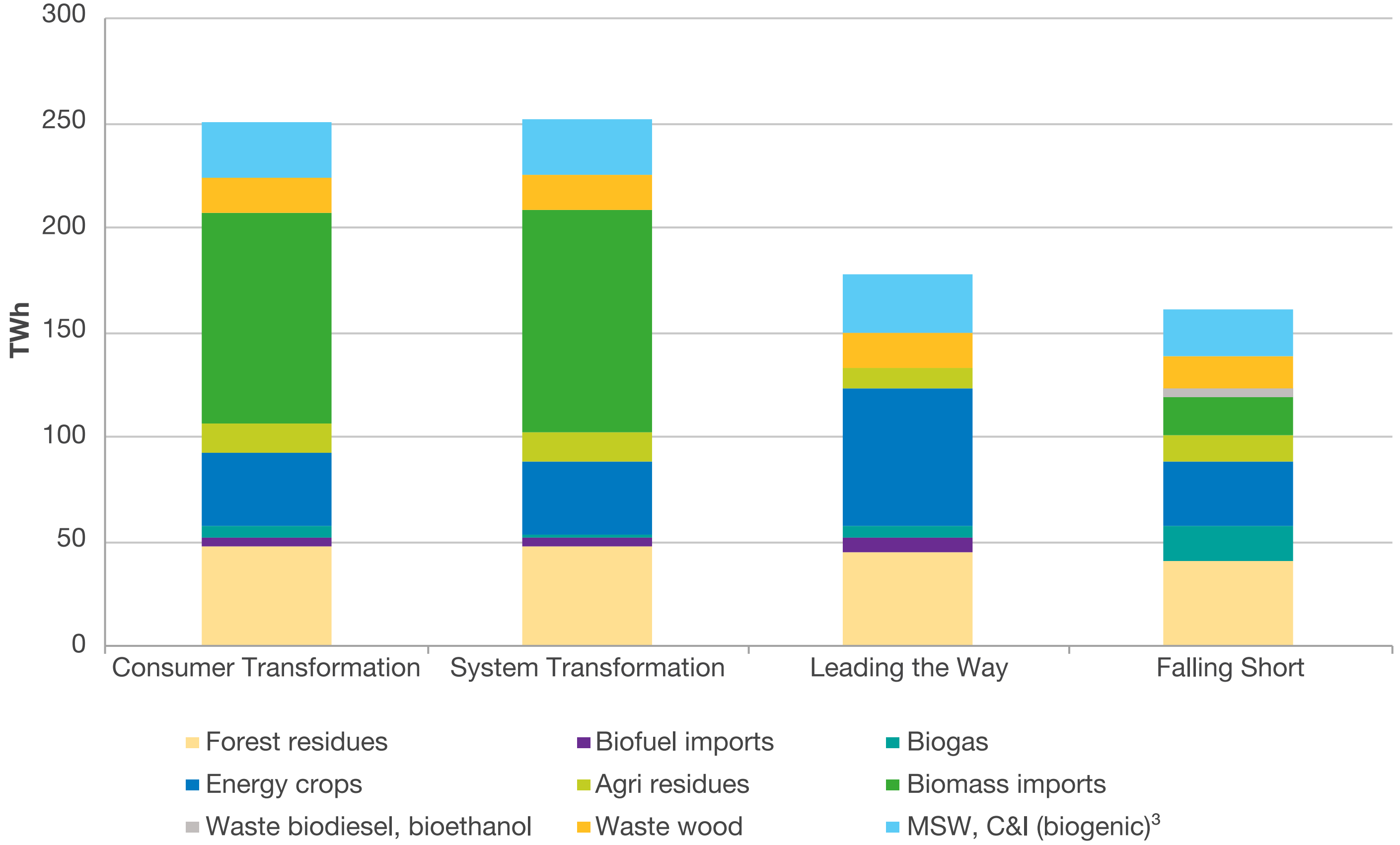


Figure ES.B.02: Total bioenergy supply in 2050 (TWh)



3 Municipal Solid Waste, Commercial and Industrial, (biogenic).

Where are we now?

We already use bioenergy from many sources for many purposes. There is interest in using more as a key enabler for decarbonisation as well as an alternative to fossil fuels, which are becoming increasingly volatile in price and have a finite supply.

Throughout 2021, biomass generation met up to 8% of the UK's electricity demand[4] and bioenergy and waste made up 11% of total energy demand in 2020 – roughly equal to all other renewables and nuclear energy combined in terms of oil equivalent.[5] This has risen from around 1% in 1990, working alongside an increase in natural gas to offset coal use.

Figure ES.B.03: UK Bioenergy and waste supply from 2000 to 2020 (TWh)

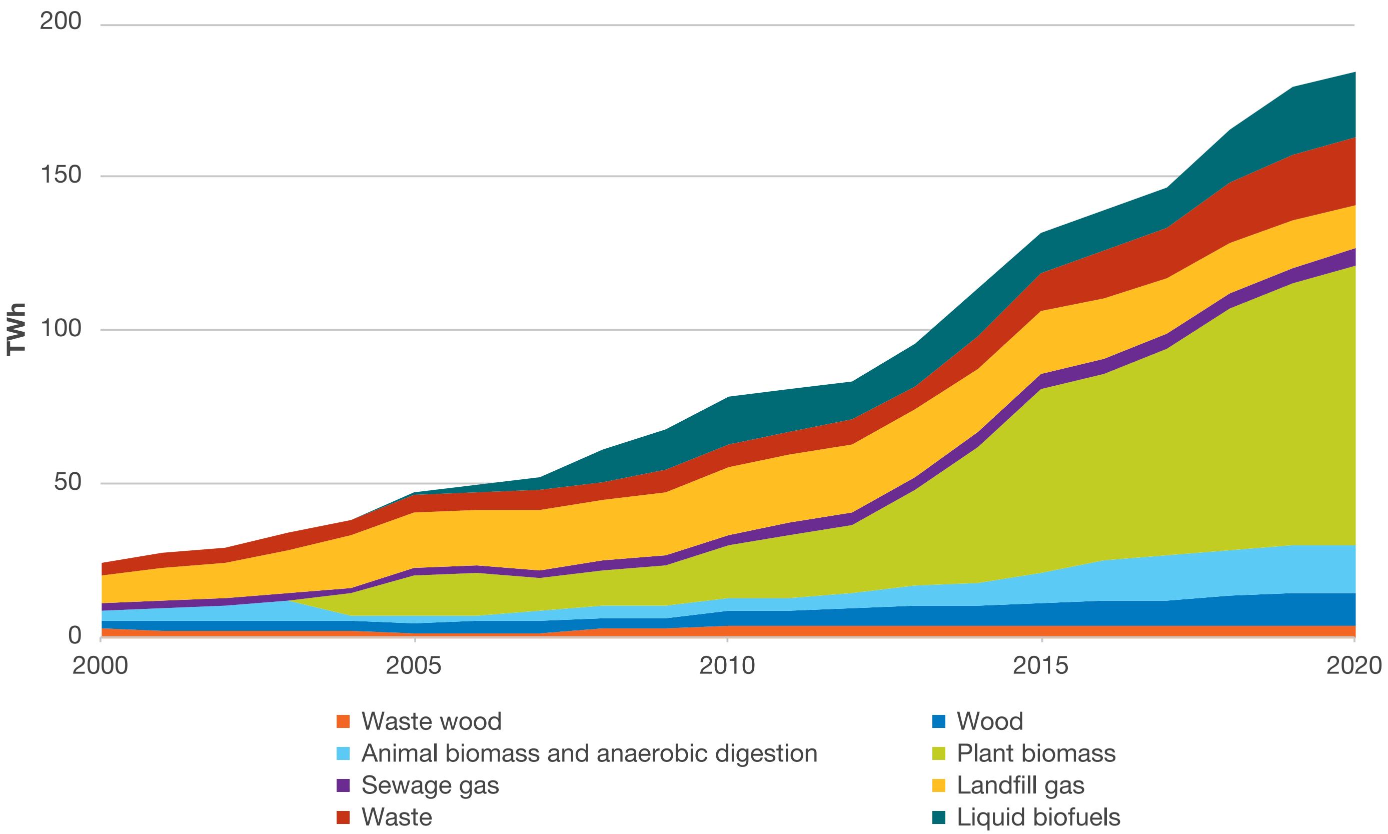
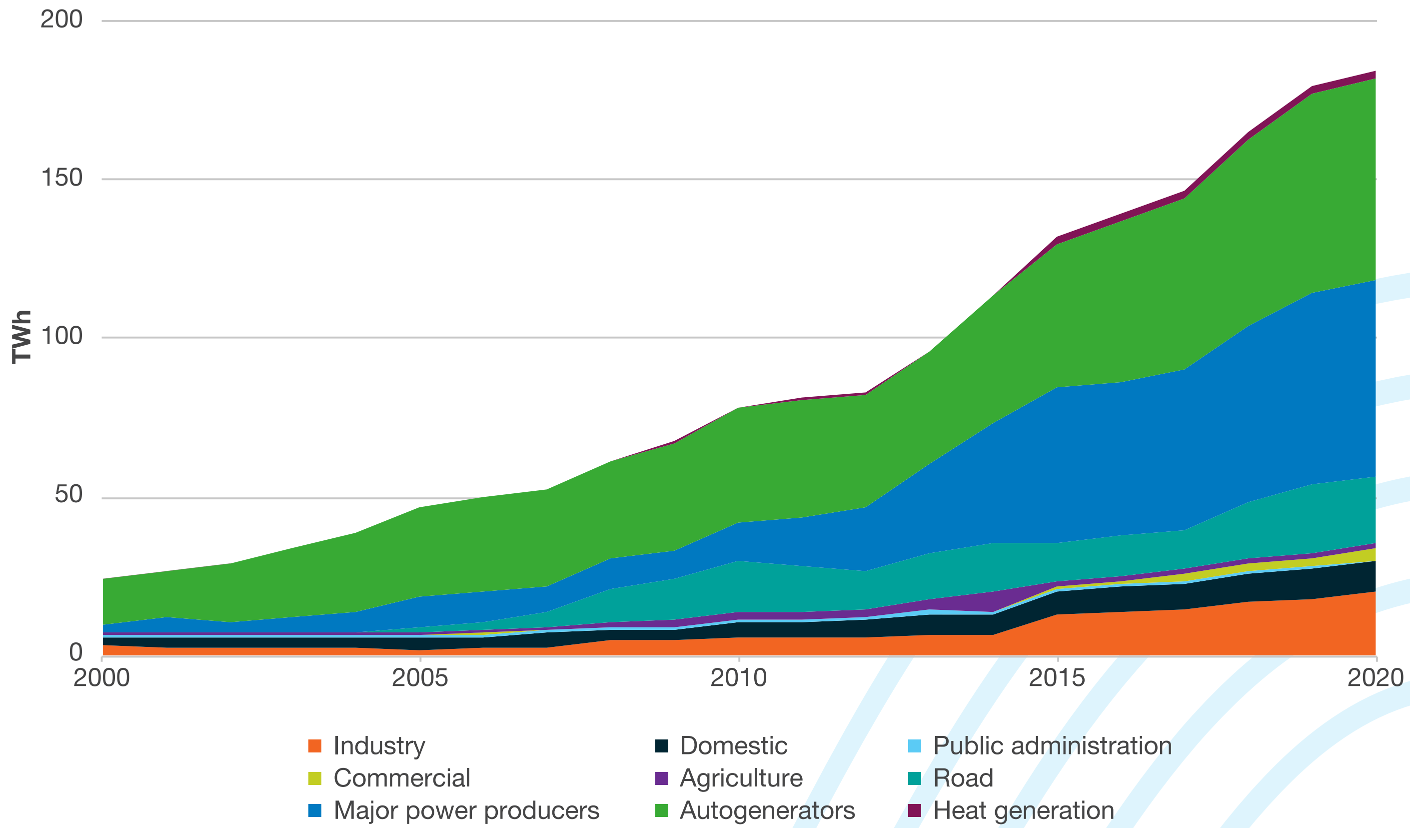


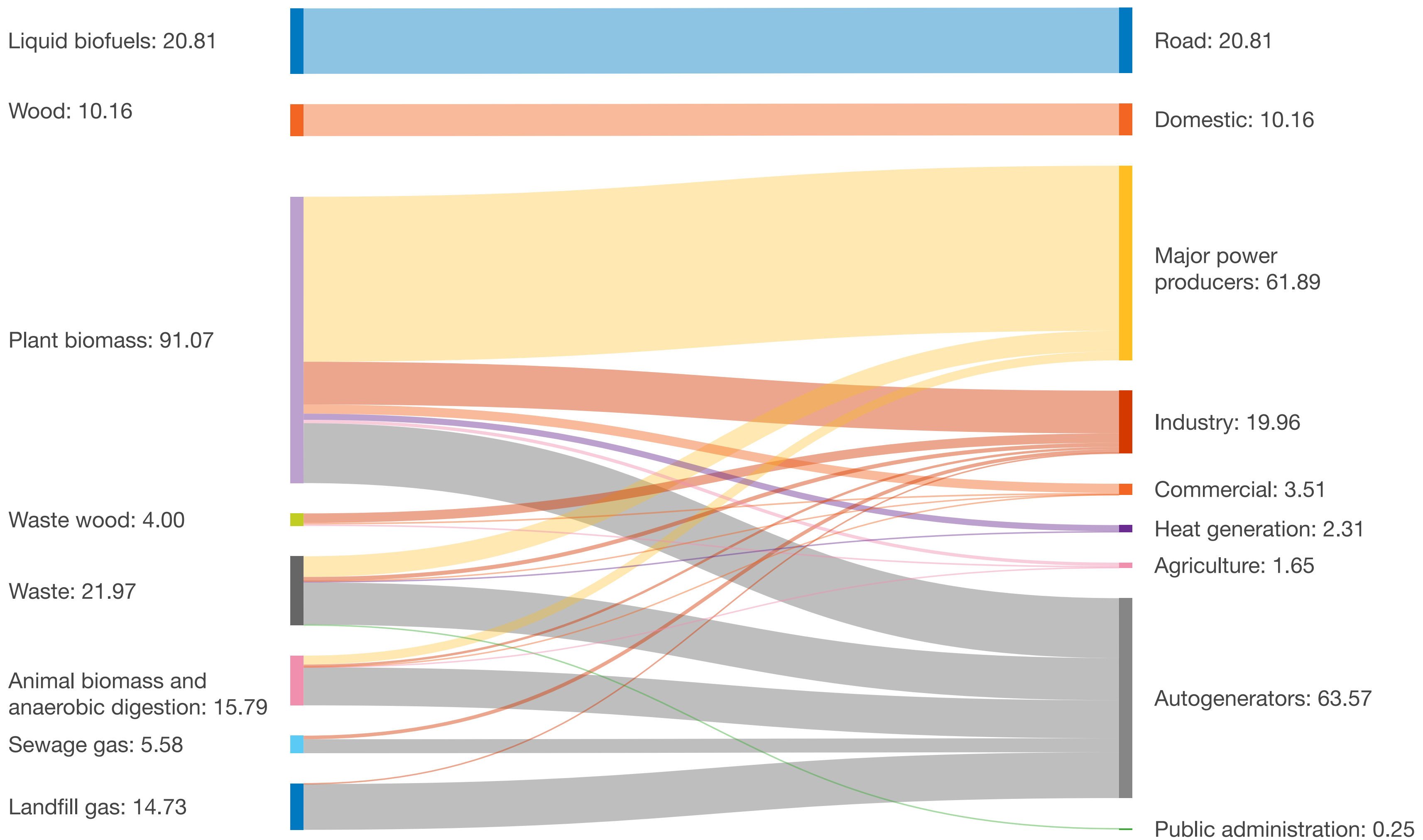
Figure ES.B.04: UK Bioenergy by end use from 2000 to 2020 (TWh)



4 nationalgrideso.com/electricity-explained/electricity-and-me/great-britains-monthly-electricity-stats
5 assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1060151/DUKES_2021_Chapters_1_to_7.pdf

2020 Bioenergy supply and demand

Figure ES.B.05: 2020 bioenergy supply and demand (184 TWh)



The largest volume of bioenergy in the UK comes from plant biomass, such as the wood pellets used in power generation. These need to be of consistent quality and in large volumes, so a great deal is imported as the UK forestry industry cannot currently provide the volumes of wood required. In 2018, over 82% of wood pellets used in the UK were from either the USA or Canada[6] and, as countries around the world start to decarbonise more, demand and competition for supplies globally is expected to increase. Over 90% of the Greenhouse Gases (GHG) emissions from imported wood pellets come from their production and transportation. Emissions from wood pellets produced in the UK are therefore currently much lower than those imported from North America. In FES modelling, we assume that all biomass is sustainably sourced.

In the UK, the Government laid out its short, medium, and long-term priorities for biomass in its November 2021 Bioenergy Policy Statement.[7] This states that biomass used in Britain should:

- Comply with emerging sustainability criteria.
- Comply with air quality targets and regulation.
- Consider lifecycle GHG emissions savings.
- Not impact our ability to achieve longer term objectives for biomass end-use.
- Integrate Carbon Capture Usage and Storage (CCUS) wherever it can feasibly deliver genuine negative emissions.
- Comply with waste hierarchy principles.

We assume these ambitions are met in the Net Zero scenarios. A further Bioenergy Strategy is expected from the Government in mid-2022. The wider outcomes of any individual policies or incentives must be considered to avoid unintended consequences or conflicts of interest.

6 ons.gov.uk/economy/environmentalaccounts/articles/aburningissuebiomassisthebiggestsourceofrenewableenergyconsumedintheuk/2019-08-30
7 assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1031057/biomass-policy-statement.pdf

FES 2022 / System View / Bioenergy supply 183

The bioenergy value chain

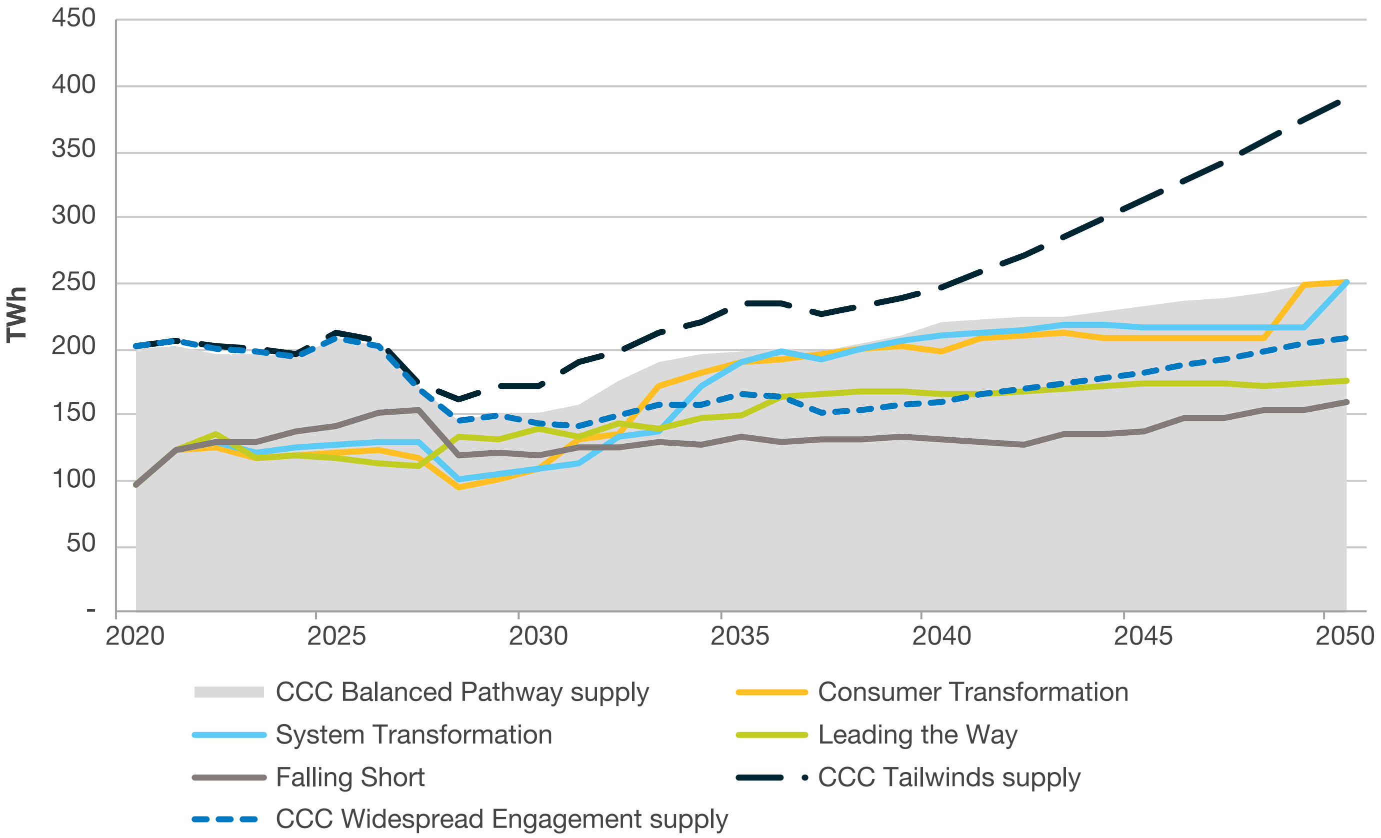
Feedstock	Processing		Outputs		End Use	
Biomass Energy crops agricultural and forest residues (GB and imported)	**COMBUSTION - Generation** (with/out CCUS)		**ELECTRICITY** negative carbon emissions if CCUS		**APPLIANCE USE LIGHTING, ELECTRIC TRANSPORT ETC.**	*Both combustion processes and outputs can be combined in e.g. Combined Heat and Power (CHP)*
	COMBUSTION - Heat (biomass boilers)		**HEAT**		**HEAT** (residential/industrial)	
	VARIOUS CONVERSION METHODS		**BIOLPG** **LIQUID FUELS e.g. BIOETHANOL, SYNFUELS**	Combustion	**HEAT** e.g. rural buildings **ROAD TRANSPORT AVIATION**	
Dry waste Such as commercial and industrial waste	**COMBUSTION - Generation and/or heat** (with/out CCUS)		**HEAT/ELECTRICITY** (negative carbon emissions if CCUS)		**HEAT, APPLIANCE USE LIGHTING, ELECTRIC, TRANSPORT ETC.**	
	GASIFICATION into **biogas**	**Combust locally**	**HEAT/ELECTRICITY**		**HEAT, APPLIANCE USE LIGHTING, ELECTRIC, TRANSPORT ETC.**	
		Process into biomethane which can be injected into grid	**BIOMETHANE**		**HEAT** (residential/industrial)	
		Conversion e.g. SMR (with/out CCUS) to create hydrogen	**HYDROGEN** negative carbon emissions if CCUS	H_2	**HEAT, ROAD TRANSPORT, SHIPPING**	
Wet waste Such as food waste, wet agricultural waste, slurries, Used Cooking Oil (UCO)/ tallow and other oils	**ANAEROBIC DIGESTION** into biogas	**Combust locally**	**HEAT/ELECTRICITY**		**HEAT, APPLIANCE USE LIGHTING, ELECTRIC TRANSPORT ETC.**	
		Process into biomethane which can be injected into grid	**BIOMETHANE**		**HEAT** (residential/industrial)	
		Conversion e.g. Small Modular Reactors (SMR) (with/out CCUS) to create hydrogen	**HYDROGEN** negative carbon emissions if CCUS	H_2	**HEAT, ROAD TRANSPORT**	
	VARIOUS CONVERSION METHODS		**BIOLPG** **LIQUID FUELS e.g. BIODIESEL**	Combustion	**HEAT** e.g. rural buildings **ROAD TRANSPORT AVIATION**	

FES 2022 / System View / Bioenergy supply 184

What affects the uptake of bioenergy?

The future of bioenergy in the energy mix is largely dependent on its value as an enabler to decarbonisation via negative emissions although other factors such as economics and the value of utilising a waste product also apply.

Figure ES.B.06: Bioenergy demand by scenario, compared to high/low CCC pathways



The table on the next page shows what makes the uptake of bioenergy more or less likely. The main things influencing the amount of bioenergy in GB's energy mix are:

1. How we account for the carbon footprint of bioenergy

Our current projections assume biomass is sustainably sourced and has net neutral emissions in line with the Intergovernmental Panel on Climate Change (IPCC) accounting framework. We recognise that this accounting framework could change in future. This is represented by minimising the amount of BECCS and total imports of biomass (and embodied emissions associated with their transportation) in Leading the Way.

2. Profitability and life-cycle cost (including carbon pricing)

At present, BECCS is relatively expensive but one of only a few options for engineered emissions removal. While they cannot by themselves produce negative emissions, higher deployment of wind and solar, which a recent IPCC report highlighted as being among the cheapest (lifecycle cost) ways to reduce emissions[8], can also reduce the price and availability of electricity and hydrogen which could make (DACCS) more viable for negative emissions. In Leading the Way, we assume that relative prices of bioenergy feedstock and electricity make BECCS less profitable and its deployment less likely, relative to e.g. System Transformation.

3. Amount of societal change (and what we need bioresources for)

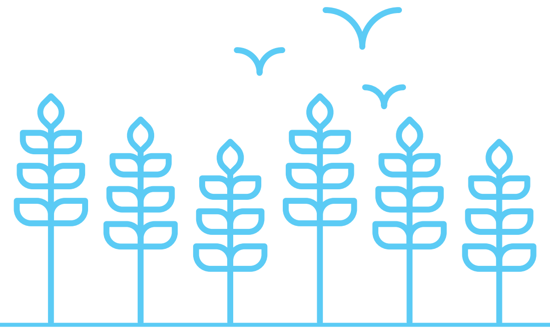
There are likely to be varying cases for bioenergy use throughout the scenarios. Leading the Way sees the lowest bioenergy demand of the Net Zero scenarios in 2050 because societal change reduces the amount of residual unabated emissions and Land Use, Land-use Change and Forestry (LULUCF) become viable ways to help offset those. At the other end of the societal change spectrum, in Falling Short, biogas and biofuels offset reductions in their fossil fuel counterparts but there isn't much additional demand. However, in System Transformation where there is more of a supply-side focus, there is additional demand for biogas for hydrogen production in addition to high levels of BECCS in the power sector.

8 report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf, page 51.

What we've found

Theme	Bioenergy use is more likely if…
Amount of societal change	We haven't been able to reduce emissions in other ways
	We need direct replacements for oil, coal and gas for which other options do not exist
	Demand for low carbon sources of methane is high (because there is greater concern over carbon footprint or greater demand for hydrogen production)
An enabler to decarbonisation	Current carbon accounting methods continue to count lifecycle emissions in country of origin/supply
	Energy crops are assumed to be replenished quickly with negligible difference in overall carbon sequestration in the long term and short-term loss of a carbon sink is acceptable to policymakers
	Bioenergy is shown to have net positive impacts on land use and biodiversity
	The carbon price is higher rather than lower
	Carbon capture rates improve significantly[9]
Supply chain and energy crops	Bioresource supply is domestic or from a reliable partner country
	Land use for bioresources can be accommodated with minimal impact on other important areas such as food production

Theme	Bioenergy use is more likely if…
Utilising a waste product	Restrictions on unabated waste to landfill get tighter
Lifecycle cost	BECCS is less expensive compared to Greenhouse Gas Removal alternatives
	Electricity price is high (because BECCS generation becomes more profitable and can compete effectively against DACCS, which becomes more expensive with a higher electricity price)
	Bioenergy feedstock is cheap
	Government subsidies promote bioenergy
Electricity generation and efficiency	Electricity generation from bioenergy becomes more efficient
	We need more dispatchable synchronous thermal generation



9 theccc.org.uk/wp-content/uploads/2018/11/Biomass-in-a-low-carbon-economy-CCC-2018.pdf, page 126.

FES 2022 / System View / Bioenergy supply 186

How is bioenergy used and what policies are in place?

Hydrogen production

Aviation

Residential heat

Biomethane production

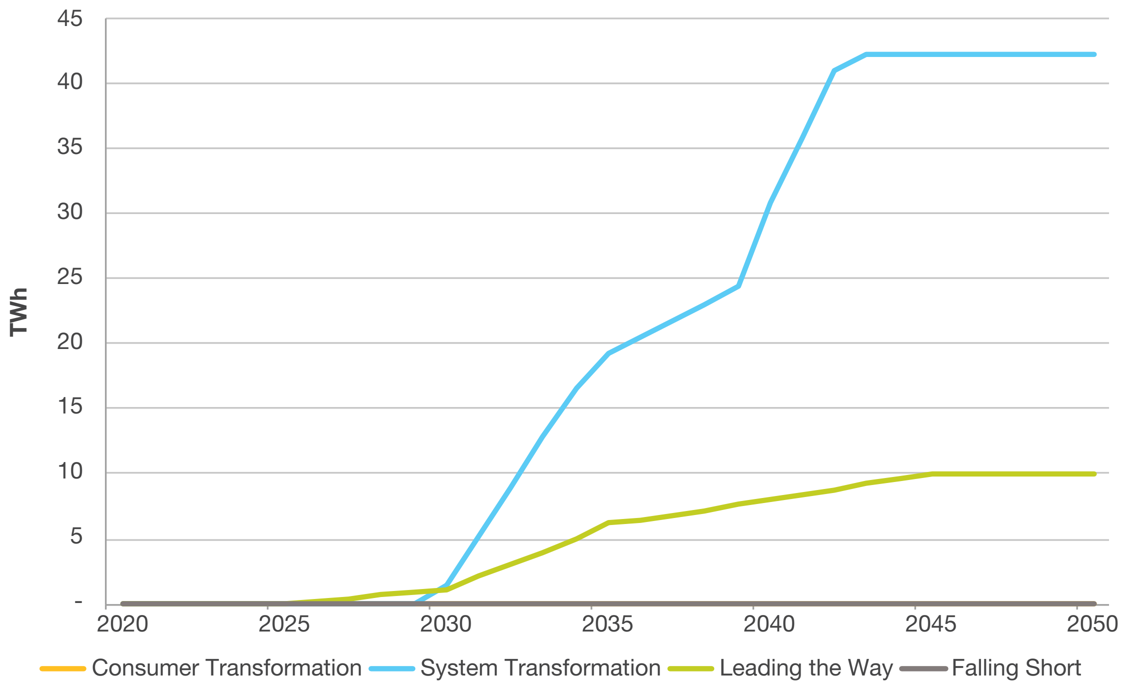
Industrial & Commercial (I&C)

Power generation

Low carbon hydrogen production

In System Transformation, 42 TWh of biomass is used to produce 33 TWh of low carbon hydrogen. This low-carbon hydrogen can come from reformation of biomethane (e.g. from Anaerobic Digestion) or direct gasification, a technology which could be deployed from the 2030s and could be combined with Carbon Capture Usage and Storage for negative emissions. The 2021 UK Hydrogen Strategy and associated consultation began the process of defining low-carbon hydrogen, which will underpin access to the Net Zero Hydrogen Fund of up to £240m. Bioenergy is not used to produce hydrogen in Consumer Transformation or Falling Short.

Figure ES.B.07: Bioenergy demand for hydrogen production (TWh)



How is bioenergy used and what policies are in place?

Hydrogen production
Aviation
Residential heat
Biomethane production
Industrial & Commercial (I&C)
Power generation

Aviation

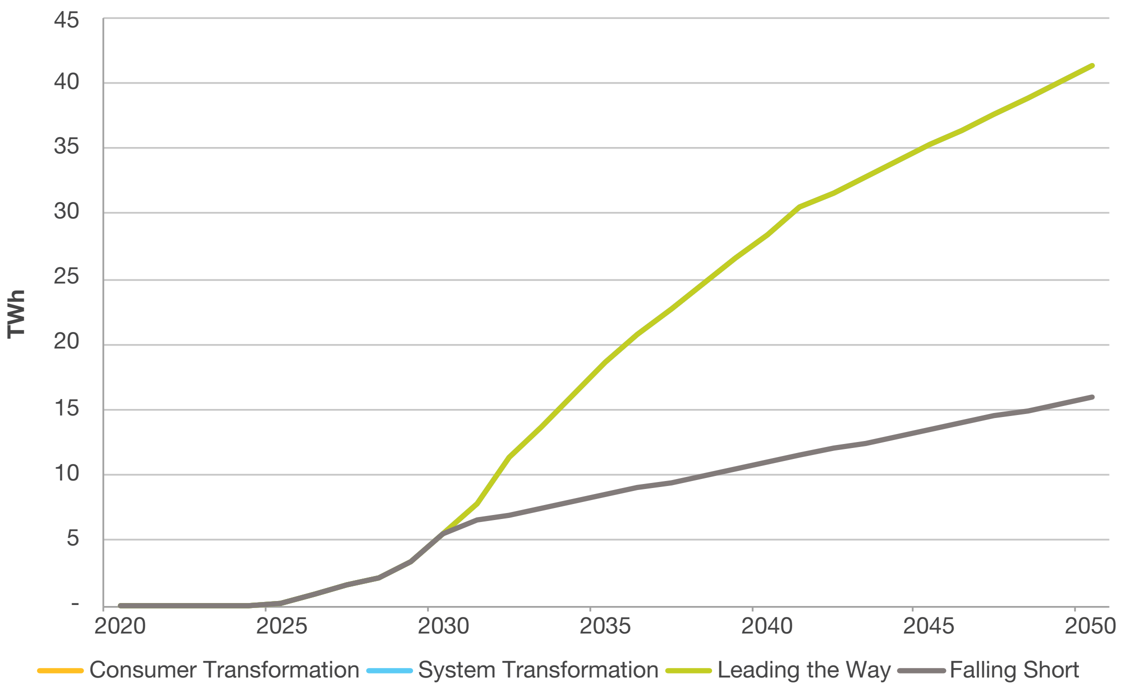
In Falling Short, 16 TWh of Sustainable Aviation Fuel (SAF) is derived from forest residues and municipal and industrial waste. These sources are joined by biofuel imports in all Net Zero scenarios to provide over 41 TWh of SAF.

SAF is largely seen as a bridging technology to fully decarbonised air travel and is up to 70% cleaner burning than conventional jet-fuel. It also emits up to 90% fewer particulates.[11]

The UK has numerous past and current competitions to drive the development of SAF including the 2021/2022 Green Fuels Green Skies competition.

All Net Zero scenarios assume the same bioenergy demand for aviation as Leading the Way (shown).

Figure ES.B.08: Bioenergy demand for aviation (TWh)



11 https://www.sustainableaviation.co.uk/wp-content/uploads/2020/02/SustainableAviation_FuelReport_20200231.pdf

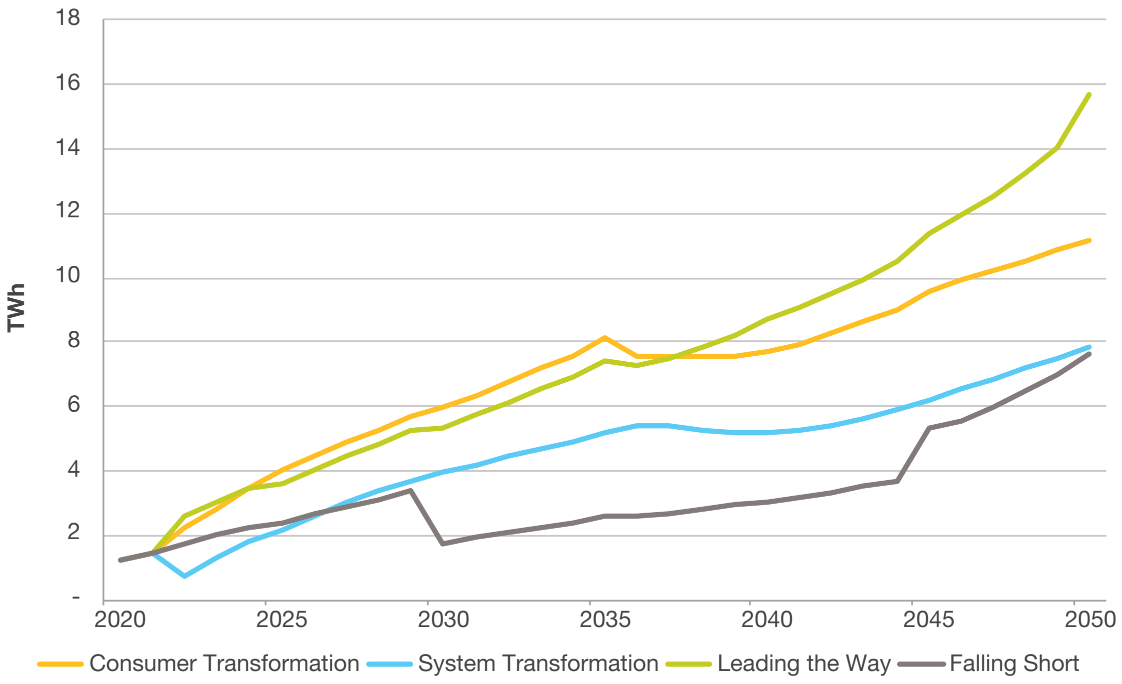
How is bioenergy used and what policies are in place?

Hydrogen production
Aviation
Residential heat
Biomethane production
Industrial & Commercial (I&C)
Power generation

Residential heat

The UK Heat and Buildings Strategy and Renewable Heat Incentive policies support solid biomass and liquid biofuels to heat homes which are off the electricity or gas grids.

Figure ES.B.09: Bioenergy demand for residential heat (TWh)



FES 2022 / System View / Bioenergy supply 189

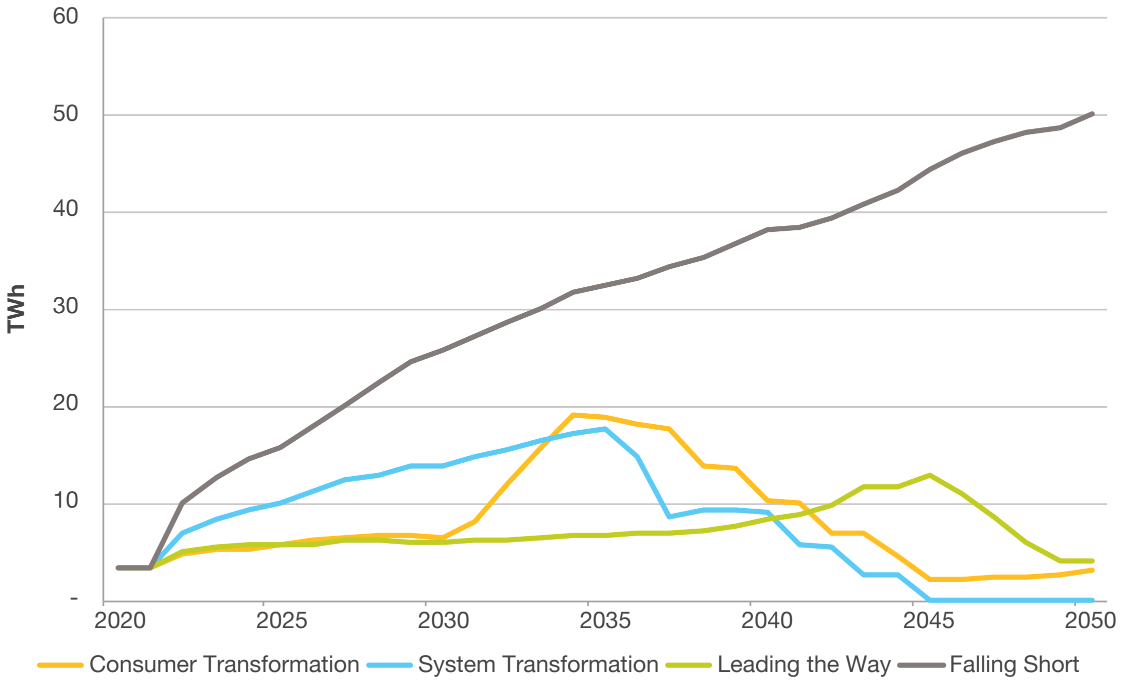
How is bioenergy used and what policies are in place?

Hydrogen production
Aviation
Residential heat
Biomethane production
Industrial & Commercial (I&C)
Power generation

Biomethane production

The Green Gas Support Scheme runs to 2040/41 but new entrants won't be accepted after 2025. In the Net Zero scenarios there is a small amount of biomethane demand in 2050 for Industrial & Commercial and domestic users but no blending into the gas grid past the mid-late 2040s. In Falling Short, demand for biogas to be blended into the National Transmission System (NTS) rises steadily to become over 31% of bioenergy demand in 2050 (50 TWh).

Figure ES.B.10: Bioenergy demand for Biomethane production (TWh)



FES 2022 / System View / Bioenergy supply 190

How is bioenergy used and what policies are in place?

Hydrogen production

Aviation

Residential heat

Biomethane production

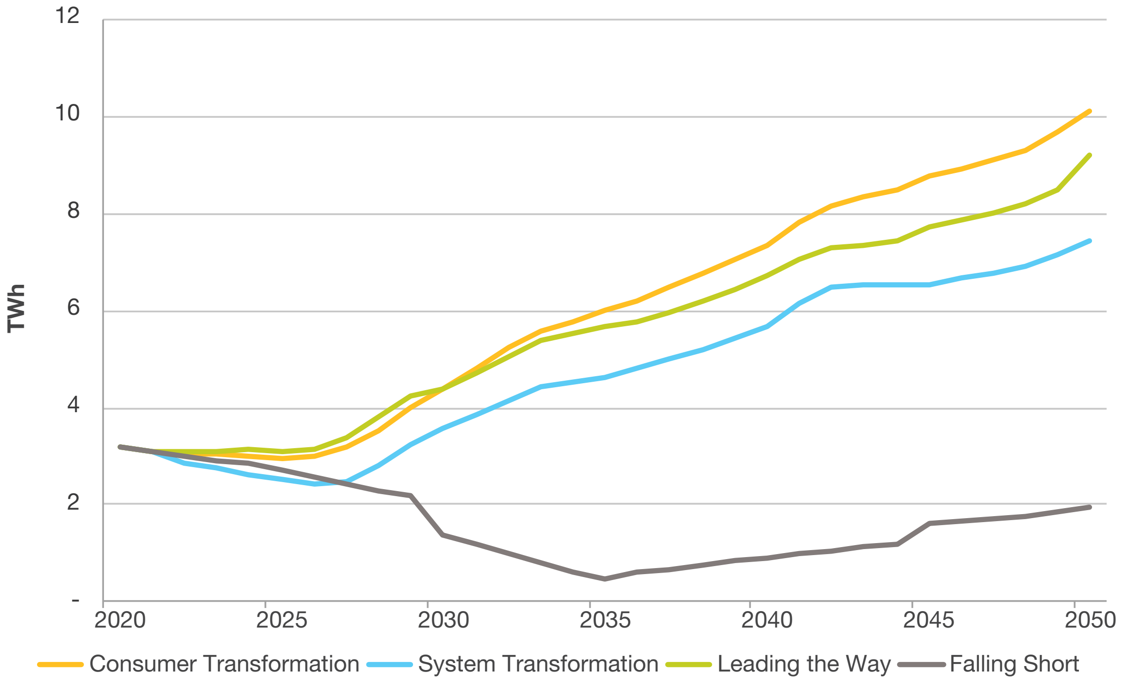
Industrial & Commercial (I&C)

Power generation

Industrial & Commercial (I&C)

The 2020 Industrial Decarbonisation Strategy (IDS) explains where biomass is already used, and that biomass is most cost effective in the cement, glass and paper industries to offset fossil fuels. The IDS also recommends prioritisation of any bioresource which can be paired with CCS to deliver negative emissions. The Industrial Energy Transformation Fund supports fuel switching to biomass for temperatures above 240°C or where the facility is off grid. The England Tree Action Plan provides commitments for increasing use of wood in construction. These policies will all evolve over time, something we see most of in the Net Zero Scenarios. Leading the Way is not the highest because of a greater emphasis in reducing net demand through societal change.

Figure ES.B.11: Bioenergy demand for Industrial & Commercial (TWh)



FES 2022 / System View / Bioenergy supply 191

How is bioenergy used and what policies are in place?

Hydrogen production

Aviation

Residential heat

Biomethane production

Industrial & Commercial (I&C)

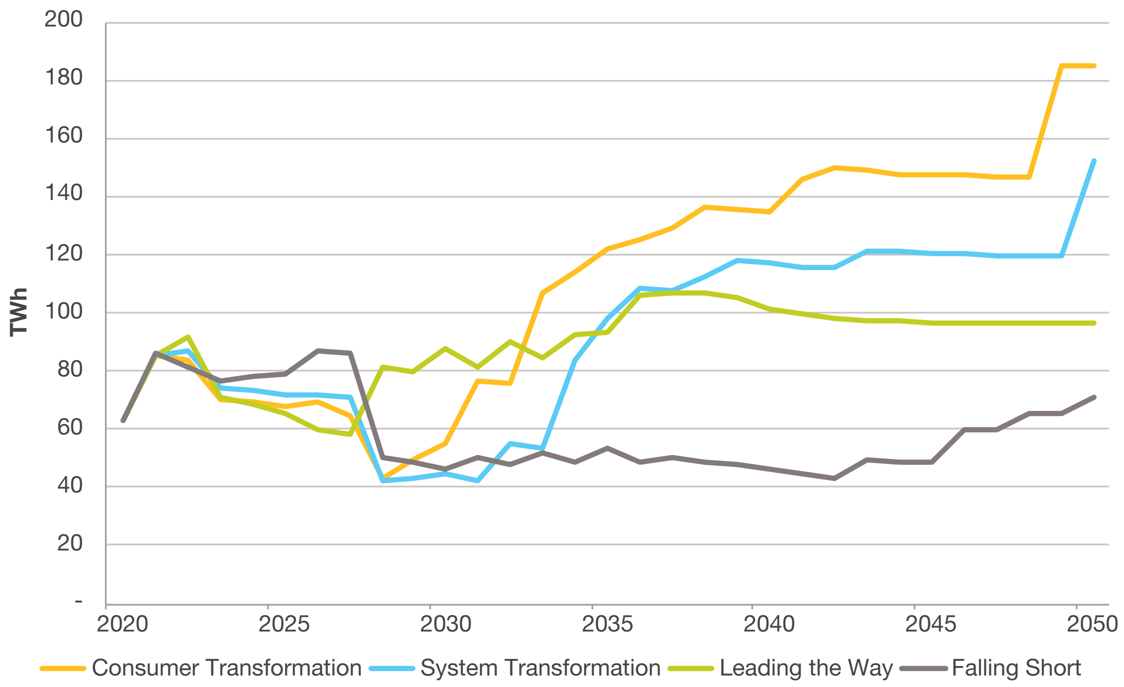
Power generation

Power generation

A detailed explanation can be found in the **Electricity Supply section**.

In 2020, biomass generated around 12% of the UK's total electricity, from a combination of waste and biomass, helping to drive fossil fuel generation down to a record low. Investment is incentivised through the Contracts for Difference (CfD) and Smart Export Guarantee schemes along with other schemes which are now closed to entrants. There are multiple schemes for power generation and an intent to stop supporting biomass generation unless it includes CCS. The Government has also committed to review and improve its sustainability criteria for biomass and create a stronger base of evidence for supply and sustainability of BECCS feedstock.[12]

Figure ES.B.12: Bioenergy demand for power generation (TWh)



12 assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1031057/biomass-policy-statement.pdf

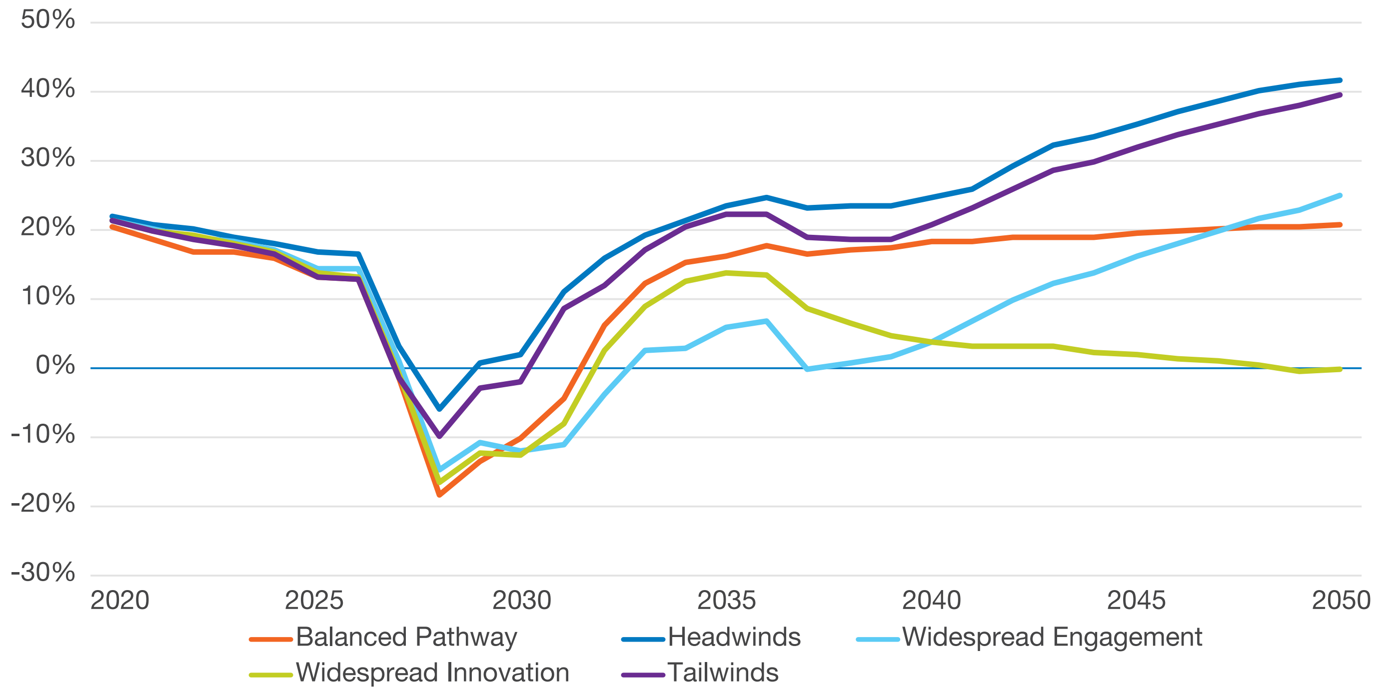
FES 2022 / System View / Bioenergy supply 192

Imports and domestic production

Imports of bioresources range from just over 40% of total bioenergy demand to almost zero with circa five years of the UK being a net exporter of biomass.

To incentivise domestic production of sustainable biomass, the Government announced £26m of funding in December 2021 through the Biomass Feedstocks Innovation Programme.[13]

Figure ES.B.13: Biomass imports as a percentage of total supply (CCC pathways)



FES 2022 / System View / Bioenergy supply 193

13 gov.uk/government/news/26-million-government-funding-to-boost-biomass-in-uk

Scenario results

The energy flow diagrams here illustrate how the different bioresources are used in each scenario in 2050. They show the importance of bioenergy for power generation with CCUS in each Net Zero scenario, which is needed for negative emissions to offset emissions from other sectors of the economy.

Consumer Transformation

System Transformation

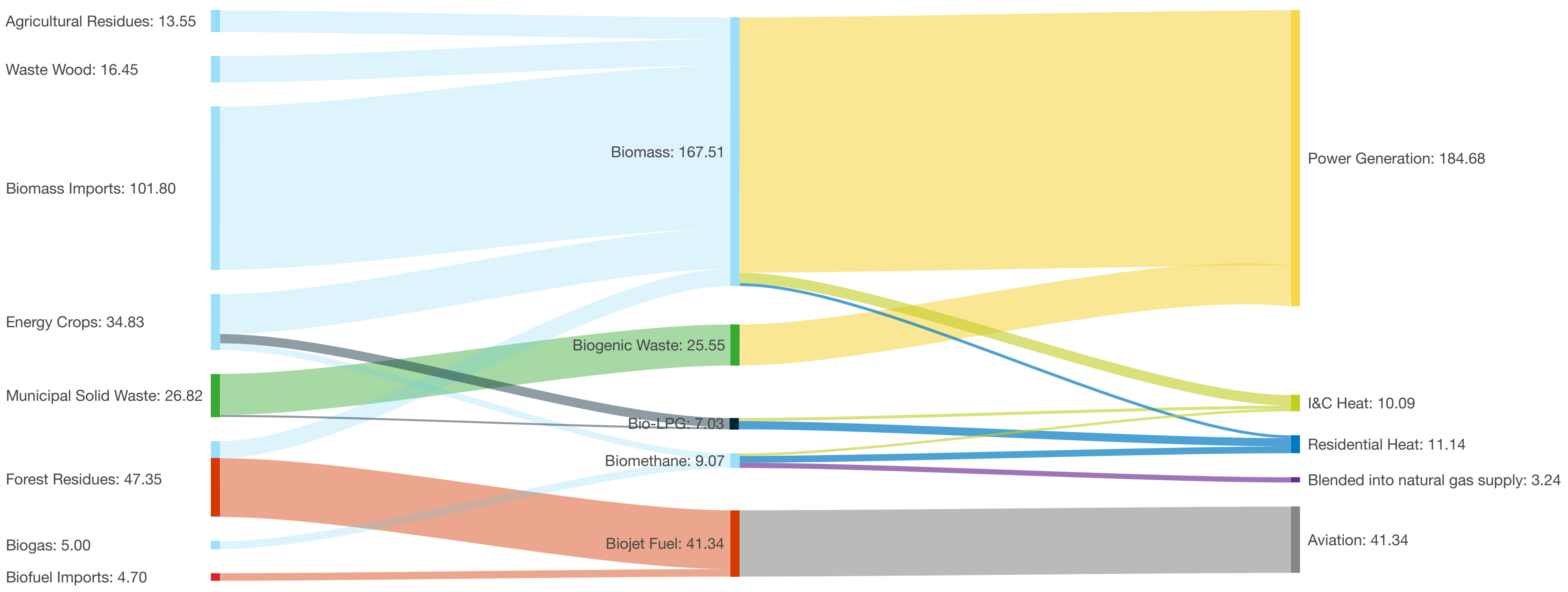
Leading the Way

Falling Short

Consumer Transformation (250 TWh):

Bioenergy is primarily used with CCUS for power generation and bio-jet fuel (90%). The remainder meets demand for I&C, residential heat and a small amount of green gas blending. Consumer Transformation has the second highest level of biomass imports.

Figure ES.B.14: 2050 Bioenergy supply and demand in Consumer Transformation



FES 2022 / System View / Bioenergy supply 194

Scenario results

The energy flow diagrams here illustrate how the different bioresources are used in each scenario in 2050. They show the importance of bioenergy for power generation with CCUS in each Net Zero scenario, which is needed for negative emissions to offset emissions from other sectors of the economy.

Consumer Transformation

System Transformation

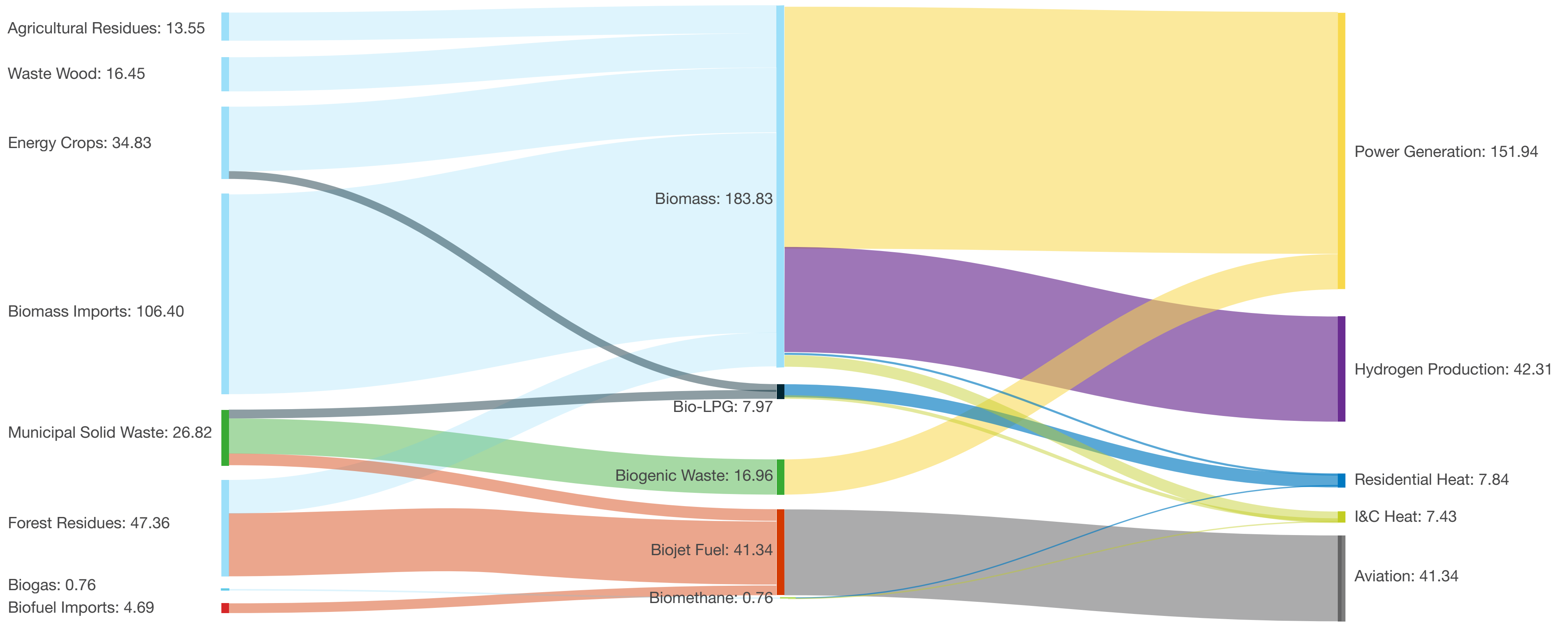
Leading the Way

Falling Short

System Transformation (251 TWh):

This scenario has the highest level of bioresource demand and the highest levels of imports (c. 44%). Demand is very similar to Consumer Transformation but, in this scenario, 42 TWh (17%) of bioenergy is used for hydrogen production.

Figure ES.B.14: 2050 Bioenergy supply and demand in System Transformation



Scenario results

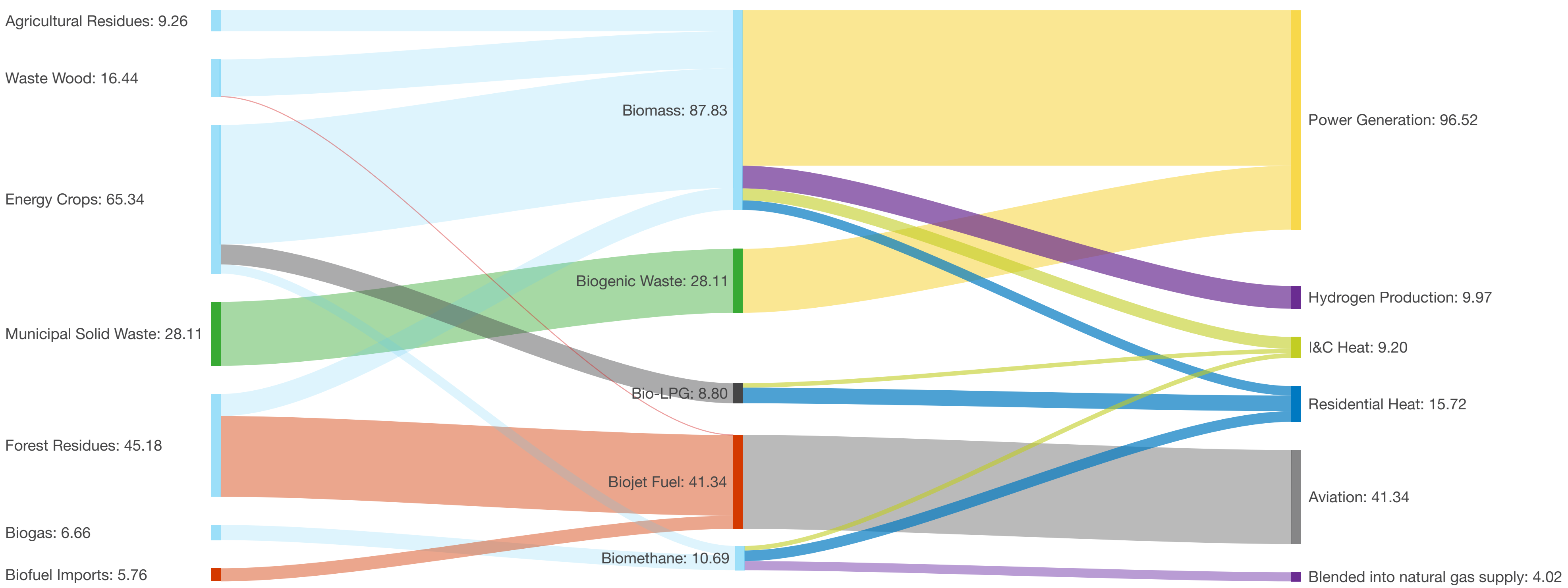
The energy flow diagrams here illustrate how the different bioresources are used in each scenario in 2050. They show the importance of bioenergy for power generation with CCUS in each Net Zero scenario, which is needed for negative emissions to offset emissions from other sectors of the economy.

Consumer Transformation
System Transformation
Leading the Way
Falling Short

Leading the Way (177 TWh):

This has the smallest increase in bioenergy demand in a Net Zero scenario, as greater consumer engagement with decarbonisation helps suppress imports. Over half of the demand is from power generation, which includes BECCS as well as energy from waste.

Figure ES.B.14: 2050 Bioenergy supply and demand in Leading the Way



FES 2022 / System View / Bioenergy supply 196

Scenario results

The energy flow diagrams here illustrate how the different bioresources are used in each scenario in 2050. They show the importance of bioenergy for power generation with CCUS in each Net Zero scenario, which is needed for negative emissions to offset emissions from other sectors of the economy.

Consumer Transformation

System Transformation

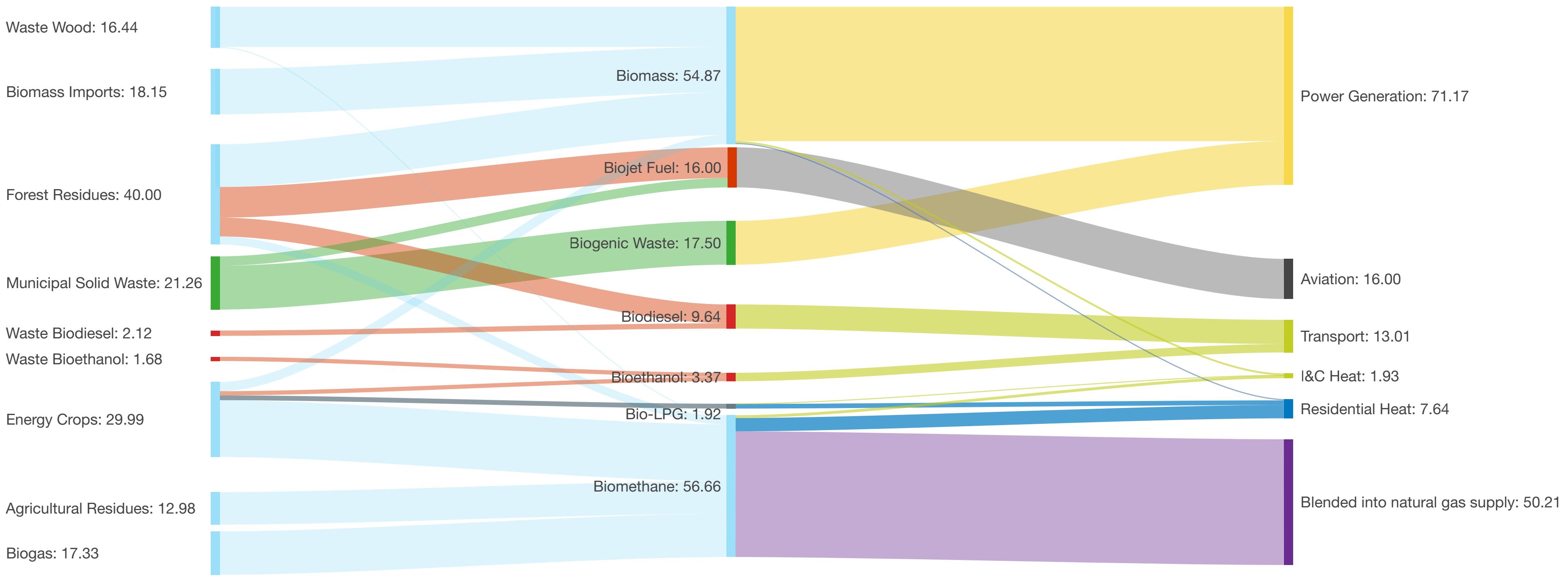
Leading the Way

Falling Short

Falling Short (160 TWh):

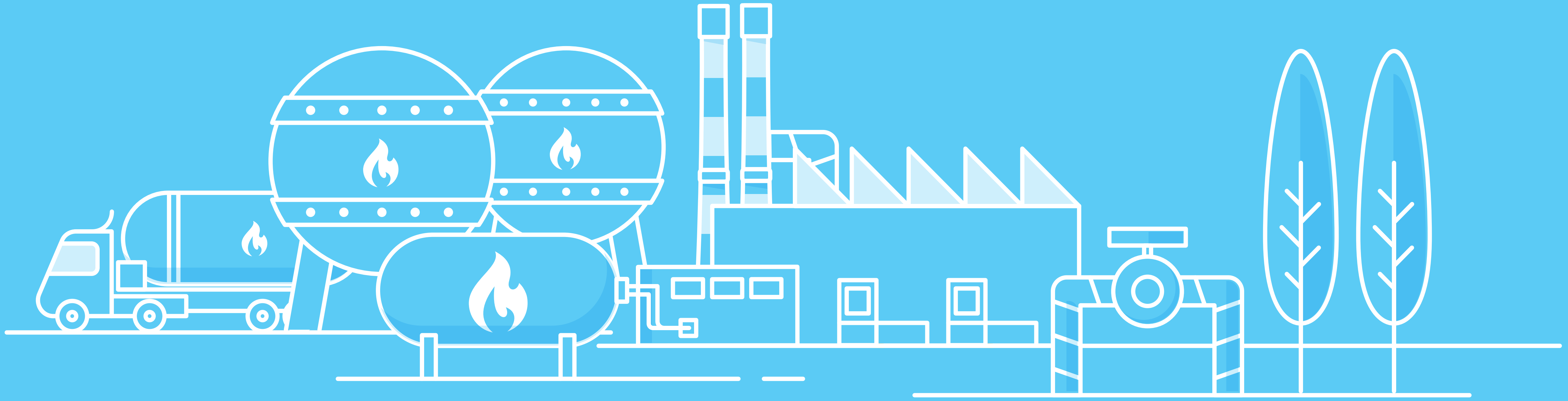
Total bioenergy demand in 2050 is the lowest of all scenarios. Roughly 31% is being used for green gas (biomethane), which is blended with natural gas to reduce its overall carbon impact.

Figure ES.B.14: 2050 Bioenergy supply and demand in Falling Short



FES 2022 / System View / Bioenergy supply 197

Natural Gas Supply



Key insights

The design of the energy system we have in Great Britain today has been shaped by the previous dominant sources of energy (coal, and then later natural gas) – from the way we provide heat for homes and industry, all the way to generation of electricity. Today, gas still meets around 40% of total UK energy demand, and the renewable integration achieved to date has been successful in part because of the ability of the gas generation fleet to flex its output to wind and solar levels. However, transitioning towards Net Zero while maintaining a reliable and affordable energy system for all will require a continued, if different, role for natural gas as it cannot be used in a Net Zero world without its emissions being captured.

- Our analysis shows that there is sufficient gas supply between now and 2050 to ensure **Security of Supply.** This is partly due to the diverse sources of natural gas available to GB, and also because we expect natural gas demand to decline through energy efficiency improvements and increased renewable generation. However, as long as gas is in demand for heat and power, we will be exposed to price fluctuations in the global energy market.
- In 2021 63% (50 bcm / 550 TWh) of Britain's gas was imported. By 2050, import levels could be as high as 98% of total supply in System Transformation though falling gas demand means the actual amount of imported gas would be less at 35 bcm (385 TWh).

The level of natural gas in 2050 is **mostly influenced by the future of residential heat and hydrogen production**. In Falling Short, annual natural gas demand remains at 65% of today's level as it is still widely used for residential heat whereas in Consumer Transformation, our most electrified scenario, this drops to just over 3%. How hydrogen is produced also makes a significant difference with System Transformation requiring over 5 times as much natural gas than Leading the Way due to its far greater reliance on methane reformation compared to electrolysis.

Gas and hydrogen infrastructure: The gas network is still being used in 2050 in System Transformation and Falling Short, albeit with modifications to transport hydrogen in the former. In Leading the Way, the network required is not as extensive and, in Consumer Transformation, it is much reduced by 2050 due to reduced demand and lower levels of hydrogen.

In all Net Zero scenarios, levels of unabated gas for power generation reduce significantly with residual gas generation capacity remaining on-line to ensure Security of Supply. In Leading the Way, no such capacity remains on the system after 2035.

BCM – Billion Cubic Metres

In GB, a good guide for converting for converting natural gas volume in bcm to energy in TWh is to multiply by 11.

Unabated combustion

Unabated combustion means burning a fossil fuel without any way to capture its emissions.

FES 2022 / The Energy System / Natural Gas supply 199

Where are we now?

Though there is enough gas to meet current GB demand, recent events have highlighted our exposure to the global gas market.

The COVID-19 pandemic saw a global drop in demand for natural gas and associated production. As the world emerges from the pandemic, demand has grown faster than supply, leading to supplies being squeezed and high wholesale energy prices around the world. This was then compounded by the global response to the invasion of Ukraine by Russia, the largest global exporter of gas. Though we get very little of our gas directly from Russia, global price rises affect us in the UK. As gas-fired generation usually sets the marginal wholesale electricity price, electricity bills have also increased because of the high gas price. The table on the next page shows what can cause the price of gas to rise sharply using real examples from before the invasion of Ukraine.

Though there is a cost-of-energy crisis here and in much of the world, supply in Great Britain remains secure, mainly because we get our natural gas from diverse sources. In 2020, over half of UK gas demand was met by indigenous sources. Between 2019 and 2020, the UK was able to meet gas demand with lower dependence on imports than usual. Net imports fell by 28% and exports were up by 18% as one of our interconnectors with Europe was converted to allow trade in two directions.[1]

We have also recently seen increases in imports of natural gas (more than what is required to meet British demand for impots) which transits through the NTS for export into mainland Europe to support the re-stock of gas storage.

Flexibility

The characteristics of natural gas generation help to operate the system with high levels of stability and ability to respond quickly to increases or decreases in demand and renewable output. Having high levels of gas generation has allowed Great Britain to rapidly increase wind and solar capacity while still being able to operate a reliable system. As the ESO, we are on track to meet our ambition of ensuring the electricity system can operate carbon-free by 2025 and our Operability Strategy Report[2] explains how we can maintain reliability as we continue to decarbonise.

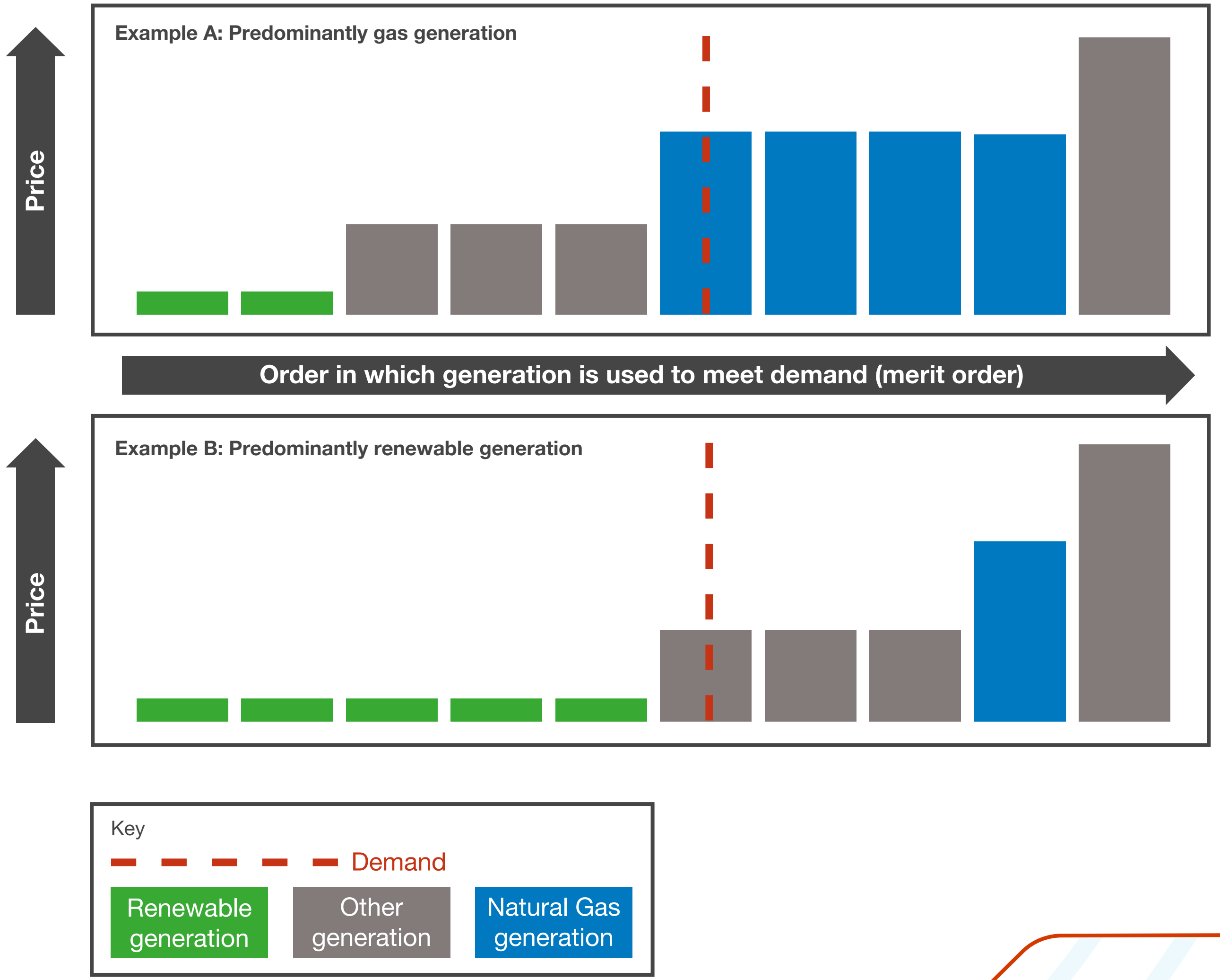
1 assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1006628/DUKES_2021_Chapter_4_Natural_gas.pdf
2 nationalgrideso.com/document/227081/download

FES 2022 / The Energy System / Natural Gas supply 200

Where are we now?

Marginal Price and the energy mix

This image shows how marginal pricing works at a very high level. Generation assets are ranked in a 'merit order', or order of preference in which they are used, with cheaper assets being used first. As demand rises, more expensive sources of generation are used. The marginal price of electricity is set by the last generation asset to be used in the mix at a given time. Today, that is often natural gas. Increased renewable generation would mean more low-cost generation capacity to meet demand before gas has to be used. The ESO's publication on Net Zero Market Reform[3] explores how pricing needs to change to enable Net Zero.



3 https://www.nationalgrideso.com/future-energy/projects/net-zero-market-reform

FES 2022 / The Energy System / Natural Gas supply 201

Where are we now?

Drivers of gas price increase in Winter 2021/22, Energy Transitions Commission March 2022[4]

Drivers of gas price increase in 2022	
Event	**Impact**
Cold northern hemisphere winter in early 2021	Depleted fossil gas storage levels
Increased demand and willingness to pay higher prices in Asia and South America	LNG delivered to these regions instead of Europe
Global demand for gas increased as COVID restrictions lifted	Boosted global demand
Limited LNG availability due to planned and unplanned outages	Constrained global supply
Russia prioritised domestic storage injections ahead of additional exports to Europe	Lower than expected fossil gas imports arrived into the EU from Russia (contractual obligations were met)
Lowest wind resource for 60 years across parts of Europe	Less energy generated from renewables and greater demand for gas across Europe to compensate
European phase-out of coal, and structural decline of nuclear power has placed emphasis on natural gas plants	Some European countries using more gas for power generation

4 Does not include the effects of the Russian invasion of Ukraine

FES 2022 / The Energy System / Natural Gas supply 202

Where are we now?

Figure ES.N.01: Natural gas supply sources in 2021 (% of total)

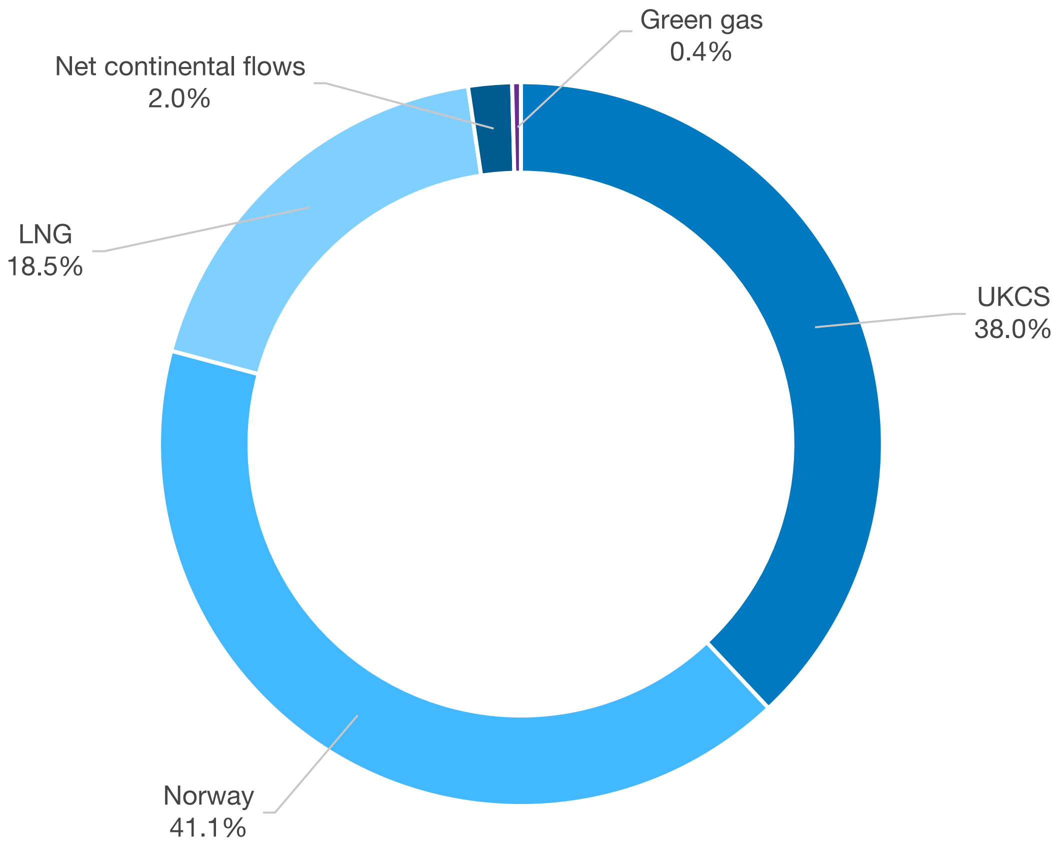
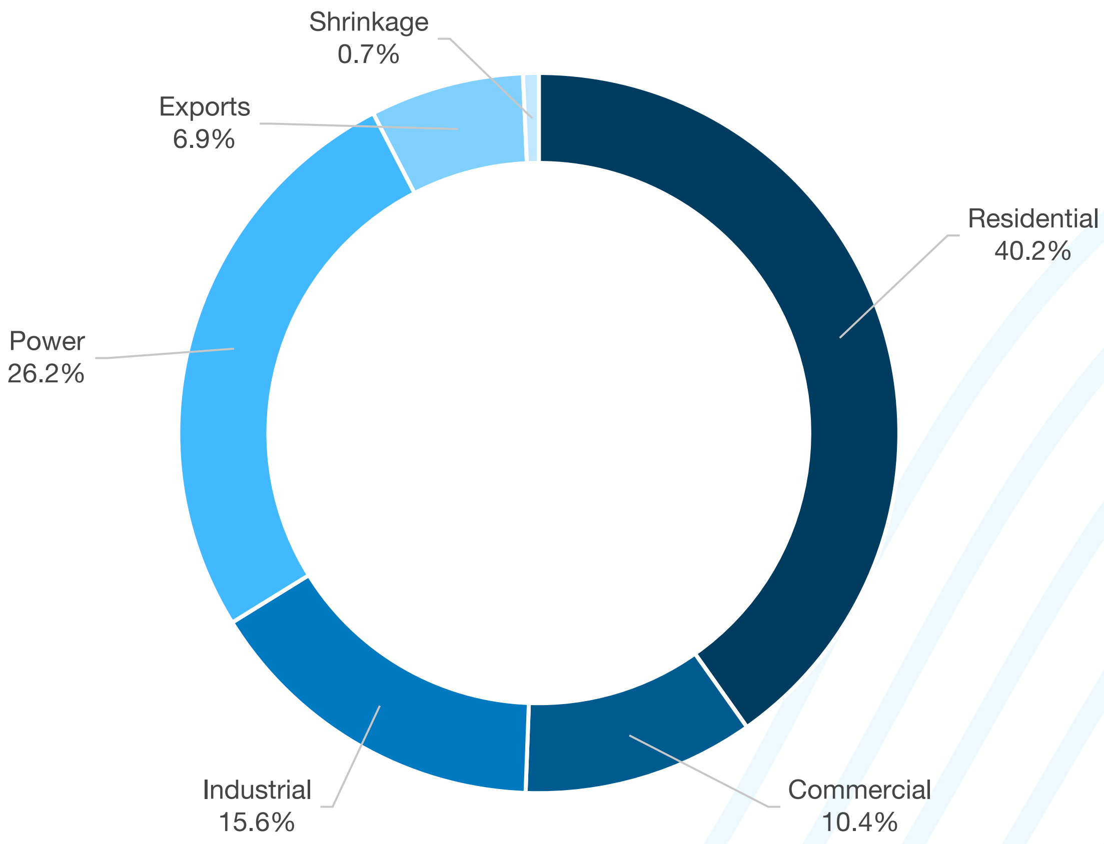


Figure ES.N.01: Natural gas demand sources in 2021 (% of total)



FES 2022 / The Energy System / Natural Gas supply 203

4 Does not include the effects of the Russian invasion of Ukraine

UK Policy Announcements

Hydrogen Strategy[5] and Investor Roadmap[6]

Our scenarios model the credible range of demand that the Government's new targets place on natural gas and its associated assets. The UK's ambitions for hydrogen are evolving quickly and the British Energy Security Strategy doubled the commitment laid out just a few months earlier in the Hydrogen Strategy. It commits up to 10 GW of hydrogen production capacity by 2030, with at least half coming from green hydrogen. There is then a pipeline of potential projects to grow this to 20 GW total hydrogen production capacity by 2037 outlined in the hydrogen investor roadmap. The Scottish government has its own ambitions for 5 GW of production capacity by 2030 and 25 GW by 2045.

Green gas[7]

The Green Gas Support Scheme (GGSS) provides incentives for production of carbon neutral methane through Anaerobic Digestion (AD) which helps to decarbonise gas while diversifying its supply. This is funded through the Green Gas Levy (GGL) which places obligations on licenced gas suppliers. Incentives from GGSS can run for up to 15 years and applications are open until November 2025. This is accounted for in our scenarios.

According to our stakeholders, the GGSS is expected to incentivise up to 45 new AD plants within four years and the business case is strong enough that some are already being commissioned without subsidy.

This growth is supported by the expected value of AD as a decarbonisation technology, which is heavily influenced by carbon pricing. The Global Methane Pledge was launched at COP26 to reduce global methane emissions by 30% between 2020 and 2030. This cannot be met without dealing with emissions from rotting waste, which AD can do while creating a useful fuel as a by-product. The infrastructure required to transport green gas depends on the scale of production and whether production can be located close to demand.

British Energy Security Strategy[8]

This lays out Government ambitions to improve energy security by supporting domestic sources, including renewables and gas from the UK Continental Shelf (UKCS) as well as reducing our long-term exposure to global energy (gas) markets where prices have spiked following COVID-19 and Russia's invasion of Ukraine. Key ambitions from the strategy include:

- 40% reduction in gas demand by 2030 through increased efficiency and faster uptake of renewables. This is broadly similar to the European Union's estimates of a possible 90% reduction by 2030 through measures in the REPowerEU Strategy[9] and Fit for 55 (FF55).[10]
- Increased dependence on UK Continental Shelf (UKCS) gas supplies. We expect more gas to be extracted from UKCS in the near term and the speed at which UKCS reserves are depleted in the longer term depends on the amount Britain imports from elsewhere.
- Potential for the oil and gas sector to be active in 2050 within a Net Zero economy.
- A decision by 2023 on blending up to 20% hydrogen into the gas grid.
- Consideration of shale gas as a source. We have therefore included this in our Falling Short scenario but note there is currently a moratorium in place on fracking projects.

5 https://www.gov.uk/government/publications/uk-hydrogen-strategy
6 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067408/hydrogen-investor-roadmap.pdf
7 https://www.ofgem.gov.uk/environmental-and-social-schemes/green-gas-support-scheme-and-green-gas-levy
8 https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy
9 eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52022DC0108
10 https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/

FES 2022 / The Energy System / Natural Gas supply 204

What we've found

The UKCS and Norway supply natural gas in all our scenarios until at least 2040. This is supplemented by imports of Liquefied Natural Gas (LNG) and continental interconnectors – especially in System Transformation and Falling Short. Demand for natural gas reduces after 2030 in both Consumer Transformation and Leading the Way, which assume more electrification of heat than the other scenarios.

By 2037, more homes are heated by electricity than natural gas in Consumer Transformation. In System Transformation, natural gas heating in homes reduces more slowly but by 2040 more homes are heated by hydrogen than by natural gas. Whilst the same pipe network may well be used, boilers will need to be able to burn hydrogen instead of natural gas.

In Leading the Way and Consumer Transformation, very little natural gas is used directly in 2050, but is still required for some industrial processes, for which the CO_2 emissions can be captured. In Leading the Way and Consumer Transformation, small amounts are used for methane reformation to produce hydrogen in industrial clusters. More details about how demand changes in the different scenarios can be found in The Energy Consumer chapter.

Liquefied Natural Gas (LNG)

Formed by chilling natural gas to condense as a liquid. Its volume reduces 600 times from the gaseous form, making it easier to transport around the world by ship.

FES 2022 / The Energy System / Natural Gas supply 205

What we've found

Figure ES.N.02: Natural gas supply from different sources, in 2030 and 2050 (TWh/year)

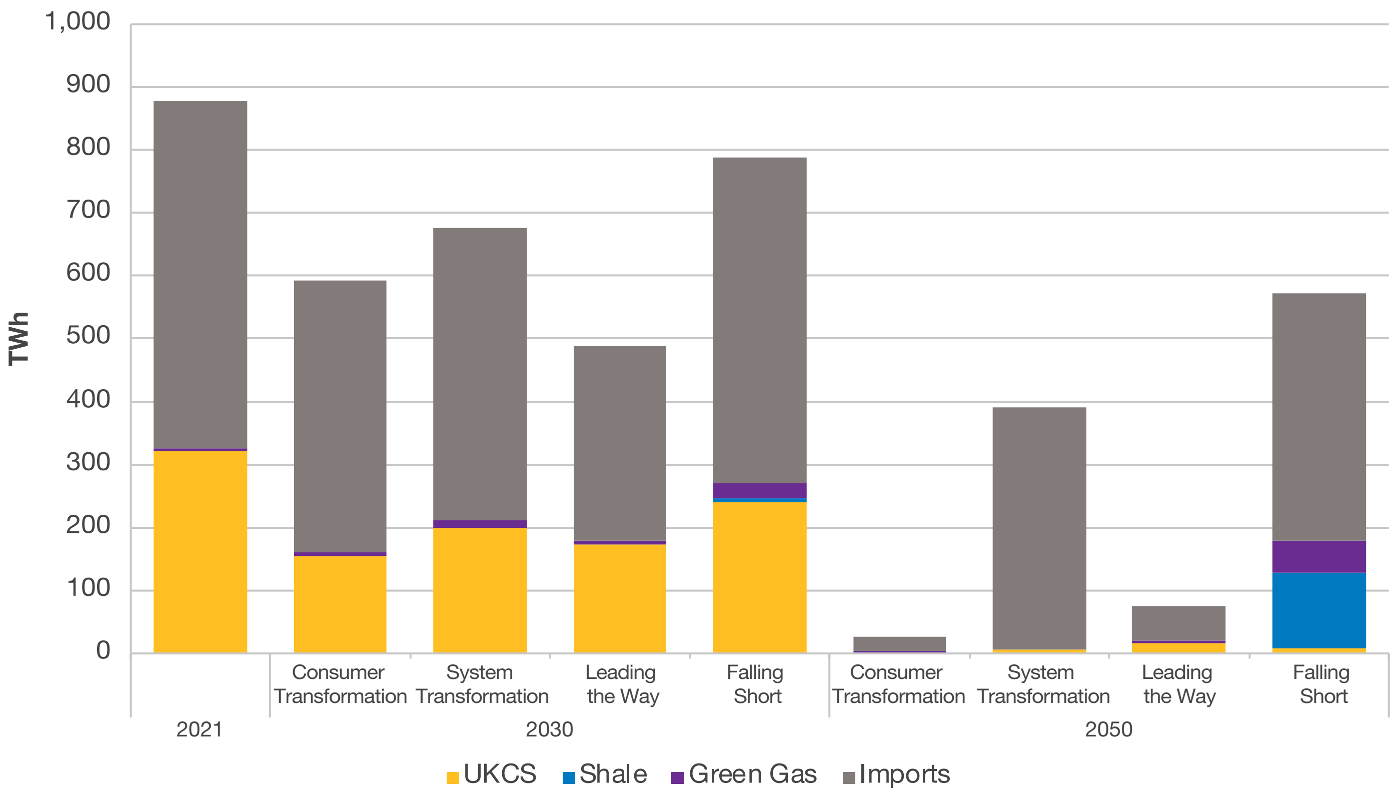
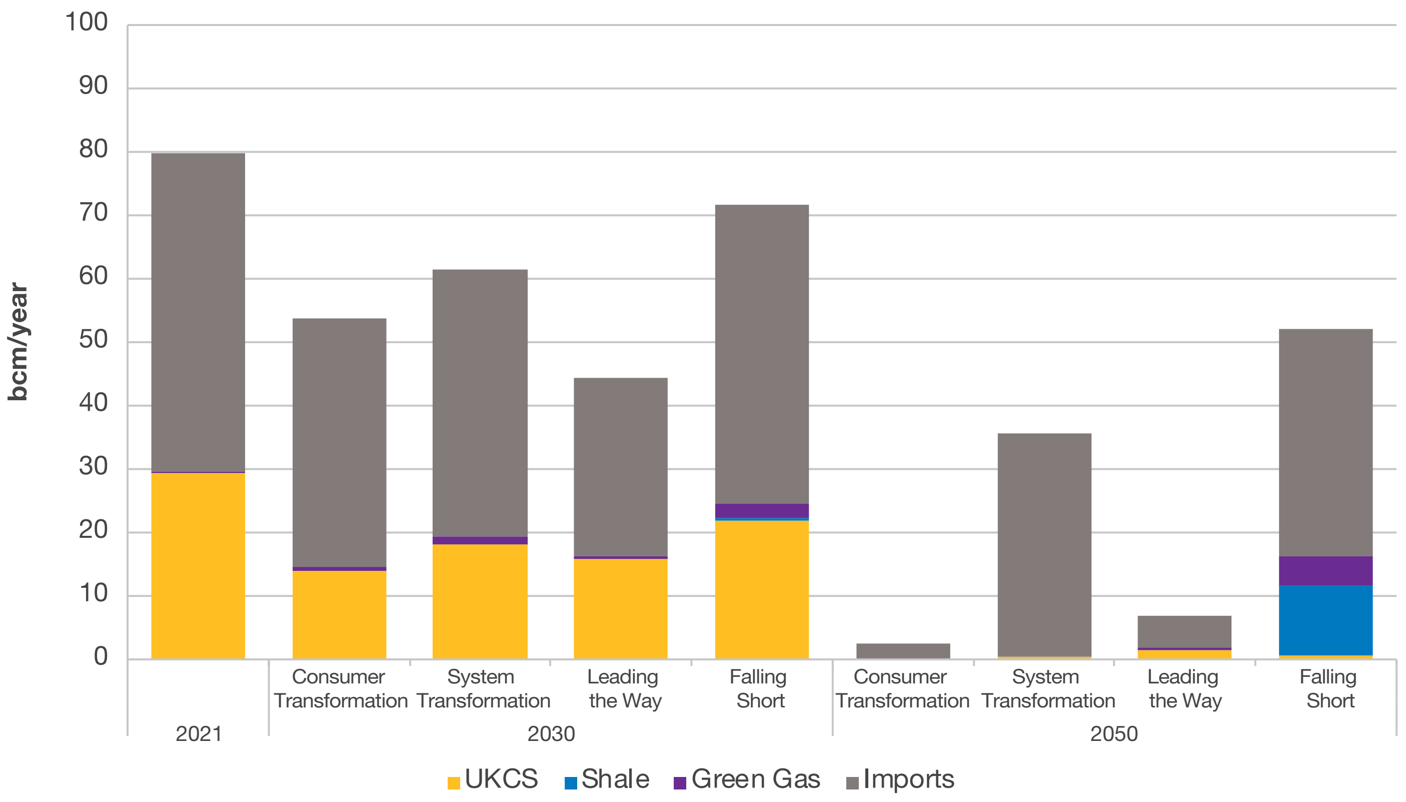
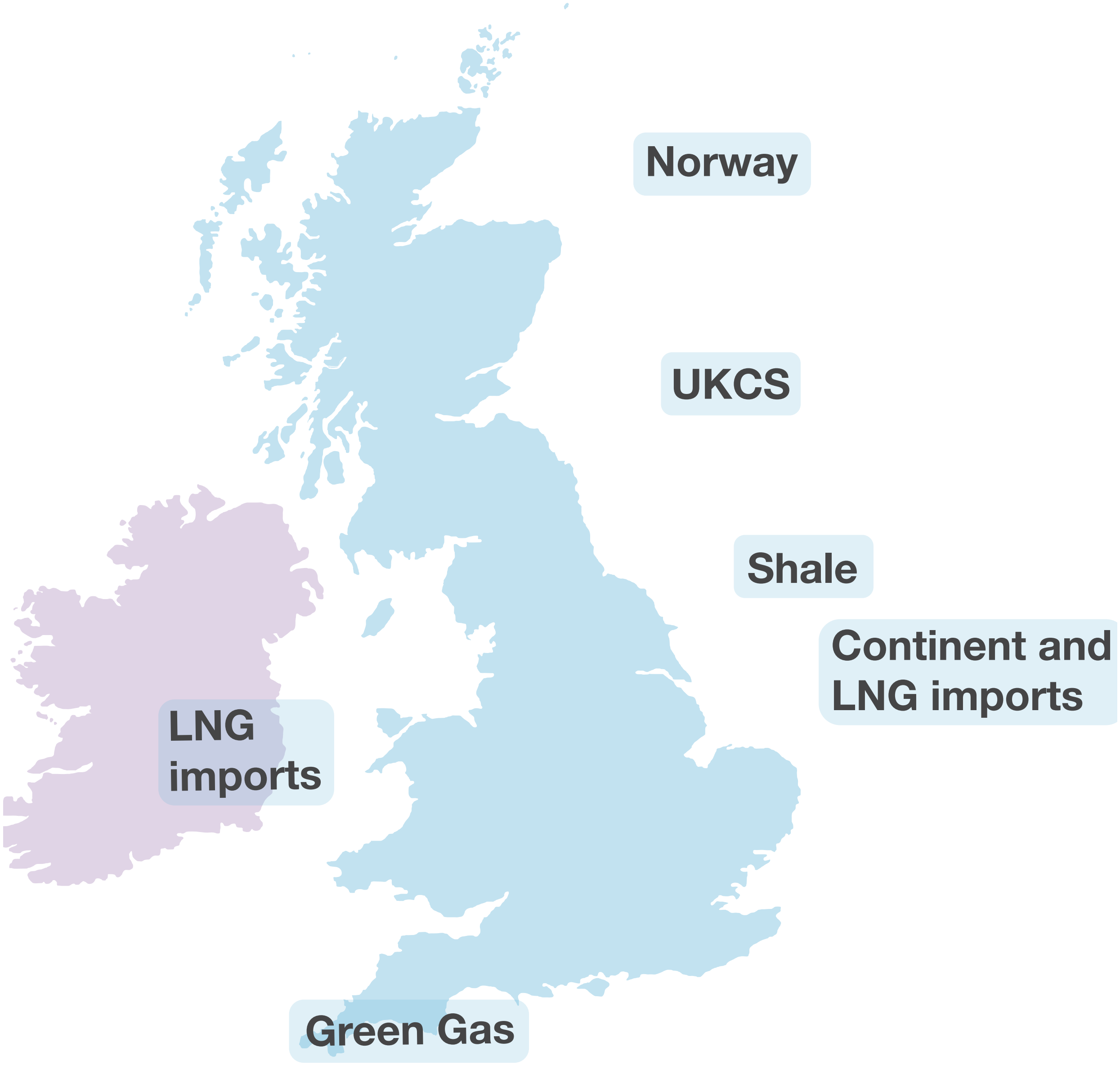


Figure ES.N.03: Natural gas supply from different sources, in 2030 and 2050 (bcm/year)



What we've found



Where Great Britain's gas comes from

Our scenarios explore the variety of natural gas supplies into Great Britain between now and 2050. We have modelled how the different sources may change over the coming decades in response to evolving demand profiles and levels.

Norway

Norway's large and flexible reserves mean it could keep supplying gas to the UK for longer than our own UKCS – especially in System Transformation, which represents the higher end of our gas supply ranges. However, in Consumer Transformation, we also anticipate the UK may stop importing gas from Norway in 2049 due to reduced demand in this more electrified scenario.

FES 2022 / The Energy System / Natural Gas supply 207

What we've found

UKCS

Overall production will fall in all scenarios between now and 2050 due to falling demand and as existing gas fields deplete. In Consumer Transformation, we expect production to stop in the mid-2040s as it becomes uneconomical to extract natural gas from new wells. In future, any natural gas needed for either a feedstock for hydrogen, in a power station or industrial process with carbon capture fitted, will have to be imported. By 2050, we expect the level of UKCS flows to be under 3% of present levels across all our scenarios.

Green gas

Green gas is made from bioresources and is considered carbon neutral. It has a role to play in all of the scenarios and the term green gas is used in our scenarios to refer to both biomethane and BioSNG. Across the scenarios, it is injected into the gas network to reduce the overall carbon intensity of the gas used in homes and businesses. Some green gas is assumed to be used off grid to provide fuel for remote and otherwise hard to decarbonise sectors. This is largely produced from waste processes (e.g. Anaerobic Digestion) rather than from other bioresources which are prioritised for other uses.

Shale gas from fracking

This is only used in the Falling Short scenario. Though there is currently a moratorium on fracking projects, Cuadrilla has until 2023 to evaluate options for the UK's two shale gas wells. The British Energy Security Strategy suggests shale gas may be considered as a viable source. However, high levels of public scrutiny would be expected, and support may be tempered by any extracted gas likely still being priced at global market value without significant government intervention in the market.

Liquefied Natural Gas (LNG) & continental imports

A second wave of liquefaction projects in the mid-2020s results in more LNG being available globally. However, demand for LNG may also rise globally as countries shift away from coal to decarbonise. Imports from the continent via existing gas interconnectors continue to play a key role in the supply of natural gas in all scenarios and LNG imports are seen in all scenarios. As LNG is shipped to Britain from abroad, its lifecycle emissions are higher than natural gas supplied from indigenous sources.

FES 2022 / The Energy System / Natural Gas supply 208

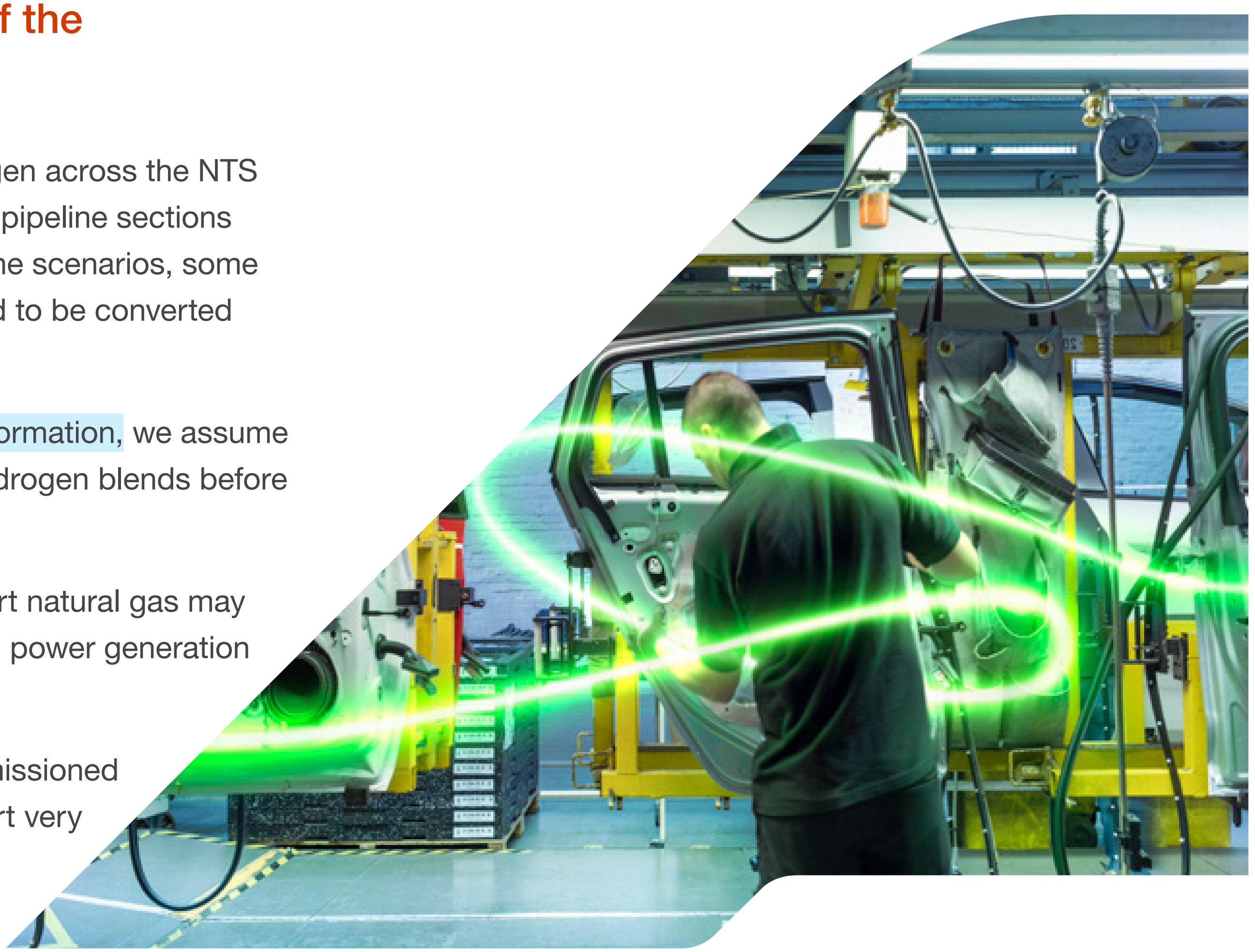
The natural gas network in a Net Zero world

As we transition to Net Zero, there are multiple possibilities for the future role of the natural gas network.

The gas National Transmission System (NTS) is over 7,500 km long and transports gas at high pressure around the country. It supplies gas to approximately 85% of homes in Great Britain through its connections to the gas distribution networks and local distribution zones. How homes and buildings are heated in future will determine the role of this extensive transmission and distribution network. That decision is dependent on factors including security of supply, the cost of retrofitting homes and the willingness of consumers to change. Our scenarios cover several possibilities:

- In System Transformation, the network may be fully repurposed to carry hydrogen as homes and buildings use it for heat in boilers similar to the natural gas ones they have today. However, in Leading the Way, the NTS could be converted to a 'hydrogen backbone', transporting hydrogen between industrial clusters and potentially to interconnectors at the Bacton Gas Terminal as well as other locations as further interconnection develops. Project Union[11], from National Grid Gas Transmission & Metering aims to get there by developing blending of hydrogen across the NTS in parallel to a strategic roll-out of new pipeline sections designed for hydrogen alone. Across the scenarios, some gas distribution networks will also need to be converted to carry hydrogen.
- In Leading the Way and System Transformation, we assume the gas system is used to transport hydrogen blends before the transition to 100% hydrogen.
- Assets that are not required to transport natural gas may be used to carry carbon captured from power generation and other processes to be stored.
- Some network assets may be decommissioned if it becomes uneconomical to transport very small volumes of gas.

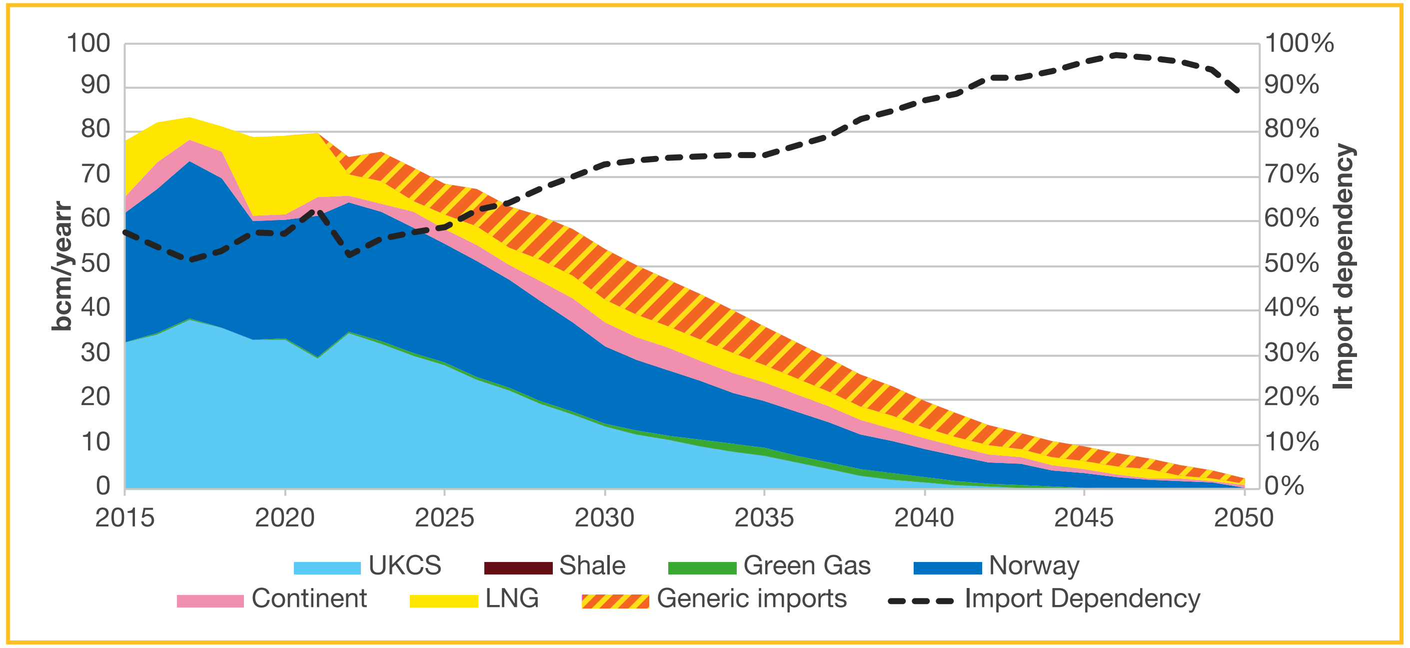
More information about the transition to hydrogen can be found in the Hydrogen supply section



11 nationalgrid.com/stories/journey-to-net-zero-stories/making-plans-hydrogen-backbone-across-britain

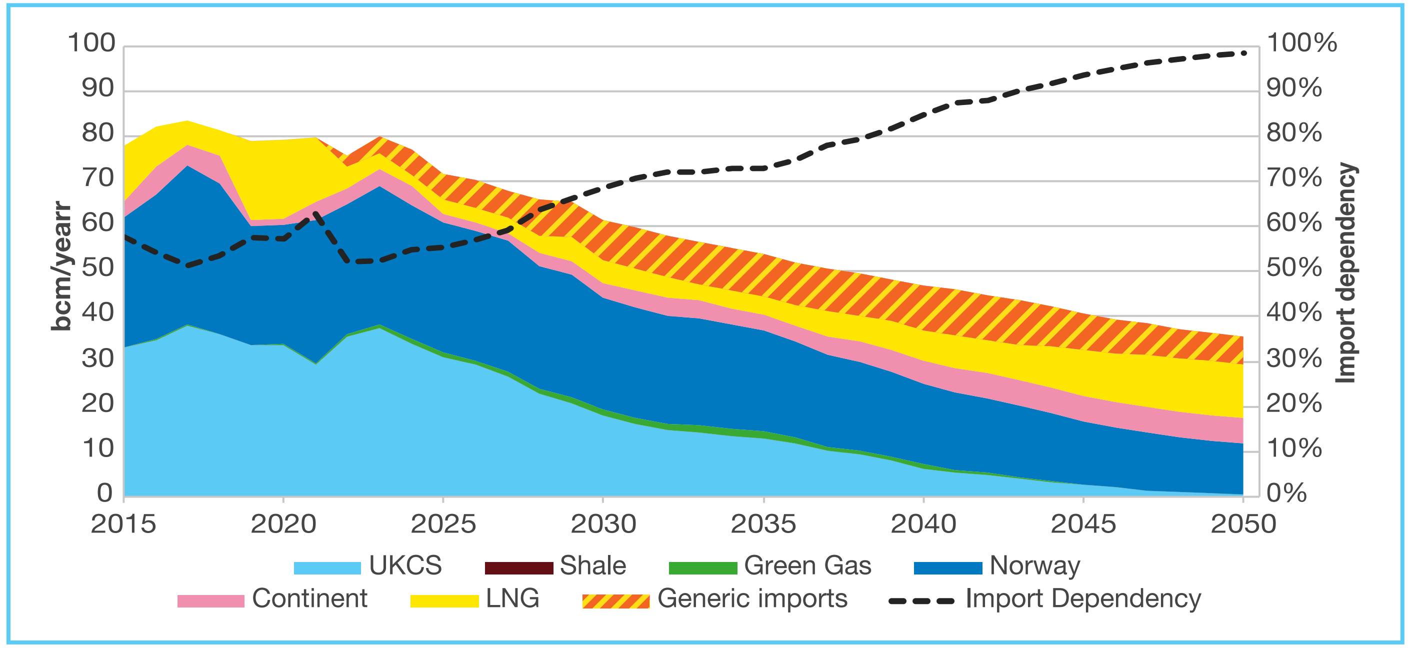
What we've found - scenario results

Figure ES.N.04: Annual gas supply and import dependency in Consumer Transformation (bcm/year)



- In this highly electrified scenario, natural gas consumption declines at a constant rate between now and 2050. This is down to natural gas being replaced in most cases by electricity for heating homes and buildings.
- The UKCS ceases to provide gas to the UK by 2046 as demand is much lower and the profile for the remaining uses requires a more flexible supply source.
- There is still a very small amount of natural gas demand in 2050, which is almost entirely met by imports (from the Continent and LNG). This gas is used in dedicated methane reformation facilities, creating hydrogen for shipping for example, and also where natural gas is still needed in some industrial applications.

Figure ES.N.05: Annual gas supply and import dependency in System Transformation (bcm/year)

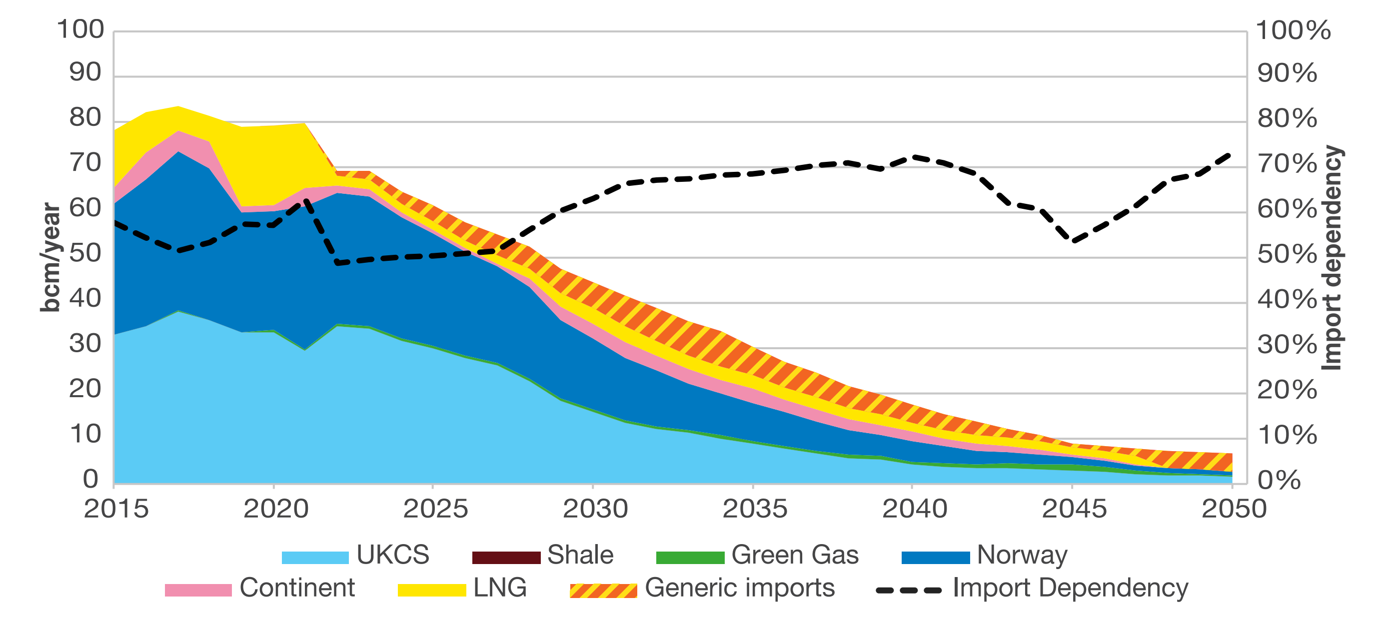


- By 2050, natural gas demand reduces to about 45% of 2021 levels, due to increased energy efficiency in homes and buildings, as well as increased electrification for heating, even though hydrogen provides more heat in this scenario than the other Net Zero scenarios.
- Demand for natural gas is predominantly for methane reformation to produce hydrogen, which is then used for heating and other applications. This is about 20% lower than our analysis showed for FES 2021. The main changes are a lower forecast for hydrogen boiler adoption and reduced demand for methane reformation as greater levels of electrolysis begin to be seen.
- After an increase in output in the mid-2020s, supply from the UKCS steadily declines to almost zero by 2050. In 2050, we are almost 100% dependent on imports, with most of the UK's gas arriving from either Norway, the continent or in the form of LNG, bought on the global market.

FES 2022 / The Energy System / Natural Gas supply 210

What we’ve found - scenario results

Figure ES.N.06: Annual gas supply and import dependency in Leading the Way (bcm/year)



- Leading the Way has the quickest reduction in natural gas demand, dropping to 55% of 2021 levels by 2030. Most of the demand between 2020 and 2050 is met by gas from the UKCS and Norway.
- In this scenario, most natural gas applications have switched to electricity or green hydrogen. The remaining demand is for some industrial applications and its combustion is combined with CCUS.
- For FES 2022, Leading the Way includes some demand for methane reformation in line with the Government’s recent announcement for specific funding.
- The UKCS is still providing a small amount of the residual annual demand in 2050, meaning that the UK can meet 27% of annual demand from domestic sources in 2050, compared to 37% in 2021.

FES 2022 / The Energy System / Natural Gas supply 211

What we've found - scenario results

Figure ES.N.07: Annual gas supply and import dependency in Falling Short (bcm/year)

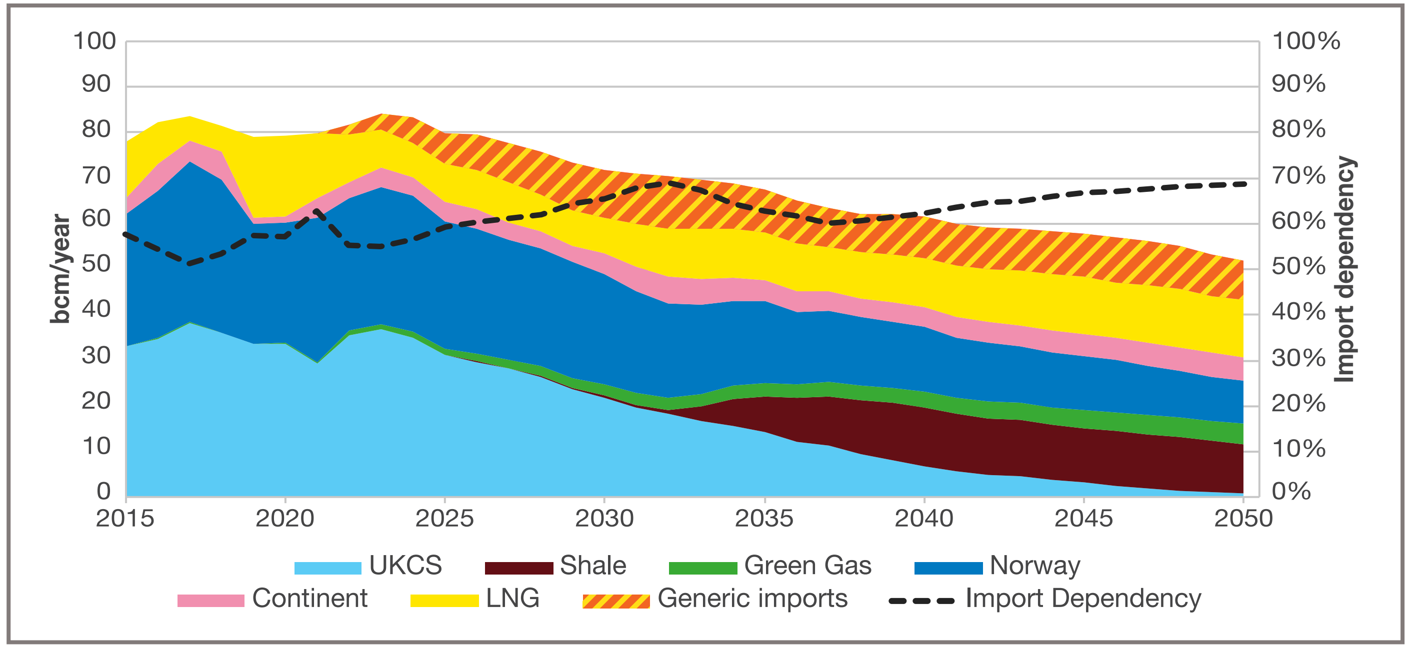
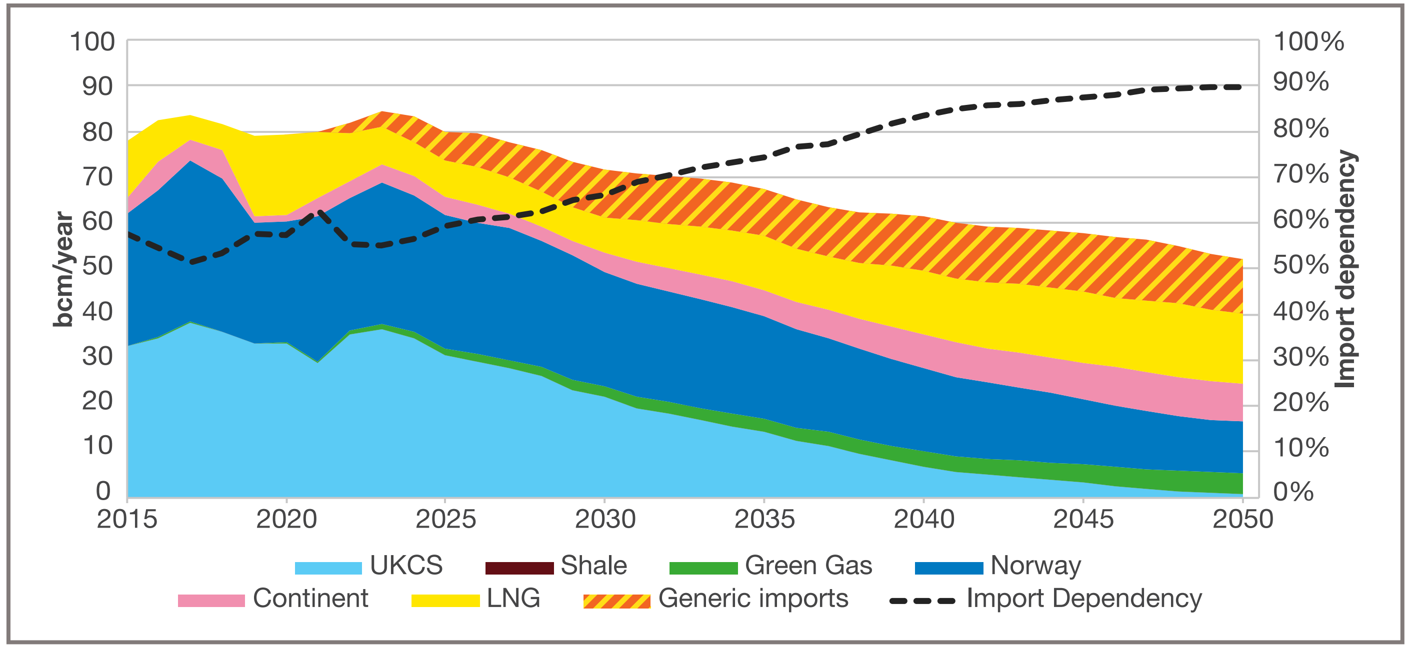


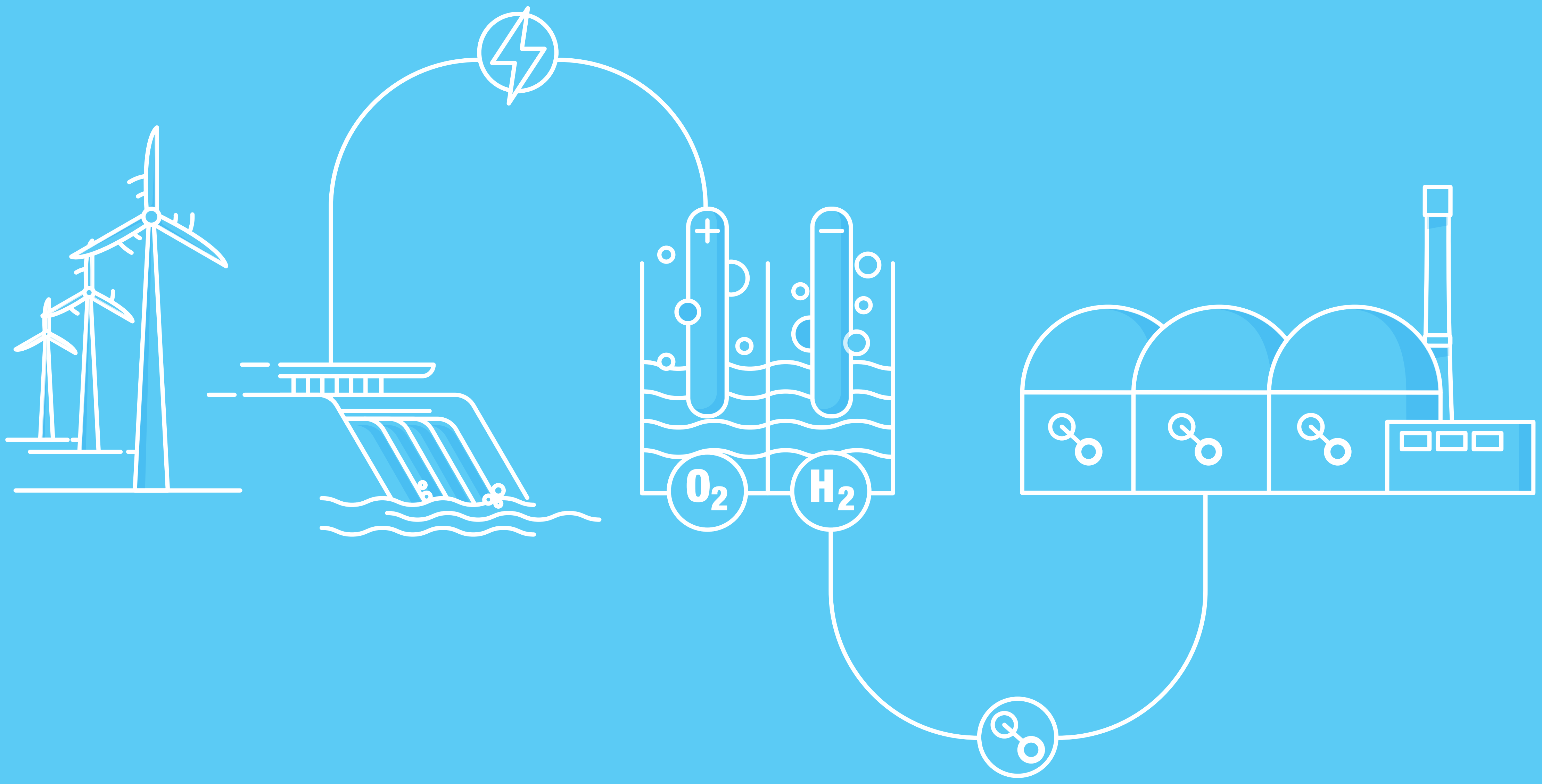
Figure ES.N.07: Annual gas supply and import dependency in Falling Short without shale gas (bcm/year)



- Natural gas demand reduces steadily to about 65% of 2021 levels. Though natural gas is still widely used in the UK to heat homes and buildings and for industrial applications, we also see increased energy efficiency in homes and buildings, as well as increased electrification for heating.
- After an increase in output in the mid-2020s, supply from the UKCS steadily declines to almost zero by 2050. Import dependency after 2030 depends to an extent on whether domestic shale gas reserves are exploited or not. Including supply from shale gas in Falling Short reduces reliance on imports from 90% to 69%.
- Green gas is also used at scale in this scenario as a means of reducing the carbon impact of natural gas by blending the two gases.

FES 2022 / The Energy System / Natural Gas supply 212

Hydrogen Supply



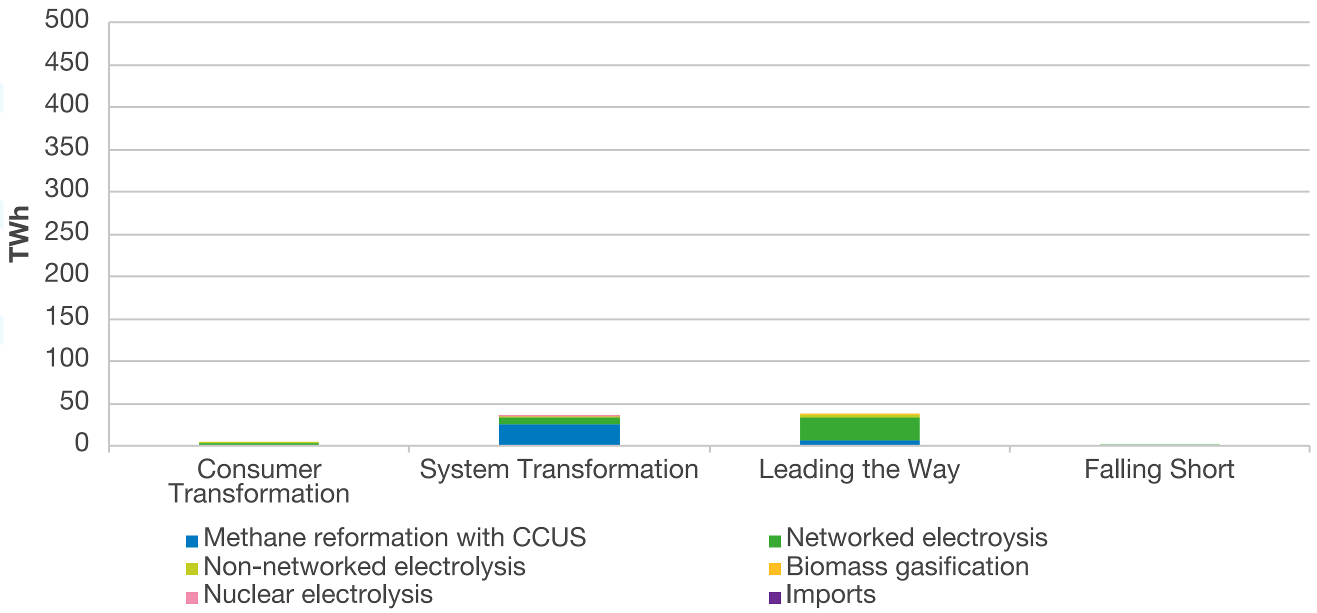
Key insights

Hydrogen is an emerging technology that plays a key role in all our Net Zero scenarios.

In addition to being able to replace most uses of natural gas in the energy mix, its production via electrolysis and ability to be stored over long time periods can help to overcome the challenges and harness the opportunities that come with increased renewable generation in the electricity system – even in Consumer Transformation. However, despite being an essential part of the future energy system, its credible range in terms of both how much energy demand it meets and how it is produced is very wide. Clarity is needed as soon as possible on the future role of hydrogen, especially in residential heating as this will support the strategic coordination and whole energy system thinking required to meet Net Zero in a way that is secure, clean, affordable and fair.

- **The credible range of possible hydrogen use is very wide** and this impacts the development of hydrogen infrastructure. While hydrogen for power generation is needed in all our Net Zero scenarios to support electricity Security of Supply, the broader levels of demand, hydrogen production methods, and end uses vary greatly between the scenarios.
- **A clear understanding of the desired benefits** hydrogen is expected to provide, as well as how costs vary for different use cases, is vital. Relatively small changes in annual load factor, electricity price or commodity (natural gas and hydrogen) price can drastically affect the commercial viability of a hydrogen value chain and so the role of markets to provide clear signals is paramount.
- Leading the Way meets the target of 10 GW of hydrogen production by 2030 set out in the British Energy Security Strategy. However, a **corresponding demand side strategy is required** to ensure that the hydrogen produced is effectively used and that the level of blending into the gas system is minimised.
- **Hydrogen supports operation of the energy system** of the future as the production of hydrogen via electrolysis helps to integrate renewable electricity generation and reduce curtailment. This is because surplus electricity can be used to produce hydrogen at times of network congestion. High levels of electrolysis in Leading the Way contribute to it seeing the lowest levels of curtailed energy.
- To fully realise the whole system benefits of hydrogen, and to provide energy security without unabated gas, **high levels of hydrogen storage will be required.** This is the case across all the Net Zero scenarios and, given the likely geological aspect of these projects, strategic investment is required now.
- Biomass gasification can be combined with CCUS to make carbon emissions from hydrogen production net negative in Leading the Way and System Transformation. This offsets residual emissions in other sectors.

Figure ES.H.01: Hydrogen supply in 2030 by technology (TWh)



Key insights

Figure ES.H.01: Hydrogen supply in 2030 by technology (TWh)

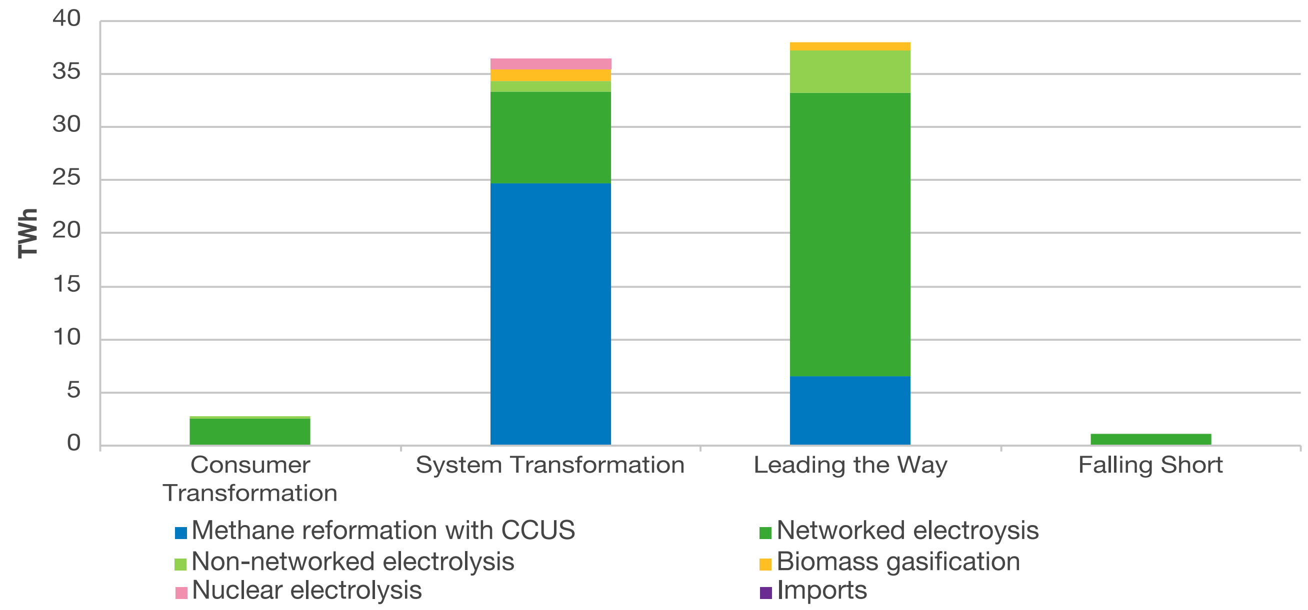


Figure ES.H.02: Hydrogen supply in 2050 by technology (TWh)

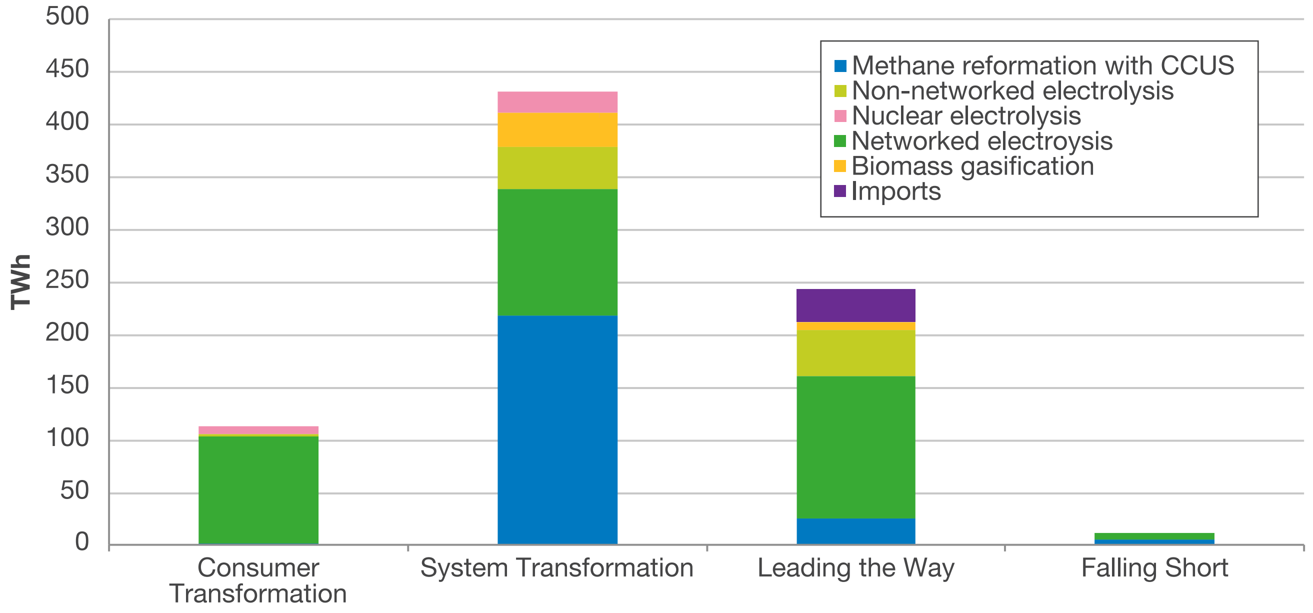
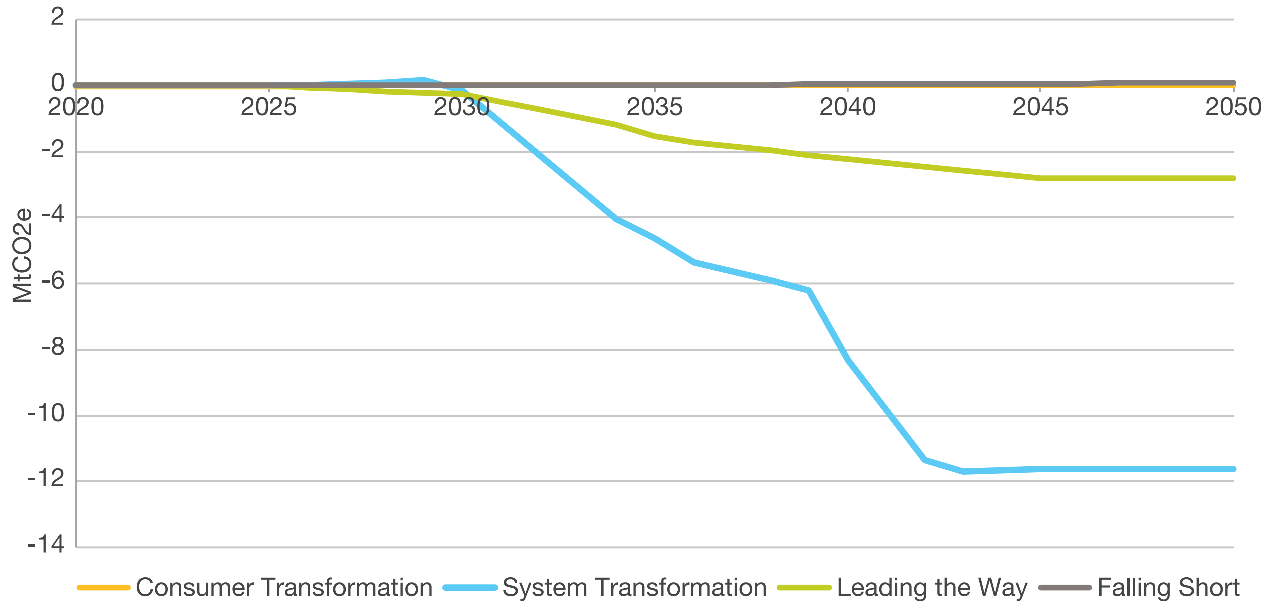


Figure ES.H.03: Emissions from hydrogen production by scenario



FES 2022 / The Energy System / Hydrogen Supply 215

Where are we now?

Hydrogen is already commonly used worldwide for refining oil and in the production of ammonia for fertilisers. Each year, around 50 Mt hydrogen (or 2,000 TWh of energy equivalent) is produced globally, of which around 0.7 Mt (~27 TWh/annum) is both produced and consumed in the UK.

Almost all current UK hydrogen production uses methane reformation without CCUS. Capturing CO_2 emissions from production or using renewable electricity could bring that very close to being carbon neutral, or even negative.

Methane Reformation

A method for producing hydrogen, ammonia, or other useful products from hydrocarbon fuels such as natural gas. In addition to Steam Methane Reforming (SMR), this could include Autothermal Reforming (ATR) which uses a pure stream of oxygen to drive the reaction and increase the hydrogen production and CO2 capture.

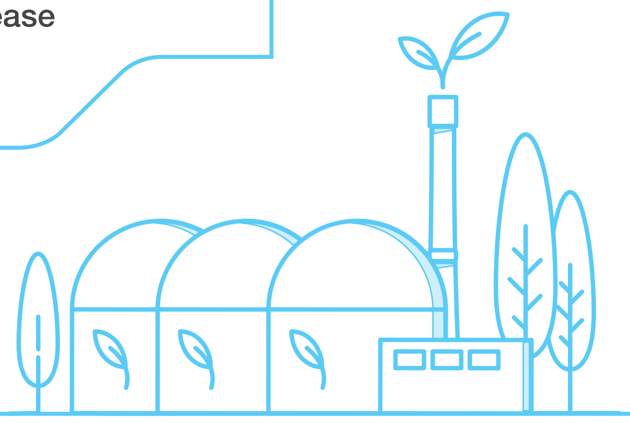
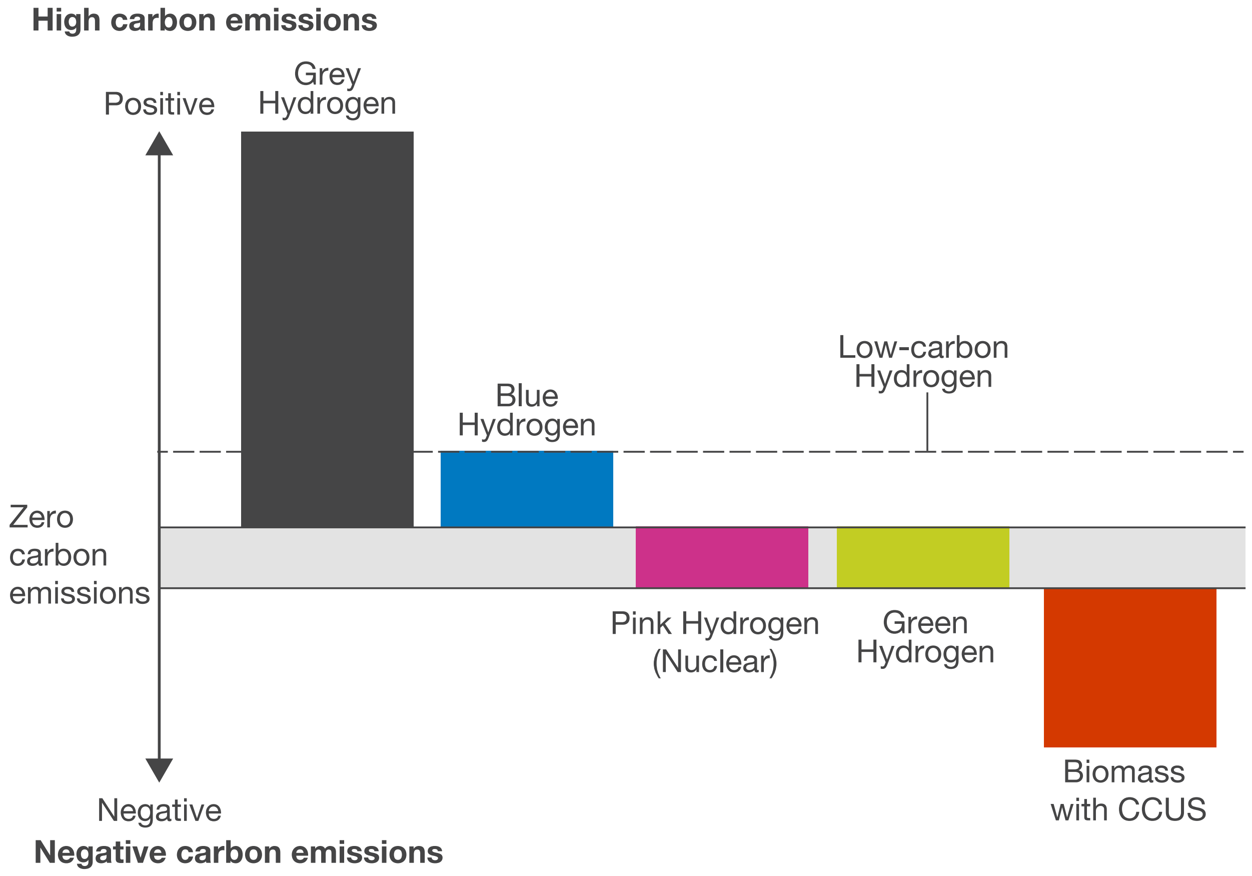


Figure ES.H.04: Different types of hydrogen production and their carbon emissions



FES 2022 / The Energy System / Hydrogen Supply 216

Where are we now?

Grey Hydrogen

Grey hydrogen is the term given to hydrogen made by methane reformation without any means to capture emissions.

Blue Hydrogen

Blue hydrogen is the same as grey, except when it is produced, up to 97% of carbon emissions are captured and either stored or used. It still involves the extraction of fossil fuels, and the associated emissions this brings, and its status as a low carbon technology is dependent on the effectiveness of carbon capture.

Nuclear

Nuclear power provides the energy for producing hydrogen. For this year's FES we have focused on low temperature electrolysis which can be combined with large or small nuclear reactors because it has the greatest commercial and technical readiness levels of all the options.

Other potential ways of pairing nuclear technologies with hydrogen production include high temperature electrolysis such as solid oxide electrolysis (using heat as well as electricity from a nuclear power plant) or thermochemical production (using high temperature chemical reactions and heat from the nuclear plant).

Green Hydrogen

Renewable electricity is used for electrolysis to produce hydrogen without carbon emissions.

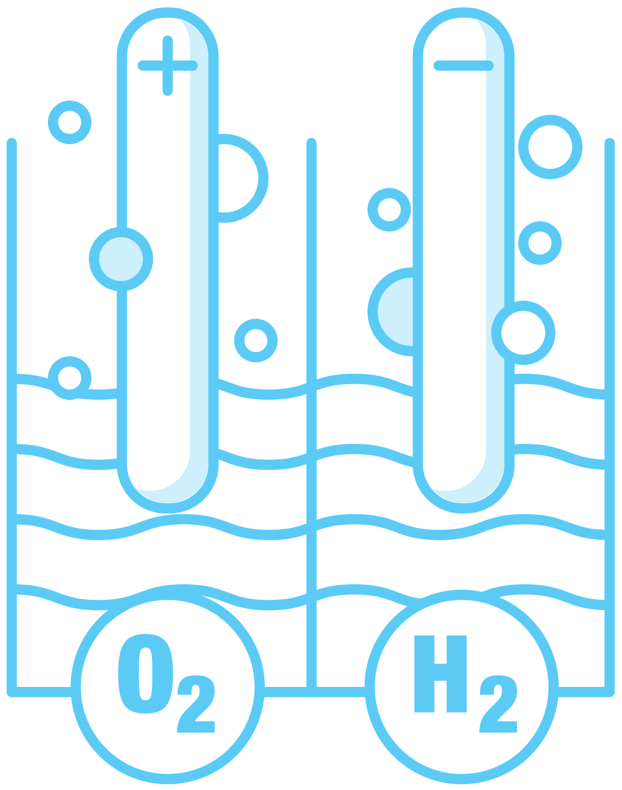
Bio + CCUS

Through gasification, biomass can be used to produce hydrogen. When this is combined with carbon capture, the CO_2 produced as a by-product is stored, making the overall process negative in terms of carbon emissions.

FES 2022 / The Energy System / Hydrogen Supply 217

Hydrogen in the whole energy system

Hydrogen produces no carbon emissions at the point of combustion and hydrogen fuel cells can generate electricity with no emissions besides water, which potentially makes it a perfect fuel for a Net Zero world. There are many ways we can take advantage of it but, to do so, we must overcome some technical and commercial challenges.



Advantages and disadvantages of hydrogen

Advantages	Disadvantages
Hydrogen provides us with **flexibility** to meet demand. It can be stored and used in electricity generation, helping to manage peak demand when fossil fuels are no longer available.	Characteristics of hydrogen, like its energy density and molecular structure, have implications for **transportation and storage**. Pipes may need to be upgraded and salt cavern storage modified to store hydrogen.
Hydrogen can replace natural gas in **heat** applications, with comparatively simple modifications to appliances (both domestic and industrial).	Currently there are no **regulations** nor market for hydrogen supply at scale, both of which are fundamental to the growth of hydrogen use.
The existing national gas **pipe network** could be repurposed for hydrogen.	Due to the process of producing, transporting and storing both hydrogen and CO_2, hydrogen is a **less energy efficient** way of heating, compared to natural gas.
Hydrogen can also be **blended** into the natural gas network (approximately 20% by volume) to reduce its carbon impact. This could be done on a regional basis as hydrogen production is gradually increased.	Given higher production costs for hydrogen in comparison to natural gas, the final product to the customer will be more expensive.
Electrolysis could produce green hydrogen using surplus **renewable electricity** at times of low demand. This avoids shutting off wind generation, which incurs costs to end-consumers.	The **costs** of producing hydrogen vary greatly, dependent on factors such as the wholesale cost of electricity and the cost of electrolysers and methane reformers.
With careful placing of electrolysers and associated hydrogen infrastructure, some electricity **network constraints** could be significantly reduced.	If the **location** of electrolysers is not carefully considered, they could add to network constraint issues caused by the increase in renewable electricity.
Producing hydrogen from the UK's natural gas supplies and renewable electricity would reduce our **dependency** on energy imports.	There is uncertainty about worldwide plans for hydrogen. A **global hydrogen market** may develop, which could supplement demand but also leave us exposed to hydrogen price volatility.

FES 2022 / The Energy System / Hydrogen Supply 218

What we've found

How we can use hydrogen

Hydrogen can help to address many of the hardest parts of the transition to Net Zero. It can meet end user demand to replace fossil fuels with minimal change to the user's experience as well as help to balance supply and demand in the electricity system. All of the different use cases come with their own combination of the challenges and benefits outlined earlier and which are explored in more detail in the Energy Consumer chapter. Variations in hydrogen use in FES are largely a result of how the scenarios are initially aligned at a high level to the axes of "speed of decarbonisation" and "level of societal change" within the framework and mirror the degree of electrification. Each scenario then evolves along the modelling process in relation to whole system impacts and how easily we can move hydrogen around the country.

Exports and opportunities for new demand

- In some scenarios, there is greater demand for green hydrogen production to avoid curtailment of electricity supply, which means there will be more hydrogen than there is currently demand for in some scenarios. This may create a commercial opportunity for exports or converting the hydrogen or new demand sources to use it.
- Hydrogen can be converted to ammonia for long distance transport via ocean tankers. Our analysis does not differentiate between different types of hydrogen export.

Figure ES.H.05: Hydrogen demand by scenario and end user in 2050 (TWh)[1]

End user	Description	CT	ST	LW	FS
Residential Heat	Hydrogen can provide a direct alternative to natural gas for heating homes and for cooking. Any appliances e.g. boilers, gas fires and cookers would need to be hydrogen-ready.	0	145	43	0
Industrial and Commerical	Hydrogen can provide the raw chemical input and high temperatures needed for some industrial processes.	13	134	76	9
Road transport and rail	Fuel cells produce electricity and water by combining high-purity[2] hydrogen and oxygen. Electricity is used to power the vehicle and liquid hydrogen can be carried on-board, with fast refuelling (compared to battery charging) making it an ideal fuel for long journeys.	3	58	6	1
Aviation and shipping		80	80	80	0
Power Generation	Hydrogen can be burned in power stations to produce electricity in the similar way that natural gas is used today, which includes the ability to provide ancillary services.	17	13	14	1
Direct Air Carbon Capture and Storage (DACCS)	In Leading the Way, heat from hydrogen combined with cheap and plentiful renewable energy makes DACCS increasingly credible as a Greenhouse Gas Removal (GGR) technology.	0	0	24	0

1 This is hydrogen for domestic consumption only and excludes exported hydrogen. Hydrogen export takes place in Leading the Way and System Transformation.
2 Hydrogen fuel cells require hydrogen to be at very high purity. This can be achieved through specialised transport of the fuel to avoid contamination or purification at point of delivery.

FES 2022 / The Energy System / Hydrogen Supply 219

What we've found

Direct Air Carbon Capture and Storage (DACCS)

Carbon dioxide can be removed from the atmosphere by stripping it from the air, after which it can be stored. It is an energy intensive process and current methods require heat (provided here by hydrogen), electricity and somewhere to store the captured carbon dioxide.

Hydrogen also helps to operate the electricity system. Hydrogen helps us to:

Balance the electricity system: Electricity supply and demand need to be carefully balanced at all times and hydrogen can help on both sides of that equation. Producing hydrogen via electrolysis can create additional demand when needed to avoid curtailing wind and solar generation and this hydrogen can then be used to generate power at times of peak demand or low renewable output.

Overcome network constraints: Strategic siting of electrolysers has the potential to reduce network constraints that occur at times of high renewable output by providing price-responsive demand.

FES 2022 / The Energy System / Hydrogen Supply 220

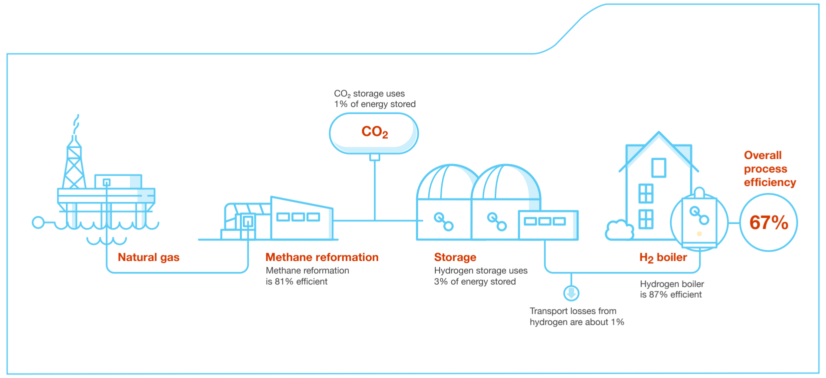
What we've found

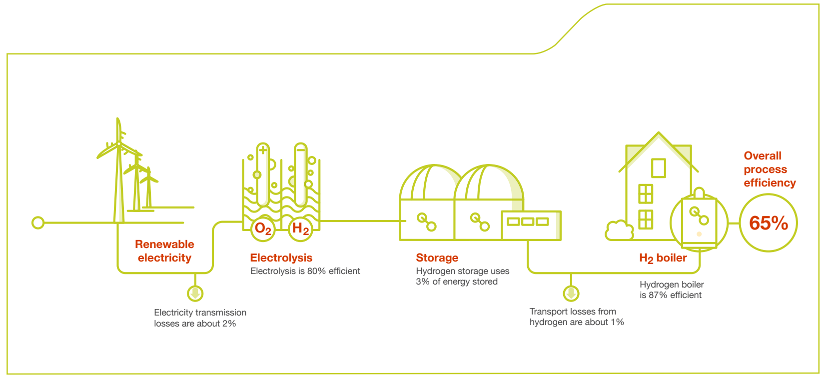
How do different use cases compare?

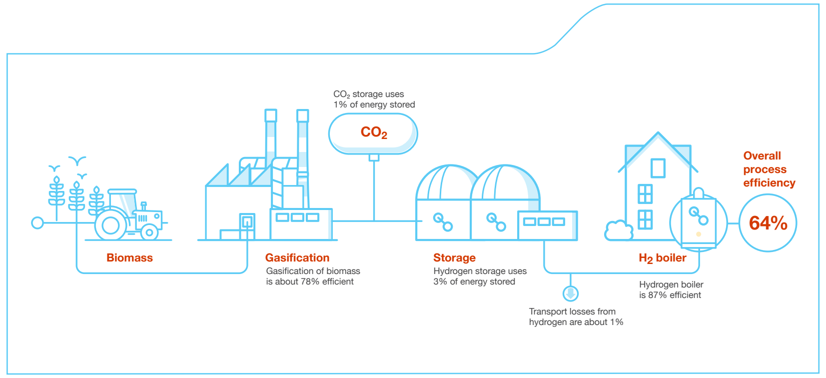
The whole energy system efficiency of using hydrogen to heat a home depends on the original feedstock, the production methods, transportation, storage and how the energy is used to generate heat. The illustrations here show the relative efficiency of the different processes to produce heat for a home. Heat pumps are very efficient at converting electricity to heat and so using hydrogen to generate the electricity for heat pump is the most efficient process here, compared to using hydrogen in a boiler to generate heat.

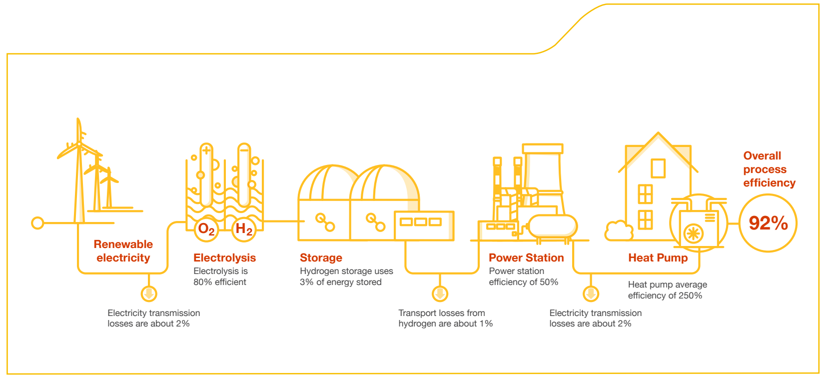
Case study: Efficiency of using hydrogen to heat a home[3]

There are different ways to produce, deliver and use hydrogen. Each scenario includes many combinations of technologies but here are some examples which show the main differences in the Net Zero scenarios.









System Transformation: Natural Gas

Leading the Way: Renewable Electricity

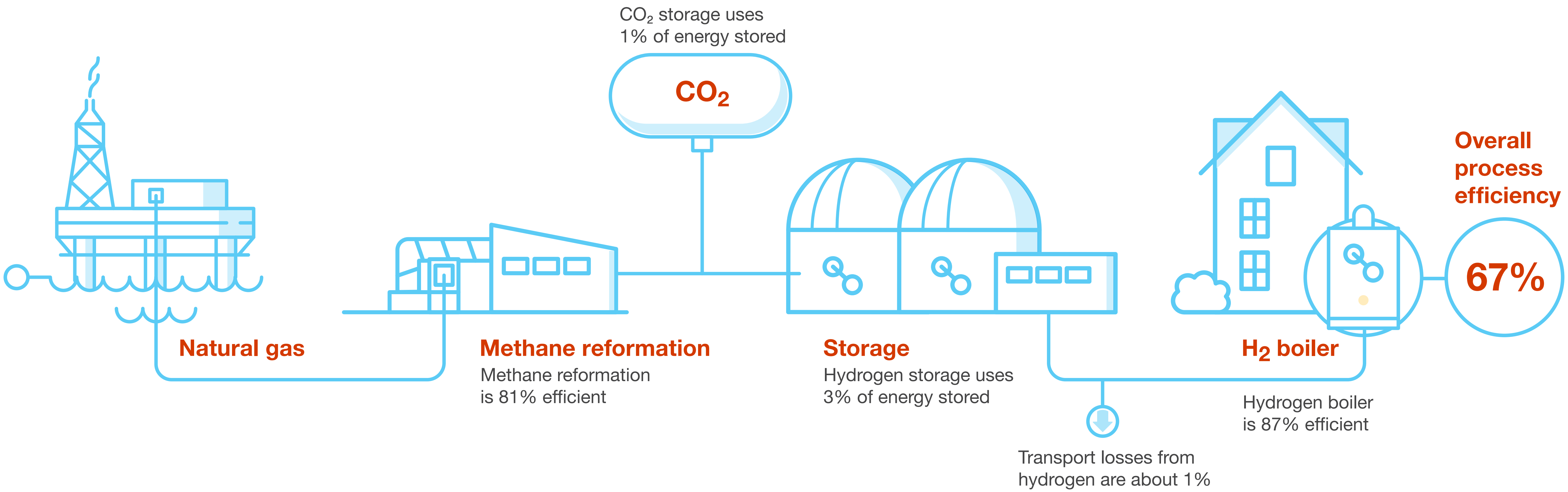
System Transformation: Biomass

Consumer Transformation: Renewable Electricity

3 Falling Short is not included as hydrogen is not used to heat homes in this scenario.

What we've found

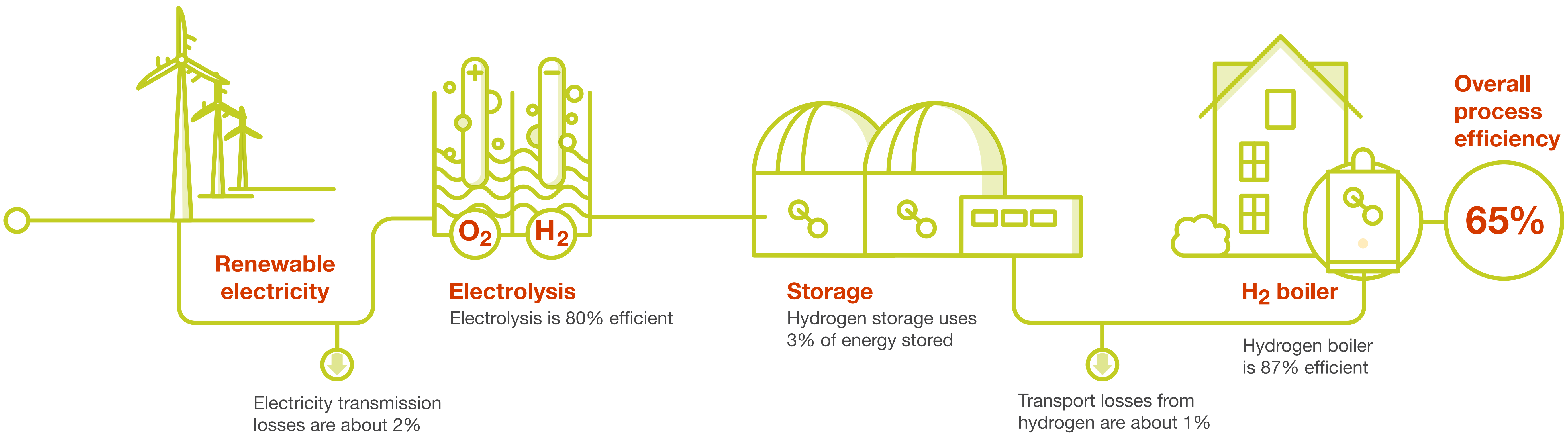
System Transformation
Hydrogen produced from natural gas and used like natural gas in a boiler.



FES 2022 / The Energy System / Hydrogen Supply 222

What we've found

Leading the Way
Hydrogen made by renewable electricity via electrolysis and used in boilers, possibly in a hybrid application with a heat pump.

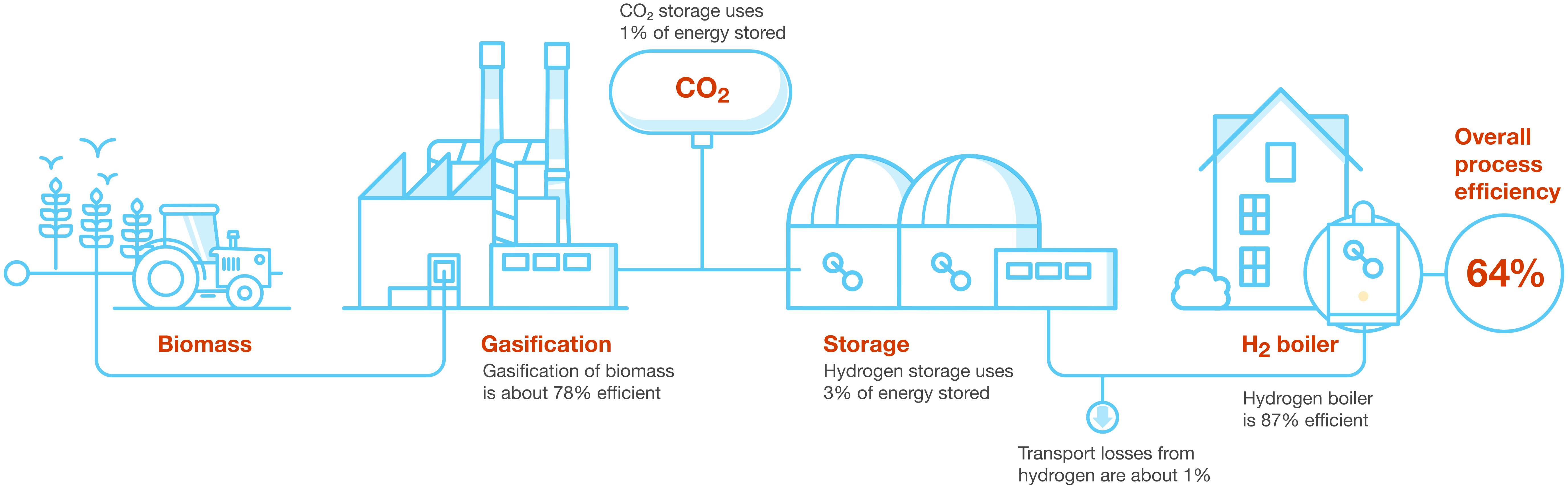


FES 2022 / The Energy System / Hydrogen Supply 223

What we've found

System Transformation

Hydrogen made from bioresources, used like natural gas in a boiler.

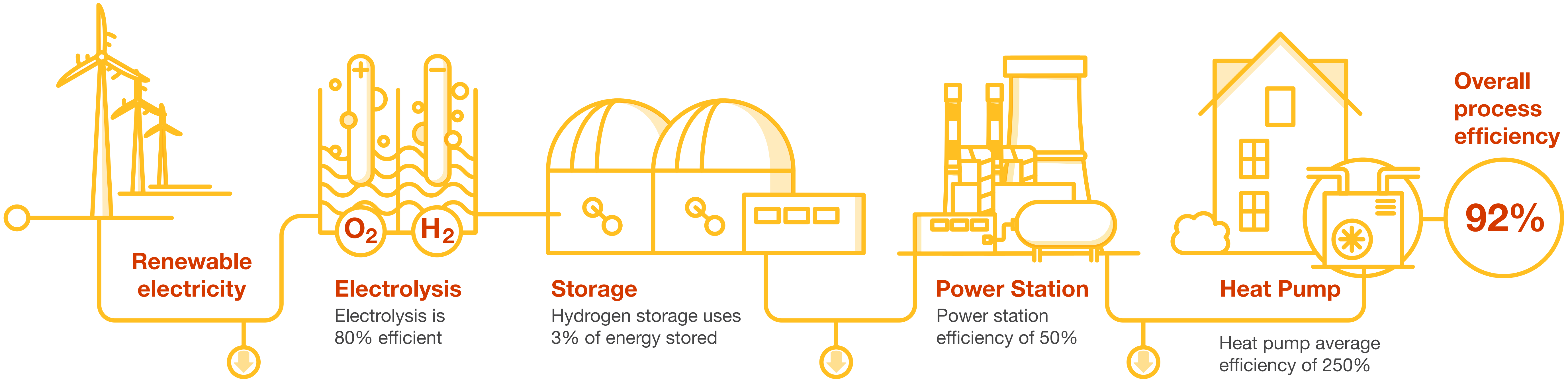


FES 2022 / The Energy System / Hydrogen Supply 224

What we’ve found

Consumer Transformation

Hydrogen made with renewable electricity via electrolysis, stored until needed at times of peak demand to generate power for a heat pump.



FES 2022 / The Energy System / Hydrogen Supply 225

Different ways of using hydrogen: how do costs compare?

Overall costs of the different production methods are equally important and we have worked with Delta-EE on an innovation project to understand what influences costs. Some of the main findings are summarised below but the report can be found here.[4] The report highlights how any analysis of the potential market and costs associated with hydrogen would have to consider the whole energy system. Costs of electrolysers and methane reformation with CCUS are fundamentally linked to the electricity market, the natural gas market and any incentives for carbon capture. This emphasises the need for market reform to improve price signals and for strategic whole system thinking.

FES 2022 / The Energy System / Hydrogen Supply 226

4 https://www.delta-ee.com/report/report-summary-hydrogen-as-an-electricity-system-asset/

Different ways of using hydrogen: how do costs compare?

Hydrogen Production[5]

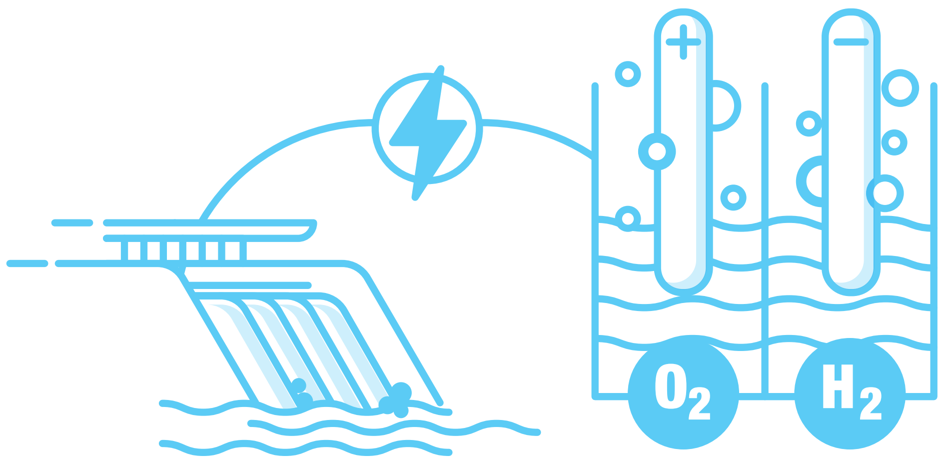
- Costs are dominated by fuel costs. Electricity for green hydrogen, natural gas for blue.
- A reliable forecast of fuel costs throughout the life of the production facility is therefore highly valuable for an operator to know. This can be provided through clear pricing mechanisms and by reducing exposure to uncertain energy markets.
- If large volumes of electricity can be accessed at low cost, and hydrogen can be stored efficiently, then a strategy of oversizing electrolysers can reduce the average hydrogen price despite lower load factors.
- Using fuel costs correct as at the start of 2022, the project found that the levelised cost of delivered hydrogen could be roughly the same for blue and green hydrogen if the latter was being used to avoid curtailment (implying lower electricity costs). For other forms of electrolysis, the equivalent cost would be around two or three times as high as blue hydrogen. The delivered cost of blue and green hydrogen (which isn't solely produced using electricity which would otherwise be curtailed) is expected to reach parity over the coming decades.

Hydrogen Storage

- Costs are highly variable depending on how frequently the storage is used, its location and how quickly it can be filled and discharged.
- A heavily utilised storage facility would add roughly 20% to the cost of hydrogen at point of delivery but this could be much higher if utilisation of the facility is lower (e.g. more strategic inter-seasonal storage).

Using hydrogen to produce electricity

- Generation load factors are the main variable affecting cost of electricity produced from hydrogen.
- Electricity prices drop significantly when load factors increase. Electricity prices for hydrogen fuelled peaking plants can be up to six times as expensive as when hydrogen is used for electricity generation at other times.
- At very low load factors, capital investment costs have a significant impact on cost of electricity produced, so retrofitting of natural gas generation plants may be favoured over new plants.



5 Delivered hydrogen costs here are a weighted average of production and storage costs.

FES 2022 / The Energy System / Hydrogen Supply 227

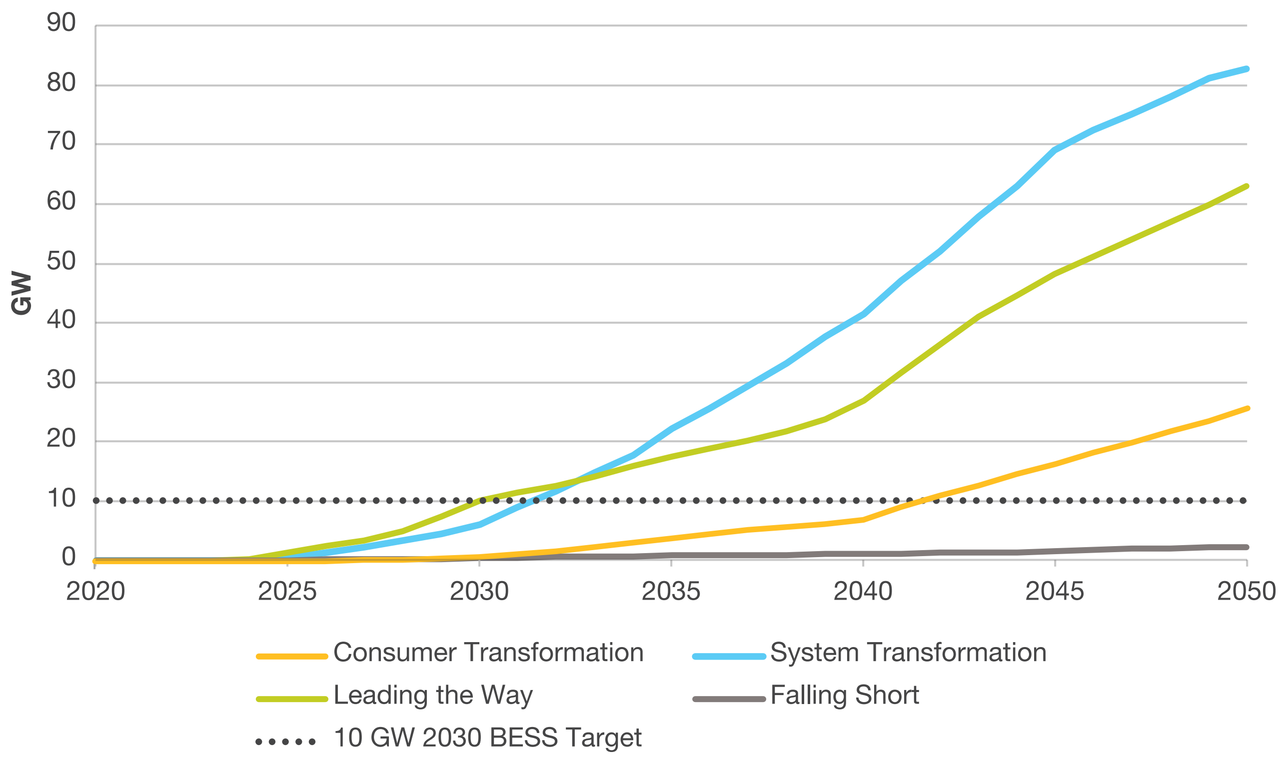
Hydrogen production in FES 2022 scenarios

- In Leading the Way, our fastest decarbonising scenario, the Government's target of 10 GW of hydrogen production capacity by 2030 is met with the majority of this capacity being in the form of electrolysis. However, unlike the same scenario in FES 2021, there is also a small amount of methane reformation recognising the current twin track approach and specific subsidy arrangements.
- System Transformation is our high hydrogen scenario and reaches 10 GW capacity in 2032. Compared to the other scenarios, a greater proportion of production is from methane reformation, which operates at higher load factors and aligns with the significant role hydrogen plays across different sectors and the largescale transition from the current natural gas network.
- Consumer Transformation sees a higher role for electrification and, as such, 10 GW of production capacity is only achieved in 2042.
- Our Falling Short scenario has little to no demand for hydrogen and therefore hydrogen production does not reach 10 GW by 2050.

To meet the Government's ambition of up to 10 GW installed hydrogen production capacity by 2030, some hydrogen is blended into the natural gas system as part of the transition to hydrogen in System Transformation and Leading the Way between the mid-2020s and 2040s. This would require new regulations and processes for supplying and billing end consumers, as well as an updated safety case. The Government has stated that blending is not a preferred long-term solution (and has been excluded from initial subsidy arrangements) but could support the initial development of the low carbon hydrogen economy.[6]

To minimise blending, there will either need to be a steep growth in demand over the 2020s or spare production capacity will need to be built in anticipation of demand which would grow later. The Data Workbook contains some sensitivity analysis which further explores how bringing forward hydrogen demand can result in a reduced requirement for blending.

Figure ES.H.06: Total hydrogen production capacity in each scenario (GW)

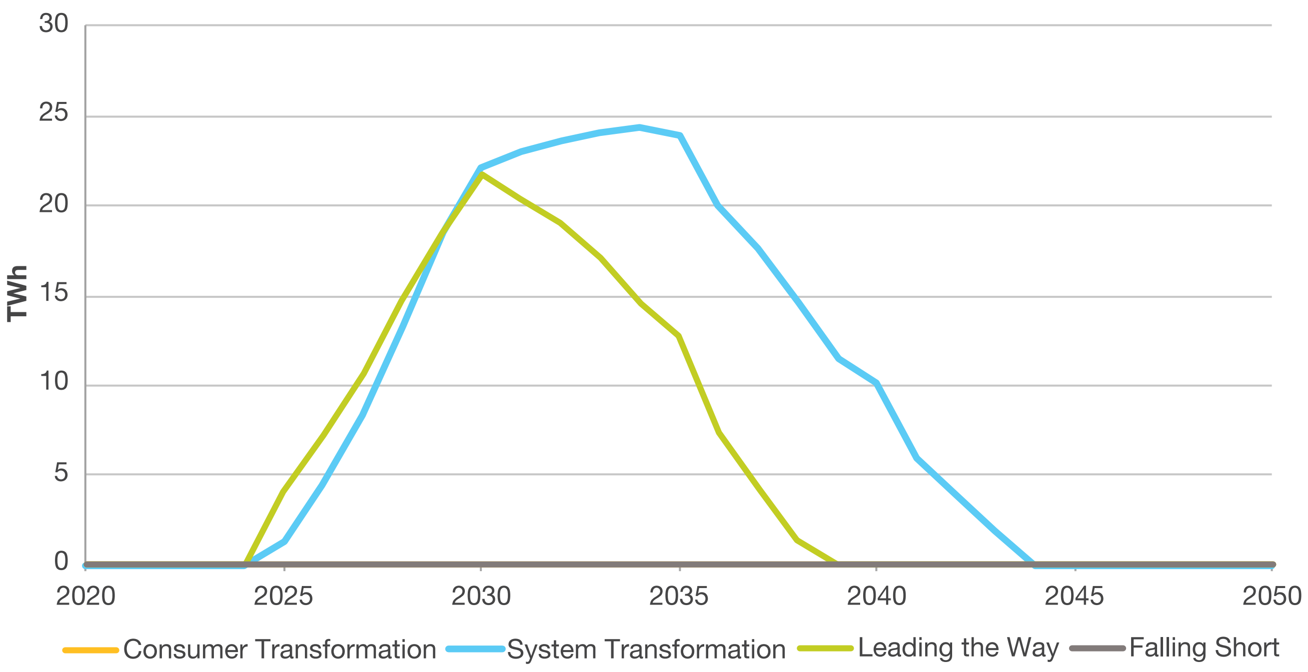


6 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf, page 78

FES 2022 / The Energy System / Hydrogen Supply 228

Hydrogen production in FES 2022 scenarios

Figure ES.H.07: Hydrogen blending into the gas network by scenario (TWh)



FES 2022 / The Energy System / Hydrogen Supply 229

How each production method compares by scenario

Our scenarios explore the uncertainty in both the methods and scale of hydrogen production to provide four credible scenarios for 2050.

Methane reformation is the main production method in System Transformation, which has the highest levels of production from all sources as it is the scenario with the highest hydrogen demand.

Electrolysis from wind or solar power is the main production source for Leading the Way and Consumer Transformation. In these scenarios with greater deployment of renewable generation, we also see corresponding high amounts of electrolysis which can absorb excess generation to minimise curtailment.

Nuclear energy combined with low temperature electrolysis has been included in both System Transformation and Consumer Transformation.

Figure ES.H.08: Networked electricity demand for electrolysis by scenario (TWh)

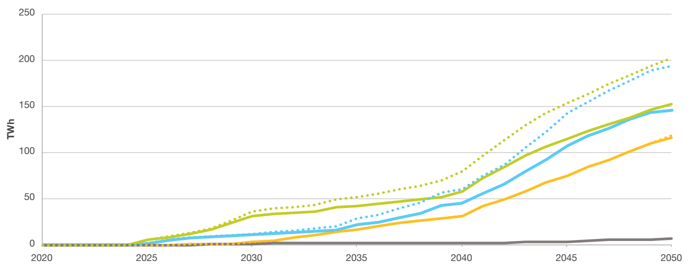


Figure ES.H.09: Natural gas demand for reformation by scenario (TWh)

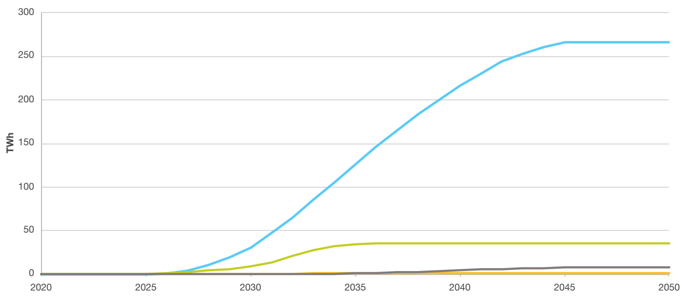


Figure ES.H.10: Nuclear electricity demand for electrolysis by scenario (TWh)

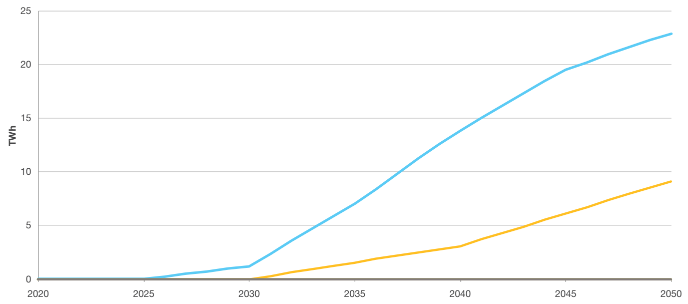
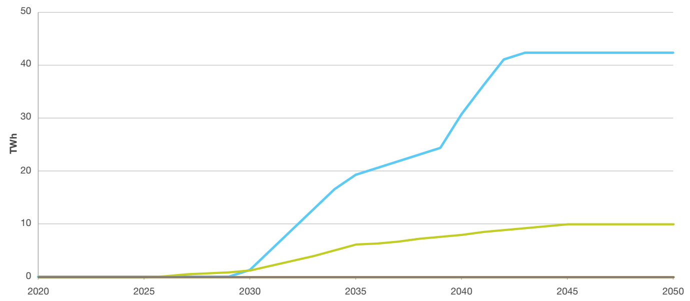


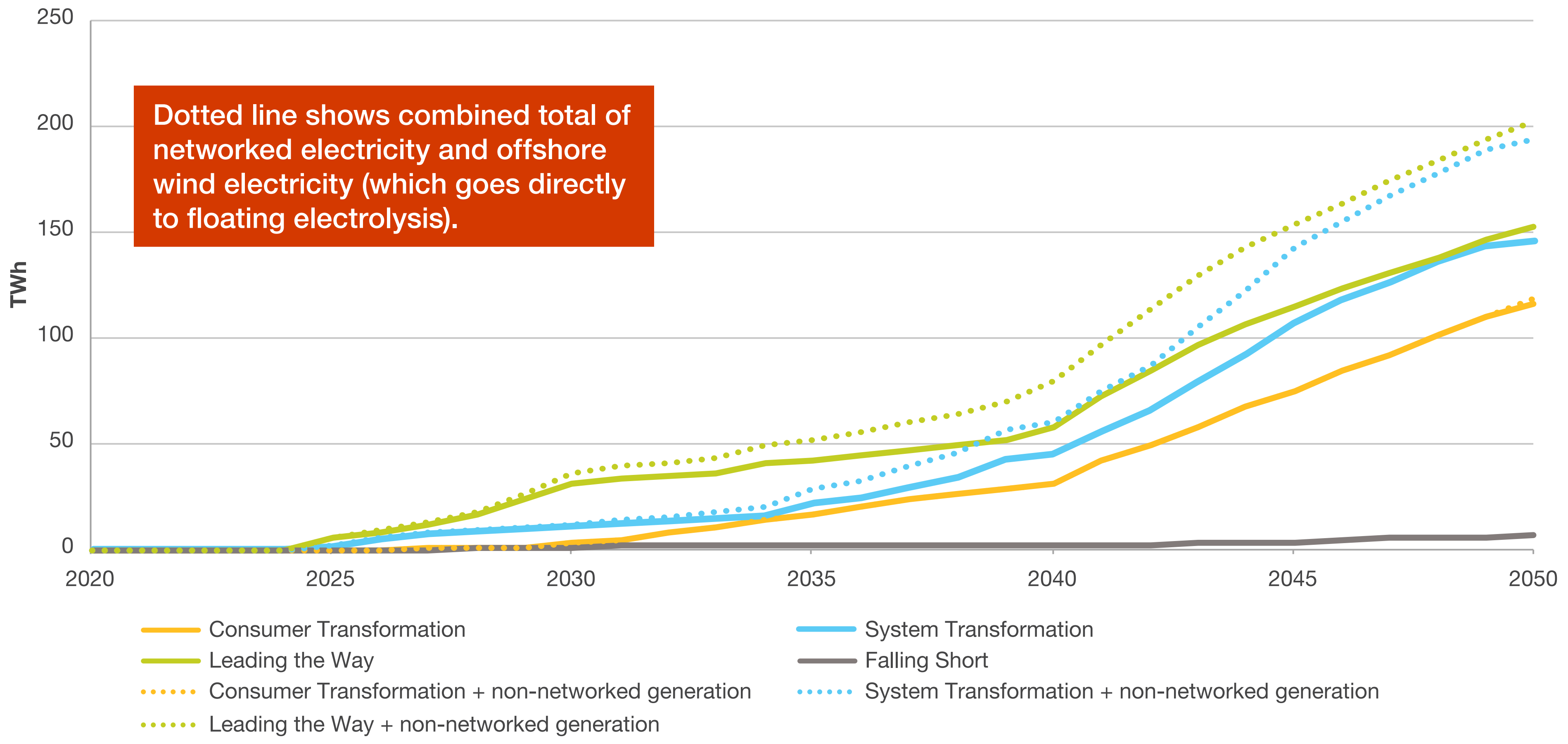
Figure ES.H.11: Bioresources demand for gasification by scenario (TWh)



FES 2022 / The Energy System / Hydrogen Supply 230

What we've found

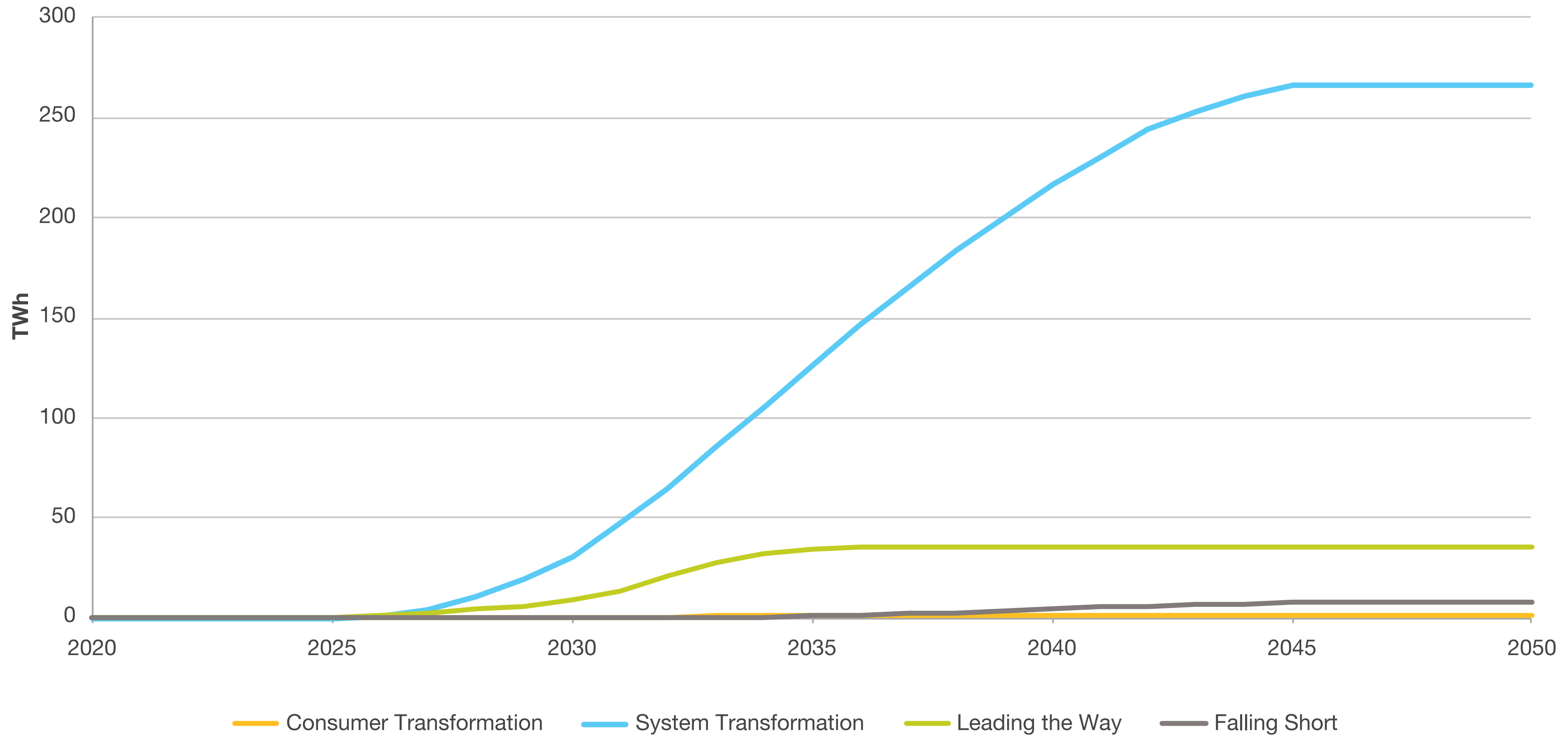
Figure ES.H.08: Networked electricity demand for electrolysis by scenario (TWh)



FES 2022 / The Energy System / Hydrogen Supply 231

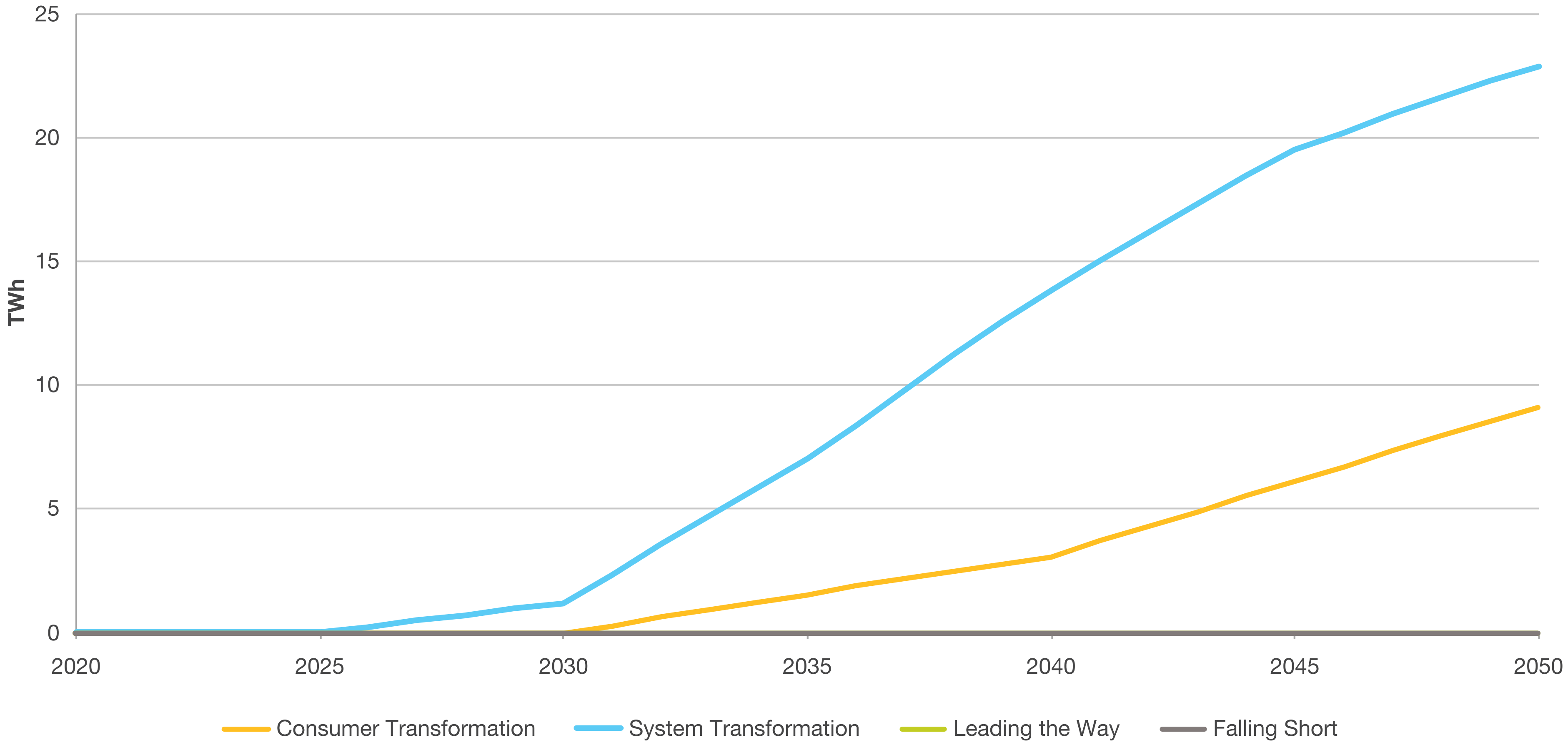
What we've found

Figure ES.H.09: Natural gas demand for reformation by scenario (TWh)



What we've found

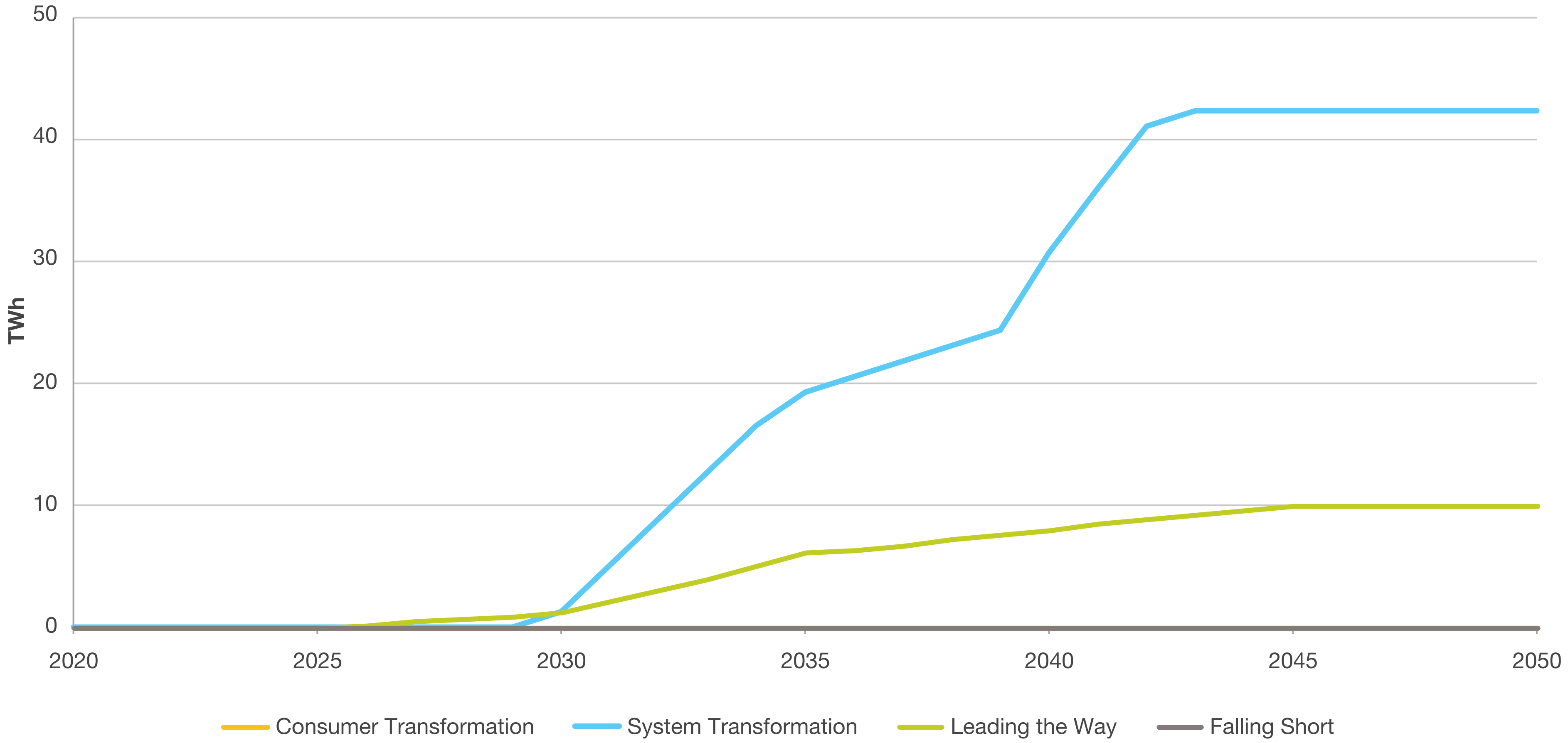
Figure ES.H.10: Nuclear electricity demand for electrolysis by scenario (TWh)



FES 2022 / The Energy System / Hydrogen Supply 233

What we've found

Figure ES.H.11: Bioresources Demand for Gasification (TWh)



FES 2022 / The Energy System / Hydrogen Supply 234

Regional Spotlight: Production locations and transition to hydrogen

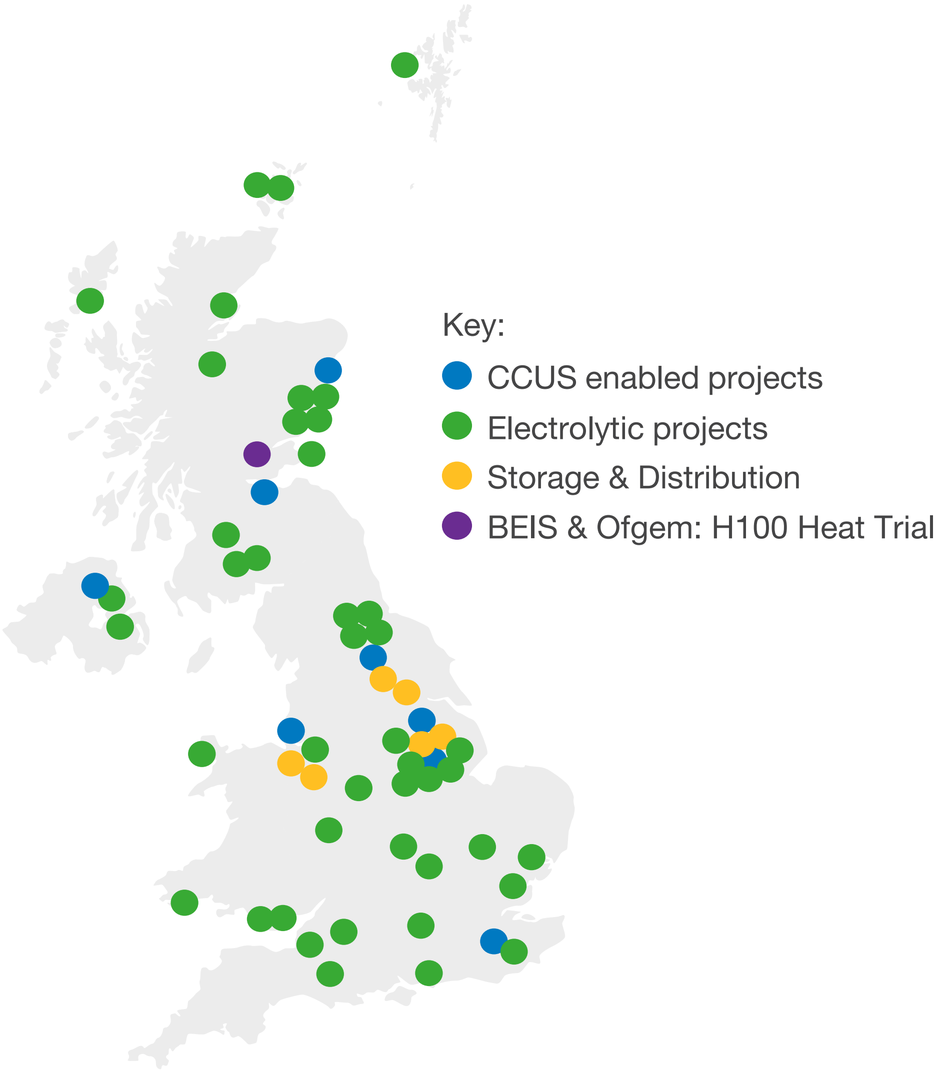
Sample of hydrogen production projects across the UK

Here we explore what may influence the location of hydrogen production projects across the UK as well as the assumptions we have made across our scenarios this year. Identifying when and where hydrogen economy opportunities will develop will become increasingly important to help us understand how the whole energy system develops from a regional perspective.

We expect many hydrogen production facilities to be developed within existing industrial clusters, supporting hard-to-electrify industrial processes which rely on high temperatures and high pressures, which means alternatives to electrification need to be considered. Several blue hydrogen trial projects are located within these clusters where CCUS deployment is being focused – these projects can take advantage of the proximity to CO_2 storage sites as well as existing infrastructure such as natural gas pipelines. Developing the demand for hydrogen in tandem with its production makes clusters an attractive option if they develop into large hydrogen demand centres. Being close to coastal ports also presents opportunities for many of the clusters. They would be able to use hydrogen as a fuel within the ports also to reduce emissions, as well as a fuel for ships (e.g. in the form of ammonia) which in turn could be used to decarbonise the maritime sector in general as well as specifically to transport hydrogen to other parts of the country or beyond as the international market picks up pace.

Another locational consideration for hydrogen production would be the proximity to urban demand centres when considering hydrogen's potential role in residential heating. If hydrogen production is assumed to be developed within a small number of industrial clusters, then the initial uptake of hydrogen boilers would therefore also be focused in these areas. We assume that the conversion and repurposing of the current gas network will be a key requirement for increasing hydrogen boiler uptake and could therefore support decisions in developing hydrogen production projects near current natural gas pipelines. Population density is also an important factor here when supplying through a network, as it reduces the cost of hydrogen as a heating source compared with less dense, off grid areas.

Sample of hydrogen production projects across the UK[7]



7 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067408/hydrogen-investor-roadmap.pdf

FES 2022 / The Energy System / Hydrogen Supply 235

Regional Spotlight: Production locations and transition to hydrogen

Hydrogen could also play a key role in integrating renewables, particularly offshore wind. Locating hydrogen production via electrolysis close to offshore wind generation could support the deployment of green hydrogen projects at scale. At the same time, due to the weather-variable nature of wind generation and the scale of capacity expected in the future, being able to convert any excess electricity into hydrogen and keep it in storage to be used when the energy is needed provides a valuable source of flexibility to the whole energy system of the future. This also presents an opportunity to locate electrolysers in areas that are near network constraints on the electricity transmission system. Carefully selecting locations that could maximise the potential electrolyser load factors whilst also minimising electricity system balancing costs represents an attractive solution in minimising overall impact on end consumer costs. We explore the locational considerations of hydrogen production and storage further in our Flexibility section here.

In some scenarios, as pilot projects are tested and proven, this will lead to a regional propagation of hydrogen as clusters are linked together and a potential hydrogen backbone is developed. This is being explored by National Grid Gas Transmission through Project Union which is investigating the feasibility of developing a hydrogen network that initially connects the Grangemouth, Teesside and Humberside clusters and, latterly, the Southampton, the North-West and South Wales clusters. The scale and challenge of converting the current natural gas network to hydrogen can be best appreciated by considering the size and scale of this current infrastructure both onshore and offshore.

Some of the locational considerations for the siting of hydrogen production will inevitably overlap and there are also factors linked to central decision making regarding the future of the hydrogen economy that are likely to lead GB down different regional development paths.

FES 2022 / The Energy System / Hydrogen Supply 236

Regional Spotlight: Production locations and transition to hydrogen

Converting the natural gas network to transport hydrogen

Though existing natural gas infrastructure has enough capacity for hydrogen transmission at the levels we expect to see in our scenarios, other modifications would be needed.

- Hydrogen has approximately a third of the energy of methane per unit volume. Nonetheless, the transmission system is expected to have enough capacity today for even the highest volumes of hydrogen in the scenarios between now and 2050 as hydrogen can be transported through the network at a higher speed than natural gas is today.
- Though there may be modifications needed on below-ground assets and inspection/maintenance methods, work to make the NTS hydrogen-capable would mostly focus on above ground infrastructure, which would largely be contained within privately owned sites (compressors and above-ground installations).
- The 25 compressor stations on the NTS could be replaced with as few as 12 more powerful stations because hydrogen travels further through pipelines than natural gas for a given amount of compression.
- For safety reasons, much of the electrical equipment on Above Ground Installations, such as metering and gas quality monitors, would need to be replaced.

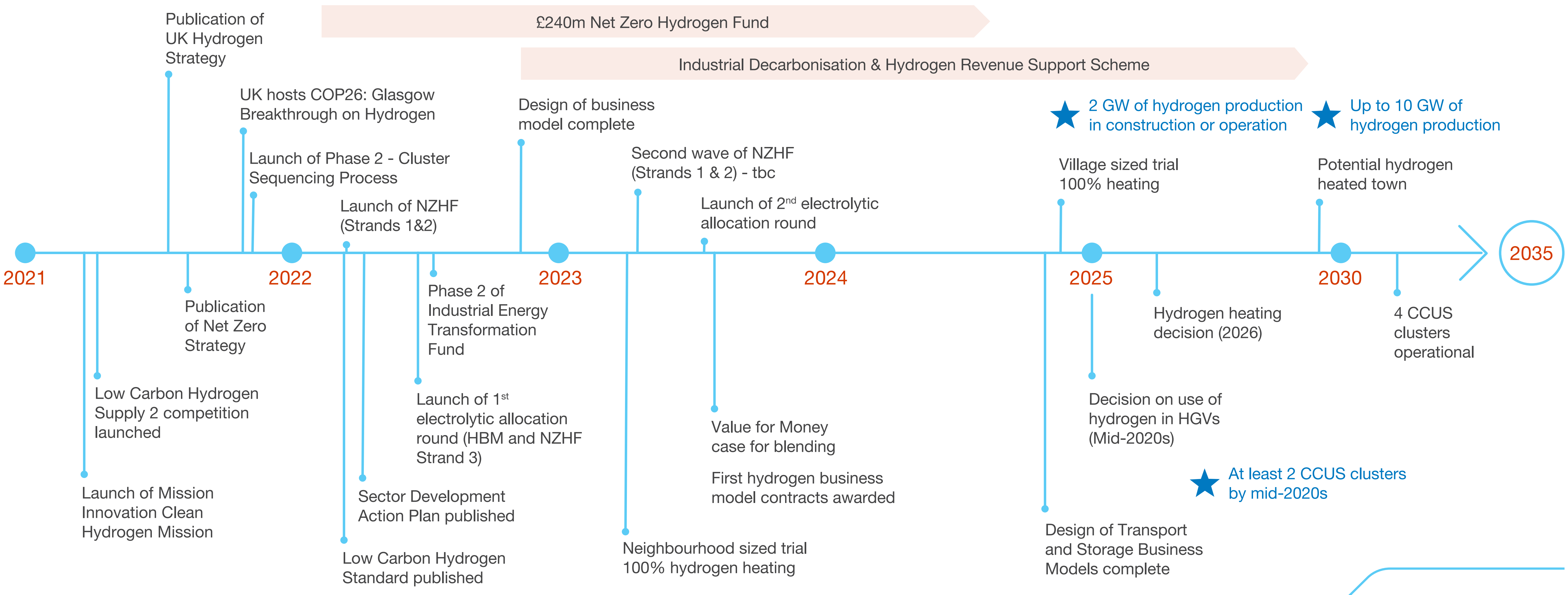
Current natural gas infrastructure[8]

FES 2022 / The Energy System / Hydrogen Supply 237

Regional Spotlight: Production locations and transition to hydrogen

Critical activities and milestones on a path to developing the UK hydrogen economy

UK Government's hydrogen investor roadmap[9]



Regional Spotlight: Production locations and transition to hydrogen

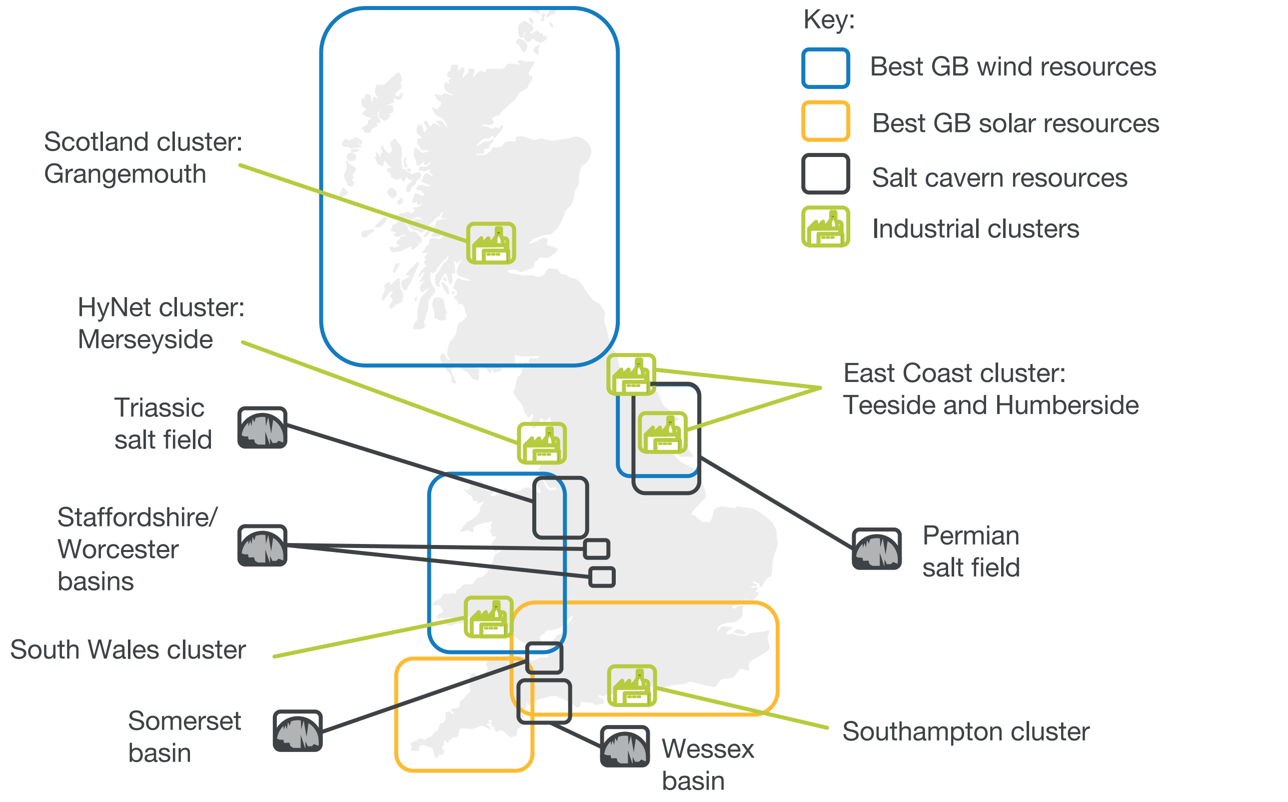
Key decision points have been highlighted, such as the use of hydrogen for heating (expected in 2026) and the use of hydrogen in HGVs (mid-2020s). Until there is further clarity in these types of area, there will be uncertainty around the production of hydrogen at scale and where it will be located geographically. If hydrogen doesn't have a significant role to play in heating for residential properties, this will have implications for a widespread transition of the current gas network, with any transition more likely to focus on connecting industrial clusters. This will then have implications for industrial sites and processes which are currently not located within larger industrial clusters and are hard to abate. It will also have implications for current Combined Cycle Gas Turbines (CCGT) and the interaction of when and where the network supplying these customers will convert from natural gas. Producers, suppliers and network operators need to be ready and there needs to be sufficient hydrogen demand, which will require decisions, coordination, incentives and investment from the Government. We reflect the uncertainty regarding the decisions on the future of hydrogen through our scenarios. Higher electrification could result in outcomes reflected in Customer Transformation and higher reliance on hydrogen is reflected in our System Transformation scenario.

While we acknowledge the direction provided by the Government's current twin track approach for supporting the deployment of hydrogen by electrolysis and methane reformation on the merits of the individual technologies, we would also highlight that there may be benefits in the long term if more strategic consideration is given to the potential role of electrolysers in the whole energy system (e.g. to reduce potential curtailment).

Having adequate hydrogen storage is another important consideration, especially from the whole energy system perspective, as this allows additional energy to be provided at times of peak demand or low renewable output. In System Transformation, storage is required due to the seasonal nature of heat demand and the baseload operation of methane reformers. In Consumer Transformation and Leading the Way, the storage is required more to facilitate long duration flexibility on the electricity system (see **Flexibility chapter** for more detail). Hydrogen storage increases rapidly in System Transformation, to reach over 55 TWh by 2050, compared to 11 TWh in Consumer Transformation.

We highlight our hydrogen production assumptions this year across our scenarios in the next section and we will continue to develop our modelling in this area as we explore the regional impacts that the transition to a hydrogen economy could have.

GB Hydrogen co-location opportunities for production, storage and industrial clusters [source: DELTA-EE innovation project][10]



10 https://www.delta-ee.com/report/report-summary-hydrogen-as-an-electricity-system-asset/

FES 2022 / The Energy System / Hydrogen Supply 239

Scenario results

Consumer Transformation

- Only limited public hydrogen network by 2050.
- Space heating in residential buildings is largely electrified with no demand for hydrogen.
- No blending into the gas network.

10 GW production capacity reached in	Production capacity in 2030	Production capacity in 2050
2042	<1 GW	26 GW

Figure ES.H.12: Hydrogen supply in Consumer Transformation (TWh)

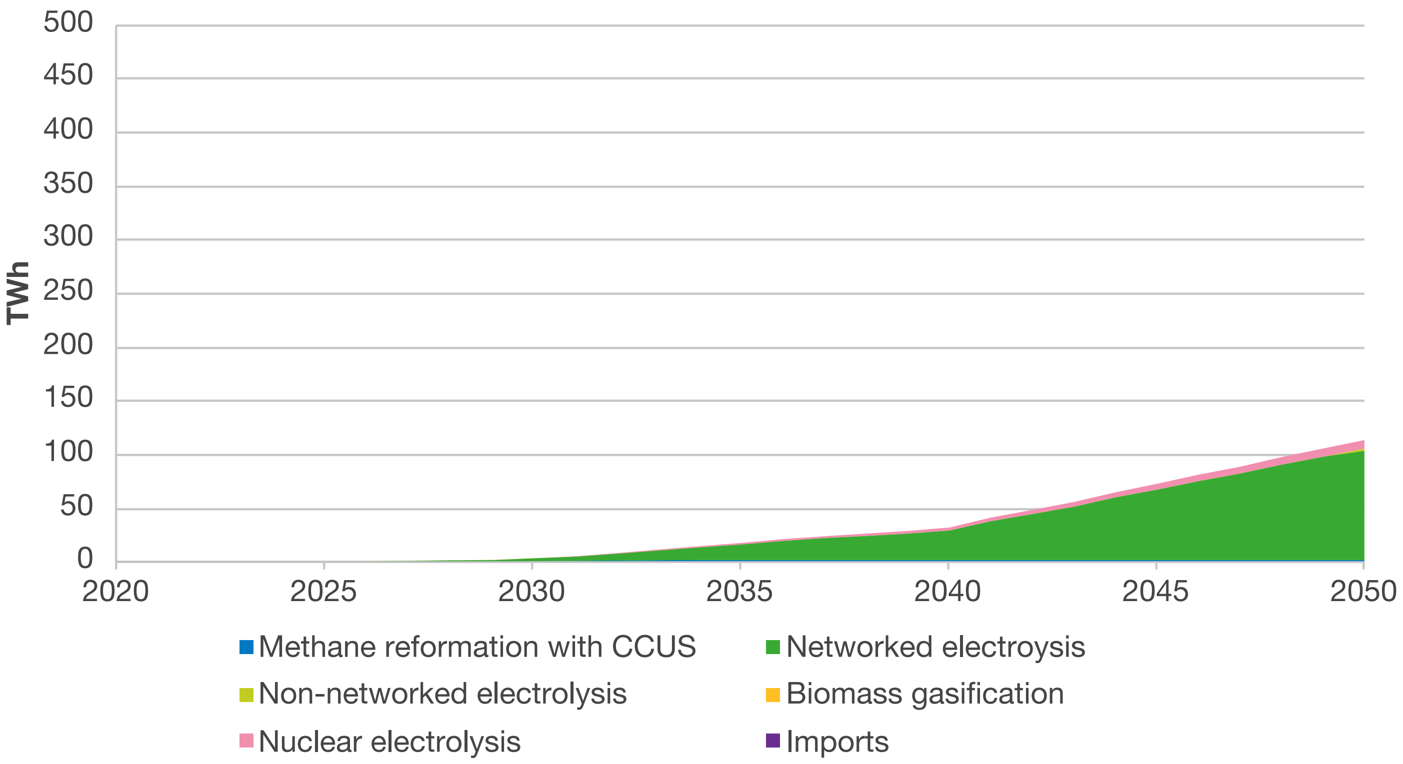
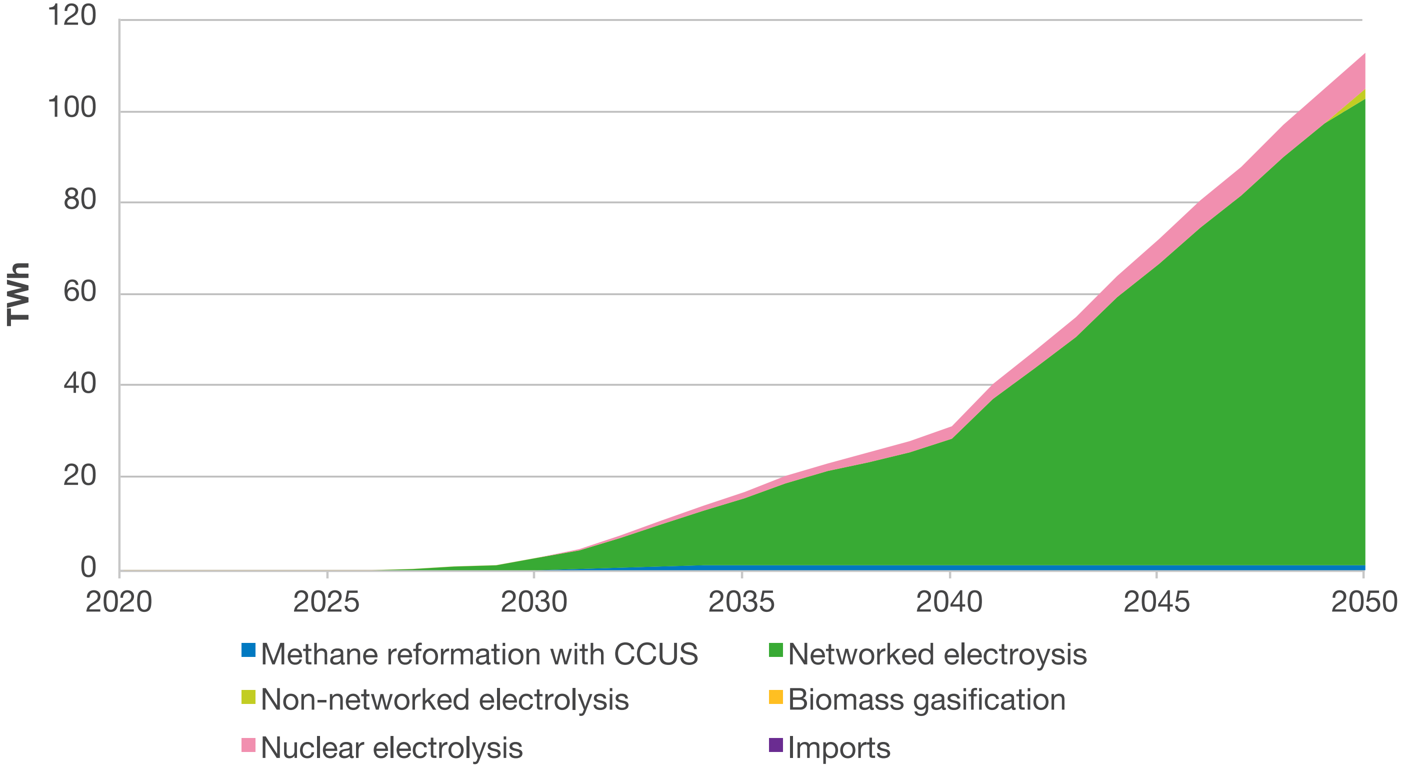


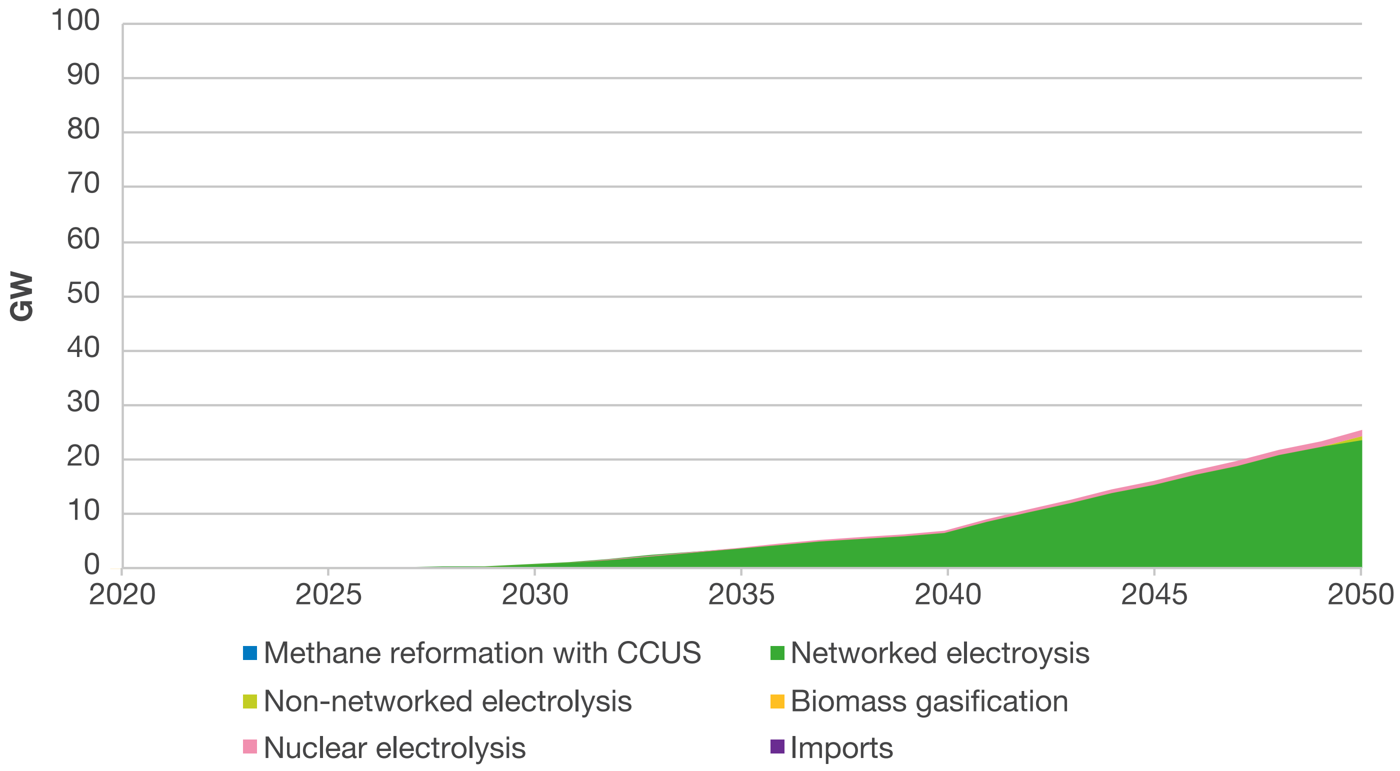
Figure ES.H.12: Hydrogen supply in Consumer Transformation (TWh) (Scaled)



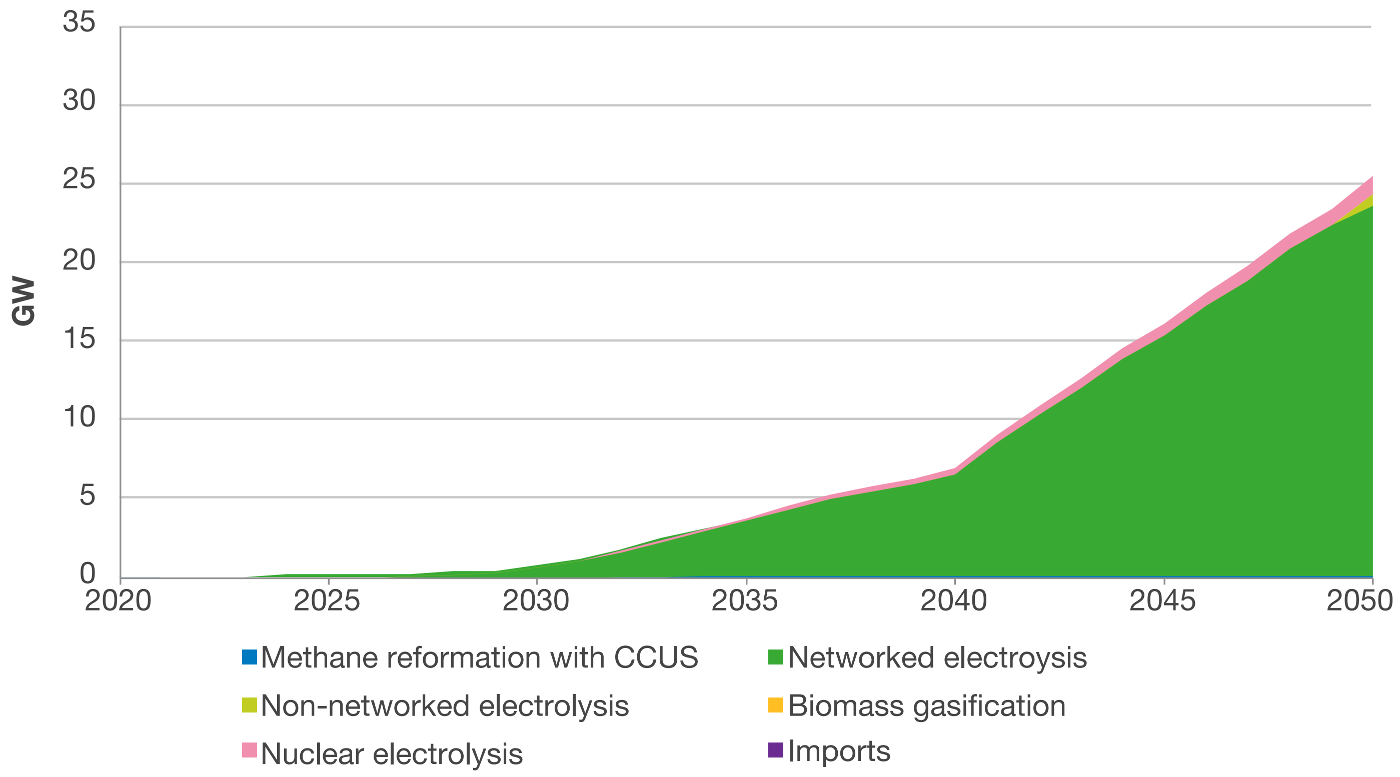
FES 2022 / The Energy System / Hydrogen Supply 240

Scenario results

ES.H.13: Hydrogen production capacity in Consumer Transformation (GW)



ES.H.13: Hydrogen production capacity in Consumer Transformation (GW) (Scaled)



FES 2022 / The Energy System / Hydrogen Supply 241

Consumer Transformation

The route to 2050

- Consumer Transformation has the lowest hydrogen supply out of the three Net Zero scenarios because electricity is prioritised for heating in this scenario. The focus is instead on using hydrogen to help operate the whole energy system by using excess renewable electricity to produce hydrogen.
- We assume no blending into the existing gas network in this scenario and hydrogen production is located close to where it is needed, such as industrial clusters.
- In a highly electrified economy, we expect a relatively stronger case for network-connected electrolysis. Hydrogen is produced from methane reformation and nuclear-powered electrolysis but in relatively smaller volumes.
- By 2030, only 1 GW of production capacity is built and there are no imports or exports of hydrogen. Production of hydrogen increases from 2040 as hydrogen demand increases to help decarbonise hard to abate sectors.

What does 2050 look like?

- Network-connected electrolysis (green hydrogen) is by far the most common method of production, utilising renewable generation at times where supply exceeds demand.
- Despite high levels of electrification, hydrogen is used to decarbonise hard to abate sectors.
- Some limited repurposing of the existing natural gas system is assumed to transport hydrogen between clusters. As there is only minimal hydrogen network, electrolysers are located close to demand or are co-located with hydrogen storage and generation.

FES 2022 / The Energy System / Hydrogen Supply 242

System Transformation

- A national hydrogen distribution and transmission network exists by 2050.
- Hydrogen use for residential space heating is widespread.
- Blending into the gas network happens between 2025 and 2043.

10 GW production capacity reached in	Production capacity in 2030	Production capacity in 2050
2032	6 GW	83 GW

Figure ES.H.14: Hydrogen supply in System Transformation (TWh)

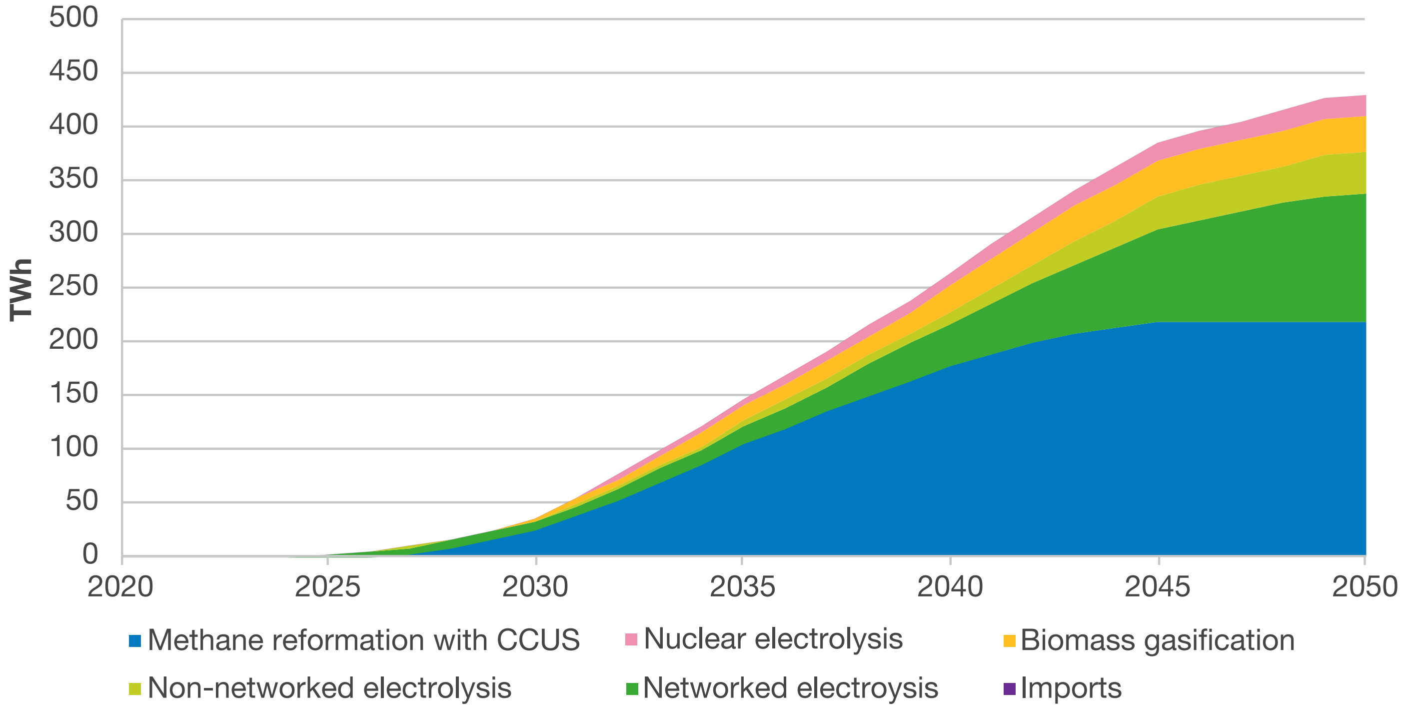
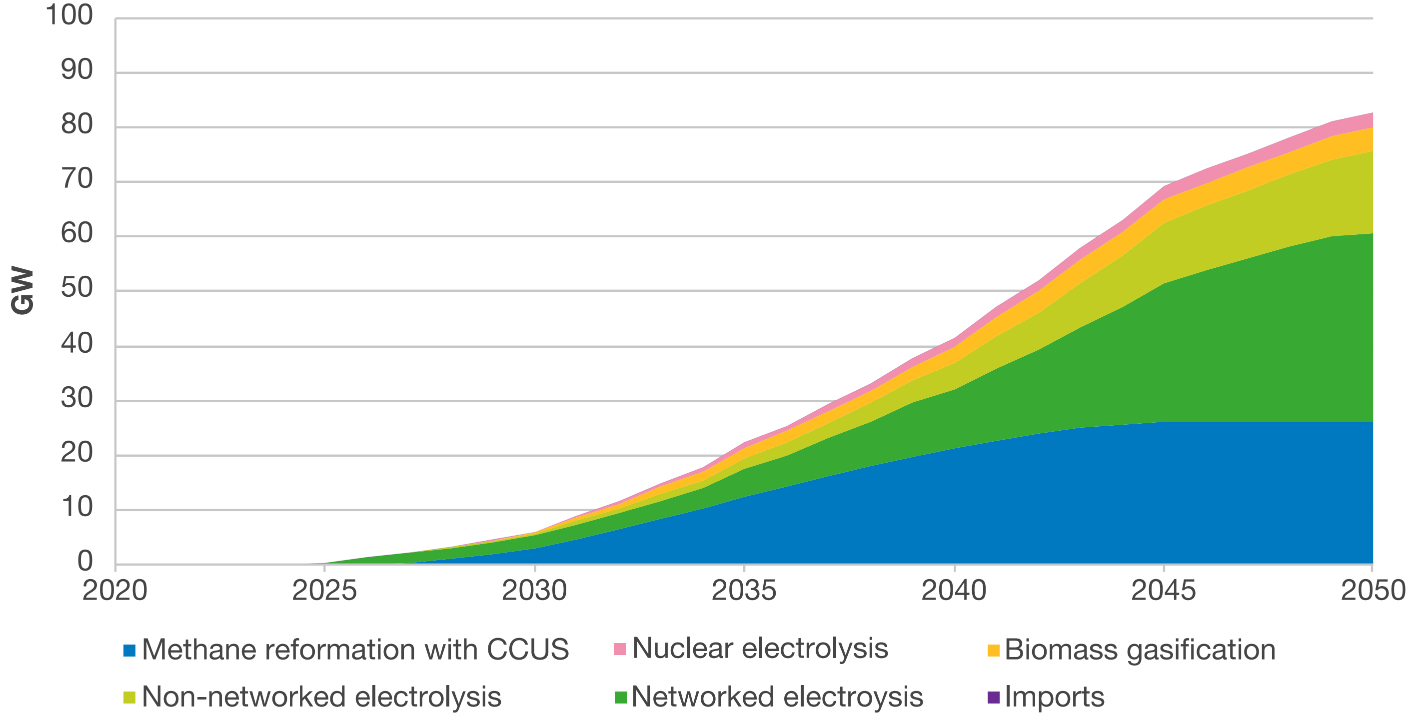


Figure ES.H.15: Hydrogen production capacity in System Transformation (GW)



System Transformation

The route to 2050

- System Transformation has the greatest level of hydrogen production capacity and hydrogen supply. It is in high demand for heat, transport, industry and power generation. From the mid-2020s, strong support and clear direction from the Government help supply and demand grow quickly over the 2030s.
- Industrial clusters start the transition. The first two clusters will have blue hydrogen supplies by 2026 and the following two by 2030. These hubs are connected to the existing natural gas network which is converted to transport hydrogen to where it is needed and captured carbon to where it will be stored.
- Hydrogen is blended into the gas grid from 2025 to 2043, after which dedicated hydrogen networks take over. Hydrogen producers and storers have much more flexibility in locating and sizing their assets, as they can rely on the gas network for offtake and distribution.
- We assume a strategy for rolling out hydrogen to the rest of the gas network is developed, beginning with some distribution networks converting in the 2030s for later connection to the NTS. Most of the conversion work has been completed by 2045.
- Methane reformation (blue) becomes the dominant form of hydrogen production initially but growth slows in the mid-2040s and electrolysis (green) takes over.
- A market for hydrogen exports develops as electrolysers begin to produce more hydrogen than required to meet domestic demand during periods of high renewable output.

What does 2050 look like?

- Although electrolysis accounts for 60% of production capacity, it only supplies 37% of all hydrogen as load factors are relatively lower than methane reformation. Around 51% of hydrogen is produced through methane reformation with CCUS.
- This scenario also sees the highest levels of production from nuclear and biomass gasification, with the latter providing almost 8% of all hydrogen produced in 2050.
- As hydrogen is used for heating, significant seasonal storage is needed to ensure sufficient supply for winter peak by storing hydrogen produced by baseload methane reformation. We expect 56 TWh of stored hydrogen to be available by 2050 (equivalent to over 10% of annual demand) – primarily in salt caverns.

FES 2022 / The Energy System / Hydrogen Supply 244

Leading the Way

- Hydrogen production is located close to renewable generation and to some demand clusters by 2050.
- Hydrogen use for residential space heating is limited to areas close to hydrogen clusters.
- Blending into the gas network happens between 2025 and 2038.

10 GW production capacity reached in	Production capacity in 2030	Production capacity in 2050
2030	10 GW	63 GW

Figure ES.H.16: Hydrogen supply in Leading the Way (TWh)

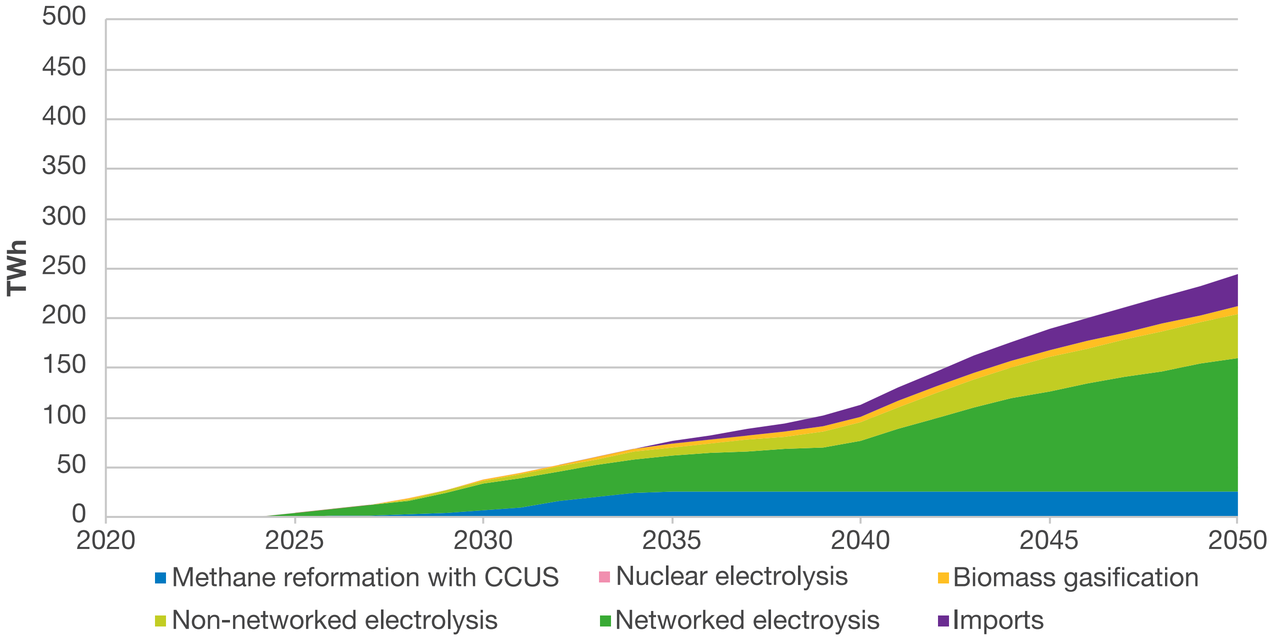
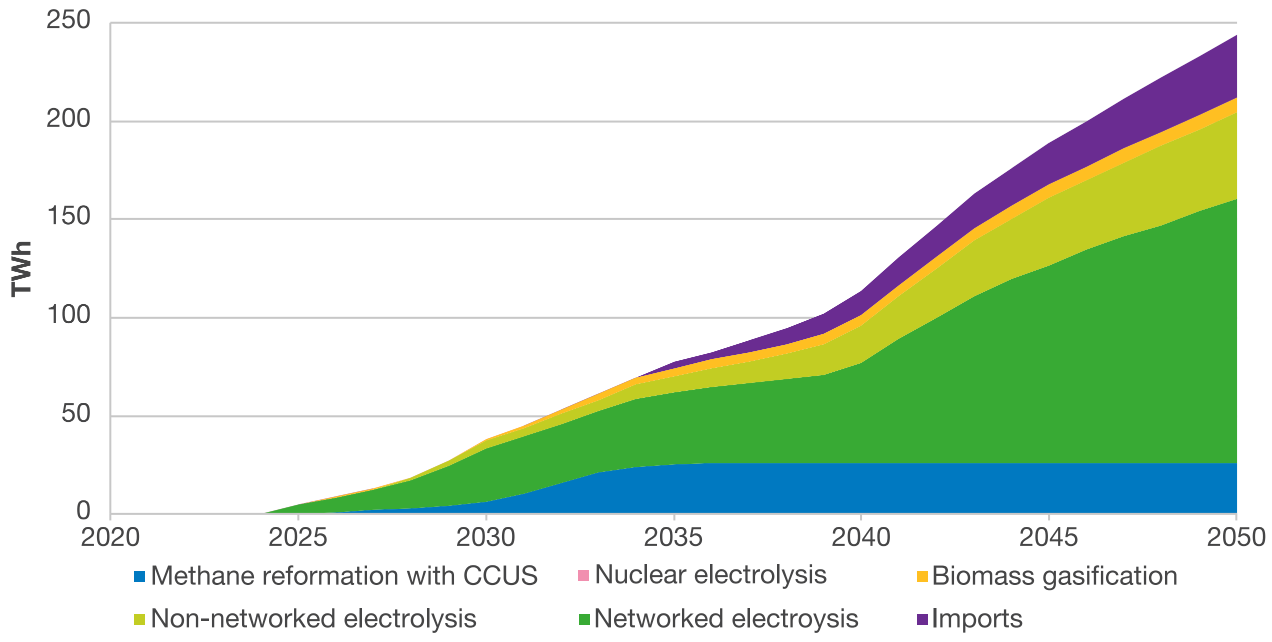


Figure ES.H.16: Hydrogen supply in Leading the Way (TWh) (Scaled)



FES 2022 / The Energy System / Hydrogen Supply 245

Scenario results

Figure ES.H.17: Hydrogen production capacity in Leading the Way (GW)

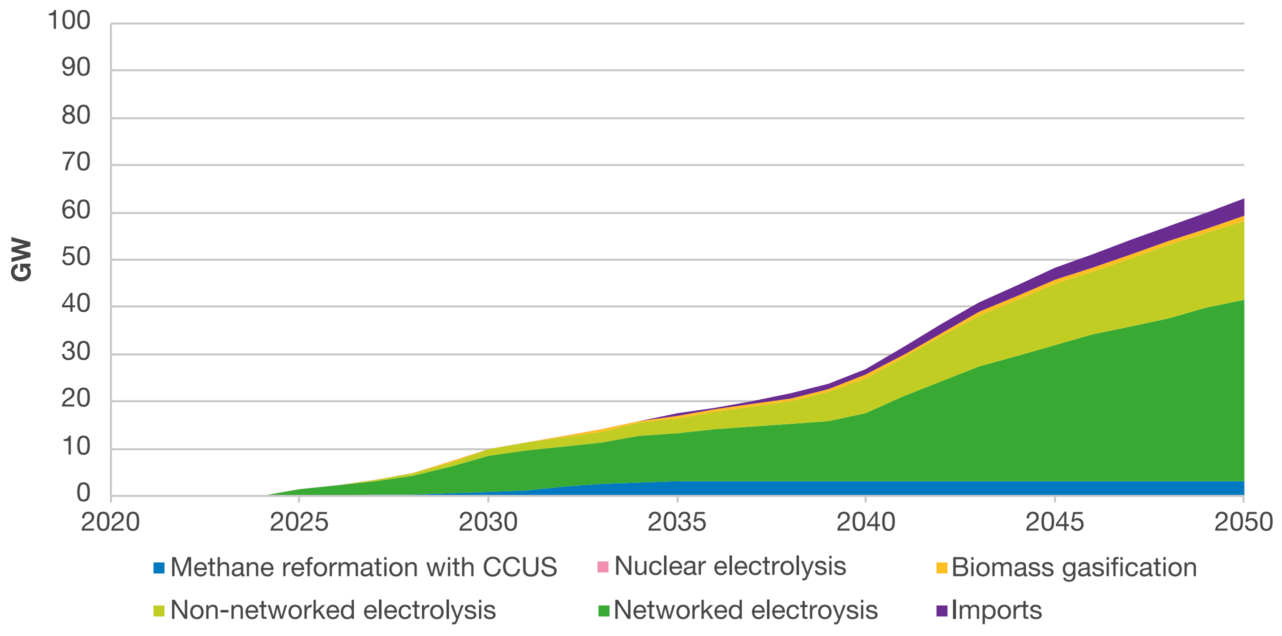
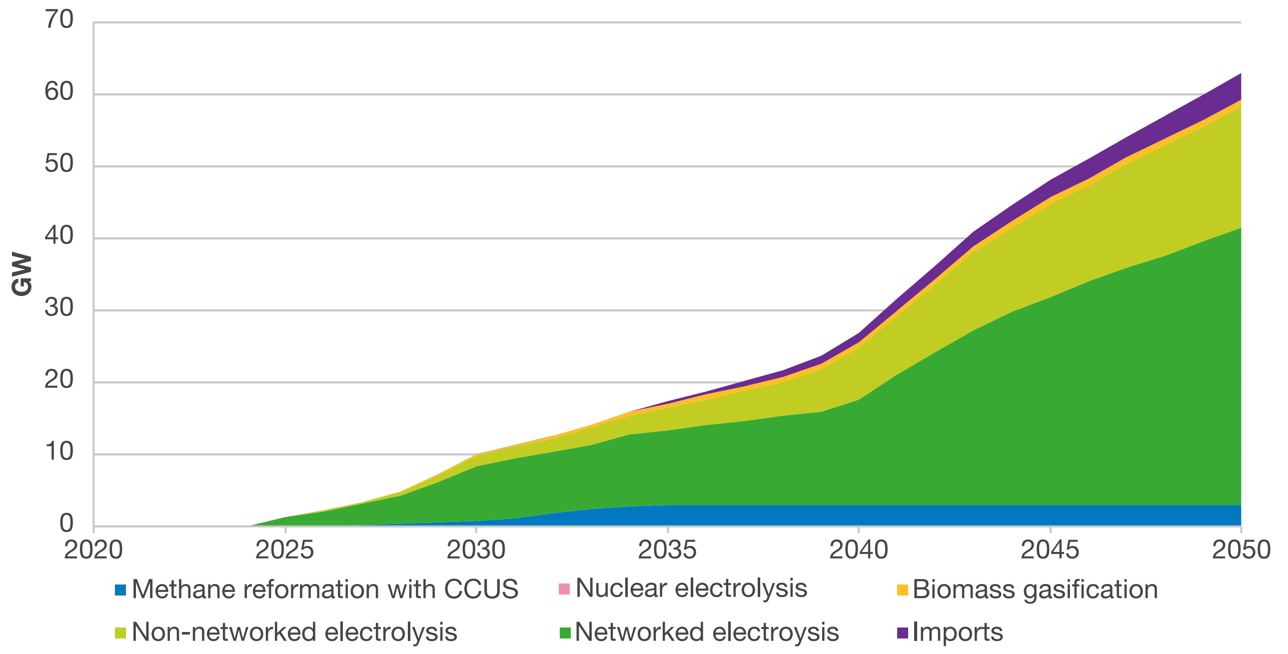


Figure ES.H.17: Hydrogen production capacity in Leading the Way (GW) (Scaled)



FES 2022 / The Energy System / Hydrogen Supply 246

Leading the Way

The route to 2050

- In Leading the Way, hydrogen is a key enabler for rapid decarbonisation in all sectors. In tandem with high levels of renewable electricity generation, we expect electrolysis capacity to be built quickly over the 2020s, which in turn gives confidence to investors, businesses, and homeowners to invest in assets and appliances which use hydrogen where appropriate.
- With clear direction and significant support from the Government, the UK meets its ambition for up to 10 GW of capacity by 2030. Almost all of this is through networked electrolysis, though the Government has provided some specific support to methane reformation capacity.
- Electrolysers are built near sources of renewable generation and can mitigate congestion on the electricity network. This is possible as these facilities are connected to a local hydrogen transmission network so that the hydrogen can be transported to where it is required.
- Offshore electrolysers will also be built alongside wind farms in the 2030s, so that hydrogen is transported to shore rather than electricity.
- Hydrogen is blended into the gas grid between 2025 and 2038 as part of the transition to 100% hydrogen. As natural gas is phased out, the network's focus is shifted to moving hydrogen between demand centres.
- We have also assumed that there is a global market for hydrogen by 2040 and it can be imported and exported by interconnector or by ship.

What does 2050 look like?

- Demand for hydrogen comes from a mix of heating and industrial needs as well as road transport, shipping and aviation.
- This scenario makes maximum use of electrolysis, either onshore or offshore. Hydrogen will also be produced from a limited amount of biomass gasification, with most bioresource used for electricity. Hydrogen production from nuclear is minimal.
- Electrolysis capacity is developed in line with renewable generation to minimise curtailment.

FES 2022 / The Energy System / Hydrogen Supply 247

Scenario results

Falling Short

- There is limited hydrogen production, mostly to meet industrial demand.
- Natural gas is still the main source of heat for homes and industry.
- No blending into the gas network.

10 GW production capacity reached in	Production capacity in 2030	Production capacity in 2050
After 2050	0.3	2 GW

Figure ES.H.18: Hydrogen supply in Falling Short (TWh)

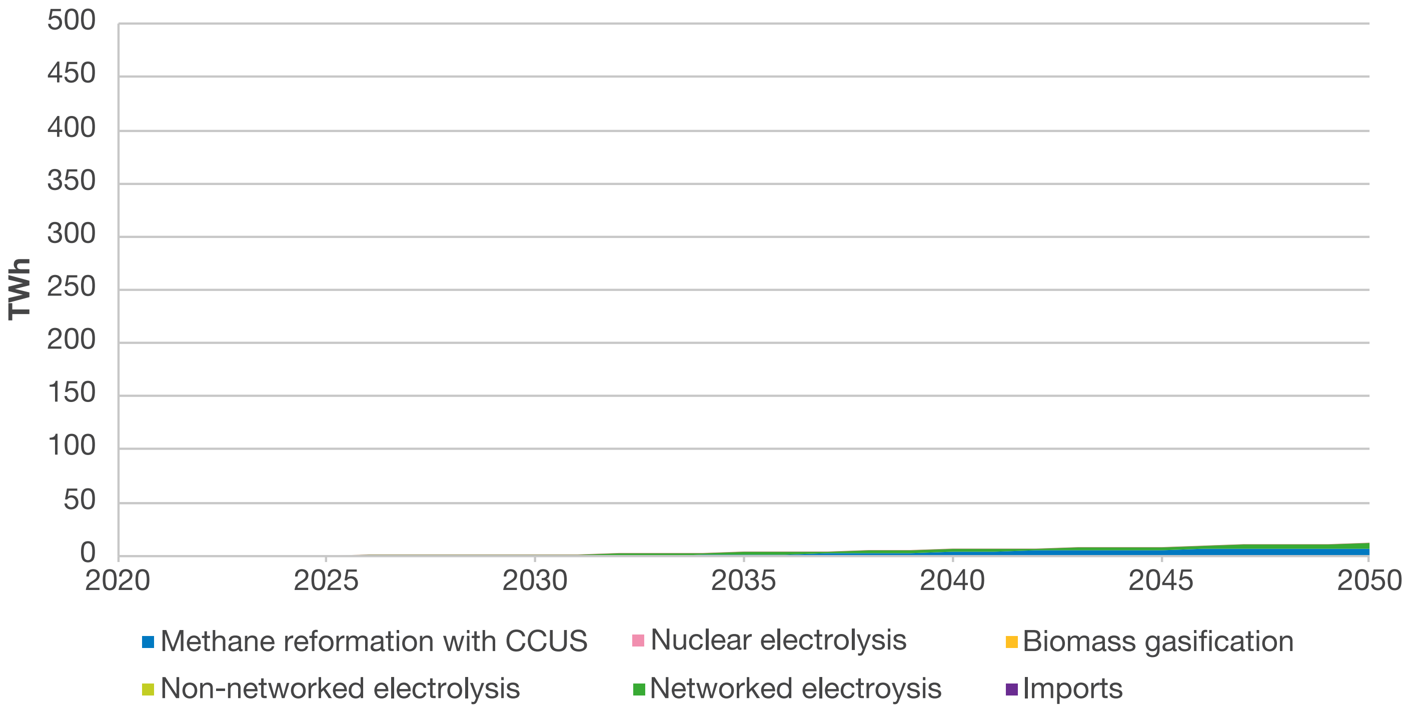
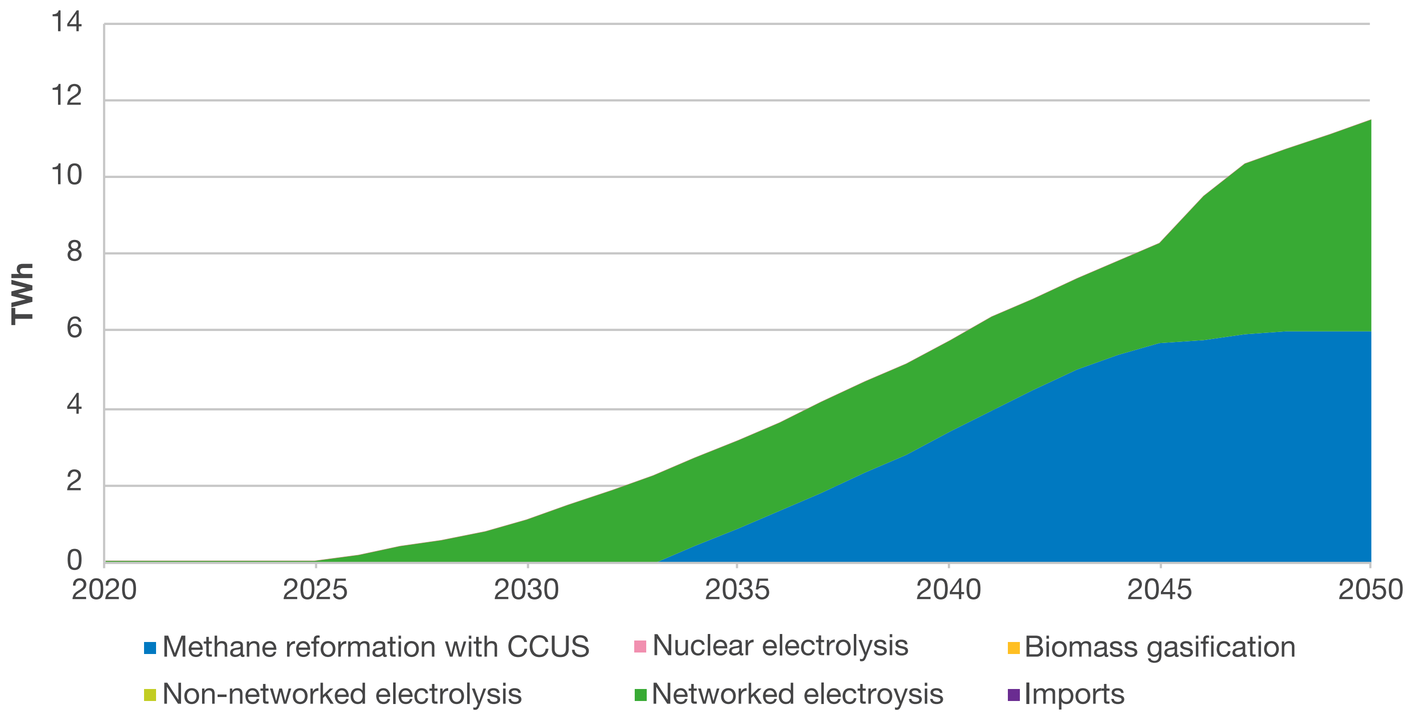


Figure ES.H.18: Hydrogen supply in Falling Short (TWh) (Scaled)



Scenario results

Figure ES.H.19: Hydrogen production capacity in Falling Short (GW)

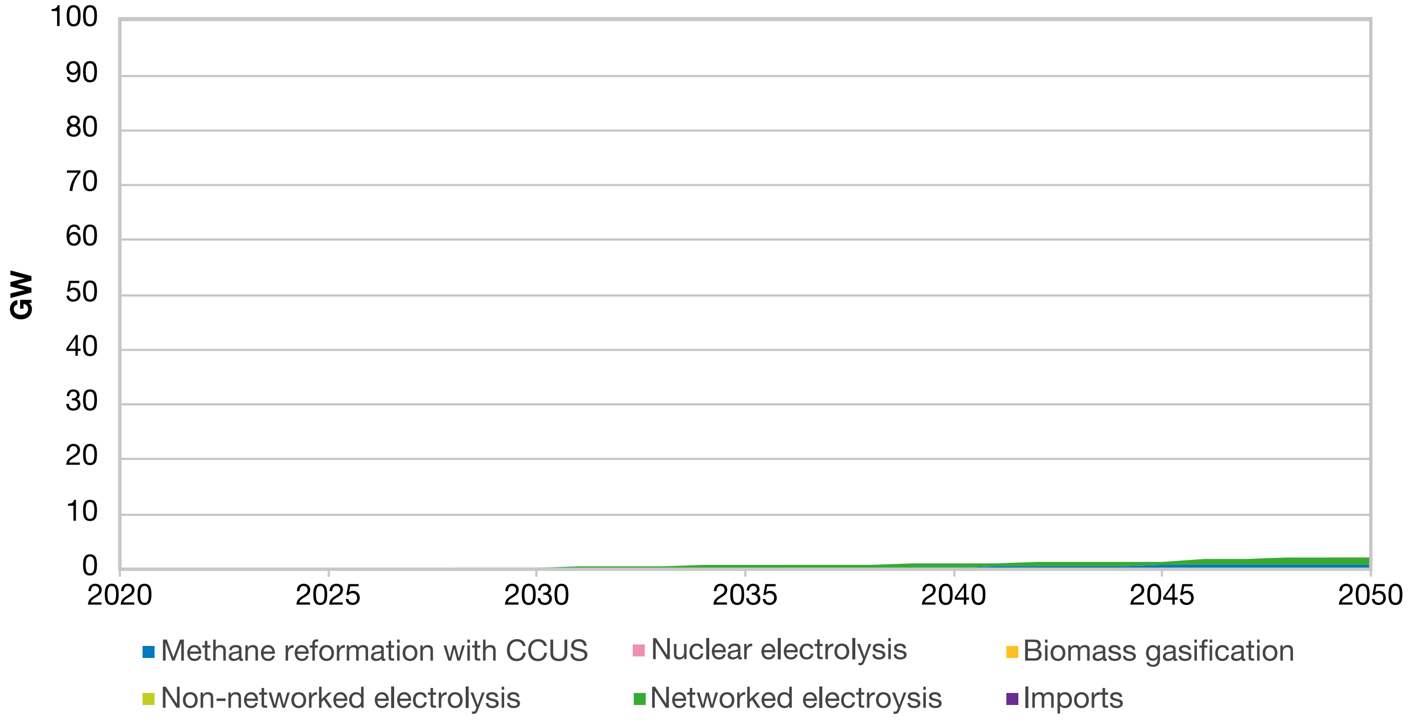
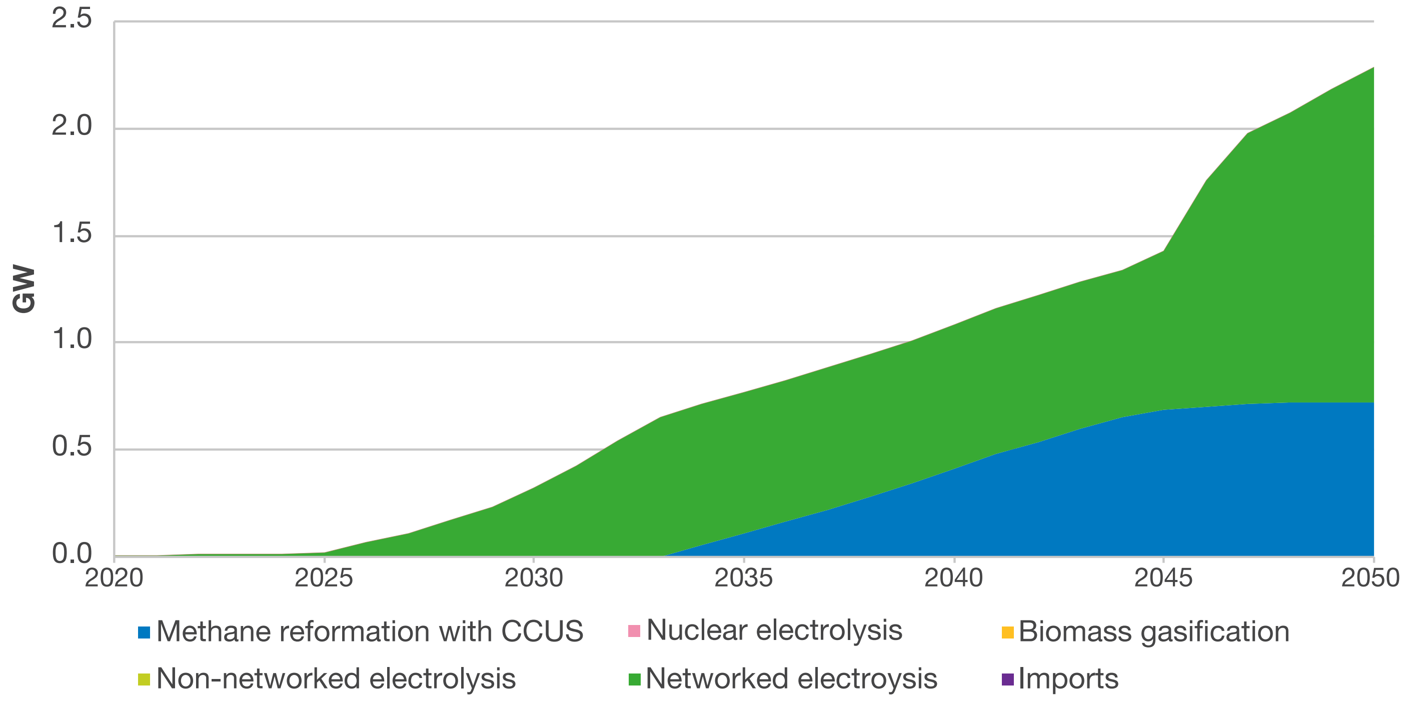


Figure ES.H.19: Hydrogen production capacity in Falling Short (GW) (Scaled)



FES 2022 / The Energy System / Hydrogen Supply 249

Falling Short

The route to 2050

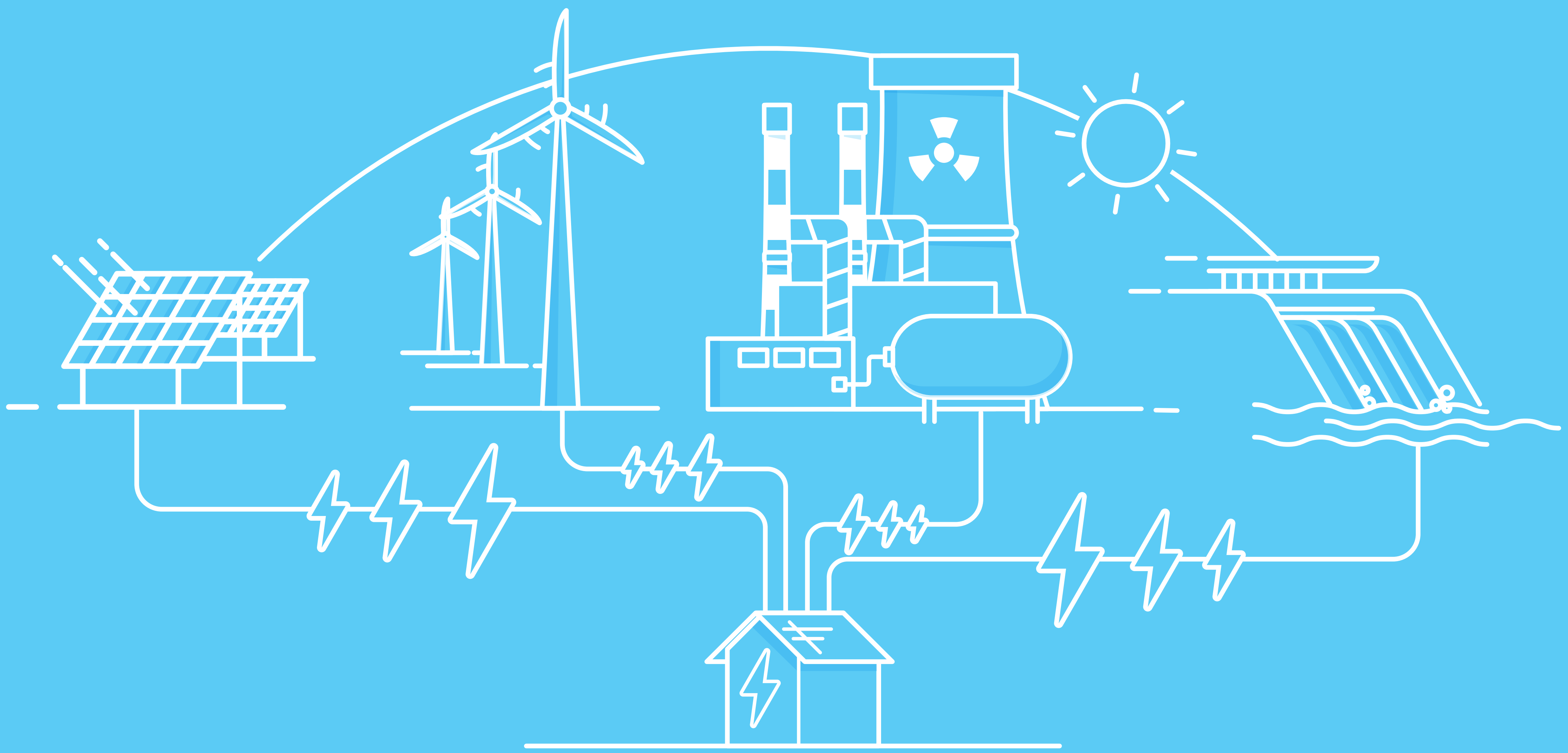
- Natural gas continues to play a central role in this scenario so there is little-to-no conversion of the hydrogen network to transport hydrogen. Production facilities are mostly located close to areas of industrial demand.
- This hydrogen initially only comes from networked electrolysis. It is later joined by methane reformation with CCUS, with the first production and storage facility being built in the mid-2030s.
- Unlike the Steady Progression scenario in FES 2021, this scenario does not include large scale blending into the gas network as this is excluded from government subsidies as a use case for hydrogen production.

What does 2050 look like?

- This scenario sees the smallest hydrogen demands as natural gas is still used for residential head and industry, with electricity meeting most of the remaining energy demand.

FES 2022 / The Energy System / Hydrogen Supply 250

Electricity Supply



Key insights

Decarbonisation of GB's whole energy system, and reducing the country's exposure to global energy markets, cannot be done without investing in our electricity system and our ability to accurately match demand to a weather-dependent supply. We have seen significant progress in the proportion of electricity from low carbon and renewable generation in recent years and this has spearheaded the wider emission reductions across the economy. Low carbon generation now accounts for 78% of annual domestic electricity supply compared to less than 30% ten years ago, and there is further potential that can be unlocked. A range of technologies with different characteristics can, in combination, help deliver secure, affordable low carbon electricity supplies and harness the potential of domestic renewable resources.

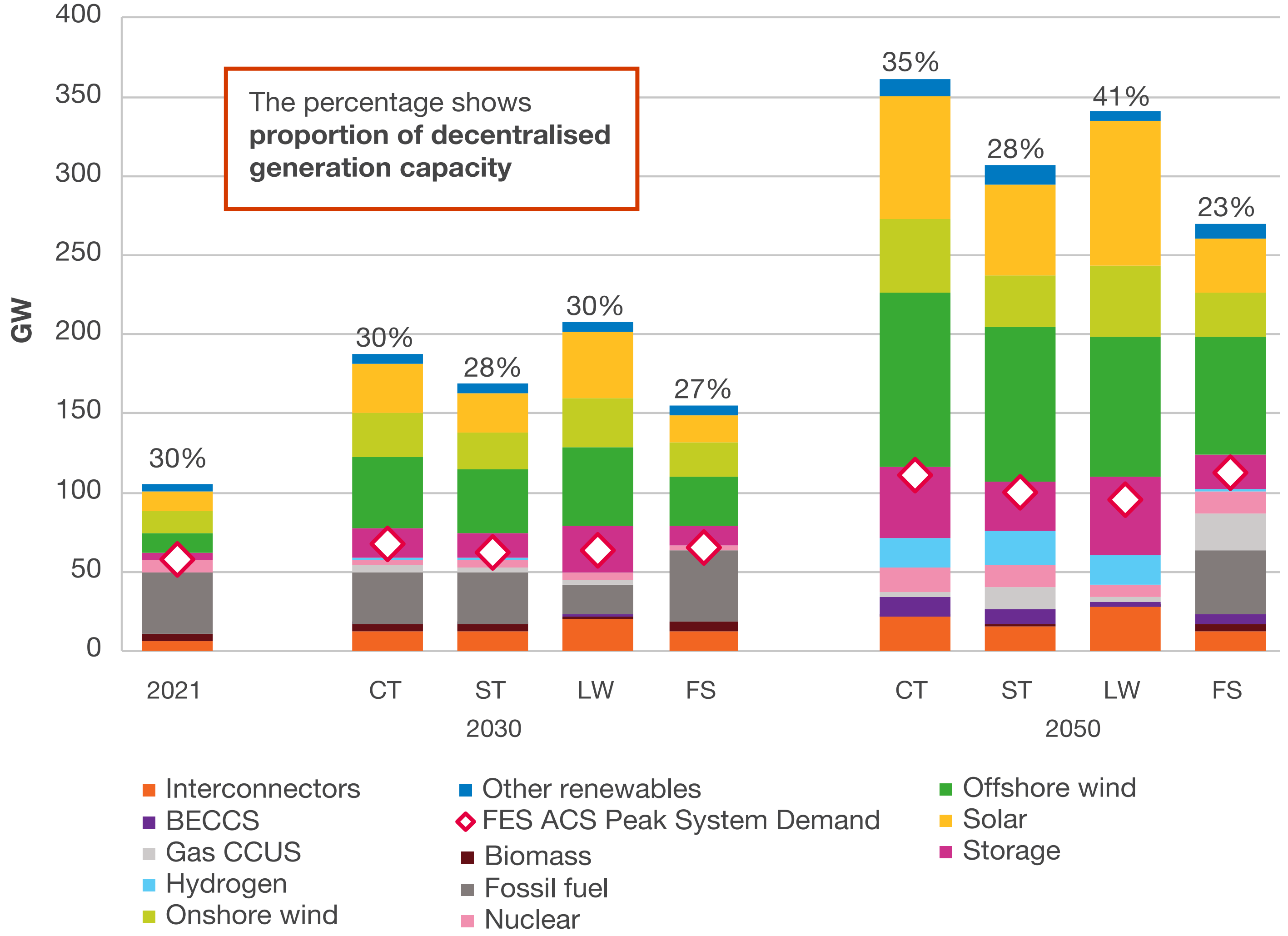
- Decarbonising electricity supply is a prerequisite for decarbonisation of other sectors like transport and heat by electrification. Load factors of gas-fired generation reduce significantly in all Net Zero scenarios and, in Leading the Way, there is **no unabated natural gas capacity** after 2035.
- The emergence of Bioenergy with Carbon Capture Usage and Storage (BECCS) generation allows the electricity system to achieve **net negative emissions** in 2033 in Consumer Transformation and Leading the Way and in System Transformation in 2034.
- Wind and solar made up 43% of domestic electricity generated in 2021 and, by 2030, they dominate accounting for 66% even in Falling Short. These levels of renewable output require the corresponding generation capacity to be much larger than previously due to the relatively lower load factor of wind and solar. This means the system evolves from one where supply responds to meet demand, to one where supply and demand need to flex to balance the energy system.

FES 2022 / The Energy System / Electricity Supply 252

Key insights

- **Energy markets will need to be reformed** to ensure the flexibility needed to integrate renewable generation efficiently is unlocked. Different flexible technologies will fulfil different roles with particular focus being required for those requiring the longest lead times (geological storage) and dependencies on other sectors (e.g. hydrogen and CCUS generation).
- High levels of renewable capacity combined with low flexibility baseload generation results in material levels of **curtailed energy from around 2030**. This is purely due to energy imbalances (i.e. rather than network constraints). The lower levels of curtailment in Leading the Way compared to the other scenarios highlights the whole system benefits of electrolysers producing hydrogen at times of oversupply.
- Integrating large volumes of renewables, especially offshore wind, will require **strategic whole system planning and coordination**, as well as anticipatory investment, to avoid exacerbating existing network constraints. Regional coordination between distribution and transmission networks, transparent locational price signals, optimised offshore solutions, and consideration of hydrogen and electricity imports and exports will all be required to provide the most secure, affordable and fair outcome for all consumers.

Figure ES.E.01: Installed generation capacity, peak demand and percentage of decentralised generation (GW)



FES 2022 / The Energy System / Electricity Supply 253

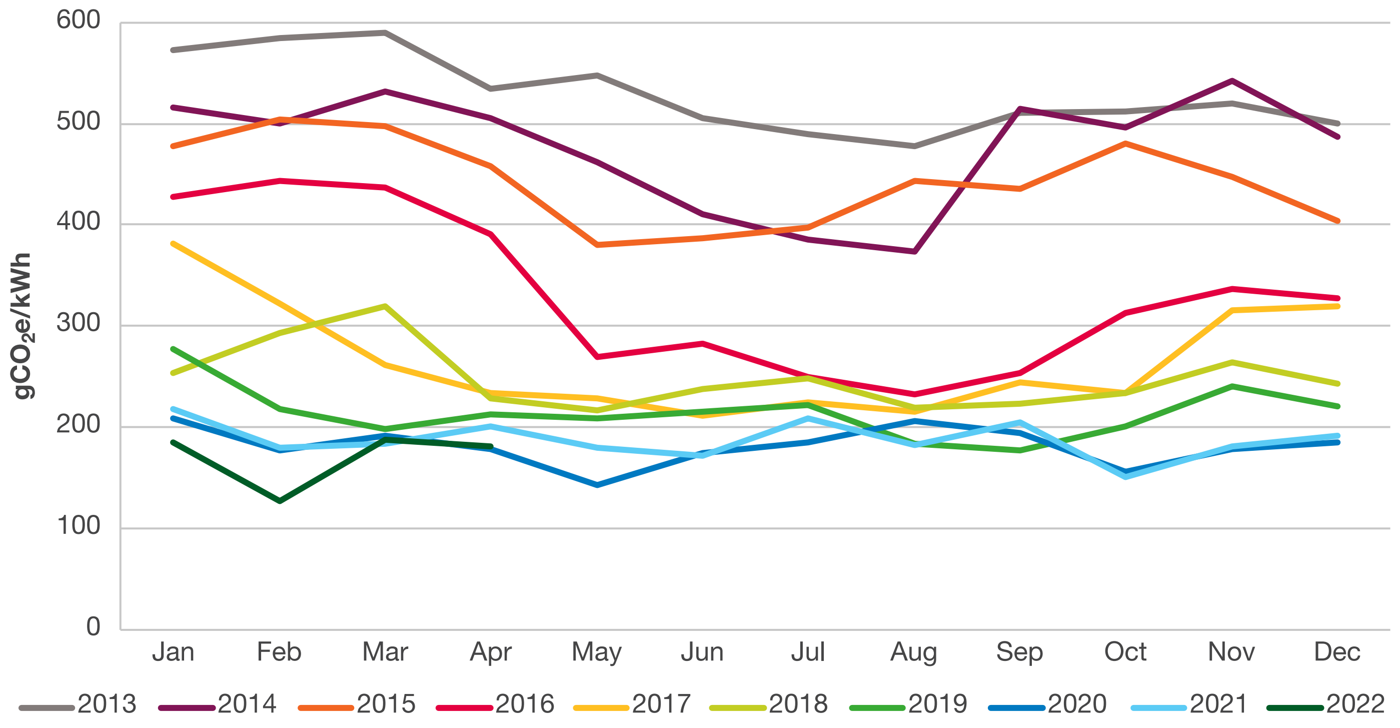
Where are we now

Today's electricity mix is made up primarily of gas, renewables and nuclear, supplemented by a few other sources. Even with increased renewable generation, we are still heavily dependent on fossil fuels to meet peak demand and to operate a reliable electricity system. The electricity system today is built around the core principle of being able to adjust supply smoothly to match demand as it changes through the day and year. Fossil fuel generation is dispatchable, meaning it can be turned on and off to match demand. In winter, coal generation plants have been used to help meet peak demand, but coal use has been declining sharply in recent years bringing carbon emissions down as a result.

Renewable generation capacity, primarily wind and solar, has quadrupled over the past 10 years from 12.5 GW in 2012 to 49 GW in 2021. This growth has been supported by government subsidies, such as the Feed-In Tariff, the Contracts for Difference (CfD) scheme and the Renewable Obligation[2] but has also been driven by rapid reductions in cost that have allowed them to start competing in a subsidy-free environment.

Most recently, under ScotWind, Crown Estate Scotland announced leases for a total of 25 GW of offshore wind capacity. In Britain, we have managed one of the fastest decarbonising electricity systems in the world, while also being one of the most reliable and today, we are well on track to being able to operate the electricity system with periods of no carbon emissions by 2025, and all the time by 2035.

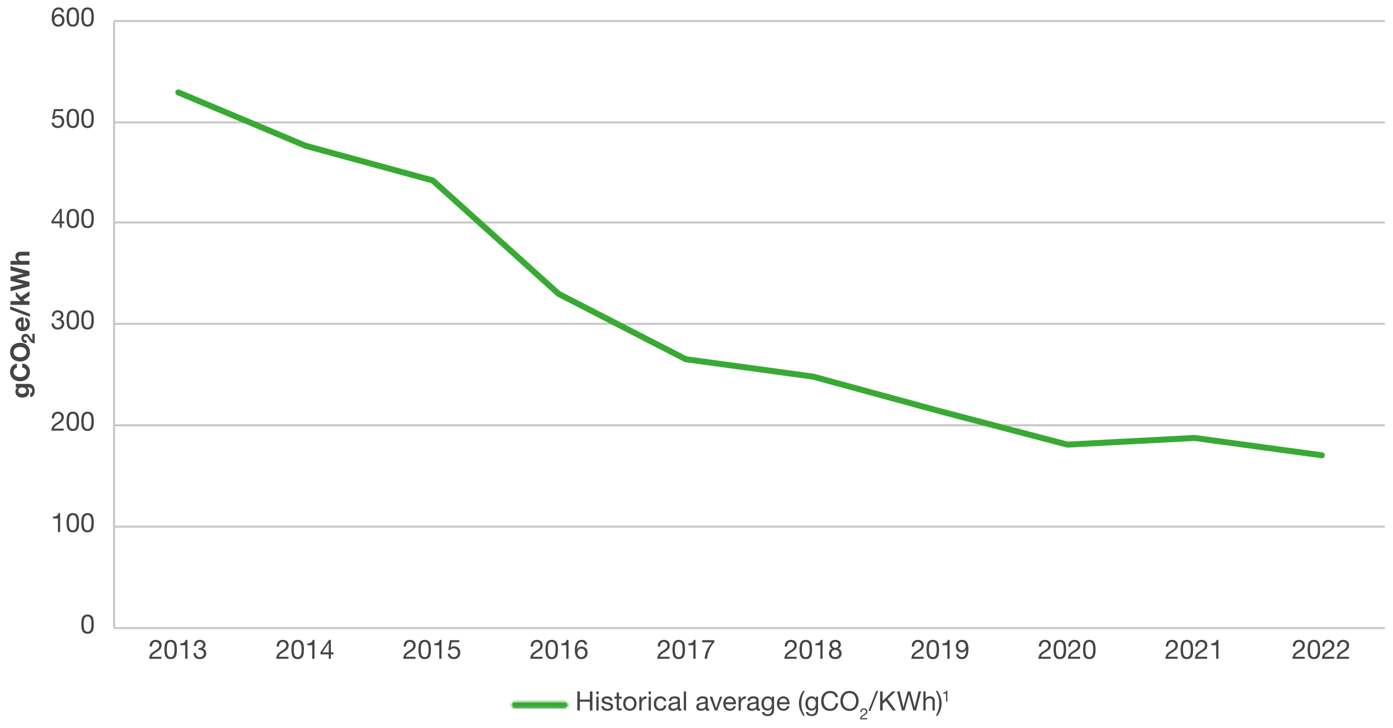
Figure ES.E.02: Historical power sector carbon intensity, constrained network (gCO_2/KWh)[1]



1 Historical and future carbon intensity should not be compared directly. Historical carbon intensity data is from a constrained network, future scenarios are unconstrained.
2 https://www.ofgem.gov.uk/environmental-and-social-schemes/renewables-obligation-ro#:~:text=Renewables%20Obligation%20Certificates%20(ROCs),they%20have%20met%20their%20obligation

Where are we now

Figure ES.E.02A: Historical power sector carbon intensity, constrained network (gCO_2/KWh)[1]



1 Historical and future carbon intensity should not be compared directly. Historical carbon intensity data is from a constrained network, future scenarios are unconstrained.

FES 2022 / The Energy System / Electricity Supply 255

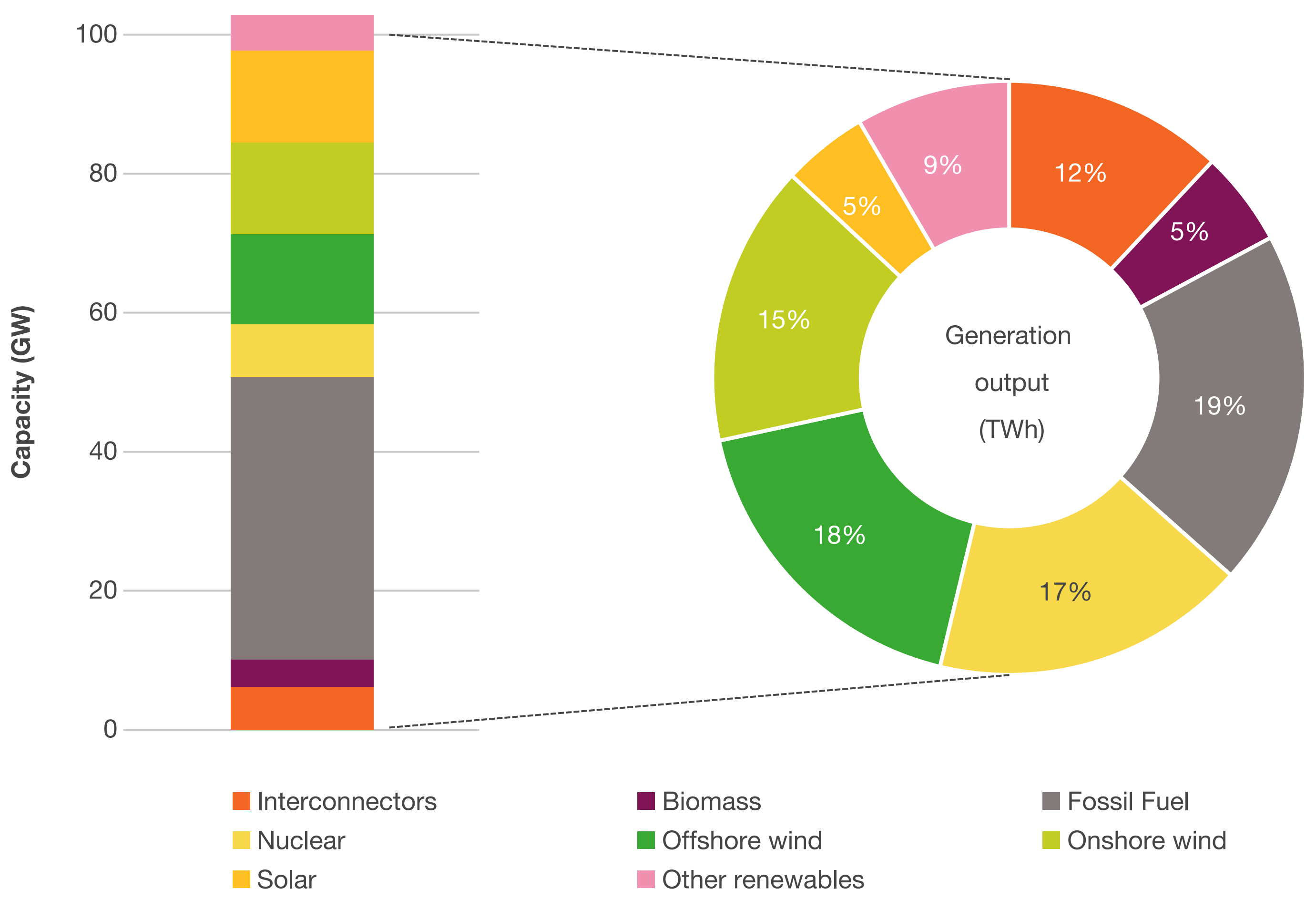
Where are we now

For the UK to meet its legal commitment of Net Zero carbon emissions by 2050, the whole energy system must enable the entire economy to decarbonise, even providing some negative emissions to offset emissions from sectors which are difficult to decarbonise. In all Net Zero scenarios, carbon neutral or carbon negative electricity generation has a significant part to play but comes with its own challenges for operating the system. Thermal generation plants such as nuclear or natural gas provide essential ancillary services to the electricity network which allow supply and demand to be matched. As we move towards more renewables, we will need to find alternative sources of ancillary services. One example is the green inertia project to bring synthetic inertia on-line to cover the ancillary services that thermal generation currently provides.[3] We explore decarbonisation here, and how the future energy system will need to be intrinsically flexible here.

In recent years, decarbonisation has been the main driver for future change to the electricity system. Over the past year, it has been joined by an urgent effort to improve energy security and reduce energy costs for consumers by reducing exposure to the wholesale gas price. In simple terms, the wholesale cost of natural gas often sets Britain's marginal electricity price because of the role natural gas generation plays as the marginal generator. Natural gas prices, and therefore electricity prices, have increased rapidly due to demand exceeding supply following the COVID-19 pandemic and the global response to Russia's invasion of Ukraine. While transitioning from generation that relies on imported fossil fuels to domestic renewables significantly improves future energy security, reduces carbon emissions and reduces exposure to global gas prices, there are also things we can do to reduce demand today. This is explored in The Energy Consumer section.

The high-level case for change is clear but how this change is delivered remains uncertain. In this section, we explore that uncertainty between now and 2050.

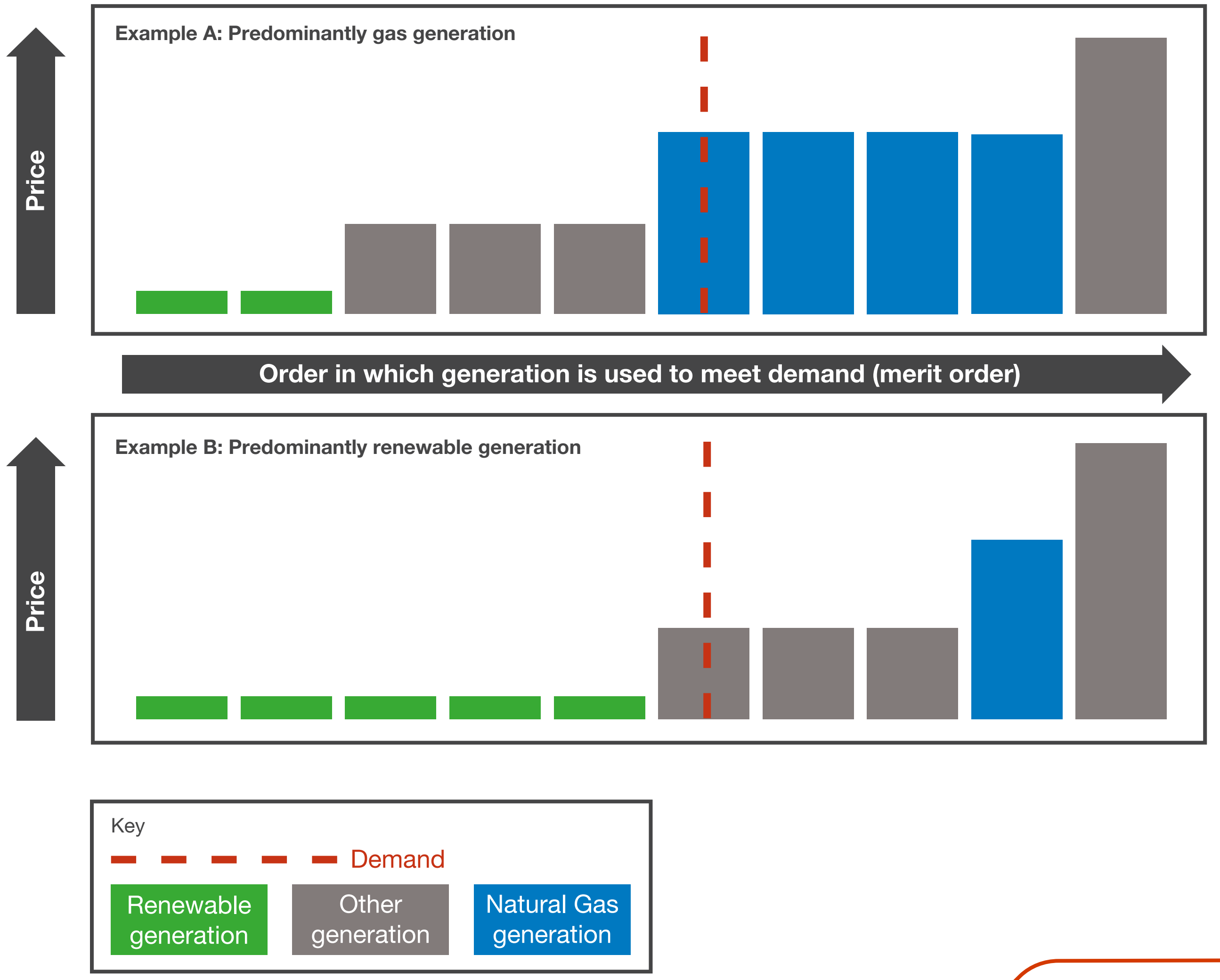
Figure ES.E.03: Electricity generation capacity (GW) and output (TWh) in 2021



3 https://www.nationalgrideso.com/news/green-inertia-projects-and-world-first-tech-tell-british-energy-success-story

Marginal Price and the energy mix

This image shows how marginal pricing works at a very high level. Generation assets are ranked in a 'merit order', or order of preference in which they are used, with cheaper assets being used first. As demand rises, more expensive sources of generation are used. The marginal price of electricity is set by the last generation asset to be used in the mix at a given time. Today, that is often natural gas. Increased renewable generation would mean more low-cost generation capacity to meet demand before gas has to be used. The ESO's publication on Net Zero Market Reform explores how pricing needs to change to enable Net Zero.



FES 2022 / The Energy System / Electricity Supply 257

Regional spotlight: Transforming GB electricity networks

GB electricity networks will need to continue to rapidly transform over the coming decades, as the system transitions away from the large, centralised fossil fuel fired generation of the past to more decentralised, low carbon sources in the future.

Figure ES.E.04: Offshore wind capacity by region (GW) Consumer Transformation

Scotland

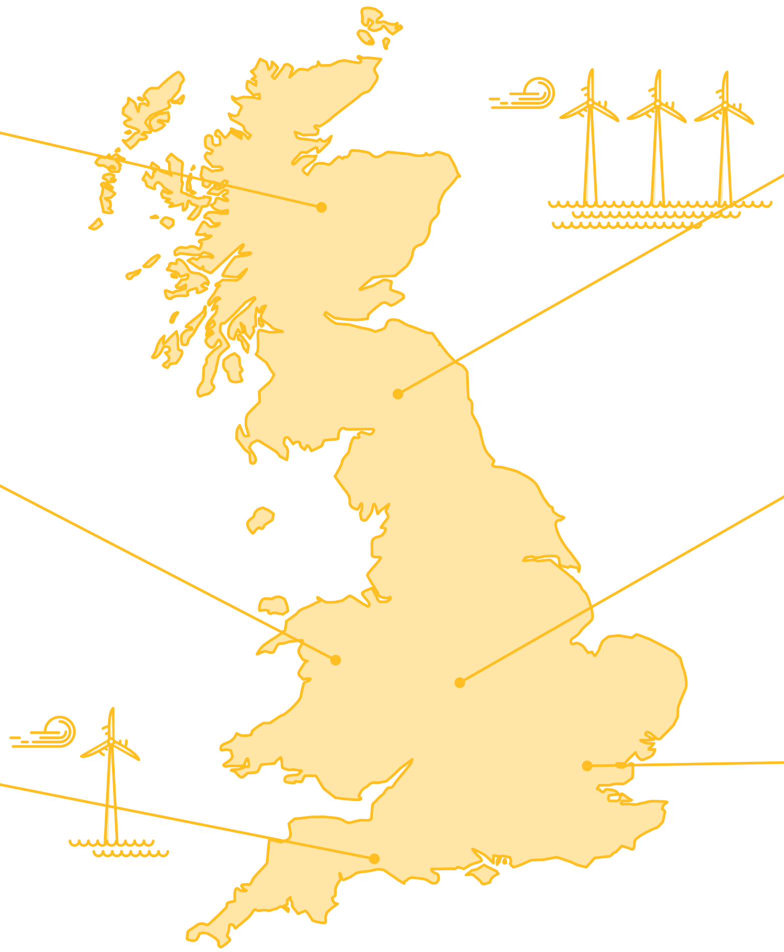
	2021	2030	2050
Offshore Wind Capacity	2	10	38
Solar PV Capacity	1	2	7
Onshore Wind Capacity	9	21	28

Wales

	2021	2030	2050
Offshore Wind Capacity	1	7	16
Solar PV Capacity	1	3	6
Onshore Wind Capacity	1	2	5

South West

	2021	2030	2050
Offshore Wind Capacity	0	0	4
Solar PV Capacity	3	6	15
Onshore Wind Capacity	0	1	2



North England

	2021	2030	2050
Offshore Wind Capacity	6	14	27
Solar PV Capacity	3	7	18
Onshore Wind Capacity	2	3	8

Midlands

	2021	2030	2050
Offshore Wind Capacity	3	11	14
Solar PV Capacity	3	7	17
Onshore Wind Capacity	0	1	2

South East

	2021	2030	2050
Offshore Wind Capacity	2	2	10
Solar PV Capacity	3	7	17
Onshore Wind Capacity	1	1	3

FES 2022 / The Energy System / Electricity Supply 258

Regional spotlight: Transforming GB electricity networks

GB electricity networks will need to continue to rapidly transform over the coming decades, as the system transitions away from the large, centralised fossil fuel fired generation of the past to more decentralised, low carbon sources in the future.

Figure ES.E.04: Offshore wind capacity by region (GW) System Transformation

Scotland

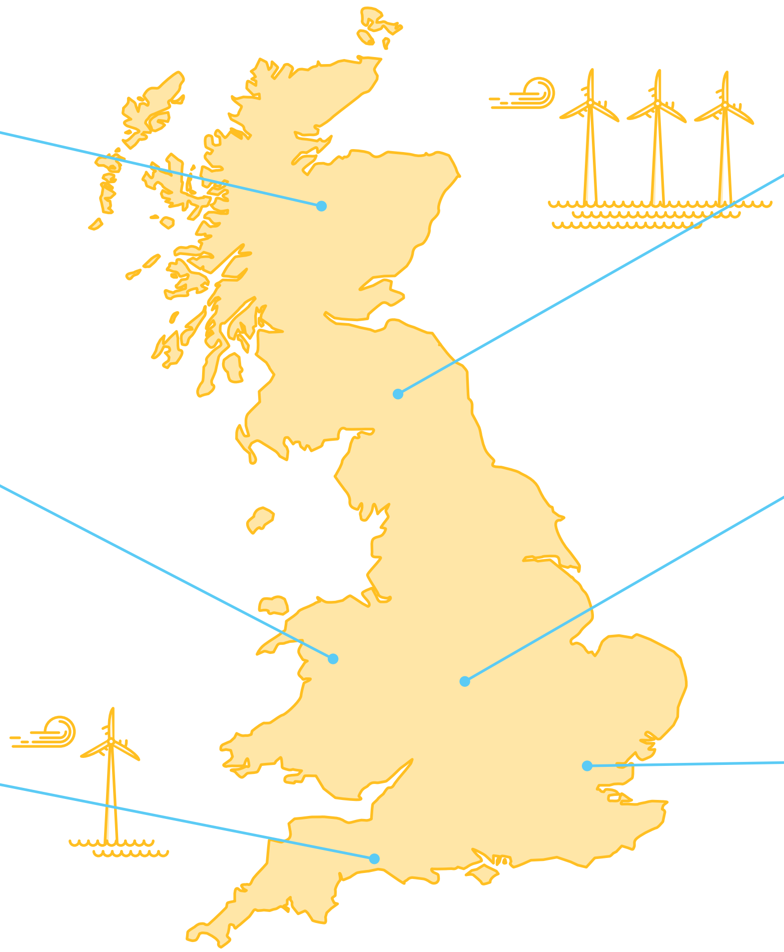
	2021	2030	2050
Offshore Wind Capacity	2	7	35
Solar PV Capacity	1	1	5
Onshore Wind Capacity	9	19	24

Wales

	2021	2030	2050
Offshore Wind Capacity	1	6	13
Solar PV Capacity	1	2	5
Onshore Wind Capacity	1	2	3

South West

	2021	2030	2050
Offshore Wind Capacity	0	0	4
Solar PV Capacity	3	5	11
Onshore Wind Capacity	0	1	1



North England

	2021	2030	2050
Offshore Wind Capacity	6	14	24
Solar PV Capacity	3	5	12
Onshore Wind Capacity	2	2	4

Midlands

	2021	2030	2050
Offshore Wind Capacity	3	11	14
Solar PV Capacity	3	5	12
Onshore Wind Capacity	0	1	1

South East

	2021	2030	2050
Offshore Wind Capacity	2	2	6
Solar PV Capacity	3	6	13
Onshore Wind Capacity	1	1	1

FES 2022 / The Energy System / Electricity Supply 259

Regional spotlight: Transforming GB electricity networks

GB electricity networks will need to continue to rapidly transform over the coming decades, as the system transitions away from the large, centralised fossil fuel fired generation of the past to more decentralised, low carbon sources in the future.

Figure ES.E.04: Offshore wind capacity by region (GW) Leading the Way

Scotland

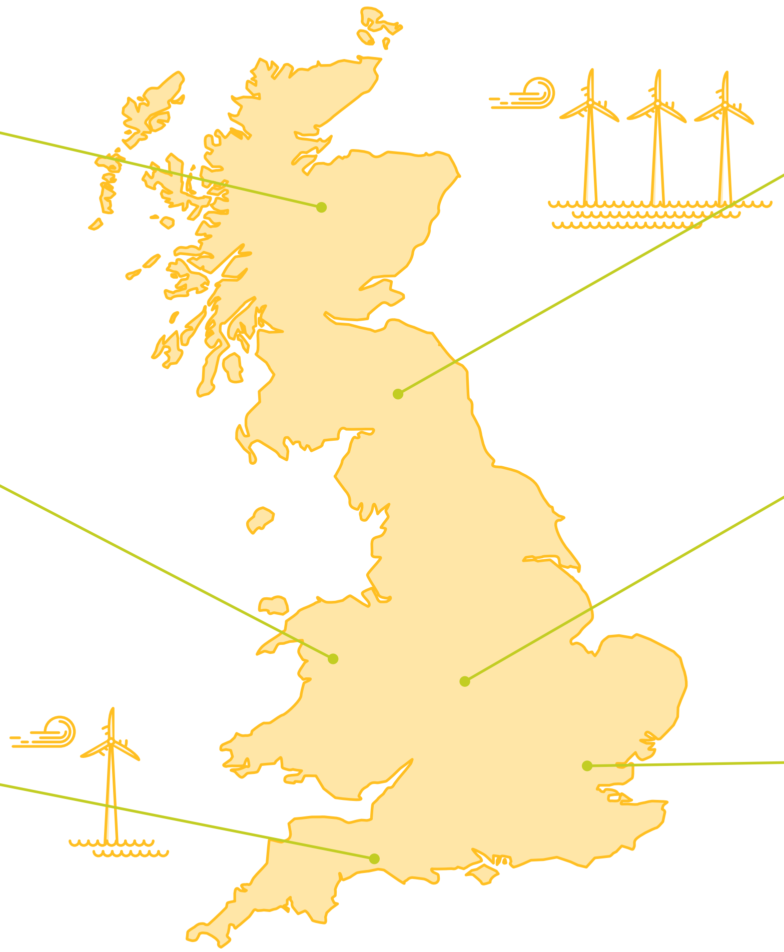
	2021	2030	2050
Offshore Wind Capacity	2	15	36
Solar PV Capacity	1	2	8
Onshore Wind Capacity	9	23	28

Wales

	2021	2030	2050
Offshore Wind Capacity	1	9	15
Solar PV Capacity	1	4	7
Onshore Wind Capacity	1	3	6

South West

	2021	2030	2050
Offshore Wind Capacity	0	0	1
Solar PV Capacity	3	9	17
Onshore Wind Capacity	0	1	1



North England

	2021	2030	2050
Offshore Wind Capacity	6	14	21
Solar PV Capacity	3	9	20
Onshore Wind Capacity	2	3	7

Midlands

	2021	2030	2050
Offshore Wind Capacity	3	10	13
Solar PV Capacity	3	8	19
Onshore Wind Capacity	0	1	2

South East

	2021	2030	2050
Offshore Wind Capacity	2	2	3
Solar PV Capacity	3	10	20
Onshore Wind Capacity	1	1	2

FES 2022 / The Energy System / Electricity Supply 260

Regional spotlight: Transforming GB electricity networks

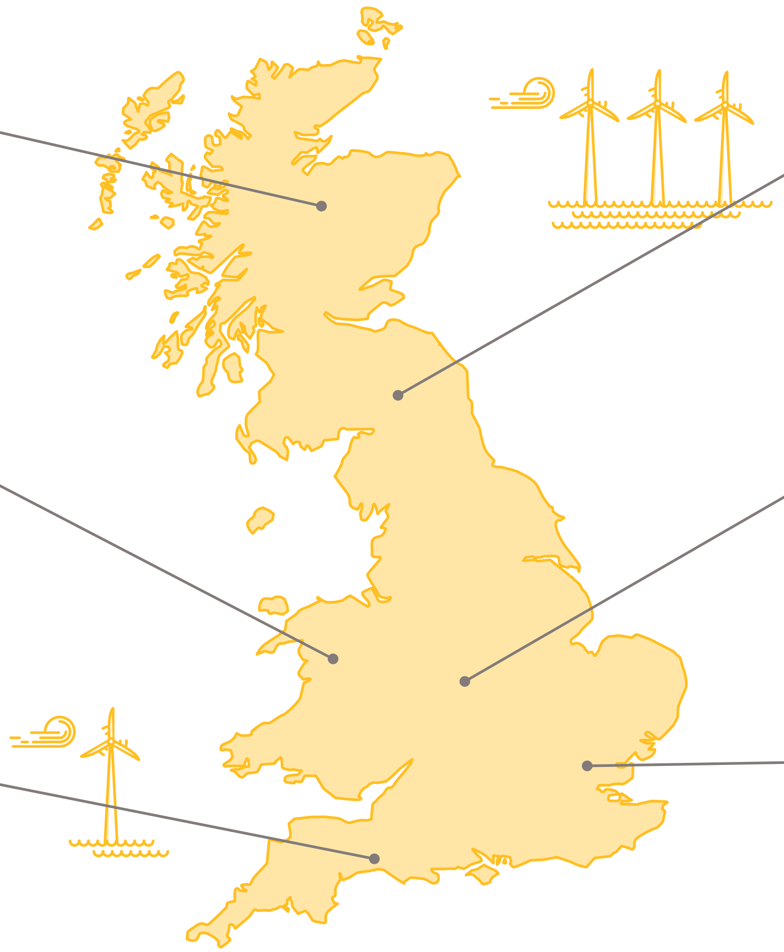
GB electricity networks will need to continue to rapidly transform over the coming decades, as the system transitions away from the large, centralised fossil fuel fired generation of the past to more decentralised, low carbon sources in the future.

Figure ES.E.04: Offshore wind capacity by region (GW) Falling Short

Scotland	2021	2030	2050
Offshore Wind Capacity	2	5	27
Solar PV Capacity	1	1	3
Onshore Wind Capacity	9	16	22

Wales	2021	2030	2050
Offshore Wind Capacity	1	3	13
Solar PV Capacity	1	2	4
Onshore Wind Capacity	1	1	2

South West	2021	2030	2050
Offshore Wind Capacity	0	0	2
Solar PV Capacity	3	4	7
Onshore Wind Capacity	0	0	1



North England	2021	2030	2050
Offshore Wind Capacity	6	11	16
Solar PV Capacity	3	4	9
Onshore Wind Capacity	2	2	3

Midlands	2021	2030	2050
Offshore Wind Capacity	3	10	12
Solar PV Capacity	3	4	8
Onshore Wind Capacity	0	1	1

South East	2021	2030	2050
Offshore Wind Capacity	2	2	3
Solar PV Capacity	3	4	9
Onshore Wind Capacity	1	1	1

FES 2022 / The Energy System / Electricity Supply 261

Regional spotlight: Transforming GB electricity networks

The system is already evolving, and will need to continue to evolve, to cater for the different characteristics of these technologies, such as greater weather dependency of renewable generators, and generation being located further from the current centres of demand. These characteristics create new challenges when moving power across the country and between regions; and in how we operate the system, as set out in the **Electricity Ten Year Statement (ETYS)**.

Today we already see large power flows from Scotland into England at times of high wind generation and, in the future, we expect to see further significant power flows associated with the additional offshore wind capacity that is expected to connect. This will mean power flows will become more and more variable with higher peaks.

Balancing the system is also becoming more challenging and requires increasing levels of redispatch (short term changes to match supply and demand), resulting in rising transmission constraint costs.

Transmission projects, such as the Western Link running down the West Coast (completed in 2017) and the Eastern Links project, which is in development off the East Coast, will alleviate some of the expected network constraints but significantly more reinforcement, as well as the development of local flexibility and early competition in network build, is needed to avoid potentially very high constraint costs.

How could wind and solar generation capacity change?

We currently have approximately 12 GW of offshore wind. The highest level of offshore wind is seen in Consumer Transformation, which sees capacity levels as high as 110 GW by 2050. In all three of our Net Zero scenarios, offshore wind makes up the largest proportion of electricity supply capacity by 2030.

Connecting these high volumes of offshore wind will be challenging in the short term, especially due to the need for significant network reinforcement to transport this energy from where it is produced to where it is needed.

Offshore wind capacity will grow across the whole of GB, but particular regions will experience significant uplift in capacity when compared to today, especially in Scotland and along the East Coast of England. We explain how our network development processes seek to address these trends in more depth later in this section.

We also expect significant growth in onshore electricity generation, particularly solar generation and to a lesser extent, onshore wind. In total, wind (both onshore and offshore) and solar provide at least 50% of generation capacity by 2050 across all our scenarios, compared to 37% today. We expect the solar capacity to grow steadily in the South-West, South-East and East Anglia, but it will increase further north in future years. Considering this change in generation in the coming decades, the electricity transmission system will face growing needs across several regions, which we highlight in our Electricity Ten Year Statement document. This trend is expected to continue, even when the future planned network reinforcements are considered, with Scotland, the North of England, East Anglia and the South Coast regions expected to experience the highest level of export constraints.

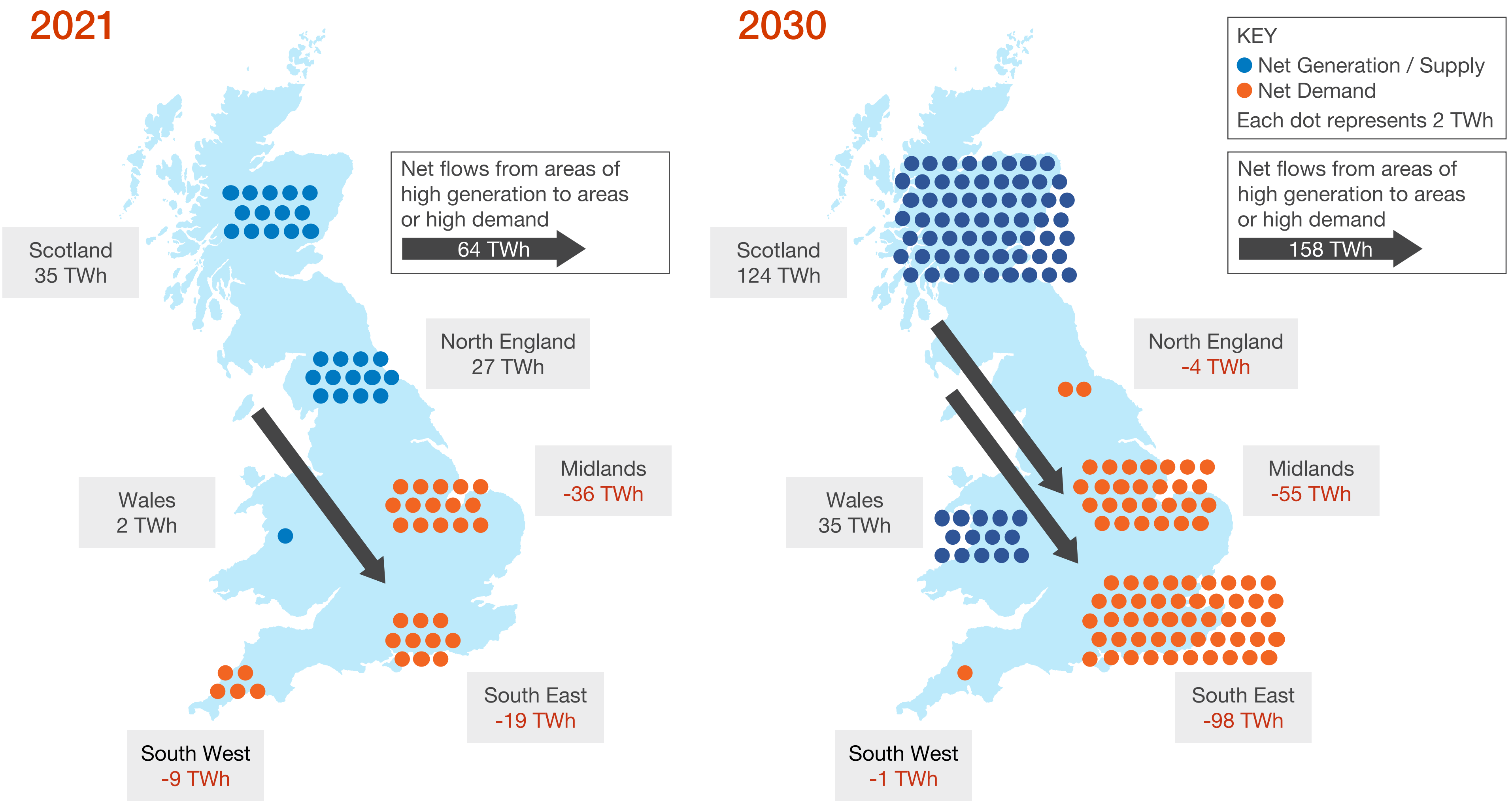
FES 2022 / The Energy System / Electricity Supply 262

Regional spotlight: Transforming GB electricity networks

What does changing generation mean for the network?

With increasing amounts of weather-variable renewable forms of generation, we expect to see not only higher peak flows on the system but also greater variability of flows, as changes in weather patterns from day-to-day and season-to-season could drive regional variations in the net transfer of flows. For example, comparing a windy, high demand day with a calm and sunny lower demand day - in a future with a very high solar and wind capacity - shows two completely different outcomes, with flows between different regions varying significantly. This means that variations in year-round conditions need to be considered when designing networks of the future. Focussing effort on a few key points in the year may no longer be suitable, as peak conditions are not the only time we see high flows in the network, especially when considered from a regional perspective. We are exploring this through improvements to our Network Options Assessment (NOA) process and associated pathfinders.

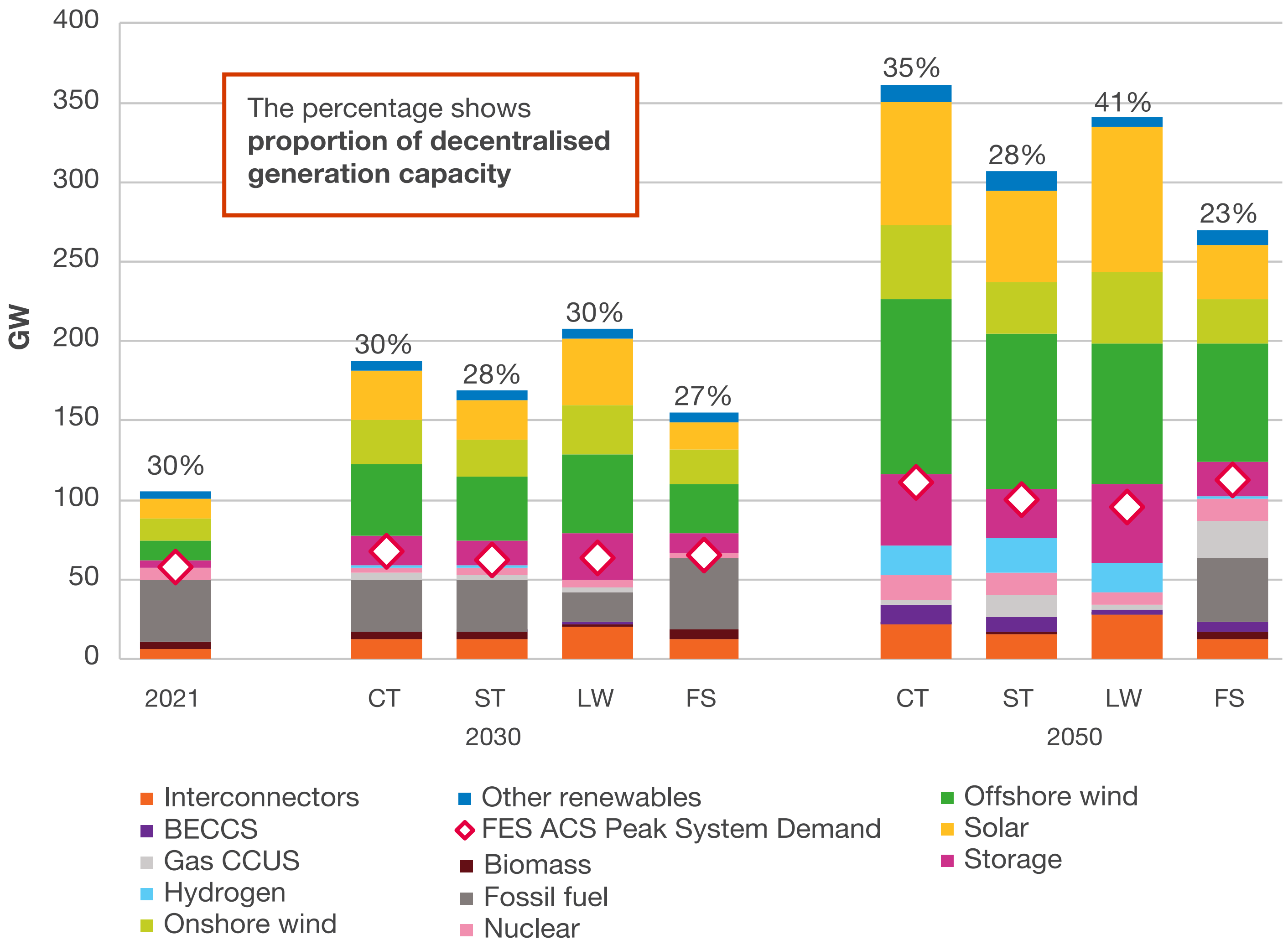
Figure ES.E.05: Regional Flows on the electricity transmission network in Leading the Way



FES 2022 / The Energy System / Electricity Supply 263

Regional spotlight: Transforming GB electricity networks

Figure ES.E.01: Installed generation capacity, peak demand and percentage of decentralised generation (GW)



The continued rise in connection of renewables directly to the distribution network will also lead to variations in the geographic distribution of flows on the network, as well as presenting additional regional operability challenges on the network. This highlights the importance of improving regional demand forecasting and the need for targeted solutions that specifically meet the unique range of challenges that each area of the energy system will experience in the future.

How are these insights used to inform network development?

The regional requirements on the electricity transmission system will be explored in more depth in our Electricity Ten Year Statement (ETYS), which follows the publication of FES. The ETYS focusses on determining the network's current capability and the future requirements, using FES data as an input.

We evaluate the network development options and publish investment recommendations in the Network Options Assessment (NOA) report, which uses both FES and ETYS as inputs and performs an economic assessment to determine the best course of action with regards to reinforcing the transmission system for the next 12 months.

Efforts are being made by a range of stakeholders to speed up the delivery of transmission infrastructure as well as to improve collaboration and coordination in identifying and delivering strategic transmission investments – both anticipatory and for system optimisation. It must also an objective, however, to optimise the aggregate cost of generation, constraints, and networks in order to achieve Net Zero at lowest overall cost to consumers.

FES 2022 / The Energy System / Electricity Supply 264

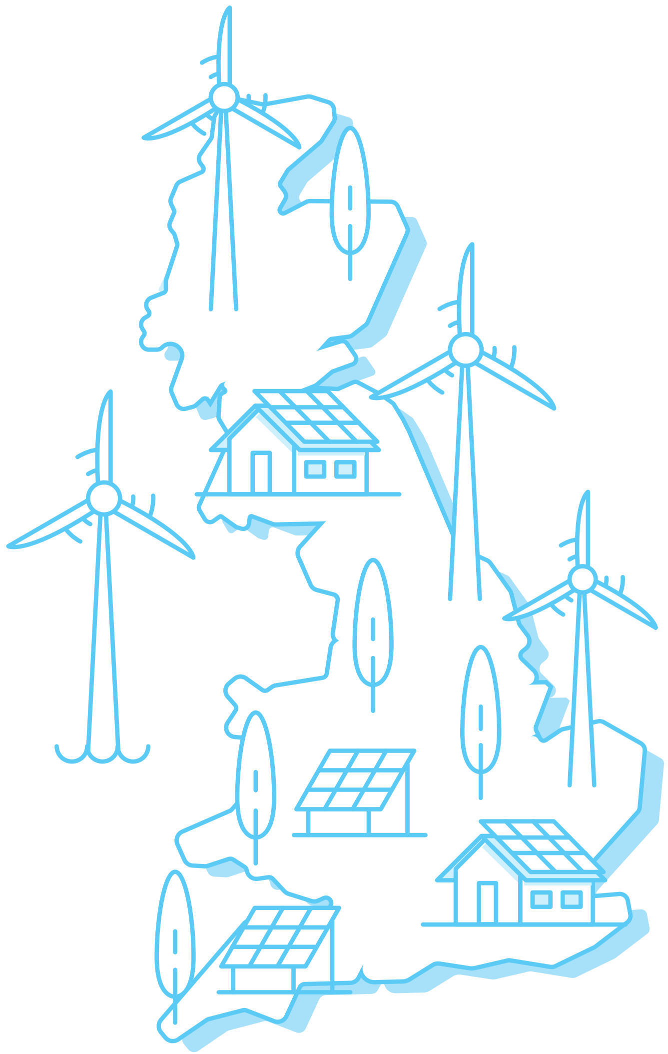
Regional spotlight: Transforming GB electricity networks

Our recently published Holistic Network Design (HND), is the first step in transitioning to a Centralised Strategic Network Plan, which is being considered as part of our Network Planning Review in collaboration with Ofgem's Electricity Transmission Network Planning Review (ENTPR). The HND shows how the proposed coordinated approach for connecting 23 GW of in-scope offshore wind impacts different regions across the UK between now and 2030. The HND is critical in enabling this infrastructure to be delivered at the scale and pace necessary to achieve 50 GW of offshore wind by 2030. Importantly, it looks holistically across four areas including the cost to consumers, impact on local communities, environmental impact and deliverability and operability, making sure that this offshore wind infrastructure is delivered in the most efficient way with the lowest impact.

The ESO's Net Zero Market Reform programme has also identified the need for stronger locational signals in both operational and investment timeframes for the GB power market. This can be achieved effectively through locational pricing whereby wholesale electricity prices accurately reflect the varying value of electricity in time and at different system locations, taking account of network constraints and losses. Compared to today's arrangements - of a single national wholesale electricity price, transmission network charges that vary by location and self-dispatch - locational pricing combined with central dispatch could over time deliver substantial whole system cost savings and benefits through: more efficient siting of generation, storage and demand; more efficient use of existing infrastructure including interconnectors; co-optimisation of energy and reserves; optimised curtailment of renewables; and reduced network build.

The analysis underpinning our Future Energy Scenarios helps us understand all these issues better and how they will change in the future. While detailed discussion of these issues is beyond the scope of FES, they are considered in more detail in publications which build on our FES analysis:

- Electricity Ten Year Statement (ETYS)
- Network Options Assessment (NOA)
- Net Zero Market Reform (NZMR)
- Offshore coordination project and Holistic Network Design (HND)
- Network Planning Review
- Early Competition



FES 2022 / The Energy System / Electricity Supply 265

Renewables dominate the GB's future electricity generation mix in all scenarios

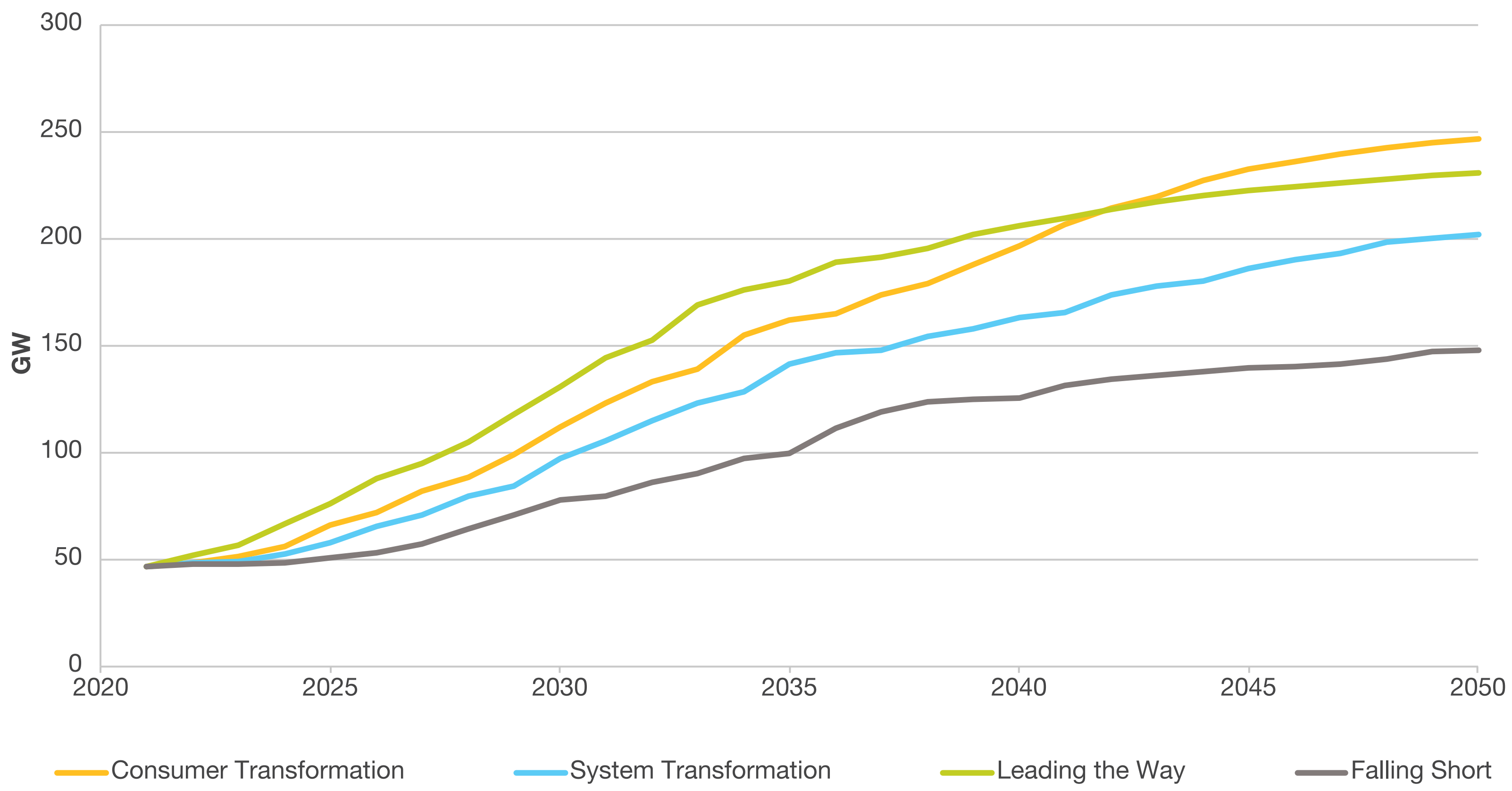
Growth of renewables in our scenarios is driven by:

- A clear target of 50 GW of offshore wind by 2030 and up to 70 GW of solar by 2035.
- Clear decarbonisation targets including the carbon budgets and reaching Net Zero by 2050.
- Capital cost of renewables reducing over time and their ability to provide some of the cheapest low carbon electricity.[4]
- Technological advances (high capacity floating offshore wind).
- Moving to annual Contract for Difference auctions, which gives stability to the supply chain and reduces investor risk.
- An assumption that planning for wind and solar installation becomes easier and quicker than it is today.

You can read more about our modelling and policy assumptions for Electricity Supply on the next page.

A full explanation of our modelling methods and assumptions can be found on the FES website.

Figure ES.E.06: Installed renewable generation capacity by scenario (GW)



4 ipcc.ch/report/ar6/wg3/figures/summary-for-policymakers/figure-spm-3/

FES 2022 / The Energy System / Electricity Supply 266

What we've found

Modelling and policy assumptions	
All scenarios meet Security of Supply standards	We include sufficient generation capacity to achieve the Security of Supply standard of no greater than a 3-hour Loss of Load Expectation (LOLE) in all scenarios. This could be through mechanisms such as the Capacity Market which incentivise generation capacity to be available, even if its annual running hours are low (i.e. to meet peak demand).
The financial value of carbon emission reduction continues on its current path	We assume that the price of the new UK Emissions Trading Scheme (ETS) will be like the EU ETS and that the two will continue on a similar trajectory to 2050. We anticipate the GB Carbon Price Support (CPS) will continue in line with government policy before gradually being phased out as the ETS increases.
No network constraints	Our modelling informs what the whole energy system of the future needs to look like and how it should operate. To do that without being biased or limited by existing design, we start by modelling to balance supply and demand without any network or operability constraints, siting generation where it is otherwise optimal. Assessment of constraints and identification of options to overcome them happens in the Electricity Ten Year Statement (ETYS), Network Options Assessment (NOA) and System Operability Framework (SOF) processes. This assumption also applies to the distribution networks. Offshore wind in Leading the Way is assumed to be coordinated as part of Holistic Network Design (HND), which considers network constraints. We start our modelling with current network constraints excluded, to ensure that we consider the full potential of any opportunities and improve the network to harness those opportunities and the benefits they bring, rather than be limited to what the network can do today.
Perfect market, perfect foresight	The electricity dispatch modelling assumes a perfect market with perfect foresight. This implies that all market participants are assumed to behave in a way that maximises their revenue and that there are no errors in forecasting (e.g. demand, wind, solar).
Negative emissions and abatement	Support for bioenergy with CCS as a source of negative emissions causes its generation capacity to increase steadily past 2027. We also assume continued government support of CCS as well as improvements in capture rate.
Deployment of wind-based generation becomes easier	The planning process is sped up in line with ambitions presented in the British Energy Security Strategy and there is sufficient grid connection capacity for offshore wind. The planning and consenting process for onshore wind becomes quicker and easier in locations where local support is high.
Flexibility and interconnectors	There is sufficient support for hydrogen to enable hydrogen fuelled power stations (i.e. a H2 network or appropriate storage). Further cap & floor support for new interconnectors is introduced. Long duration storage costs come down.
Technology Mix	We decide when to include a technology in our modelling based on its commercial and technological readiness as it stands today and how we expect it to evolve over time. All solutions are considered for every annual FES cycle and we rely on trusted stakeholders to stay informed about developments as they happen.

FES 2022 / The Energy System / Electricity Supply 267

What we've found

Electricity supply and demand across the scenarios

We create our generation backgrounds for each scenario to meet its energy demand ensuring Security of Supply (SoS). Therefore, the level of peak demand drives the capacity we need, and the scenario framework helps shape what type of capacity we add. We assume a full and intact network for our analysis, which means we do not model network constraints or outages. Constraint modelling is carried out as part of the NOA process. We create the generation backgrounds to ensure that Security of Supply is met. You can read more about Security of Supply in the Flexibility chapter here.

In the Net Zero scenarios, peak demands are almost double by 2050 compared to today but generation capacities triple as renewables running at lower load factors make up a greater portion of the generation mix.

Consumer Transformation has the highest annual and peak demands of all the scenarios as transport and heat demands are met by electricity. Leading the Way sees lower peak demands through energy efficiency measures and the highest levels of consumer engagement in demand flexibility.

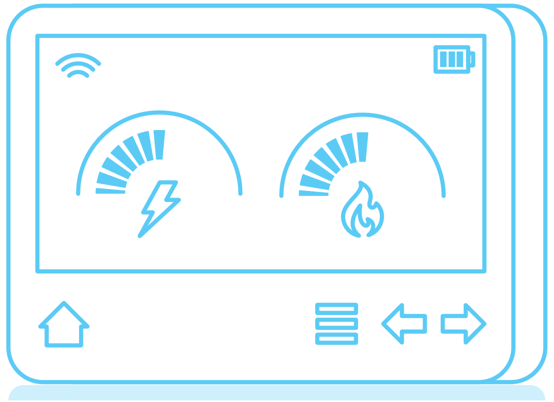
Both scenarios use electricity to produce most of their hydrogen through electrolysis.

In System Transformation, although hydrogen has replaced much of end user fossil fuel demand for heating and industrial processes, some sectors such as transport still undergo a lot of electrification. This, as well as some demand for hydrogen production though electrolysis, leads to a net increase in electricity demand.

In Falling Short, despite missing the UK's legal commitment to reach Net Zero by 2050, significant progress is still made to electrify large parts of the economy. Natural gas generation capacity remains on the system but at much lower load factors than today. Even in our slowest decarbonising scenario, we expect to see more than a 200% increase in renewable generation capacity which the electricity network must be able to manage. Therefore, immediate investment in electricity infrastructure is a no-regret action for GB's whole energy system.

Decentralised generation:

- High levels of societal change in Leading the Way and Consumer Transformation lead to higher uptake of decentralised generation as communities have greater appetite for renewable generation.
- System Transformation and Falling Short, with their lower levels of assumed societal change, rely more on higher levels of transmission connected generation capacity.

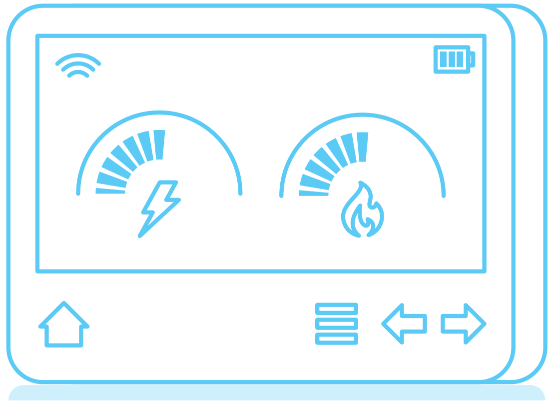


FES 2022 / The Energy System / Electricity Supply 268

Electricity supply and demand across the scenarios

Decentralisation

The level of decentralisation indicates how close the production and management of energy is to the end consumer. High levels of decentralisation create closer links between sources of energy supply and demand via local networks, and consumers take a more active part in managing their energy needs. While this has the benefit of reducing demand losses, it typically comes at the cost of lost economies of scale from the larger power plant. In a decentralised world, far more small-scale energy supplies connect to the distribution networks, including renewables. On a yet smaller-scale, consumers access technology to manage their own electricity needs in a more localised manner.

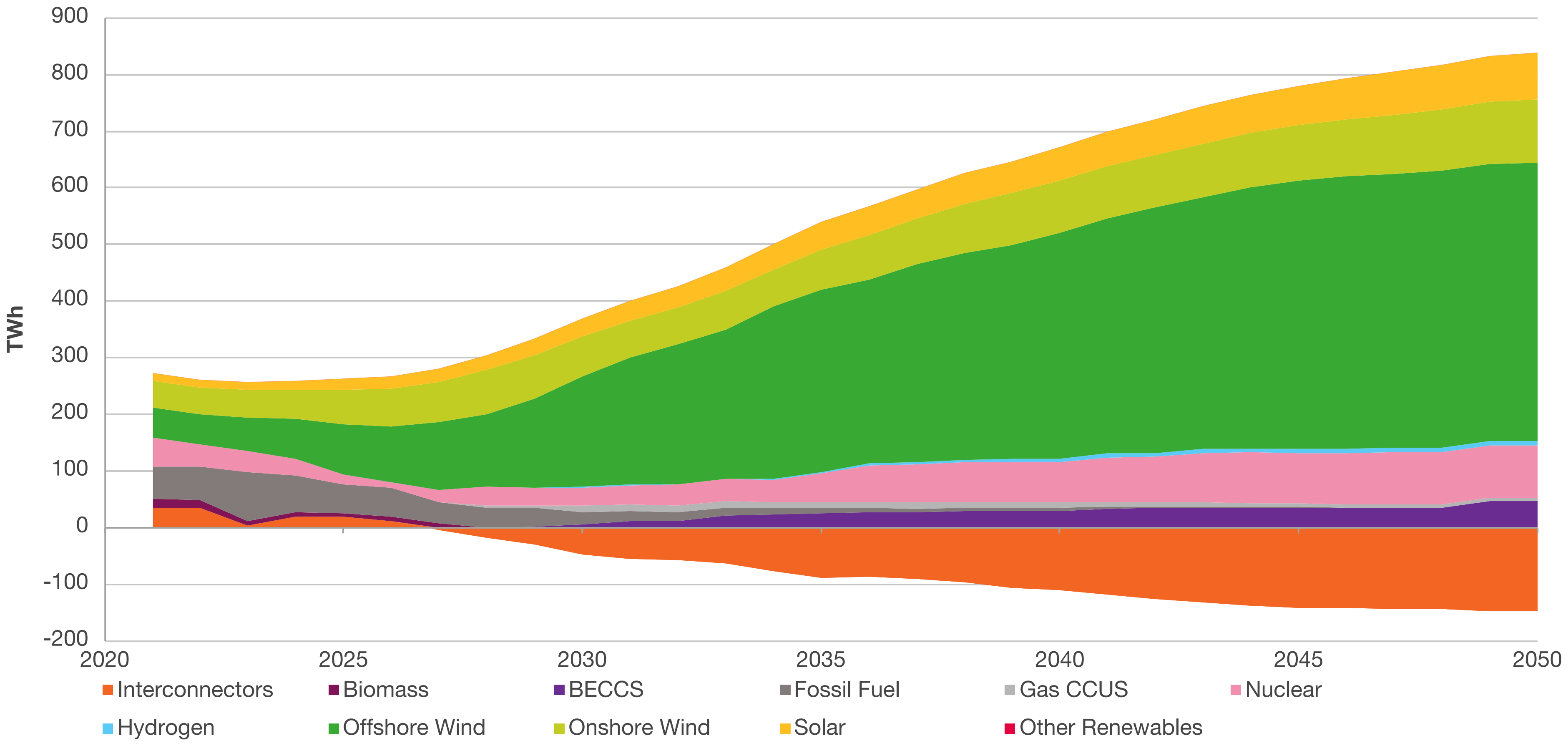


FES 2022 / The Energy System / Electricity Supply 269

Scenario overviews

We see an increase in renewable generation in all scenarios, particularly offshore wind, which grows to make up over half of electricity supply by the late 2030s. Natural gas as a proportion of output reduces through the 2020s, displaced by renewables as the largest share of generation. In 2050 wind, solar, nuclear and BECCS provide over 90% of generation output in all Net Zero scenarios. These charts show all electricity which gets supplied to the network to meet annual demand. They therefore exclude non-networked wind, non-networked solar and any curtailed generation.

Figure ES.E.07: Electricity generation output by technology (TWh) in Consumer Transformation

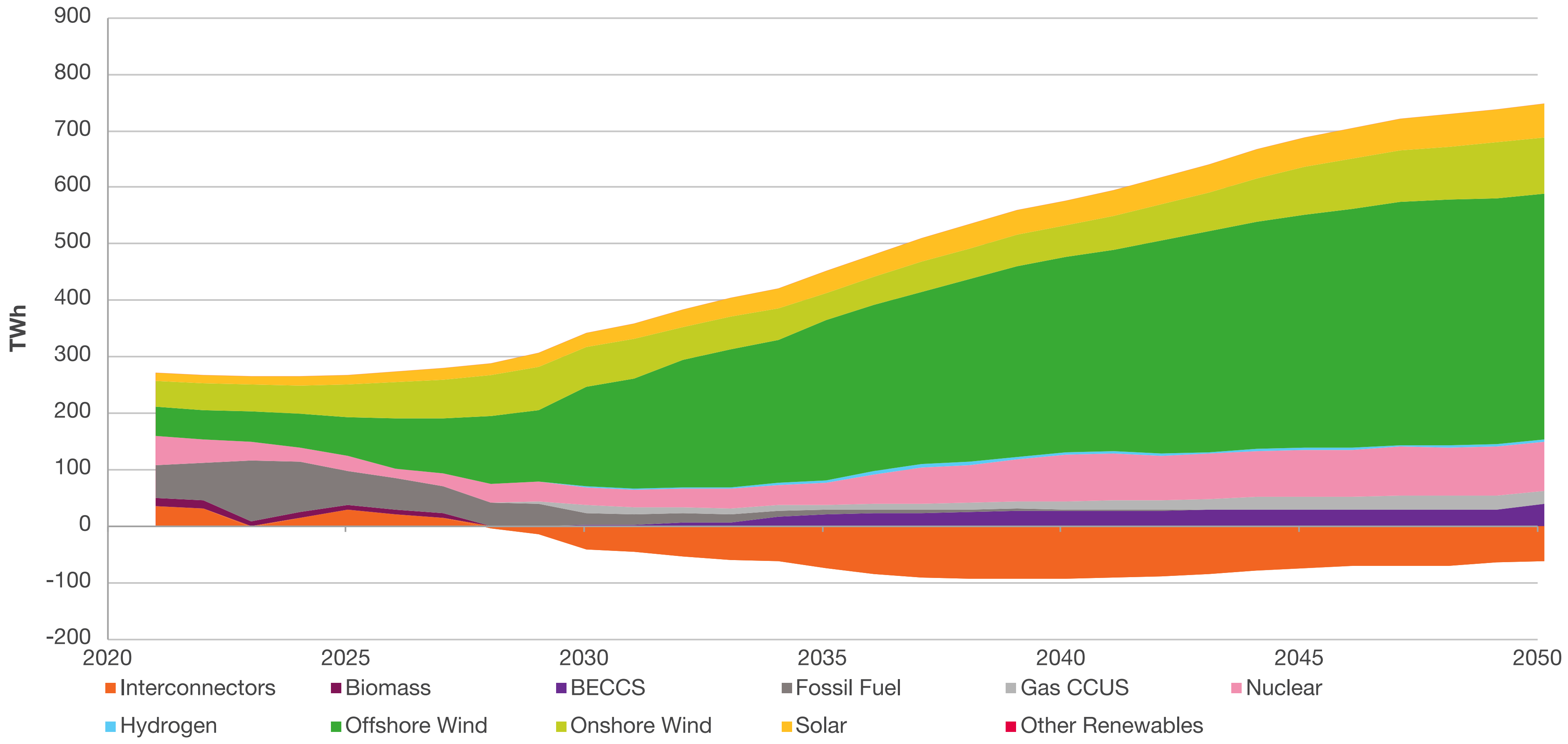


FES 2022 / The Energy System / Electricity Supply 270

Scenario overviews

We see an increase in renewable generation in all scenarios, particularly offshore wind, which grows to make up over half of electricity supply by the late 2030s. Natural gas as a proportion of output reduces through the 2020s, displaced by renewables as the largest share of generation. In 2050 wind, solar, nuclear and BECCS provide over 90% of generation output in all Net Zero scenarios. These charts show all electricity which gets supplied to the network to meet annual demand. They therefore exclude non-networked wind, non-networked solar and any curtailed generation.

Figure ES.E.07: Electricity generation output by technology (TWh) in System Transformation

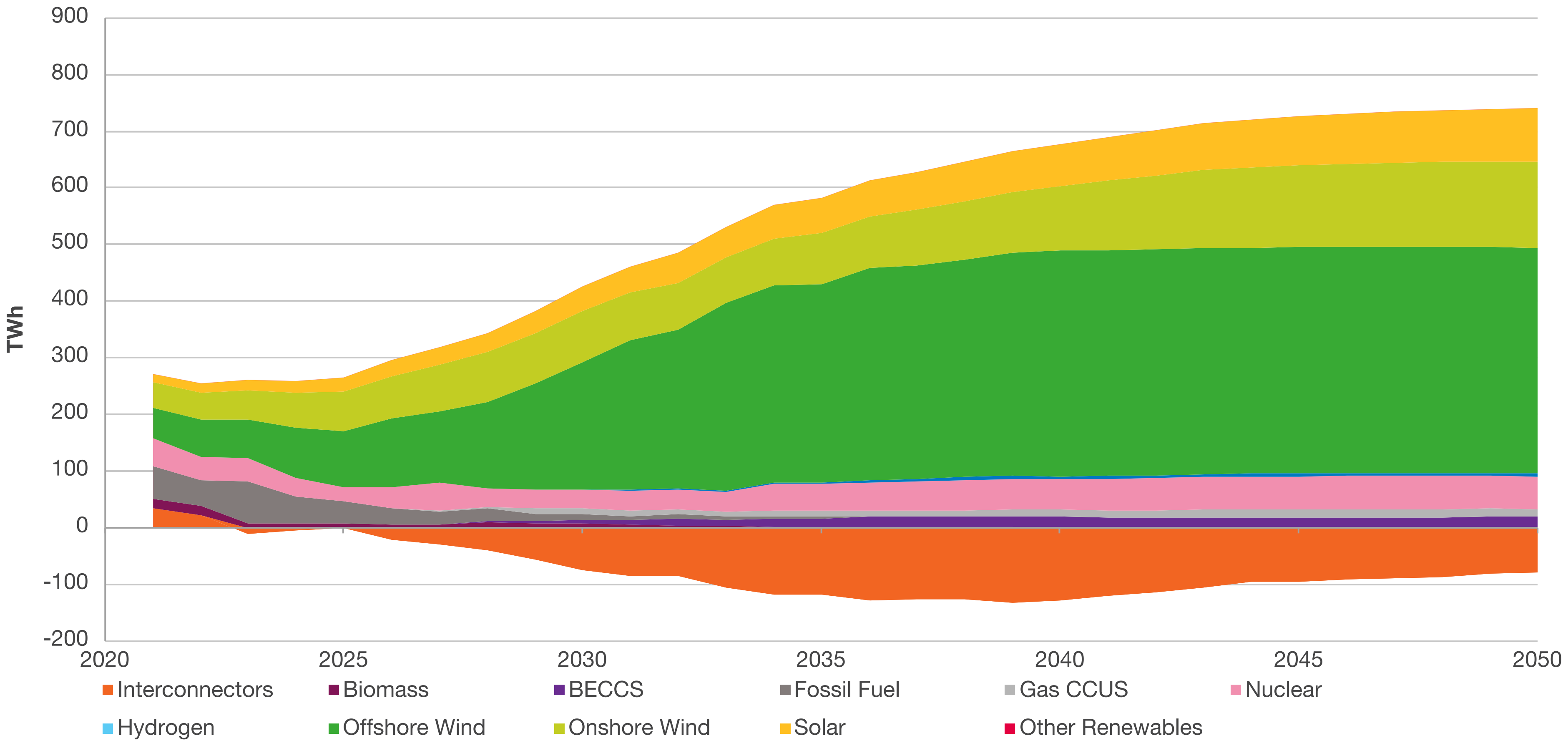


FES 2022 / The Energy System / Electricity Supply 271

Scenario overviews

We see an increase in renewable generation in all scenarios, particularly offshore wind, which grows to make up over half of electricity supply by the late 2030s. Natural gas as a proportion of output reduces through the 2020s, displaced by renewables as the largest share of generation. In 2050 wind, solar, nuclear and BECCS provide over 90% of generation output in all Net Zero scenarios. These charts show all electricity which gets supplied to the network to meet annual demand. They therefore exclude non-networked wind, non-networked solar and any curtailed generation.

Figure ES.E.07: Electricity generation output by technology (TWh) in Leading the Way

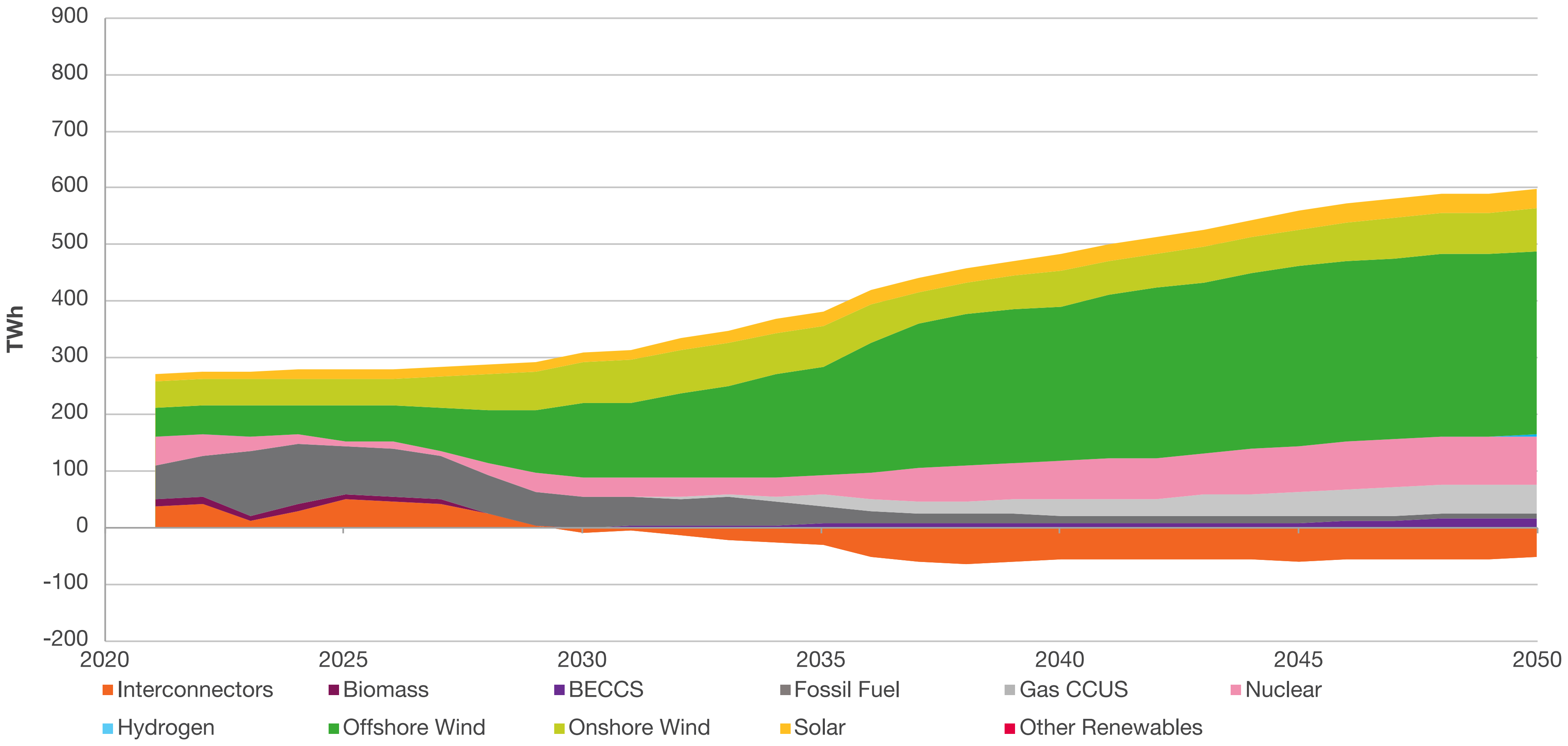


FES 2022 / The Energy System / Electricity Supply 272

Scenario overviews

We see an increase in renewable generation in all scenarios, particularly offshore wind, which grows to make up over half of electricity supply by the late 2030s. Natural gas as a proportion of output reduces through the 2020s, displaced by renewables as the largest share of generation. In 2050 wind, solar, nuclear and BECCS provide over 90% of generation output in all Net Zero scenarios. These charts show all electricity which gets supplied to the network to meet annual demand. They therefore exclude non-networked wind, non-networked solar and any curtailed generation.

Figure ES.E.07: Electricity generation output by technology (TWh) in Falling Short



FES 2022 / The Energy System / Electricity Supply 273

Scenarios overview: Electricity Supply

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- Consumer Transformation sees rapid uptake of renewable generation, particularly offshore wind and solar, to support a highly electrified economy. The Government's 2030 offshore wind target is narrowly missed, reaching 50 GW in 2031, but with continued growth after this point – all the way to 110 GW in 2050, the highest of all the scenarios.
- Gas generation output reduces rapidly through the 2020s but is still used to support Security of Supply. Its capacity declines in the 2030s, offset by continued increases in renewable and nuclear generation, including significant numbers of Small Modular Reactors (SMRs), growth in hydrogen generation capacity and BECCS. The power sector reaches net negative emissions in 2033.
- Interconnectors also play an increasingly important role, to provide flexibility for weather dependent generation, and to make greater use of installed wind generation capacity by avoiding curtailment.

What does 2050 look like?

- Total electricity generation capacity is 298 GW, plus a further 68 GW of electricity storage and interconnection. Electricity generation output is over three times that of today at 877 TWh, with 160 TWh exported.
- Wind, solar, nuclear and BECCS provide 94% of electricity, supplemented by many technologies delivering small amounts of energy.
- High levels of hydrogen generation capacity, interconnection and storage provide flexibility to help meet peak demands, while there is a large net export of electricity over the interconnectors.
- The power sector delivers 52 $MtCO_2e$ of negative emissions through BECCS.

FES 2022 / The Energy System / Electricity Supply 274

What we've found

Scenarios overview: Electricity Supply

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- This scenario sees greater growth of large-scale technologies connected to the gas transmission network. The Government's 2030 offshore wind target is missed, reaching 50 GW in 2032, but with continued growth after this point.
- Growth in renewable generation is still rapid, although slower than the other Net Zero scenarios, with more limited growth in decentralised technologies such as onshore wind and solar.
- This scenario sees the greatest increase in hydrogen generation from 2030, alongside the development of gas CCUS to offer flexibility as unabated gas generation is phased out post-2030.
- Large-scale nuclear plants play an increasingly important role after 2030.
- Interconnection capacities increase steadily but provide a smaller share of flexibility over time compared to the other Net Zero scenarios.

What does 2050 look like?

- Total electricity generation capacity is 281 GW, plus a further 48 GW of electricity storage and interconnection. Electricity generation output is well over twice that of today at 839 TWh, with 82 TWh exported.
- Wind, solar, nuclear and BECCS provide 91% of generation output. Gas CCS and hydrogen provide less than 4% of generated electricity but play an important role in meeting Security of Supply.
- There is a large net export of electricity over the interconnectors across the year; this helps manage renewable generation output.
- The power sector delivers 44 $MtCO_2e$ of negative emissions through BECCS.

FES 2022 / The Energy System / Electricity Supply 275

What we've found

Scenarios overview: Electricity Supply

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- This scenario sees the most ambitious growth in renewable technologies, reaching the Government's target of 50 GW of offshore wind by 2030 and continuing to increase through the 2030s. It also sees high levels of onshore wind growth.
- BECCS generation is developed ahead of 2030.
- Nuclear generation remains steady after the deployment of SMR demonstration plants in the early 2030s.
- Natural gas generation is phased out rapidly, with no capacity remaining after 2035. Alternative flexible generation technologies including hydrogen need to be ramped up rapidly ahead of this date.

What does 2050 look like?

- Total electricity generation capacity is 284 GW, plus a further 79 GW of electricity storage and interconnection, meeting lower annual and peak demands than the other Net Zero scenarios. Electricity generation output is three times that of today at 814 TWh, with 108 TWh exported.
- Wind, solar, nuclear and BECCS provide 94% of generation output; these are supported by high levels of interconnection and storage and some flexible hydrogen generation to meet peak demands.
- There is a net export over the interconnectors.
- The power sector delivers 21 $MtCO_2e$ of negative emissions through BECCS.

FES 2022 / The Energy System / Electricity Supply 276

Scenarios overview: Electricity Supply

Consumer Transformation

System Transformation

Leading the Way

Falling Short

The route to 2050

- Falling Short sees more gradual decarbonisation of the power sector.
- Growth in offshore wind continues, with 31 GW installed by 2030, but with more limited growth of onshore wind and solar.
- After 2035, there is limited phase-out of gas generation, offset by some growth of gas with CCUS and large scale new nuclear in the 2040s.
- Emissions from the power sector fall below 36 $MtCO_2e$ by 2030 and decline gradually after this point driven by the shift away from unabated gas. Interconnection capacity continues to grow up to 2030 while storage continues to gradually increase.

What does 2050 look like?

- Total electricity generation capacity is 236 GW, plus a further 35 GW of electricity storage and interconnection. Electricity generation output is over twice that of today at 622 TWh, with 76 TWh exported.
- Wind, solar, nuclear and BECCS provide 84% of generation. The electricity system is dominated by renewables, particularly offshore wind, but fossil fuels still play a key role, with gas generation, along with interconnectors, providing flexibility to support renewable generation and CCUS generation the highest across the scenarios.
- The power sector delivers 17 $MtCO_2e$ of negative emissions through BECCS.

FES 2022 / The Energy System / Electricity Supply 277

What we've found

Load factors

Load factors vary across the scenarios according to their mix, with the amount of renewable generation capacity influencing load factors across the whole energy system.

- Some technologies have low load factors, such as gas generation, but stay on the system for Security of Supply. Natural gas load factors keep reducing as renewable generation increases.
- Nuclear typically runs with higher load factors, running as baseload generation.
- Gas CCS does not run at baseload but operates at a higher load factor than hydrogen.
- Hydrogen generation operates with very low load factors in the Net Zero scenarios, as does unabated gas in Falling Short, indicating their role is primarily to support Security of Supply.
- Bioenergy with Carbon Capture and Storage (BECCS) plants run close to their full output when they are used, with a greater proportion being turned on in winter months to meet higher peak demands.
- The annual load factor of BECCS is higher in Leading the Way compared to the other Net Zero scenarios because its lower capacity relative to fuel availability allows it to run more.
- Load factors for offshore wind are higher than today, as technological advances improve efficiencies. Load factors for solar remain low, but total generation output increases due to a large increase in installed capacity. Load factors for renewable generation are capped by the variable nature of renewable energy resources.
- As capacity for wind generation increases, so too does the challenge of managing excess generation. In the Flexibility chapter, we discuss and how we can avoid this through flexible demand, but we are still likely to have some curtailment of generation. Our modelling assumes it is wind that is curtailed but this would depend on future market arrangements.
- Though our modelling focusses on the load factors of generation, it is important to note that utilisation of the network also varies by scenario. Coordinated planning ensures that location of key infrastructure and generation assets can be as efficient as possible for the whole energy system.

FES 2022 / The Energy System / Electricity Supply 278

What we've found

Load factor (also known as capacity factor)

Load factor is defined as how much electricity a plant produced compared to its potential for generation over the same period.

High load factor example: a 'base-load' generator, such as a nuclear plant, operating continuously at a steady state.

Low load factor example: unabated gas generation to only be used for meeting peak demands past 2035 in Consumer Transformation and System Transformation.

Variable renewable technologies typically have a substantially lower load factor than fossil fuel generation can potentially provide due to the nature of the resources they are harnessing. For example solar photovoltaic (PV) generation is limited by hours of daylight. Because we can't control when the wind is blowing or the sun is shining, the generation capacity required to meet annual demand is very high. When we cannot use excess generation, we must turn it off (curtailment), which potentially wastes electricity. There are several ways to manage this excess, such as electrolysis to produce green hydrogen, export via interconnectors, storage and demand side flexibility, where we vary the level of demand to match the level of available generation. These are discussed further in the flexibility section.

Average UK load factors over the last five years range from 11% for Solar PV, 27% for onshore wind and 40% for offshore wind through to 72% for plant biomass combustion (BEIS Energy Trends 2021).[5] This means that generating an equivalent amount of energy to that currently coming from fossil fuels requires significantly higher installed renewable capacity.

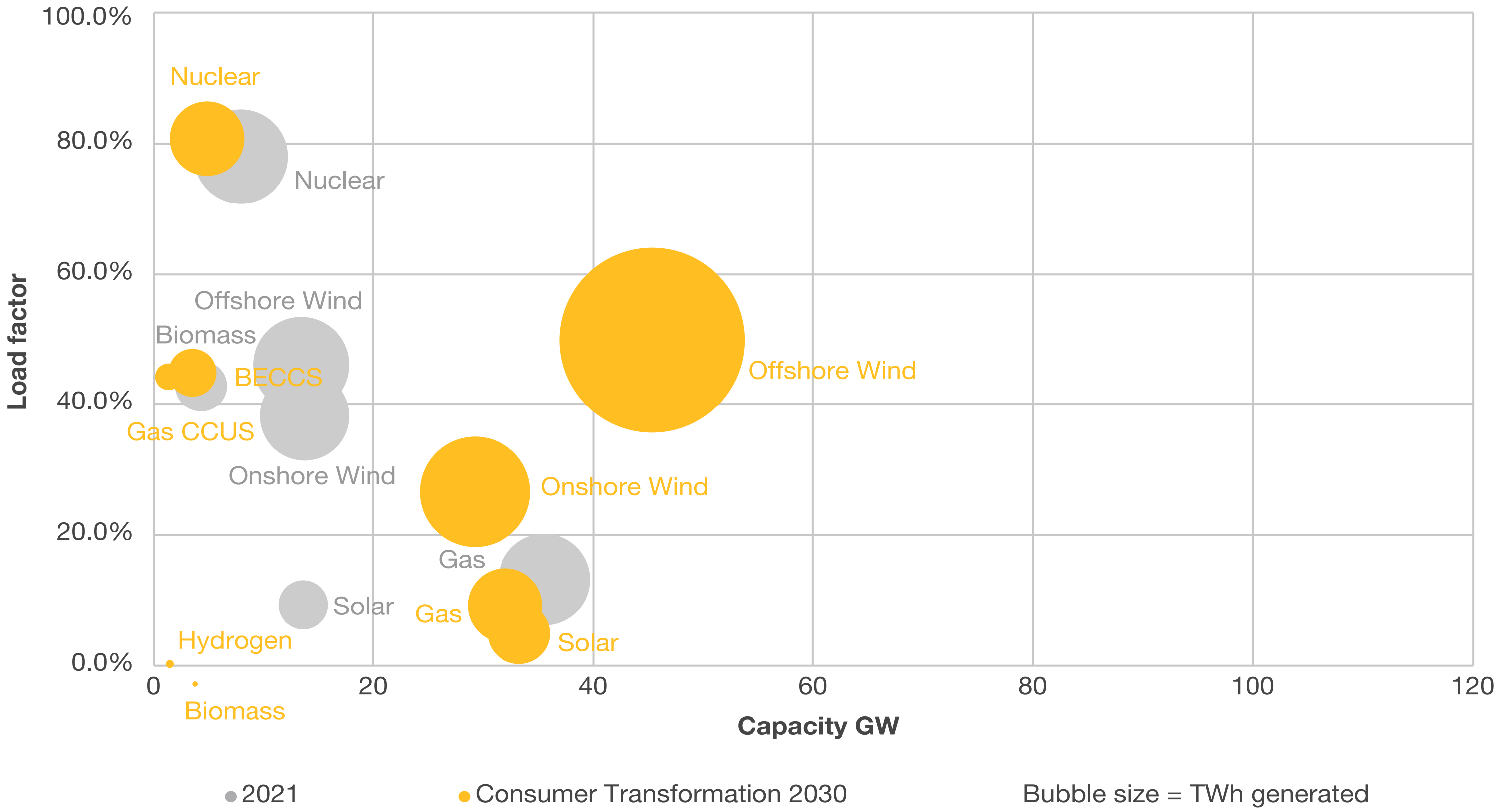
Larger wind turbines, particularly those offshore, have higher annual load factors, with those built in recent years getting up to 50%. Seasonal load factors for wind are typically higher in winter than summer due to higher average wind speeds.

5 gov.uk/government/collections/energy-trends

FES 2022 / The Energy System / Electricity Supply 279

What we've found

Figure ES.E.08: Load factor, Capacity (GW) and Generation (TWh) in Consumer Transformation



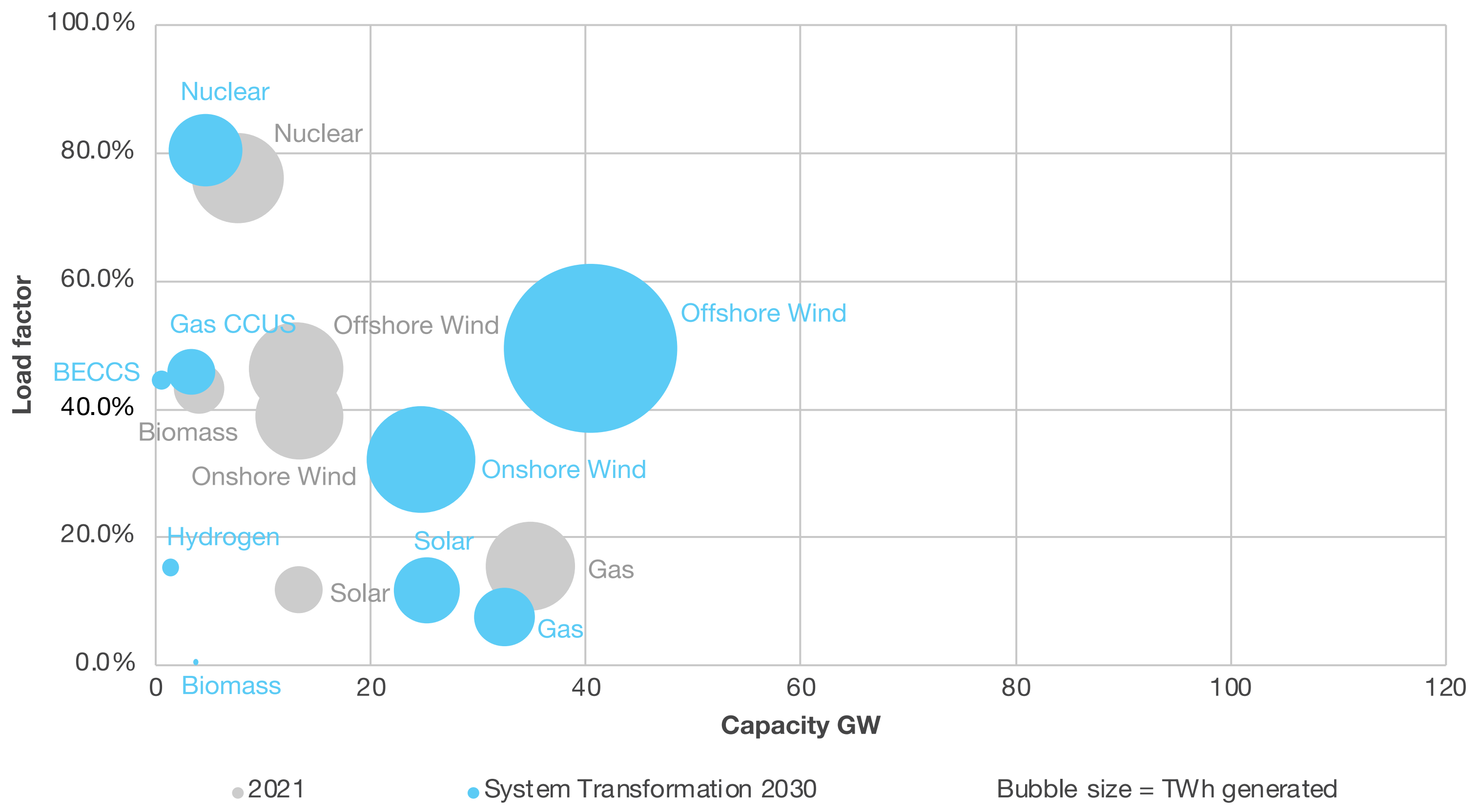
2030 Consumer Transformation | System Transformation | Leading the Way | Falling Short

The size of the circles in these charts shows the generation output (TWh). The scale is relative to other circles within the same chart. For accurate comparison of generation output between years, please refer to the Data Workbook.

FES 2022 / The Energy System / Electricity Supply 280

What we've found

Figure ES.E.08: Load factor, Capacity (GW) and Generation (TWh) in System Transformation



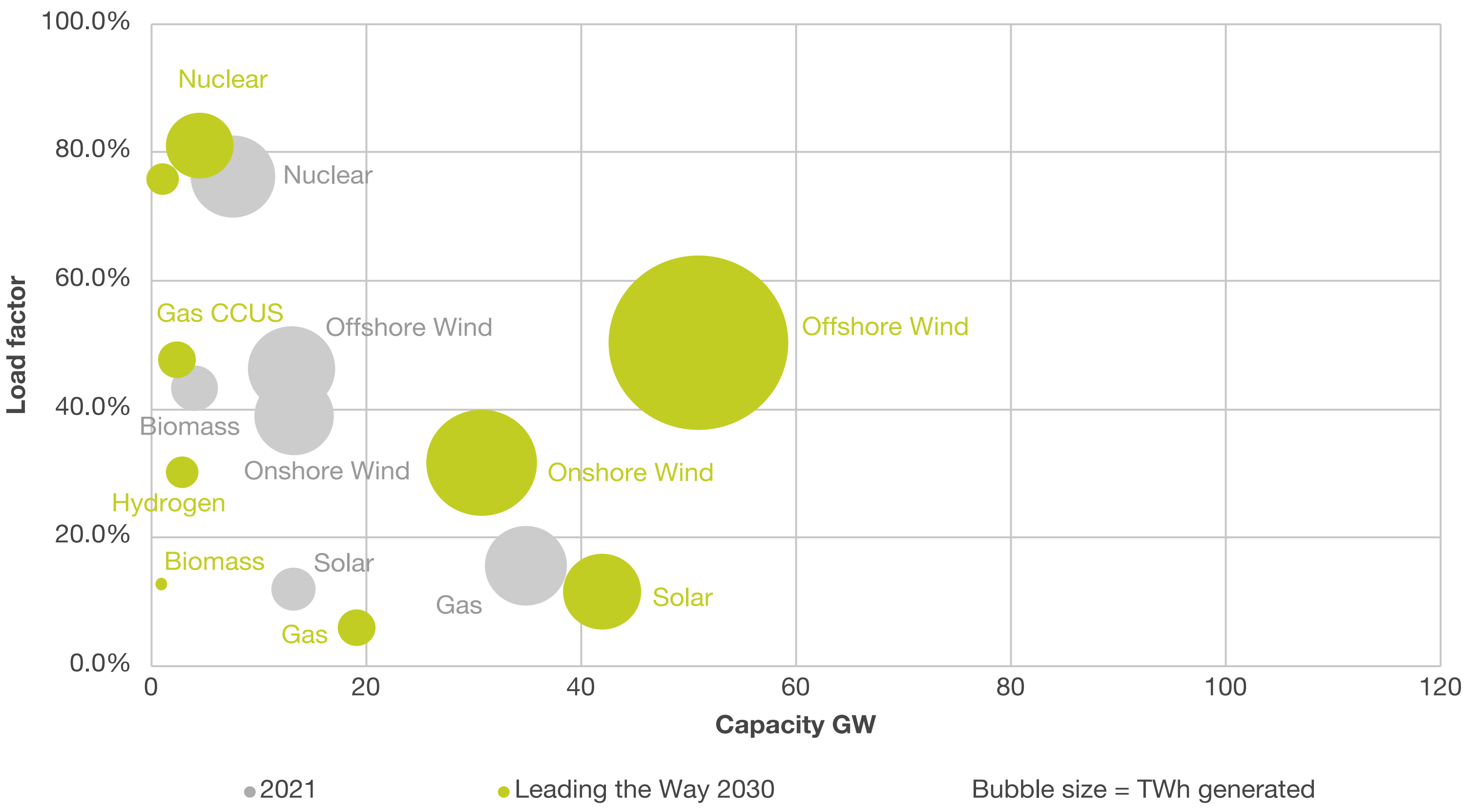
2030 Consumer Transformation | System Transformation | Leading the Way | Falling Short

The size of the circles in these charts shows the generation output (TWh). The scale is relative to other circles within the same chart. For accurate comparison of generation output between years, please refer to the Data Workbook.

FES 2022 / The Energy System / Electricity Supply 281

What we’ve found

Figure ES.E.08: Load factor, Capacity (GW) and Generation (TWh) in Leading the Way



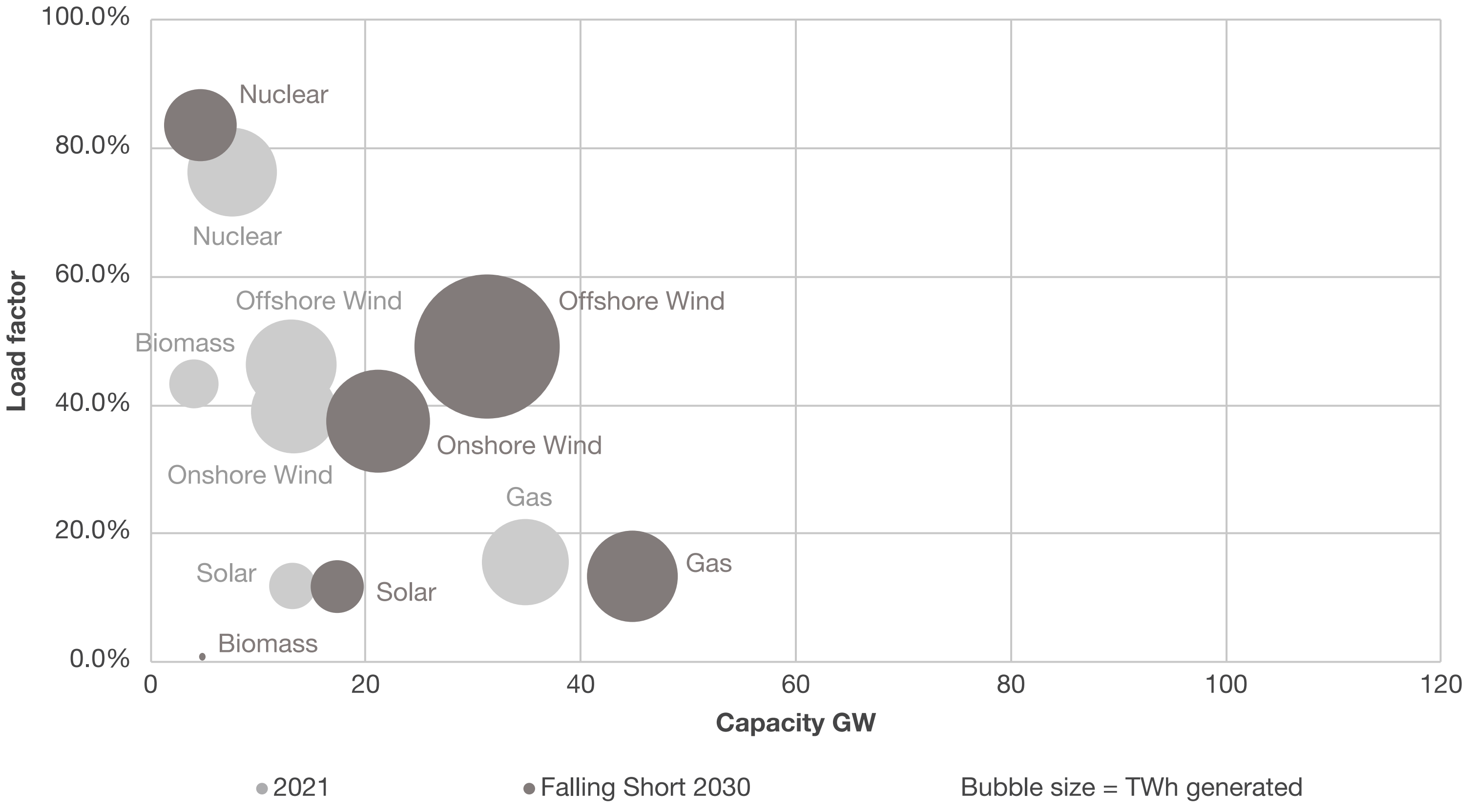
2030 Consumer Transformation System Transformation Leading the Way Falling Short

The size of the circles in these charts shows the generation output (TWh). The scale is relative to other circles within the same chart. For accurate comparison of generation output between years, please refer to the Data Workbook.

FES 2022 / The Energy System / Electricity Supply 282

What we've found

Figure ES.E.08: Load factor, Capacity (GW) and Generation (TWh) in Falling Short



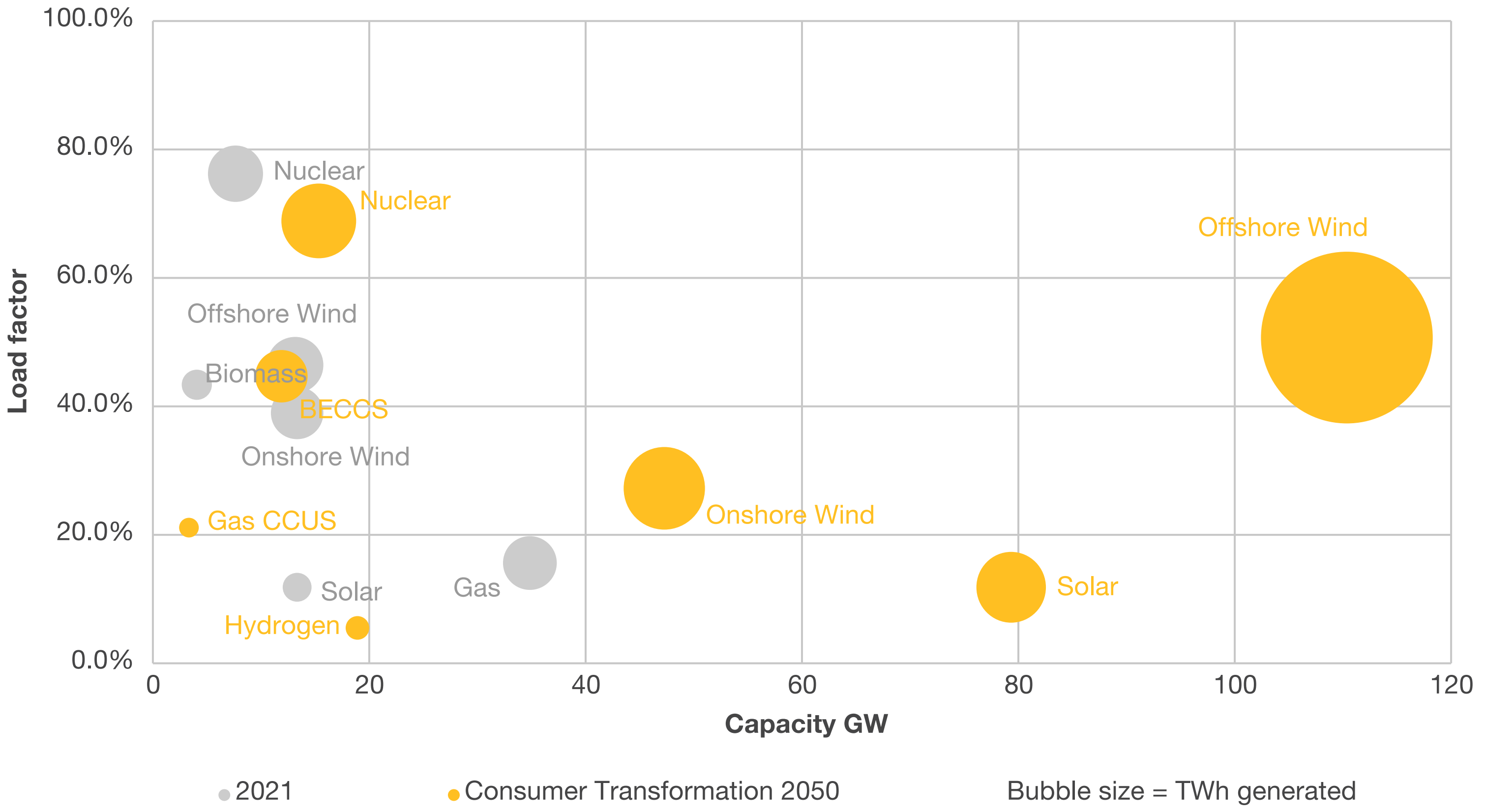
2030 Consumer Transformation System Transformation Leading the Way Falling Short

The size of the circles in these charts shows the generation output (TWh). The scale is relative to other circles within the same chart. For accurate comparison of generation output between years, please refer to the Data Workbook.

FES 2022 / The Energy System / Electricity Supply 283

What we've found

Figure ES.E.09: Load factor, Capacity (GW) and Generation (TWh) in Consumer Transformation



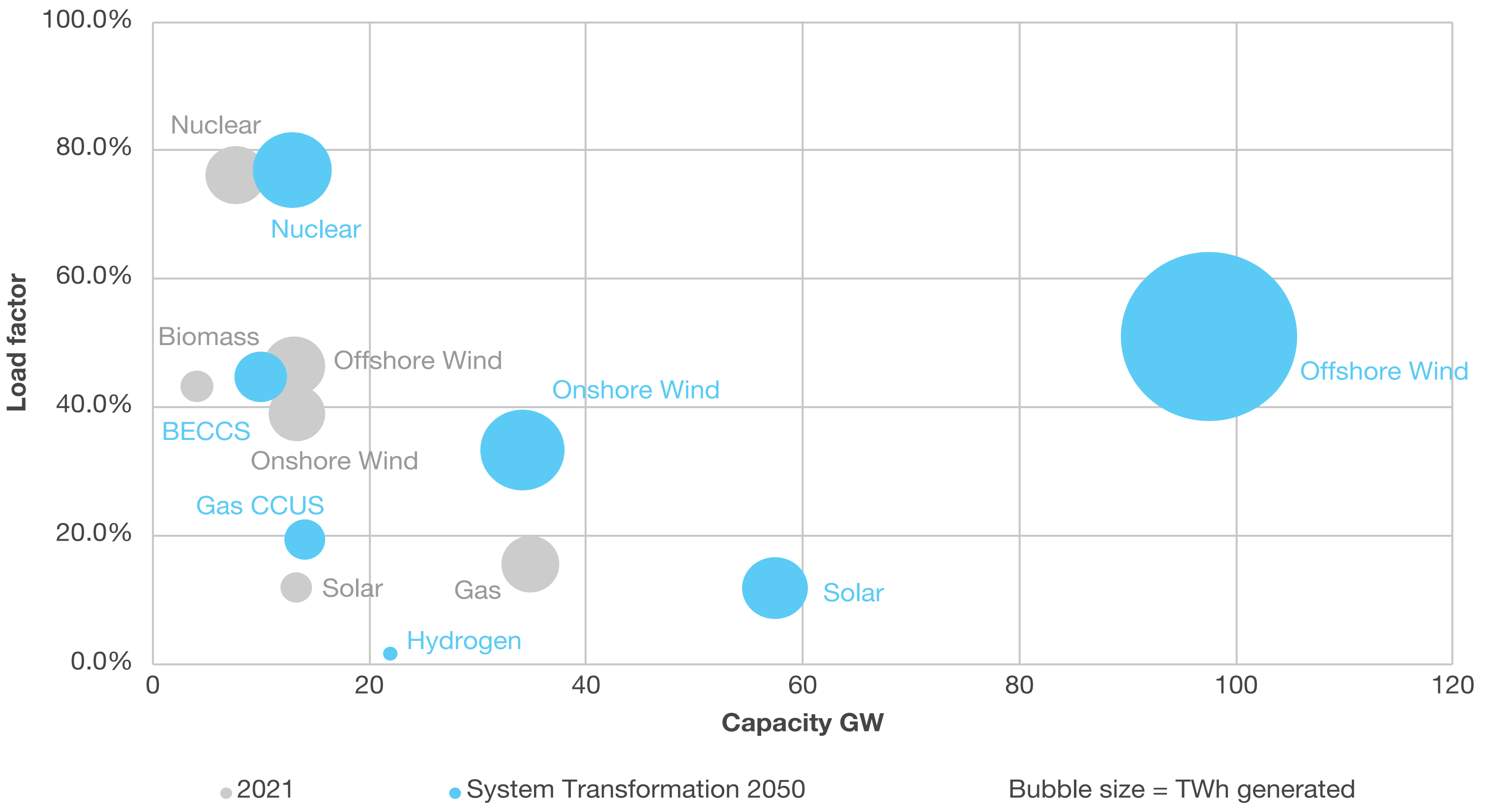
2050 Consumer Transformation | System Transformation | Leading the Way | Falling Short

The size of the circles in these charts shows the generation output (TWh). The scale is relative to other circles within the same chart. For accurate comparison of generation output between years, please refer to the Data Workbook.

FES 2022 / The Energy System / Electricity Supply 284

What we've found

Figure ES.E.09: Load factor, Capacity (GW) and Generation (TWh) in System Transformation



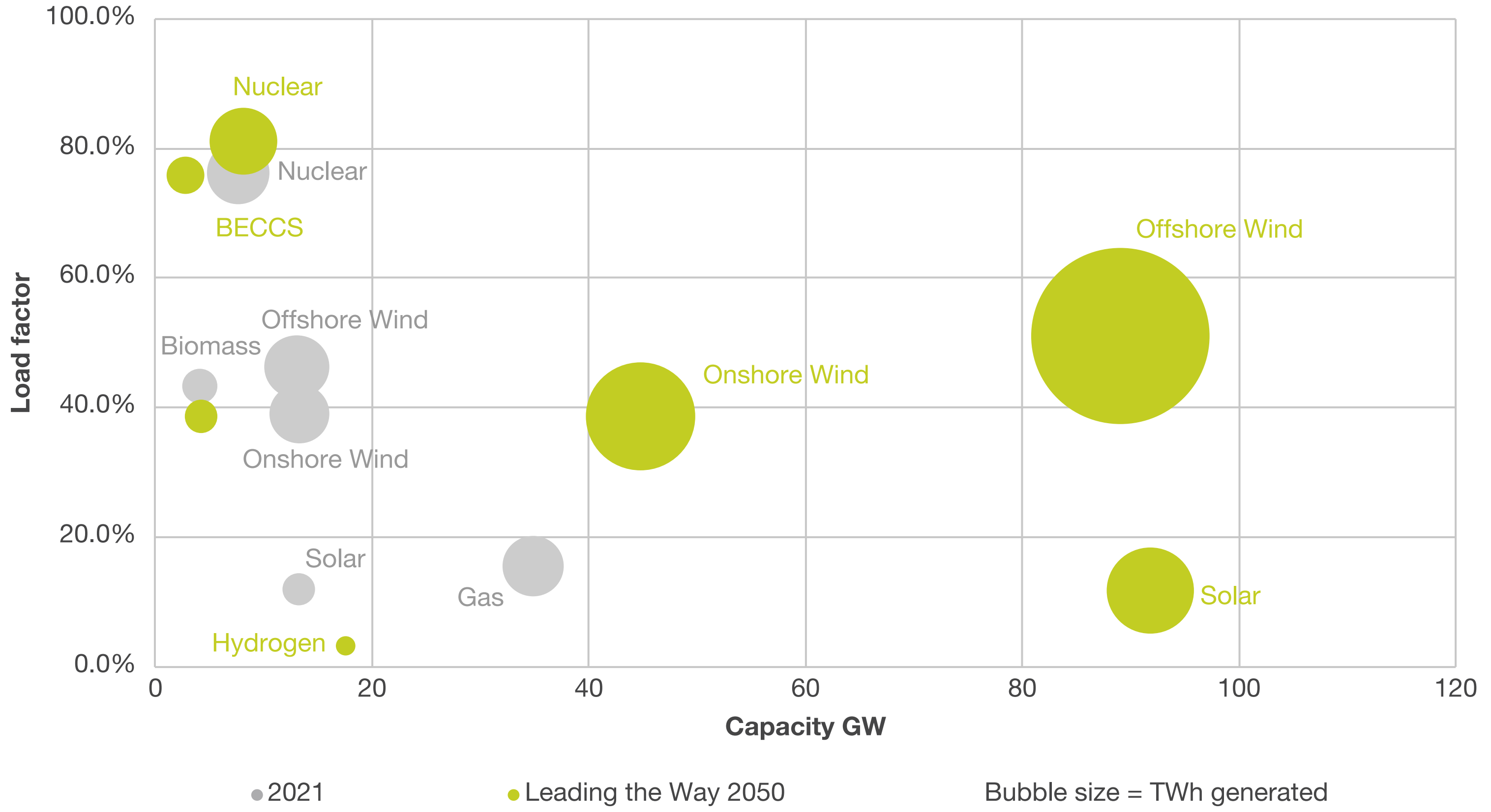
2050 Consumer Transformation | System Transformation | Leading the Way | Falling Short

The size of the circles in these charts shows the generation output (TWh). The scale is relative to other circles within the same chart. For accurate comparison of generation output between years, please refer to the Data Workbook.

FES 2022 / The Energy System / Electricity Supply 285

What we've found

Figure ES.E.09: Load factor, Capacity (GW) and Generation (TWh) in Leading the Way

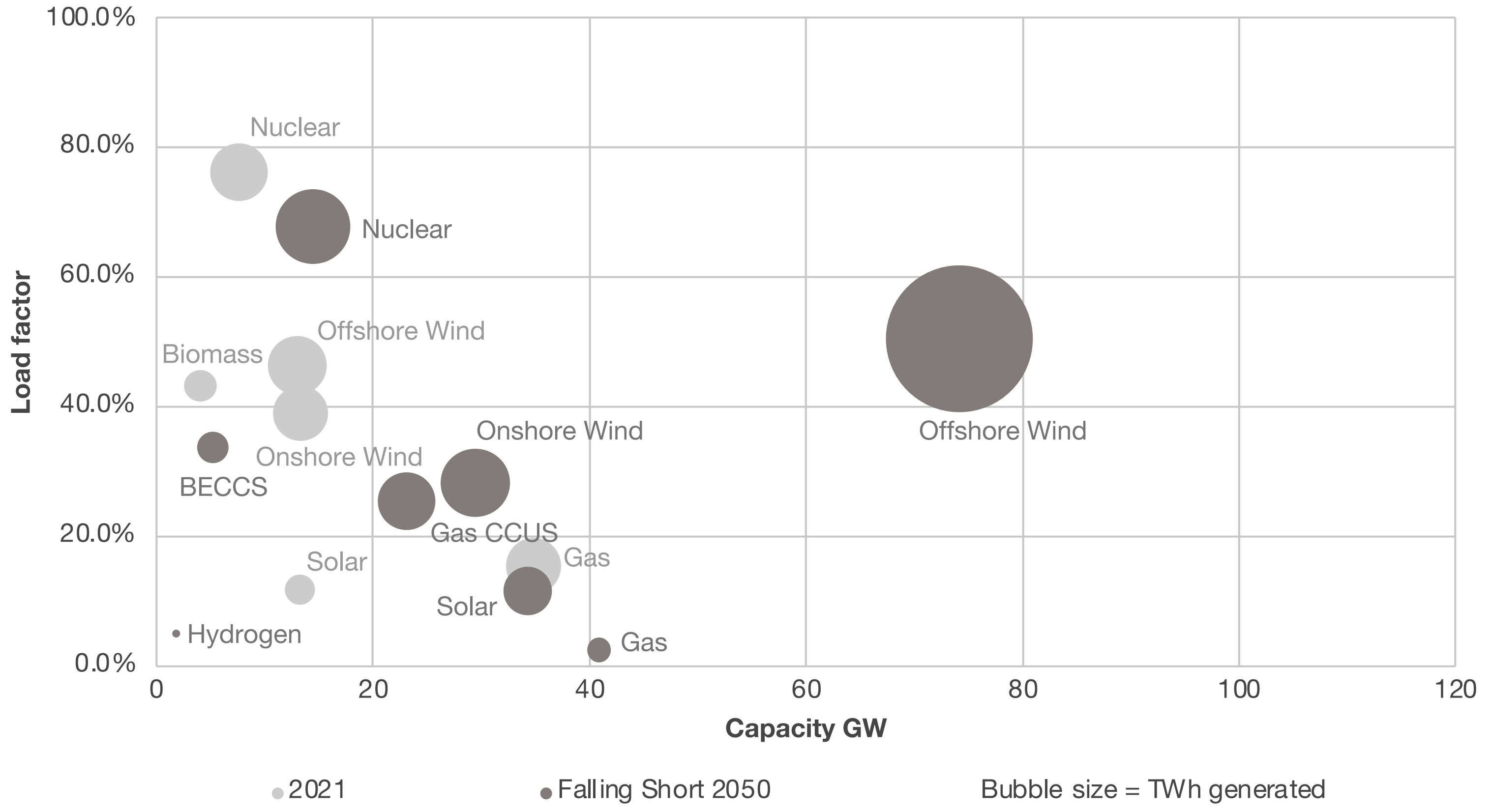


2050 Consumer Transformation System Transformation **Leading the Way** Falling Short

FES 2022 / The Energy System / Electricity Supply 286

What we've found

Figure ES.E.09: Load factor, Capacity (GW) and Generation (TWh) in Falling Short



2050 Consumer Transformation System Transformation Leading the Way Falling Short

The size of the circles in these charts shows the generation output (TWh). The scale is relative to other circles within the same chart. For accurate comparison of generation output between years, please refer to the Data Workbook.

FES 2022 / The Energy System / Electricity Supply 287

Carbon intensity

Power sector carbon emissions are expected to fall rapidly in the early 2020s in all scenarios.

The carbon intensity of electricity generation has fallen significantly as we have reduced coal-based generation and increased renewable generation. Between 2013 and 2021, it dropped by 65% from 529 gCO_2/KWh to 188 gCO_2/KWh. By 2050, we expect the carbon intensity of electricity generation to become net-negative through the use of BECCS. BECCS plants come online from the late 2020s in the Net Zero scenarios and the carbon intensity of electricity generation becomes net negative before 2035. In the Net Zero scenarios, these negative emissions are eventually enough to offset the residual emissions in the rest of the power sector and hard to abate sectors. The role of negative emissions is discussed in more detail in the Net Zero chapter.

Excluding BECCS, carbon intensity in the power sector falls below 10 gCO_2/kWh by 2044 in all Net Zero scenarios. These are from sources with low levels of annual output such as energy from waste and in System Transformation some residual emissions from gas CCUS generation.

In Falling Short carbon intensity peaks in 2024 and falls to -12 gCO_2/kWh by 2050 (17 gCO_2/kWh without BECCS). This is driven by the shift from unabated gas generation to gas CCUS, with unabated gas capacity primarily remaining on the system to support Security of Supply. In the Net Zero scenarios, gas generation reduces rapidly through the 2020s and 2030s.[6]

Carbon intensity rises in the next few years as nuclear plants are decommissioned but this is followed by the commissioning of Hinkley Point C in the mid to late 2020s, which contributes to emissions falling after 2024 in all scenarios. Integration of renewable generation is central to decarbonisation in all scenarios. In its 2022 report on Mitigation of Climate Change, the IPCC highlights wind and solar generation as the most cost-effective (net lifecycle cost) and far-reaching ways to decarbonise the economy, followed by demand reduction and energy efficiency.[7]

6 These charts represent an unconstrained dispatch. In reality, emissions would be higher when renewables are constrained off for network reasons and have to be replaced by fossil fuel generation. The Data Workbook includes an estimate of what the emissions would be in a real, constrained network for the first five years of the scenarios.
7 report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf, page 51.

Figure ES.E.10: Future CO_2 intensity of electricity generation (gCO_2/kWh)

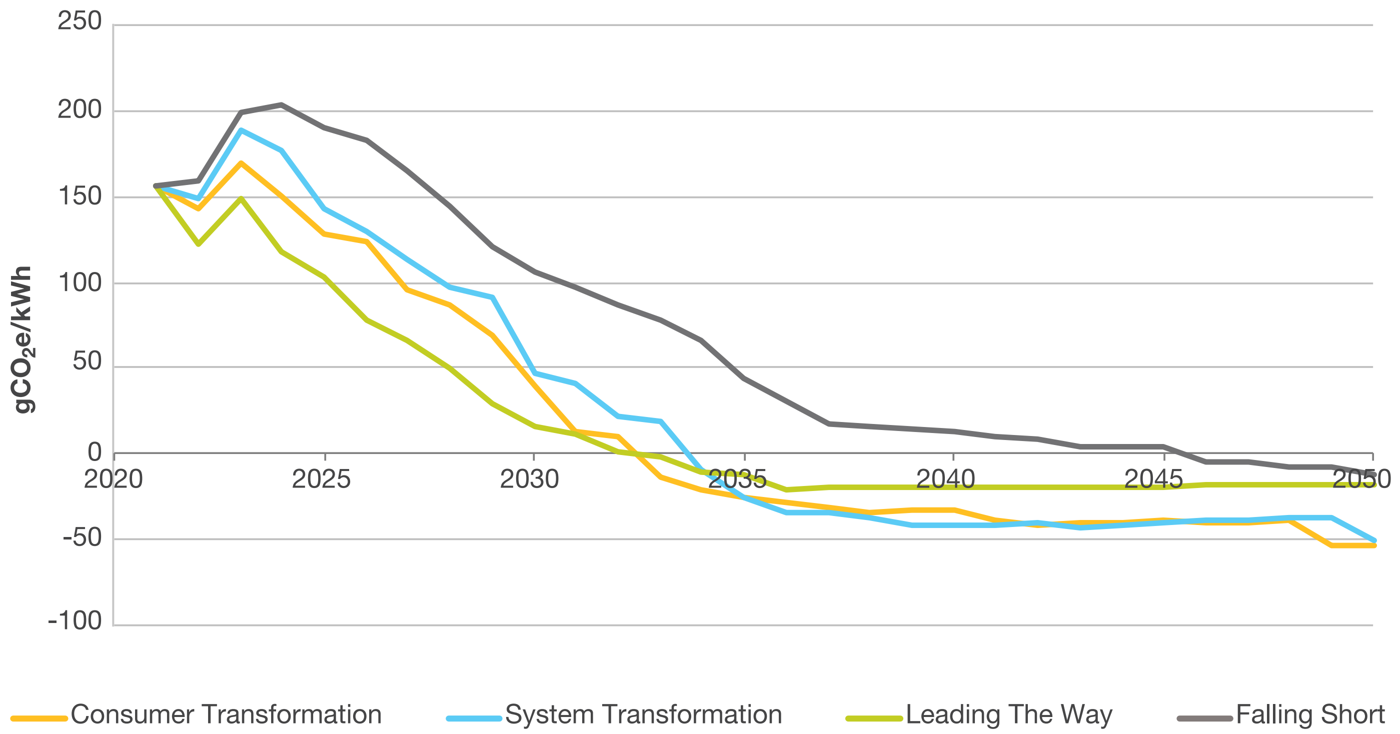
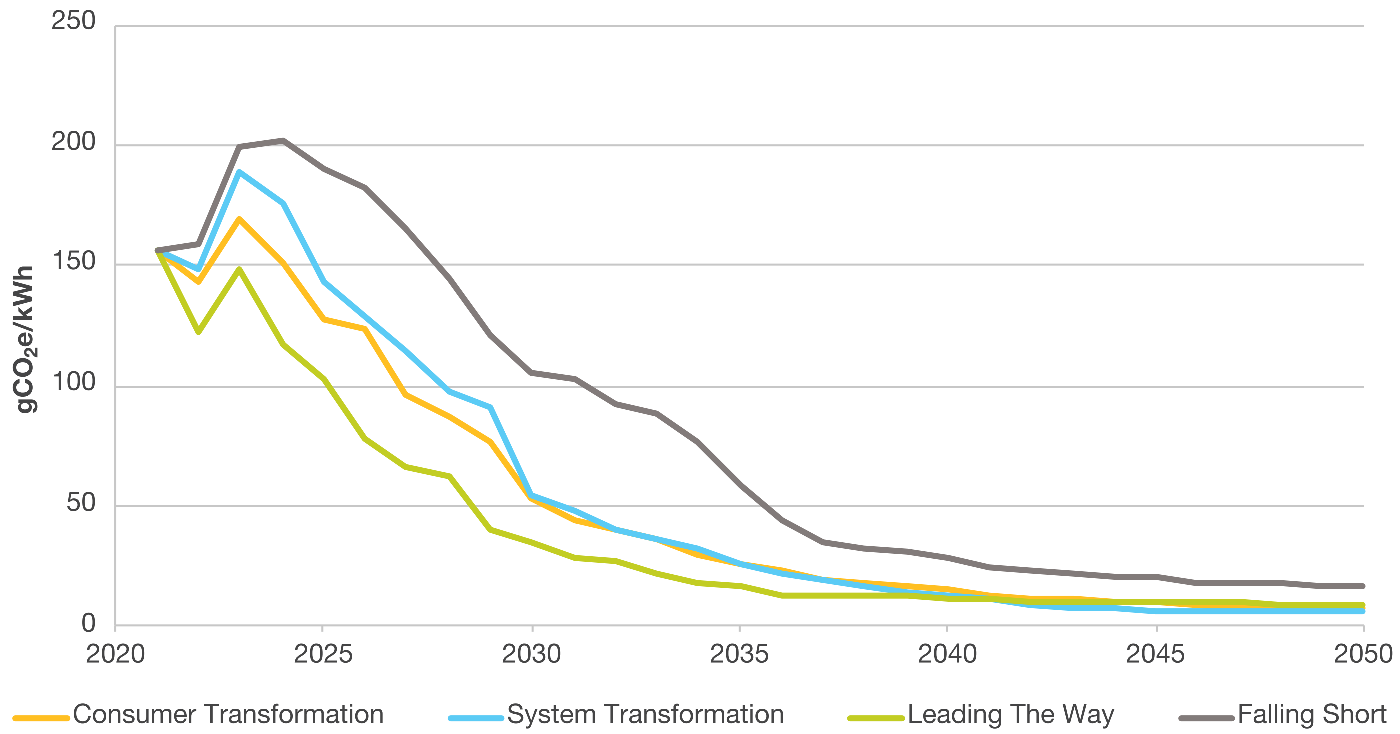


Figure ES.E.10: Future CO_2 intensity of electricity generation excluding negative emissions from BECCS (gCO_2/kWh)

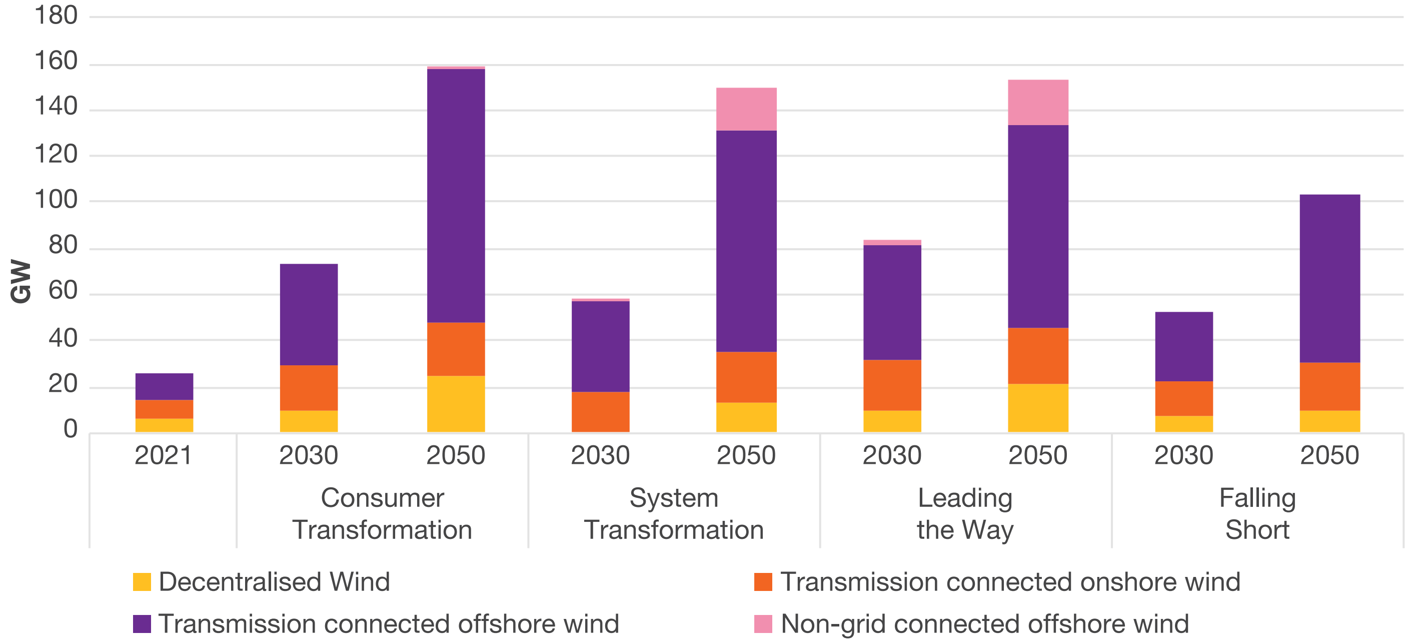


FES 2022 / The Energy System / Electricity Supply 289

Wind

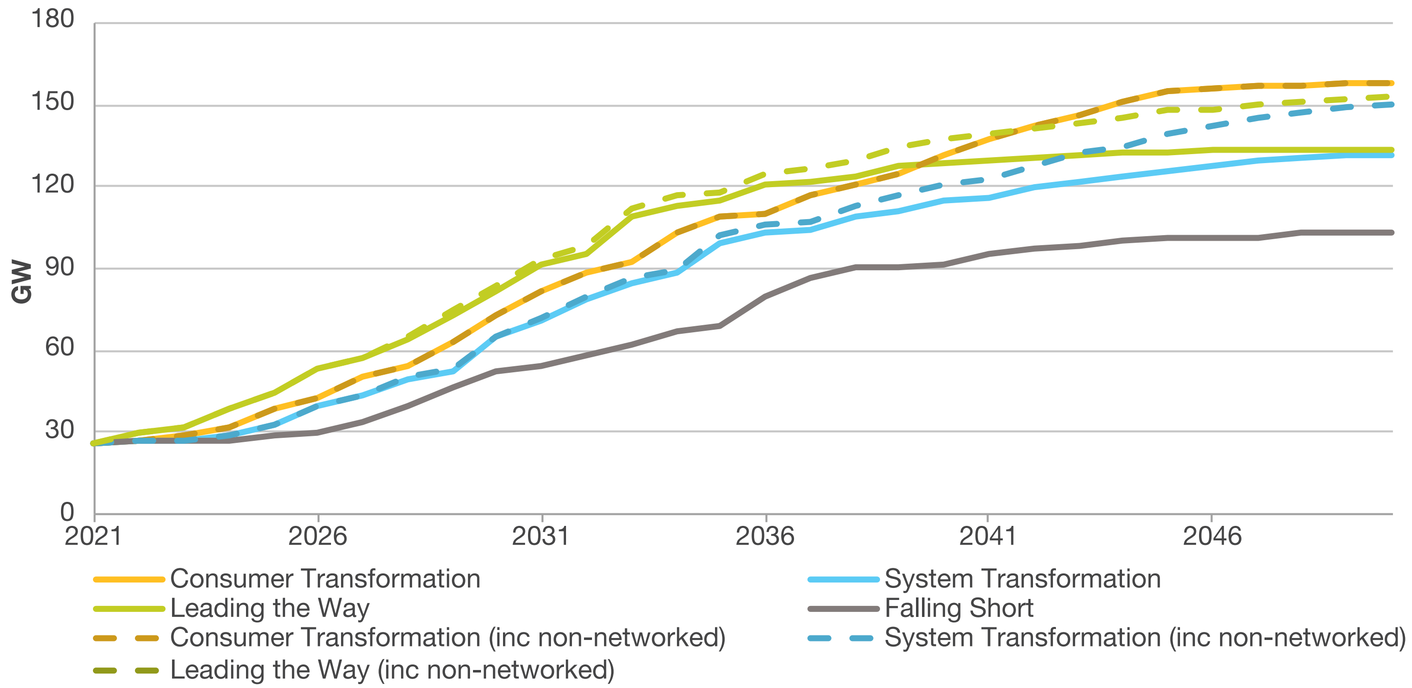
Total wind capacity increases in all scenarios, mainly driven by a growth in offshore wind. Scenarios with high societal change have higher levels of onshore wind.

Figure ES.E.11: Installed wind generation capacity (GW)



By 2030, and on into 2050, wind generation capacity is larger than any other source in all scenarios. The UK's territories include many sites which are suitable for different types of wind generation and much of the conversation about the future of energy in GB relates to how we integrate this potential supply into the energy system. This can be achieved through improved flexibility as well as siting the generation in a way that's efficient for the whole energy system.

Figure ES.E.12: Total wind generation capacity (onshore and offshore)



Wind

Figure ES.E.13: Installed offshore wind generation capacity (GW)

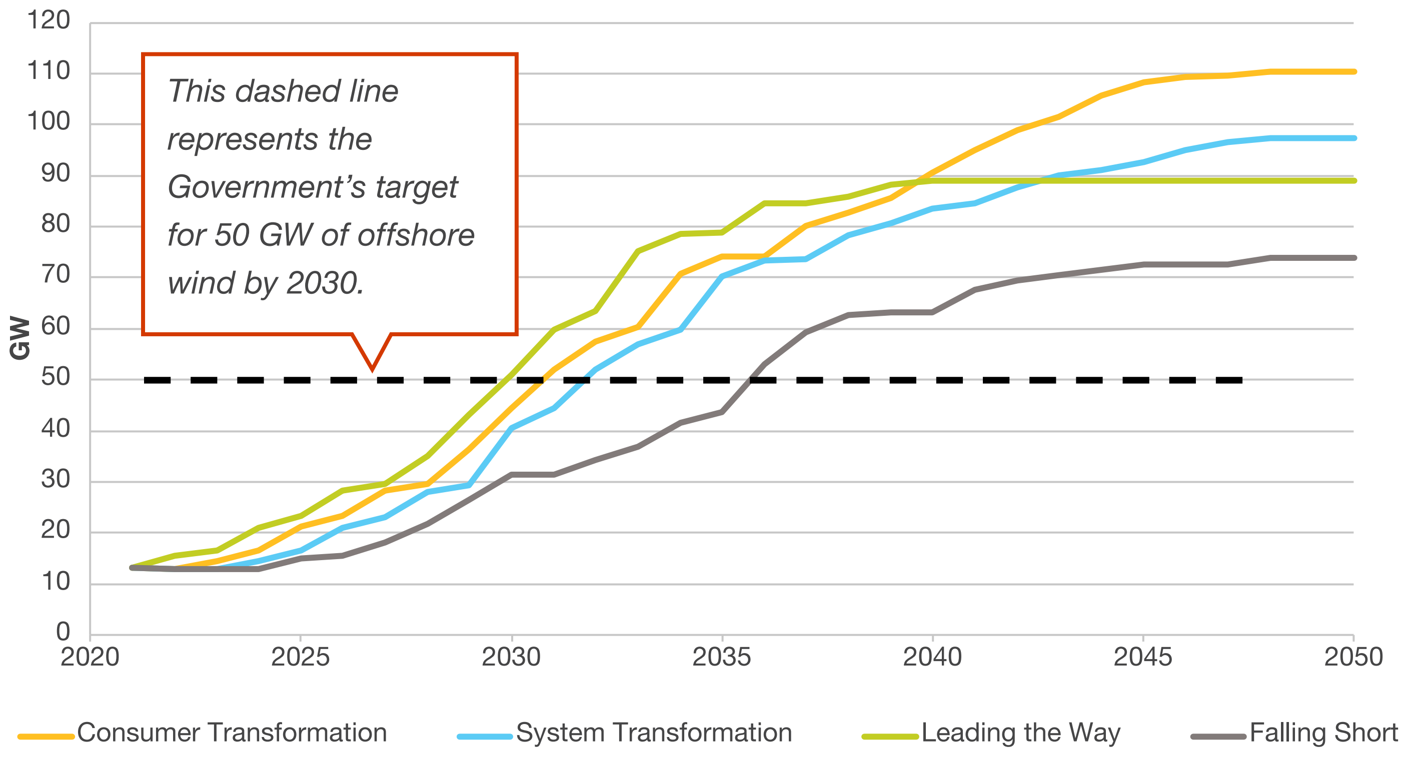
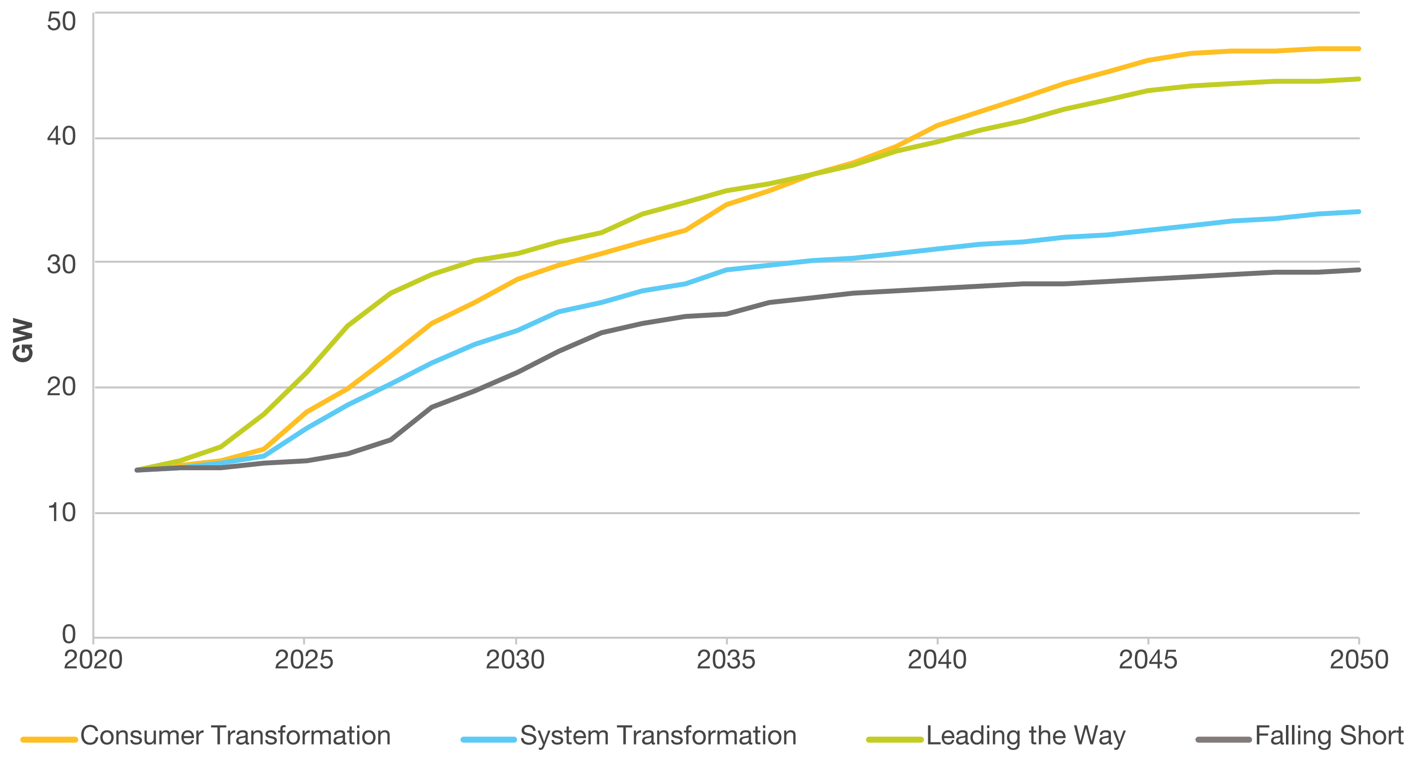


Figure ES.E.14: Installed onshore wind generation capacity (GW)



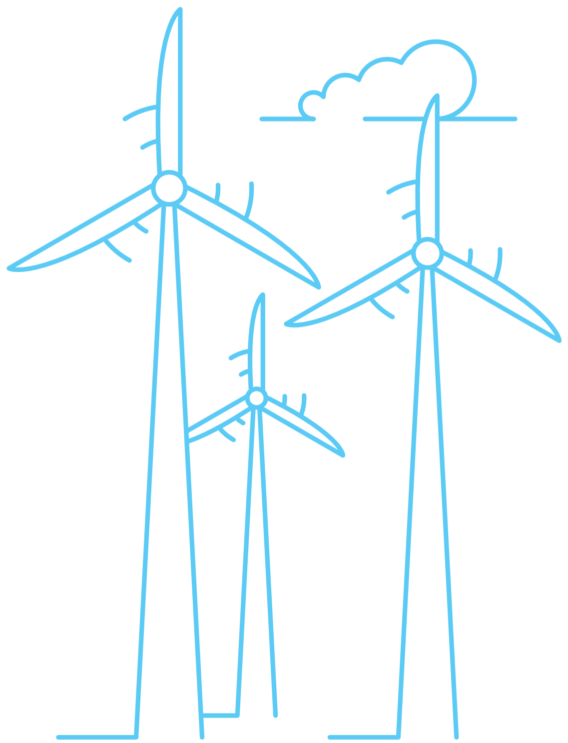
Generation capacity

In Leading the Way, the UK's recent ambition for 50 GW of offshore wind by 2030 is met and the other Net Zero scenarios are close behind. Even Falling Short reaches 50 GW in 2036. Appetite for investment is already present today but the British Energy Security Strategy plans to address potential deployment issues in relation to grid connection, turbine size, physical constraints, supply chain capacity and the length of the planning process. Physical constraints include port and installation fleet capacity. Our current max installation capacity is around 4 turbines per day, but we need to be closer to 6 per day to meet the UK's target. Supply chains are also stretched with competition from wind developers around the world though we expect clearer notice and processes for capacity auctions to help with this.

The pipeline of potential wind projects has continued to increase, from all around the UK, underlining its potential for providing the future backbone of GB electricity supply. An example of this was the ScotWind auction[8] which awarded 17 sites leases for 25 GW of offshore capacity, over half of which was for floating wind. In the British Energy Security Strategy, the Government raised its ambition for floating offshore wind by 2030 from 1 GW to 5 GW. This will significantly increase our wind resource using deep-water sites.

Even in our slowest decarbonising scenario, Falling Short, we expect a rapid and large increase in wind capacity which will require significant network investment. Offshore generation requires infrastructure to bring the power onshore and to move it from coastal landing points to demand centres. Our work on the Offshore Coordination Project will streamline the process, with offshore connections reducing the need for individual cables coming to shore for each wind farm. In the Net Zero scenarios, there is also a need to replace any ancillary services that were previously provided by natural gas generation. This network investment is an essential, no-regret action which we must take immediately to transition to more secure, cleaner, affordable energy in the long term.

While future offshore wind projects will be transmission connected, there is a mix of transmission and distribution connection for onshore wind, with higher take up of transmission-level onshore wind in Scotland. This take-up happens much more rapidly in the scenarios with higher levels of societal change, with Consumer Transformation doubling network-connected onshore wind capacity to 29 GW by 2030 and reaching 47 GW in 2050. In System Transformation and Falling Short, lower levels of societal change result in greater local opposition and difficulty gaining planning permission but capacity still increases to exceed 29 GW by 2050 in all scenarios. In Leading the Way and System Transformation, we see some non-network connected wind generation which is used to power electrolysis for hydrogen production. In Leading the Way, it is also used to power some DACCS plants directly.



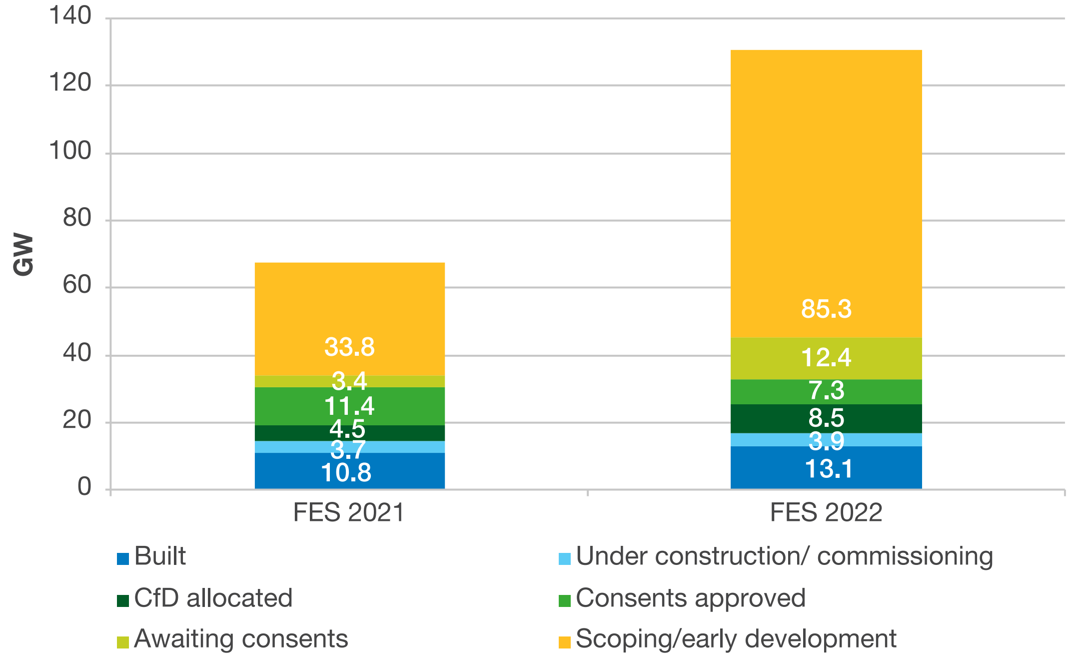
8 crownestatescotland.com/news/scotwind-offshore-wind-leasing-delivers-major-boost-to-scotlands-net-zero-aspirations

FES 2022 / The Energy System / Electricity Supply 292

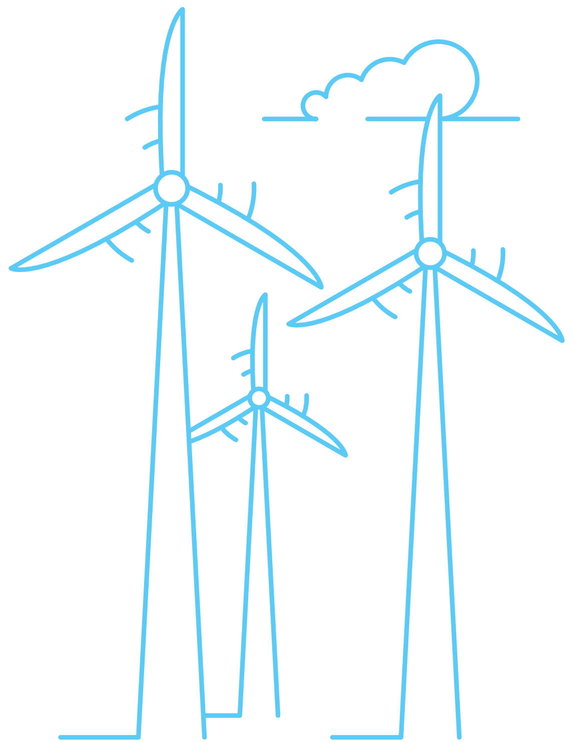
Significant increase in the offshore wind pipeline since FES 2021

We expect between 50% (Falling Short) and 60% (Leading the Way) of projects to make it from scoping through to being built. Investor confidence is very high and the real growth in the project pipeline has meant FES 2022 is far less reliant on ‘generic unnamed’ projects, which simulate potential proposals which we would expect to see in future.

Figure ES.E.15: Increase in offshore wind generation capacity pipeline between FES 2021 and FES 2022



Wind pipeline (GW at each stage)	FES 2021	FES 2022
Scoping/early development	33.8	85.3
Awaiting consents	3.4	12.4
Consents approved	11.4	7.3
CfD allocated	4.5	8.5
Under construction/ commissioning	3.7	3.9
Built	10.8	13.1



Generation capacity

Solar

We expect continued price reductions, such as the recent removal of VAT on domestic energy efficiency measures, to increase the uptake of solar panels through the late 2020s, although this growth is more limited in Falling Short. There are a wide range of outcomes for solar development across our scenarios, depending on factors including price reductions of solar panels and electricity network capacity.

In Leading the Way, our maximum solar generation scenario, solar generation is co-located with flexible technologies at different connection voltages (i.e. with electrolysis or grid-scale battery storage for solar farms and with domestic batteries for roof-top solar). There is also co-location of solar with electrolysis to produce hydrogen as well as high uptake of domestic solar. Co-location is seen in other scenarios to varying degrees.

There is day to day uncertainty due to weather but in general, solar generation is quite predictable over the course of a year and the position of the sun and its expected radiation levels over the year are well known. This means it can be a great asset for meeting annual demand levels, especially when coupled with suitable storage.

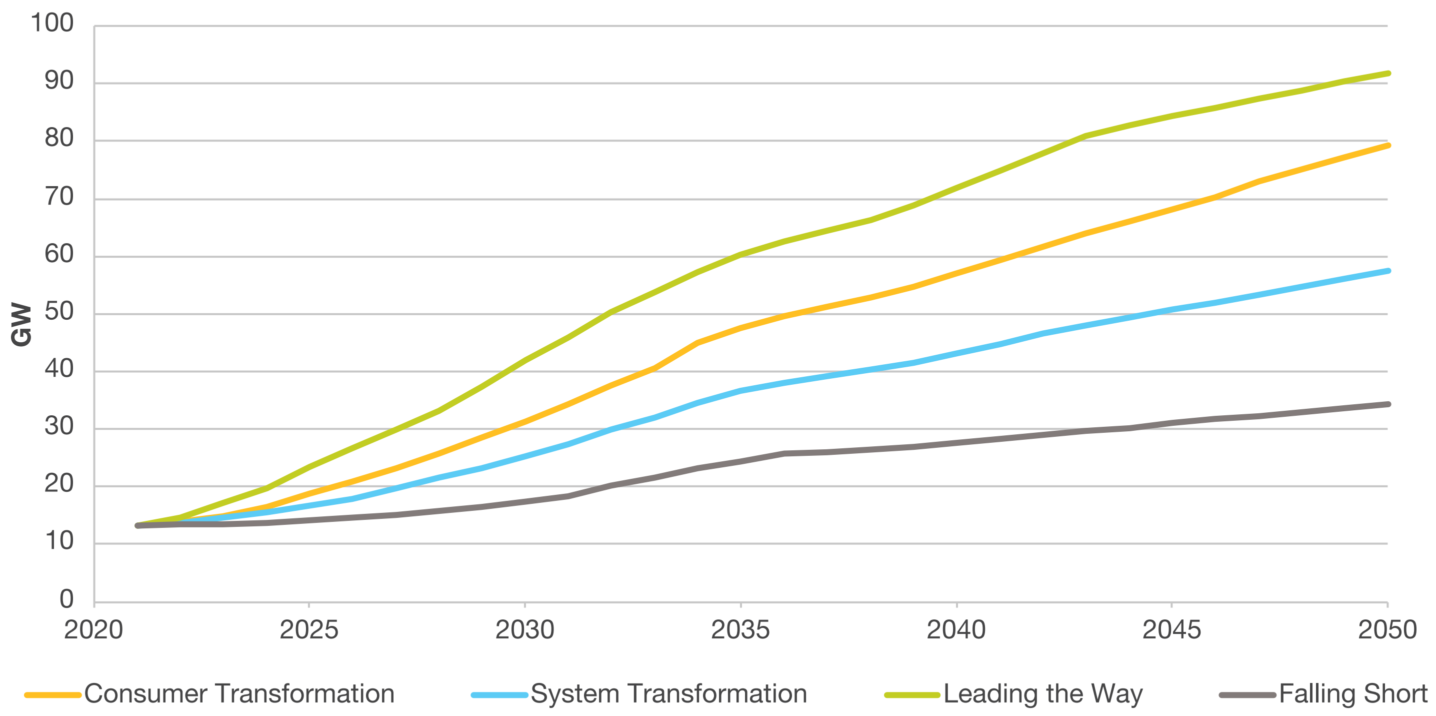
The case for homeowners, builders and businesses to install rooftop solar generation is growing. This is partly due to the rising cost of energy shortening payback periods but also higher energy efficiency standards for new homes. 400 MW per year of new solar capacity could be from new build houses by 2023.

The British Energy Security Strategy expects a five-fold increase in deployment of solar generation by 2035, with up to 70 GW installed. This generally aligns with our modelling for solar generation but is slightly higher than we see in Leading the Way.[9]

Potential blockers to further development include grid capacity and connections, land and planning, skills and the supply chain of solar panels (240 GW of new solar generation capacity could be deployed globally in 2023 alone[10]).

If an installer/operator can overcome these, the business case for solar generation is currently strong because of recent high electricity prices.

Figure ES.E.16: Installed solar generation capacity (GW)



9 Modelling for these scenarios was completed prior to the publication of the British Energy Security Strategy.
10 https://www.pv-magazine.com/2021/02/23/bloombergnef-expects-up-to-209-gw-of-new-solar-for-this-year/

FES 2022 / The Energy System / Electricity Supply 294

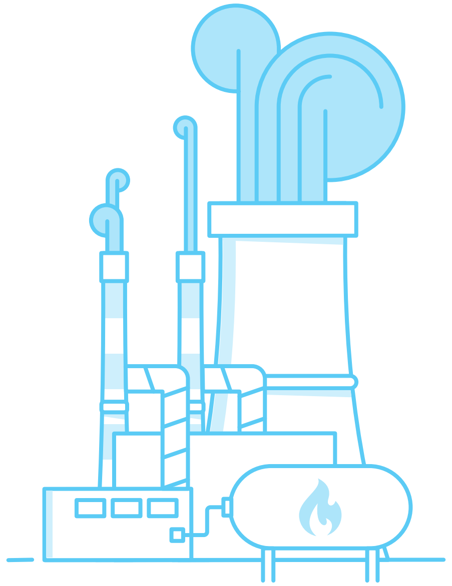
Fossil fuels

Natural gas fired generation continues to play an important role in the GB electricity mix, with significant capacity providing flexibility throughout the 2020s. This flexibility aids system operability and provides the flexibility needed to integrate renewable generation. However, our dependence on gas generation leaves electricity prices exposed to extreme changes in the wholesale price of gas; as well as it being a major source of GB's carbon emissions. Phasing out unabated natural gas capacity by 2035 will require immediate action on deployment of CCUS, hydrogen generation, long duration storage as well as reduction in peak demand (through efficiency measures).

The Climate Change Committee (CCC) has called for a complete end of unabated gas for power generation by 2035, subject to meeting Security of Supply. We expect unabated gas generation to decline steadily until it is phased out in our Net Zero scenarios. In System Transformation and Consumer Transformation, a small amount of gas generation capacity remains on the system to meet peak demand on rare occasions. In Leading the Way, no unabated gas generation capacity remains after 2035, partly because we invest earlier in other flexible generation, but also because of demand side action.

Natural gas generation with CCUS comes on in the late 2020s. While it plateaus in Leading the Way and Consumer Transformation, growth continues in System Transformation and Falling Short with the latter reaching over 20 GW of capacity by 2050. In System Transformation, this aligns to high use of CCUS in other sectors such as hydrogen production. In Falling Short, high levels of natural gas remain in use for sectors such as residential heating, but there is still a strong appetite for keeping carbon intensity of generation low to reap the decarbonisation benefits of transport electrification.

Coal generation continues to decrease as we see all remaining coal fired generation plants come off the system by 2024 in all scenarios, even after accounting for any service extension resulting from the British Energy Security Strategy.



Did you know: 2025 zero carbon operation

The ESO has an ambition to be able to operate the electricity system carbon free by 2025 and is developing the tools to deliver on this ambition. This means we will have transformed the operation of the electricity system such that we can operate it safely and securely at zero carbon whenever there is sufficient renewable generation on-line and available to meet the total national demand. To meet Net Zero, by 2035 the electricity system will need to be running without any unabated fossil fuel generation most of the time, with gas generation remaining on the system only as needed to support Security of Supply.

Generation capacity

Figure ES.E.17: Installed unabated natural gas generation capacity (GW)

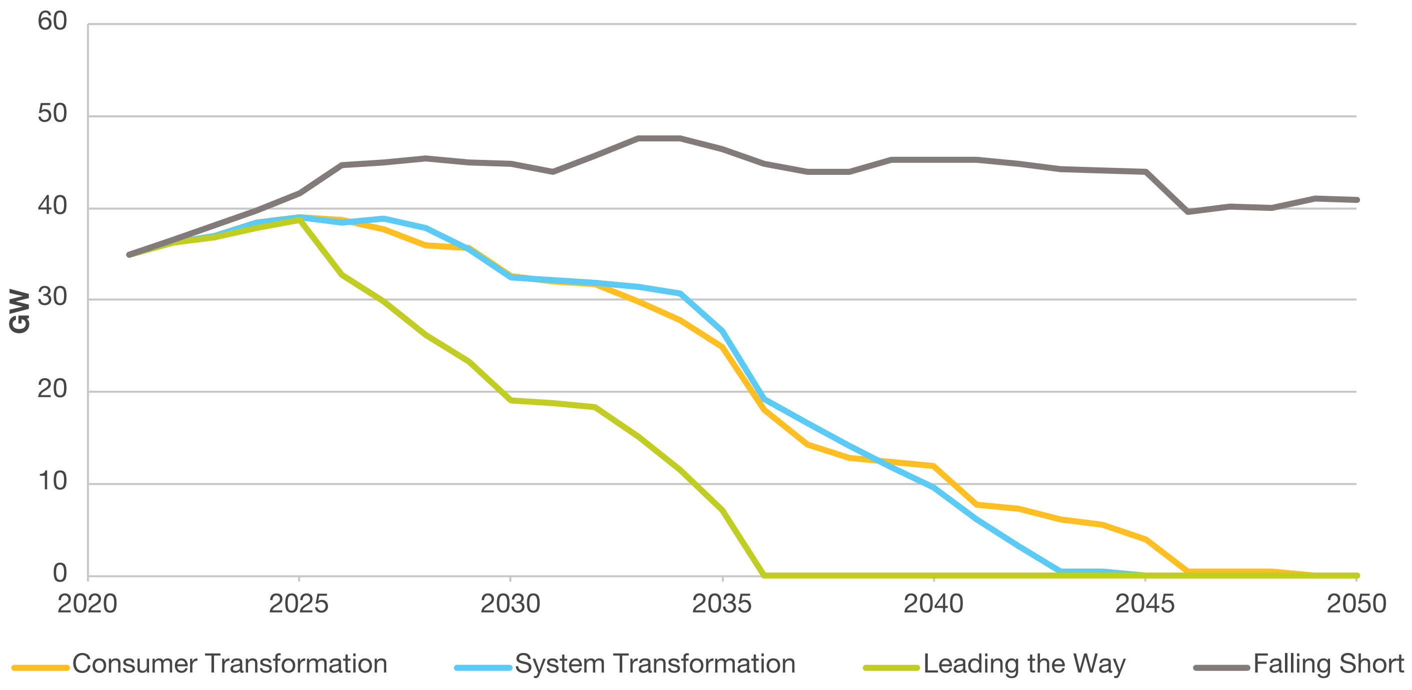
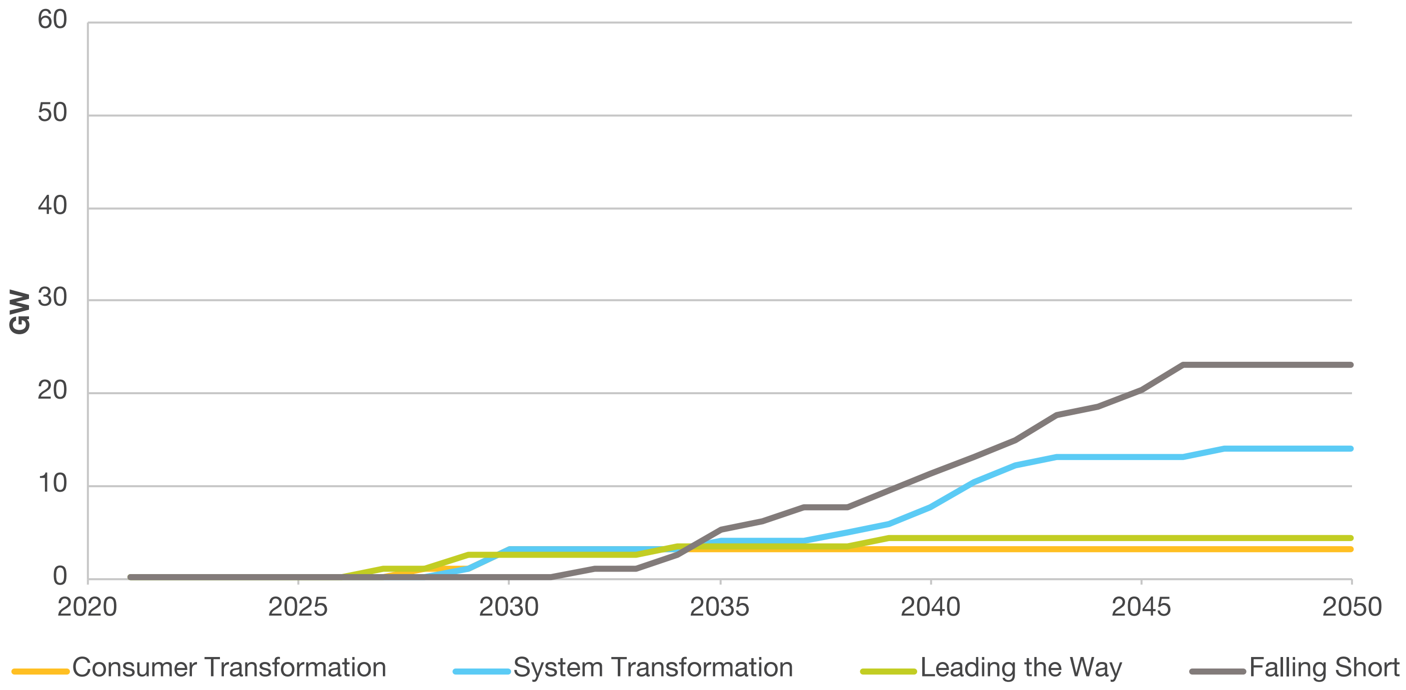


Figure ES.E.18: Installed abated (CCUS) natural gas generation capacity (GW)



FES 2022 / The Energy System / Electricity Supply 296

Bioenergy and BECCS

In FES, BECCS is primarily included to help decarbonise the economy by providing negative carbon emissions which offset residual emissions in sectors which are difficult to fully decarbonise. Leading the Way has the lowest levels of BECCS because it prioritises emissions reductions through behavioural change and Direct Air Carbon Capture and Storage (DACCS), an emerging technology which is made viable by the presence of excess renewable capacity and a way to access it at a competitive price. Negative emissions delivered from different sources are explored in more detail here.

In all scenarios, BECCS runs during winter months and is limited in summer months to avoid creating excess generation and to help meet higher energy demand over winter. Bioenergy plants provide a source of synchronised generation and ancillary services: essential to the reliable operation of future energy systems which are dominated by renewables. In 2050 we expect individual BECCS plant to operate at full output to achieve maximum efficiency, but with more units being brought online in the winter months.

We see the development of BECCS across the Net Zero scenarios in the late 2020s, after Carbon Capture Usage and Storage (CCUS) technology has been scaled up. There continues to be some biomass generation without CCUS, however this is minimal in the Net Zero scenarios due to the competition for limited bioresources from a range of sectors. The Bioenergy supply chapter explores the different sources of bioresources and the sustainability of the supply chain.

FES 2022 / The Energy System / Electricity Supply 297

Generation capacity

Figure ES.E.19: Installed BECCS generation capacity (GW)

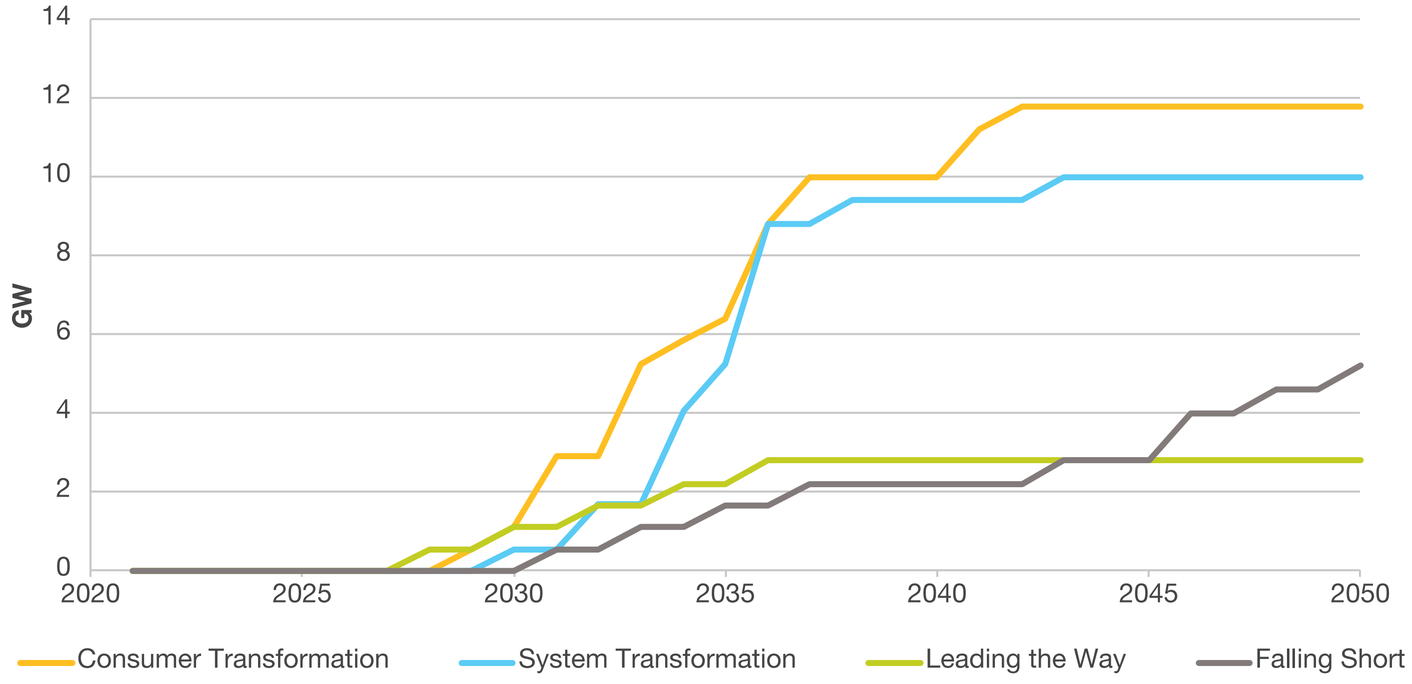
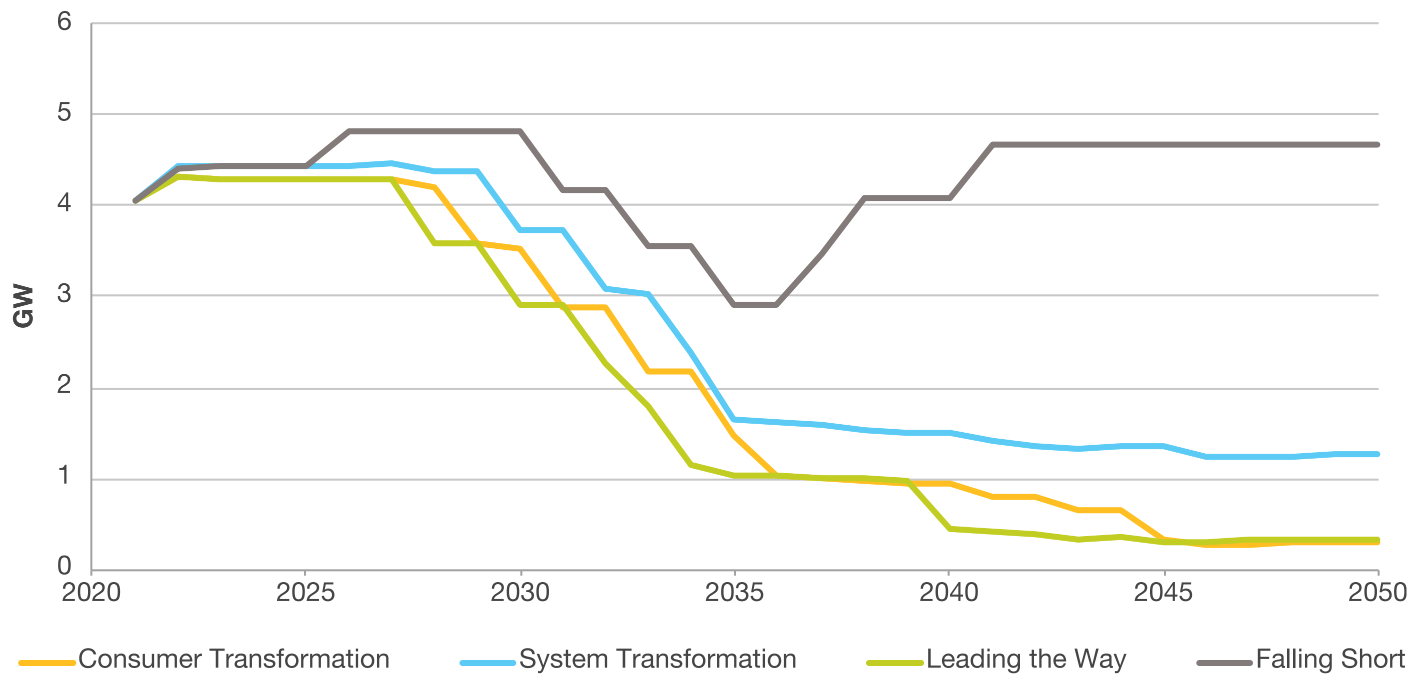


Figure ES.E.20: Unabated Biomass generation capacity (GW)



FES 2022 / The Energy System / Electricity Supply 298

Nuclear

Leading the Way sees the least amount of change in nuclear generation capacity between now and 2050 as decommissioning happens later and new nuclear is commissioned earlier which means we don't see such a pronounced drop around 2025 as we do in the other scenarios. By 2035, nuclear generation capacity stops growing in Leading the Way due to progress on energy efficiency and flexibility combined with growth in other generation technologies. In the other scenarios, we see faster decommissioning in the short term but a steady increase in capacity from the mid-2030s.

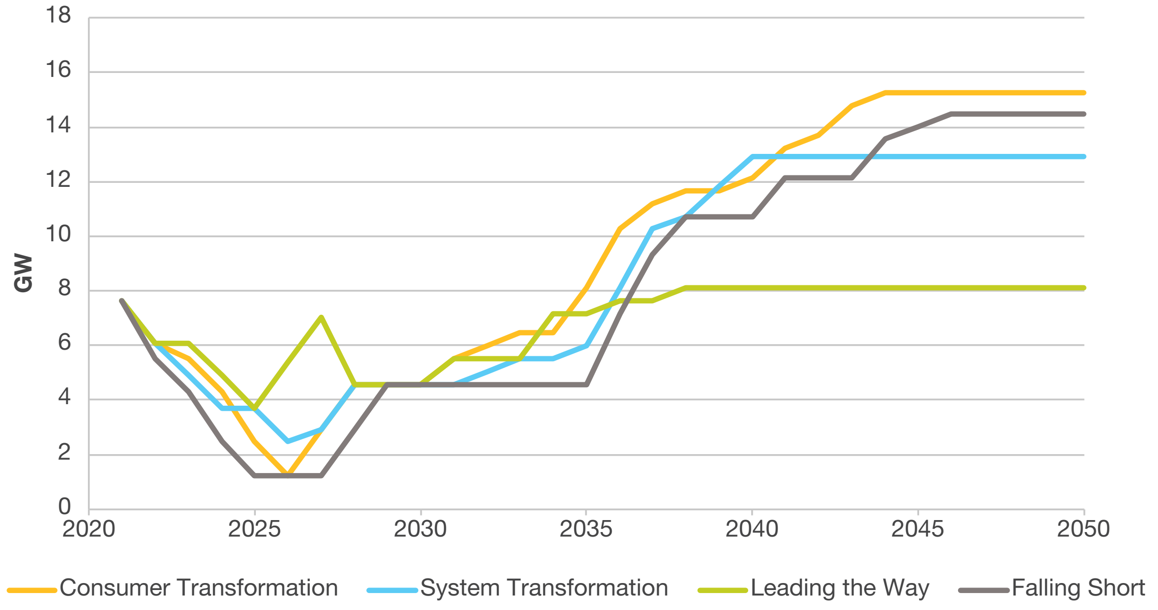
Nuclear generation will continue to be affected by stations reaching the end of their life through the 2020s. Hinkley Point C is expected to come online in the late 2020s which helps offset some of this decline, but nuclear capacity doesn't recover to current levels in any scenario until 2035. This is due to the very long lead times on new nuclear projects. While there are no other large-scale nuclear projects at advanced stages of development, the Government aims to bring one large nuclear project to final investment decision by the close of Parliament in 2024.

In FES, we assume nuclear runs as baseload with high load factors but note that it can be used to provide some flexibility when used in conjunction with hydrogen production by electrolysis. The heat produced by nuclear electricity generation helps to meet demand for low carbon heat, which also helps the economic case for nuclear.

Consumer Transformation relies primarily on Small Modular Reactors (SMRs), with the first of these deployed from the early 2030s in line with the aims of the Advanced Nuclear Fund to bring forward demonstrator projects. These are significantly smaller than the GW-scale traditional nuclear reactors and designed to be more easily replicable and scalable. System Transformation on the other hand primarily sees the development of traditional large-scale nuclear projects. The lower energy demands in Leading the Way mean there is only very limited new nuclear development after Hinkley Point C.

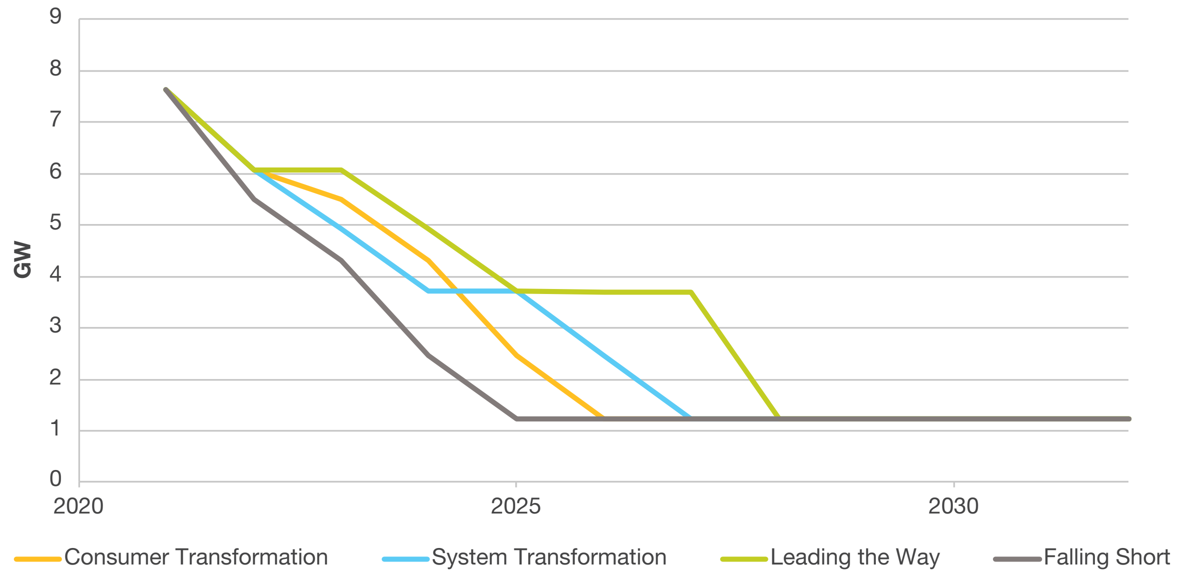
The British Energy Security Strategy includes an ambition for up to 24 GW of nuclear generation capacity in 2050. Our highest scenario, Consumer Transformation, grows to reach just over 15 GW in 2050. In this scenario, with high levels of renewable capacity, significant levels of baseload generation can be challenging as they contribute to curtailment issues at times of low demand and high renewable output. Higher levels of nuclear generation capacity could potentially be integrated if it was able to operate more flexibly in line with demand and renewable output. One way of doing this could be via hydrogen production through electrolysis being incorporated as part of the design and employed when electricity prices are low.

Figure ES.E.21: Installed nuclear generation capacity (GW)



FES 2022 / The Energy System / Electricity Supply 299

Figure ES.E.22: Nuclear plant decommissioning as shown by installed nuclear capacity of existing fleet (GW)



Small Modular Reactors (SMRs)

Small modular reactors offer an alternative approach to delivering nuclear power generation. A traditional nuclear power plant provides around 1-3 GW of capacity. SMRs are less than half that at 300-500 MW but at this size, they are roughly equal to a gas generation plant, so can be deployed as like for like replacements in terms of capacity. These could be delivered by a range of competing designs, though none are yet operational. They are assumed to be connected to the transmission system and located on existing sites of nuclear generation, but their smaller footprint does make them easier to locate. Their location will depend upon several factors such as land availability, proximity to the coast or suitable water supply, environmental and social factors and skills and capabilities in the local area. Multiple SMRs working together can also provide greater flexibility.

British Energy Security Strategy explains how The Nuclear Energy (Financing) Bill will enable a Regulated Asset Base (RAB) funding model for new nuclear projects. £210 million in Government funding has been pledged for Rolls Royce to develop SMR design.[11]

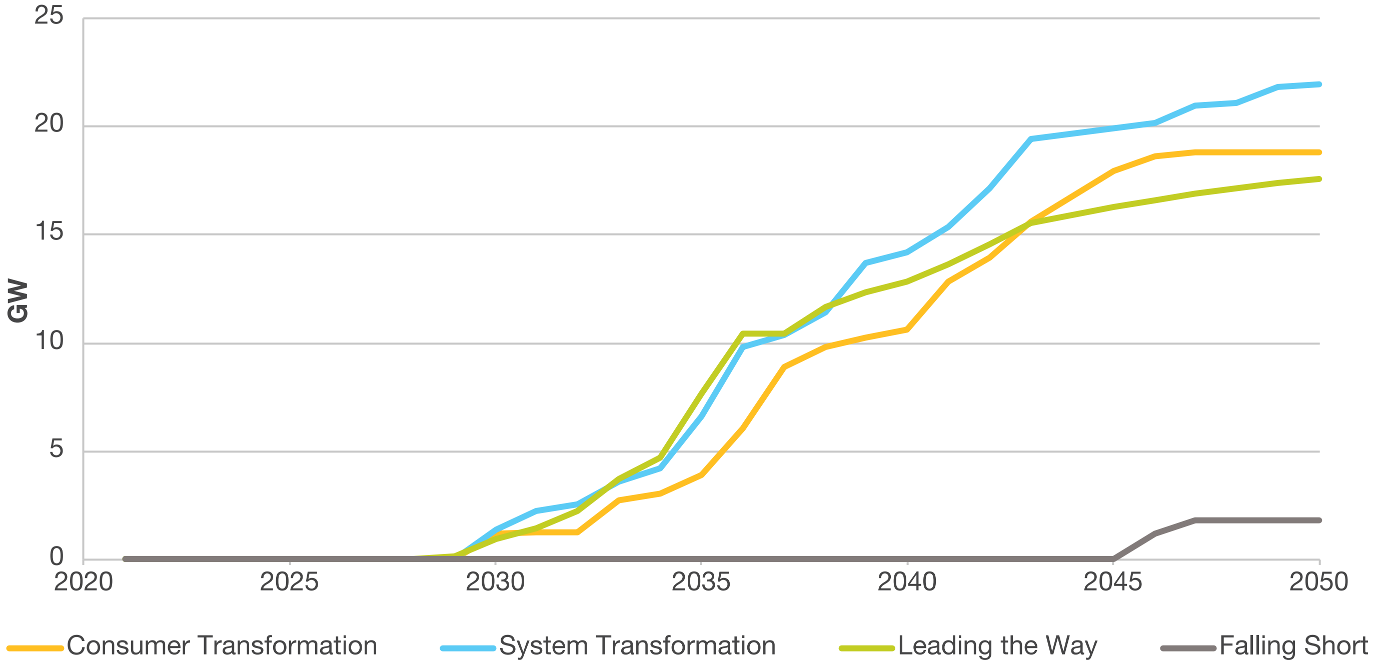
11 https://www.gov.uk/government/news/uk-backs-new-small-nuclear-technology-with-210-million

FES 2022 / The Energy System / Electricity Supply 300

Hydrogen

Hydrogen is used to generate electricity in all our scenarios. It is an essential part of a carbon neutral energy system even though it makes up less than 10% of electricity generation capacity in all scenarios. Its main use in the Net Zero scenarios is to manage periods of high demand and low renewable generation and may also be able to provide some ancillary services, which are provided by natural gas generation today. Unlike in the Net Zero scenarios, high levels of natural gas generation in Falling Short mean there is little need for hydrogen generation and only 1.8 GW of capacity exists by 2050.

Figure ES.E.23: Installed hydrogen generation capacity (GW)[12]



The overall process of hydrogen production and combustion for generation has a low energy conversion efficiency; however, high electricity prices when hydrogen turbines are running would make them competitive in the Net Zero scenarios. Some form of capacity-based support like the current Capacity Market may be needed to deliver enough generation capacity. Electrolysis paired with hydrogen peaking plants also offer wider benefits to the whole energy system, mainly as a source of flexible demand and peak generation.

For low annual running hours, we see hydrogen turbines as more cost-effective than gas with CCUS due to the high up-front costs of CCS technology; however, this balance shifts as annual output requirements increase. In System Transformation, the gas transmission network is converted to deliver hydrogen, so the highest level of hydrogen generation is seen in this scenario as projects can be developed across the country. The use of hydrogen in this scenario is important due to the lower levels of flexibility provided by consumers as the scenario sees lower levels of societal change.

In Leading the Way there is a 'hydrogen transmission backbone', connecting industrial clusters, and portions of the distribution network are converted to deliver hydrogen, where this is the best option. Where this does happen, we would expect to see the development of distribution-connected hydrogen generation. In Consumer Transformation, the absence of a hydrogen network means hydrogen generation is assumed to be sited close to sources of hydrogen production and storage sites.

12 Hydrogen blended into to natural gas network is counted as fossil fuel generation in FES.

FES 2022 / The Energy System / Electricity Supply 301

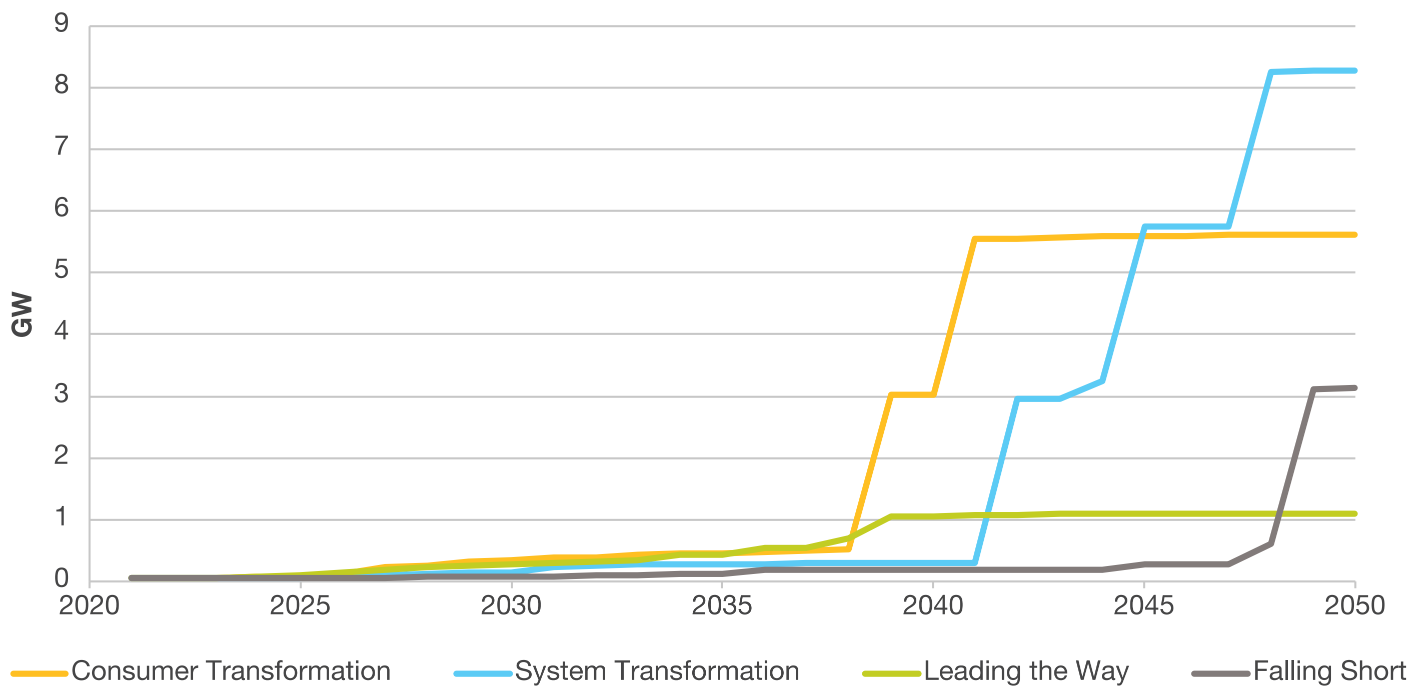
Marine

Marine energy generation uses the natural movement of water to produce electricity. This is a highly predictable form of generation, particularly for tidal generation. Though generation output varies through the course of a given day, total daily generation is very dependable. Tidal range works in a similar way as a hydroelectric dam, converting potential energy from water as it moves between high and low tide. This can be done by building artificial lagoons or by siting tidal barrage generation in natural choke points, such as the entry to a bay or estuary. Tidal stream uses turbines underwater to generate electricity directly from tidal flow, in much the same way as wind turbines do above the surface. The UK has some of the highest tidal ranges in the world with estimates of potential generation capacity ranging from 30 to 50 GW for all wave and tidal energy.

While marine generation technology is ready and the assets can have a long life, it is typically very expensive to install, which limits its deployment in our scenarios. Leading the Way sees the lowest installed capacity in 2050 as there is lower overall demand which is met by cheaper alternatives. In all scenarios we see many small tidal stream installations as well as wave generation. In Consumer Transformation, successive tidal range projects in the early 2040s bring capacity up to just over 5 GW by 2041. The same projects are completed slightly later in System Transformation, but they reach a greater capacity (just over 8 GW by 2050) to meet security of supply standards. The first tidal lagoon in Falling Short is operational just before 2050.

The British Energy Security Strategy has committed that £20 million per year will be ringfenced for Tidal Stream projects in an effort to bring costs down.

Figure ES.E.24: Installed marine generation capacity (GW)



FES 2022 / The Energy System / Electricity Supply 302

Interconnectors

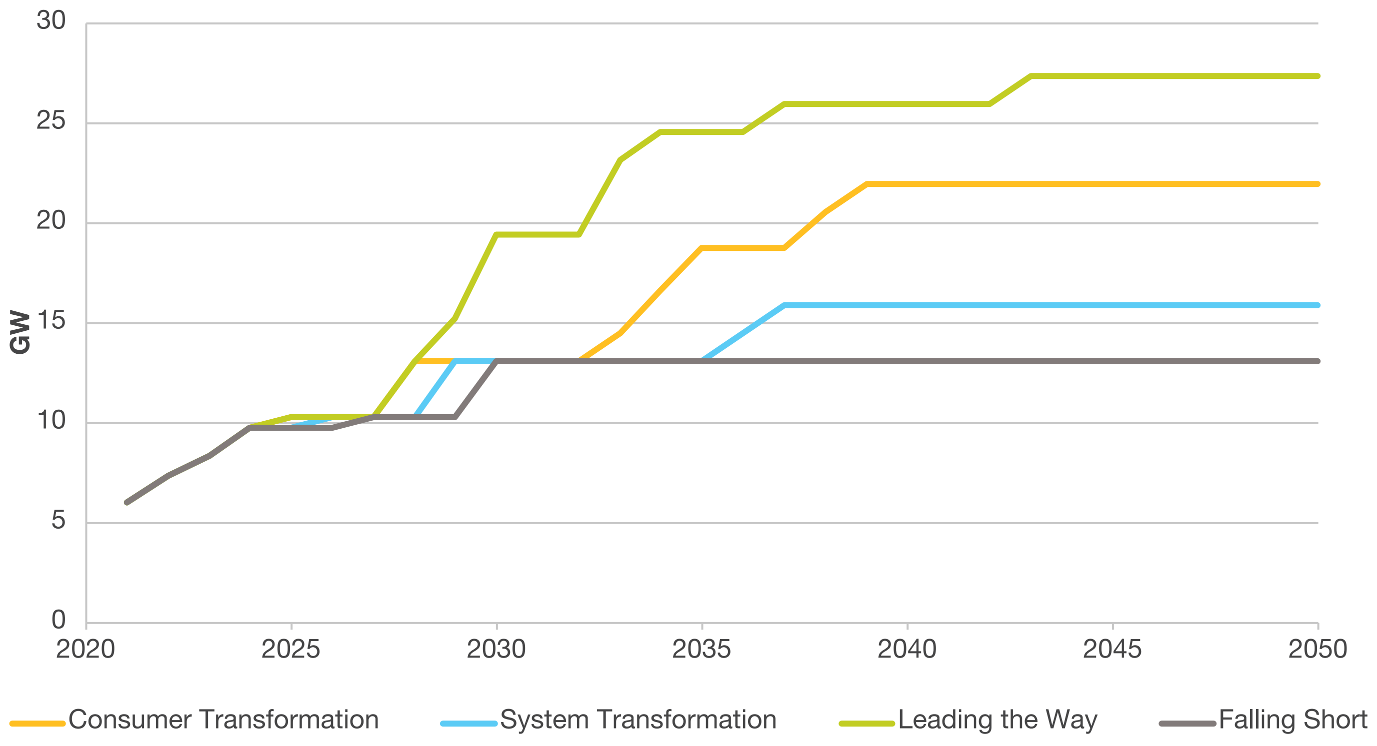
Our modelling includes the seven interconnectors we have today, and we considered a pipeline of 19 other projects in various stages of maturity, most of which could come online between the mid-2020s and mid-2030s.

Interconnectors are used in all scenarios for trading electricity with continental neighbours. We expect interconnector flows to follow price signals and to help avoid wastage of excess generation. By connecting grids in different countries, we can share some of the benefits and characteristics of our generation mixes with each other. This is especially true in scenarios which have the greatest demand for **Flexibility**, which means Leading the Way and Consumer Transformation see the highest electricity interconnector capacity.

Interconnectors can be used to help meet peak electricity demand. This can reduce the amount of generation capacity that needs to be kept available, and its associated costs, but this must be balanced with the potential for increased dependency on neighbouring countries. Either way, interconnection with a diverse set of partners gives Britain options for operability. In all scenarios, we see GB become a net exporter of electricity by 2030.

Interconnector capacity and peak flows into GB increase in all scenarios, especially to meet peak electricity demands. While there is currently work ongoing to explore the potential benefits of more granular locational pricing, our analysis currently assumes a single wholesale market for Britain. A move to more locational price signals would affect interconnector flows around the country, more of which is explained in the **Flexibility chapter**.

Figure ES.E.25: Installed interconnector capacity (GW)



FES 2022 / The Energy System / Electricity Supply 303

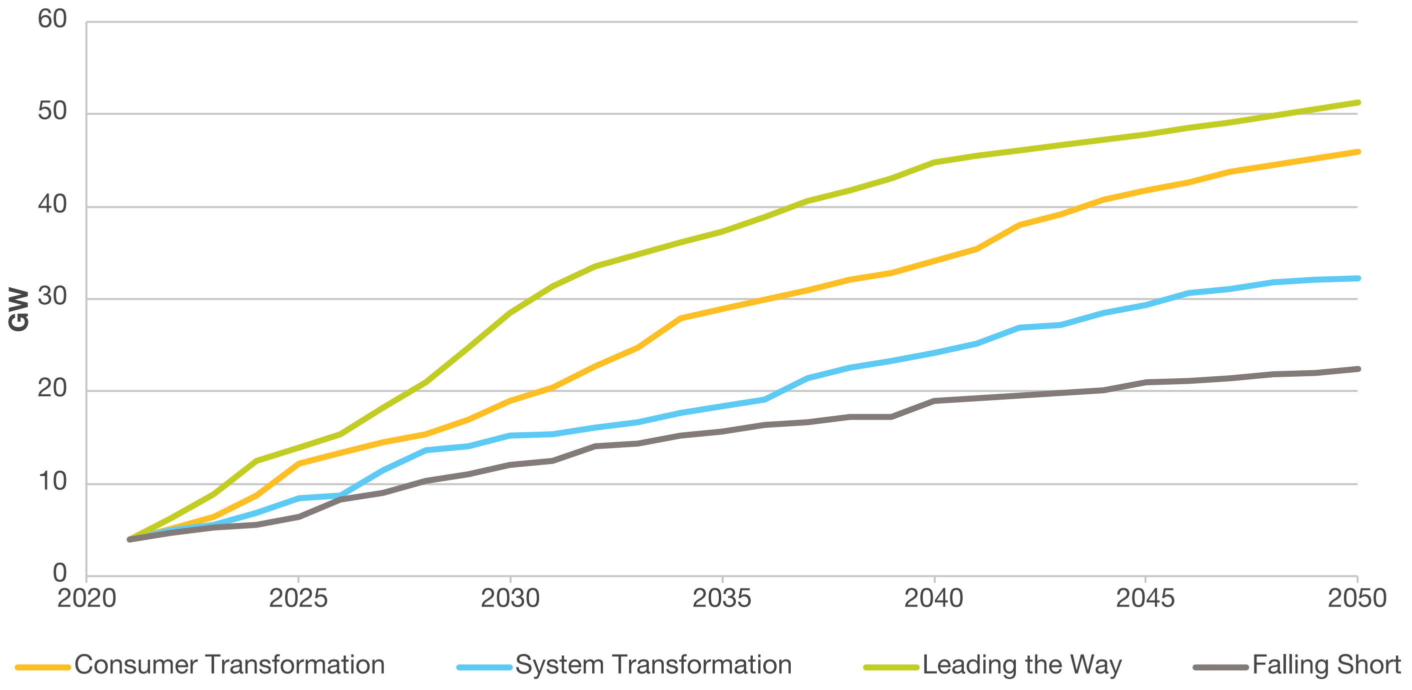
Electricity storage capacity

Electricity storage capacity increases in all scenarios to ensure peak demand can be met reliably as an increasing proportion of our electricity is generated from weather dependent renewables. We need somewhere to store excess energy at times of high renewable generation, and somewhere to get energy from when demands are high and generation output is low.

So, the amount of storage in a scenario is proportional to its dependence on renewable generation and electrification of demand (mainly heat and transport). It is also dependent on the uptake of technology as well as market design and policy which help with flexibility, such as smart-tariffs, interconnector capacity, Vehicle-to-Grid (V2G) and locational pricing (which can incentivise efficient siting of storage). Based on our analysis and stakeholder engagement for FES 2022, we are significantly increasing the amount of storage we expect to see by 2050 and how early it is deployed in all scenarios (FES 2021 Leading the Way: 43 GW; FES 2021 Steady Progression: 20 GW). We see especially rapid growth early on in Leading the Way as rapid deployment of renewables and closure of gas generation means that storage needs to be available sooner and in larger capacities.

Pumped hydro storage provides almost all our 25 GWh electricity storage volume today and continues to grow in all scenarios. By 2050, it is joined by V2G, Liquid Air Energy Storage (LAES), Compressed Air Energy Storage (CAES) and battery storage. We expect battery storage to make up the largest share of storage power capacity in all scenarios by 2050 to help with shifting demand within the day and managing network constraints as battery costs fall. The Flexibility chapter explores these different types of storage (including the important distinction between GW and GWh capacities) and why it is so crucial to the whole energy system of the future.

Figure ES.E:26: Electricity storage capacity, excluding V2G and hydrogen storage (GW)[13]



'Storage' here excludes vehicle to grid and hydrogen as stores of energy.

13 Hydrogen storage itself is not directly comparable with electricity storage which is why it is not included here. The equivalent electricity storage is the bundled product of electrolysis, hydrogen storage and hydrogen generation.

Flexibility

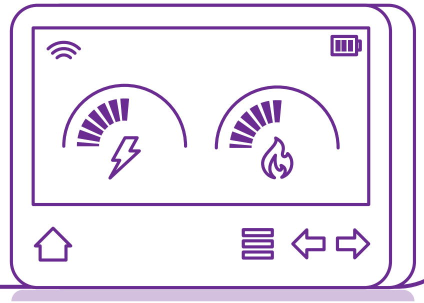
Introduction - what is flexibility and why do we need it?

Energy systems need to match supply and demand, we call this energy balancing. Energy system flexibility is the ability to adjust supply and demand to achieve that balance. For the electricity system this needs to happen in real time whilst for the gas network it can be over a slightly longer timeframe. Flexibility also allows us to keep the flows of energy through the networks within safe limits. FES models energy flows on unconstrained networks, but the network impacts of these flows are analysed in other ESO and industry publications.

Flexibility is crucial to operating the system where the supply and demand of energy needs to be balanced over different timescales, from minutes or less to across seasons or even years. Demand and supply can both vary for different reasons. Demand will vary according to the needs of energy consumers, for example, greater demand for heating in cold weather, or increased demand for lighting at night. Supply depends on factors like the availability of fuels and weather conditions affecting renewable generation output. Additionally supply, and increasingly demand, will vary to reflect price signals from the market. Prices will be high when supply is scarce but low when it is plentiful (and vice versa for demand). However, for some consumers some demand may not be flexible or negotiable, for example heat.

Interactions between different forms of energy on the system are important. Current peak heat demands in winter are several times higher than peak electricity demands so natural gas provides a significant amount of flexibility by meeting most of this heat demand. As sectors such as heat and transport electrify there will be higher electricity peaks, while electricity generation will become more variable as levels of wind and solar generation increase. So electricity supply and demand will become more weather sensitive, and a larger relative level of flexibility will be required than before.

Up until now flexibility has been largely about adjusting energy supply to meet demand. This has been enabled by a reliance on flexibility from fossil fuels which are easy to store. In the case of gas, flexibility comes from storage and the ability to compress or expand gas within the network, known as linepack. As the energy system transitions away from gas to renewables and the electricity supply becomes more weather sensitive, demand will increasingly have to be enabled to adjust to meet supply. When supply is high, demand will need to increase to consume or store additional energy, and when supply is low demand will need to reduce. This will require increased digitalisation to enable consumers to participate in demand side flexibility, and new markets to incentivise it.



Linepack

This is the amount of gas in the network at any given time. The acceptable range over which this can vary and the ability to further compress and expand this gas is called 'linepack flexibility'.

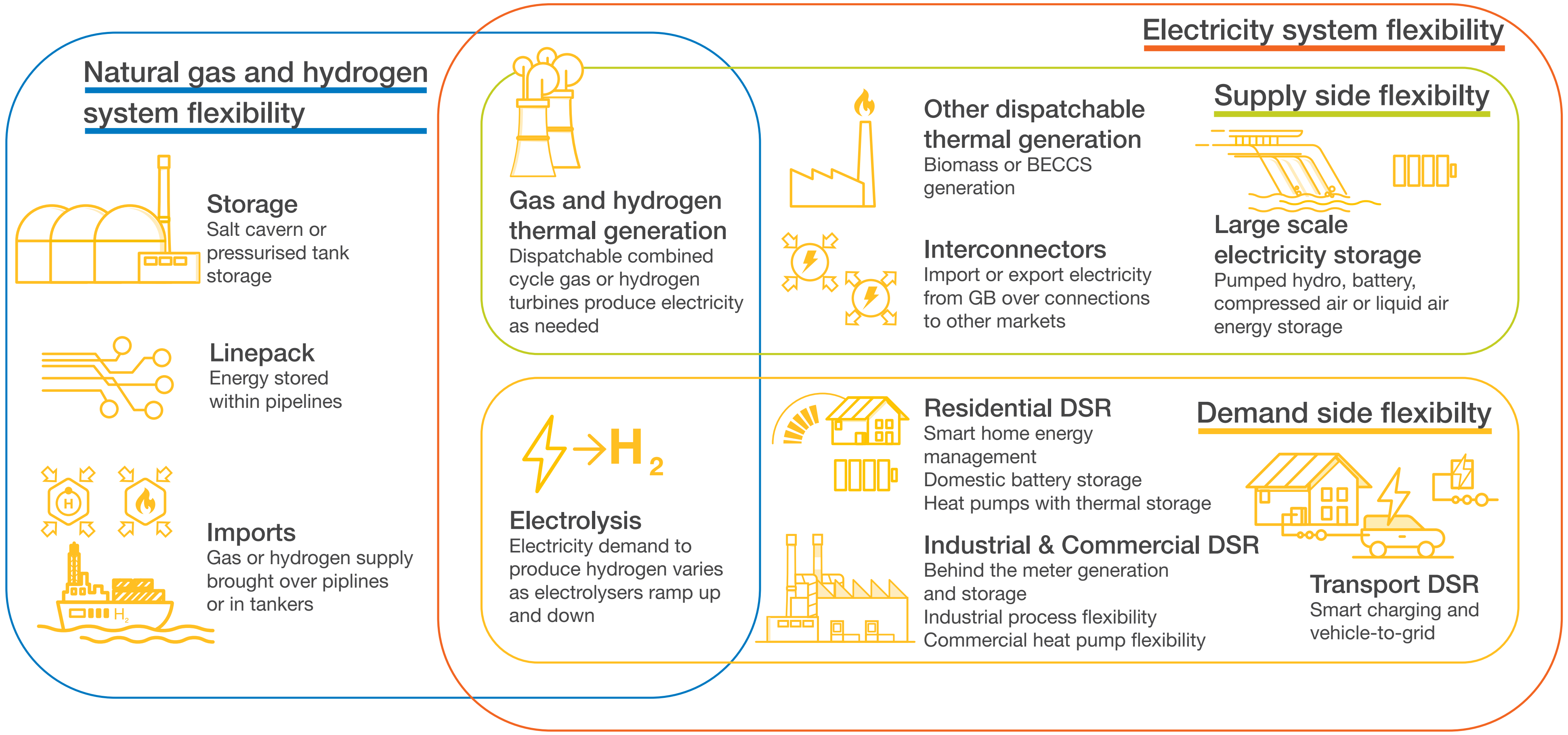
Throughout the day, gas supply and demand is rarely in balance. If demand exceeds supply, levels of linepack in the National Transmission System (NTS) will decrease, along with system pressures. The opposite is true when supply exceeds demand.

FES 2022 / Flexibility 306

Introduction - what is flexibility and why do we need it?

Historically, meeting Security of Supply (SoS) has been most challenging during times of peak demand, when increased energy supply was needed to meet this demand. However, as more demand side flexibility becomes available, and demand can ramp up or down in response to price signals, this is likely to change. We may see periods of high renewable generation output with higher demands than our traditional winter peak. As more of our energy demand is electrified this makes flexibility more important in keeping costs down by minimising peak demand.

New sources of flexibility bring opportunities. Alongside demand side flexibility, other technologies which support a transition to Net Zero such as interconnectors and energy storage can provide flexibility from the supply side. In some scenarios we can use hydrogen for flexibility, absorbing excess wind and storing energy to meet peak demand at a later date. It can also help network investment and operability constraints, reducing the need for electricity network reinforcement by producing hydrogen close to generation and then moving it around the country.



FES 2022 / Flexibility 307

Introduction - what is flexibility and why do we need it?

Security of Supply standards

At all times the electricity and gas systems must meet Security of Supply standards, ensuring our energy supplies are reliable. These standards are different for gas and electricity due to the different challenges of operating each system, for example a greater link between cold temperatures and demand in the case of the gas network:

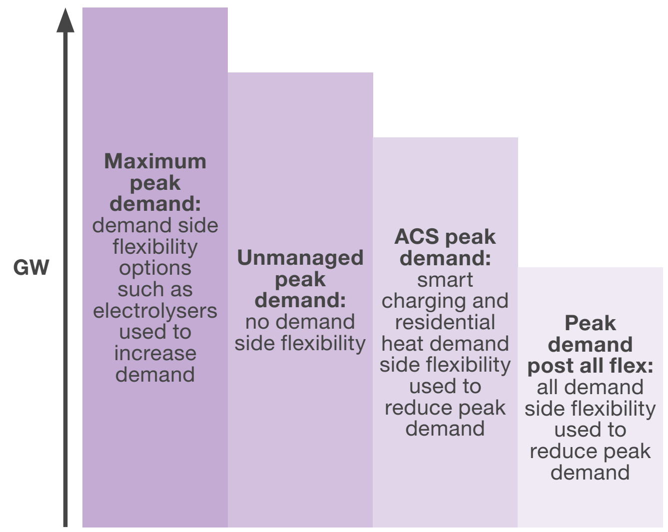
- For electricity, a reliability standard is set by the Secretary of State – currently three hours per year Loss of Load Expectation (LOLE). This measures the risk, across the whole of winter, of demand exceeding supply under normal operation. When considering peak electricity demand, the Average Cold Spell (ACS) definition of electricity demand is used[1].
- For natural gas, there must be enough supply to meet the peak demand on a very cold day (a 1-in-20 peak winter day[2]) even if the single largest piece of supply infrastructure were to fail (known as the N-1 scenario)[3].

Our analysis ensures these standards can be met in all years and all scenarios. As more sectors are electrified, we may need to consider whether these standards are still fit for purpose. As more heat demand is met by the electricity system, electricity demands will become more sensitive to the weather, and our standards must be robust enough to meet these new challenges. As we saw in Texas in 2021, extreme weather events can be extremely challenging for energy systems and careful planning is needed to prepare for them.

Peak demand

There are several types of peak electricity demand referred to in this chapter:

- **Unmanaged peak demand:** refers to the maximum electricity demand before any demand side flexibility takes place to reduce demand. This does include a degree of natural diversity.
- **ACS peak demand:** used in conjunction with the Capacity Market and when ensuring security of supply standards are met. It is the maximum electricity demand over an average winter after smart charging and residential heat demand side flexibility have been applied.
- **Peak demand post all flex:** this refers to the maximum electricity demand after all demand side flexibility has been applied.
- **Maximum peak demand:** as well as using demand side flexibility to reduce demand, it can also be used to increase demand when electricity supply is very high, for example by running electrolysers when it is windy. In this report this is referred to as maximum peak demand.



1 ACS demand for electricity is the maximum demand over an average winter and is consistent with the treatment of demand in the electricity Capacity Mechanism. As an average it has a 50% chance of being exceeded in any given year.
2 Peak demand for gas is the level that, in a long series of winters with connected load held at levels appropriate to the winter in question, would be exceeded in one out of 20 winters, with each winter counted only once.
3 If the gas network reduces in size as we decarbonise the dependence on single pieces of gas infrastructure will increase. The future of the gas network is discussed in more detail in the Natural Gas Supply section.

Key insights

To reach Net Zero, flexibility solutions will be required at greater levels than present today. New energy markets and improved digitalisation are needed to ensure the right types of flexibility are present in the right places, at the right time.

- As the energy system changes, the flexibility challenges it faces will also change:
  - Increasingly peak demand will not be the only driver of system stress – it will be driven as much by **peaks and troughs of electricity supply** as by peak demand.
  - Electrification of other sectors will increase the scale of electricity flexibility needed.
  - Large amounts of flexibility with **duration of a few hours** will be needed to match supply and demand within day. This includes up to 35 GW of electricity storage with an average discharge duration of less than 4 hours by 2050.
  - Flexibility from unabated natural gas will significantly reduce as the energy system decarbonises, so **new ways will need to be found** to deliver the services historically provided by unabated gas.
- New solutions are needed to meet these developing challenges:
  - **Demand side flexibility** will be increasingly important in an electrified, renewable world, increasing from around 6 GW today to potentially over 100 GW by 2050. It is used both to turn up demand when supply is high and to turn it down or shift demand when supply is lower.
  - Hydrogen, energy storage and interconnectors will all also contribute to future flexibility, although there is still uncertainty around exact roles.
  - **Large-scale inter-seasonal energy storage** improves Security of Supply and is essential to meeting Net Zero, but the amount needed (between 11-56 TWh in 2050 under Net Zero scenarios) is dependent on the rollout of hydrogen (for example for heating and industry), hydrogen storage, and other sources of flexibility available in each modelled scenario.
- High levels of wind capacity can, on windy days, lead to **high levels of curtailment**, peaking at over 80 TWh under System Transformation in the mid-2030's. To avoid curtailment, flexible solutions such as energy storage, interconnectors, Demand Side Response (DSR) or electrolysis could be used to maximise the use of renewable electricity.
- The **location of flexibility** is a key consideration: flexibility can deliver more value in some locations than others. For example electrolysers may be sited close to renewable generation and network constraints, or storage may be co-located with renewables. Appropriate and tailored price signals and incentives will be needed from policy and the energy market to encourage these new solutions, from flexible DSR to inter-seasonal storage.
- To meet Net Zero an increasing need to balance renewable generation with demand and a reduced reliance on unabated natural gas means additional sources of flexibility will need to be deployed. **Strong market signals** and the correct enabling conditions, such as locational pricing, increased digitalisation and a coordinated **demand side strategy** are needed to ensure the right types of flexibility are in the right places, at the right time. This requirement forms a key part of the case for change in our Net Zero Market Reform work.

FES 2022 / Flexibility 309

Current sources of flexibility - gas

Today, the vast majority of our flexibility is delivered through the gas system. Gas can be easily stored and can provide flexibility over a range of timescales and volumes for both the gas and electricity networks. Broadly this can be split into two types of flexibility categorised by duration:

1. **Real-time:** The flexibility provided by linepack means demand on the gas network can be met even if gas supply doesn't match gas demand in real time. This in turn allows gas fired power stations to be ramped up and down to ensure electricity supply can meet electricity demand in real time.

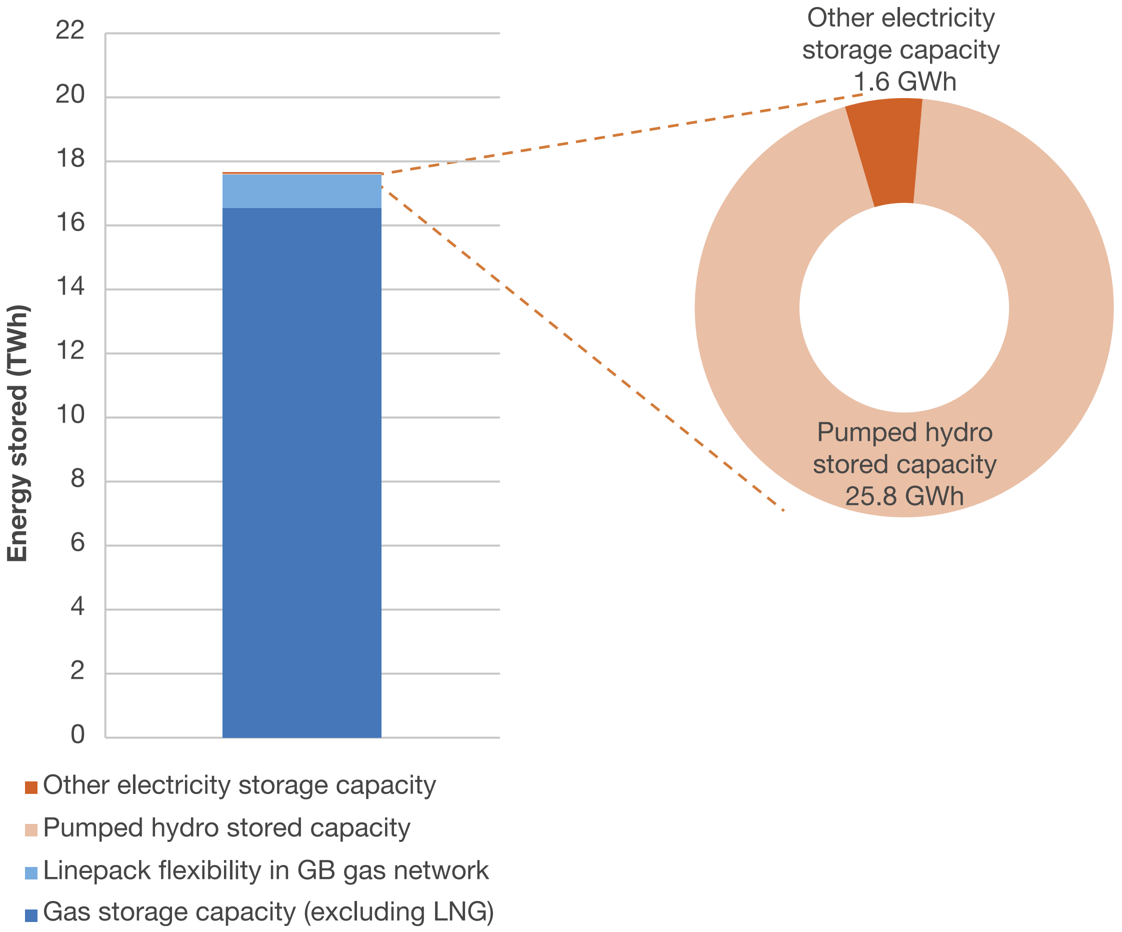
2. **Seasonal:** gas supply can be increased during winter to meet the seasonal peak demand, largely for heat. It can then be reduced during summer when demand is lower.

This flexibility is delivered by storage on the gas network from linepack, but also by additional connected storage sites and the ability to vary upstream production. Storage capacity for gas is substantially higher than for electricity, which is less than 0.2% of the energy stored in natural gas today. At the end of 2021 there was approximately 16,000 GWh of gas in storage, and over 1,000 GWh of flexibility from linepack in the network. There is less than 30 GWh of electricity storage capacity, of which 94% is from pumped hydro storage sites, with around 6% from other forms like batteries (see Figure FL.01).

Gas storage capacity has declined in recent years from 4.7 bcm to around 1.5 bcm with the closure of the major storage site, Rough, in 2017. Dedicated storage sites have been replaced with imports from Norway, the Netherlands and Belgium, as well as increasing imports of Liquefied Natural Gas (LNG). More detail on this is in the Natural Gas Supply section.

Although there is close to 9 bcm of potential new gas storage sites with planning permission, the economics for developing new sites are very challenging, with no final investment decisions on storage sites being made in at least the last five years.[4] Conversion of these sites to store hydrogen will become increasingly important to replace some of the flexibility provided by natural gas as its role diminishes towards Net Zero, see Key Message 4. Finding a regulatory model that supports the development of sufficient hydrogen storage will also be crucial.

Figure FL.01: Electricity and gas storage capacity in 2021[5]



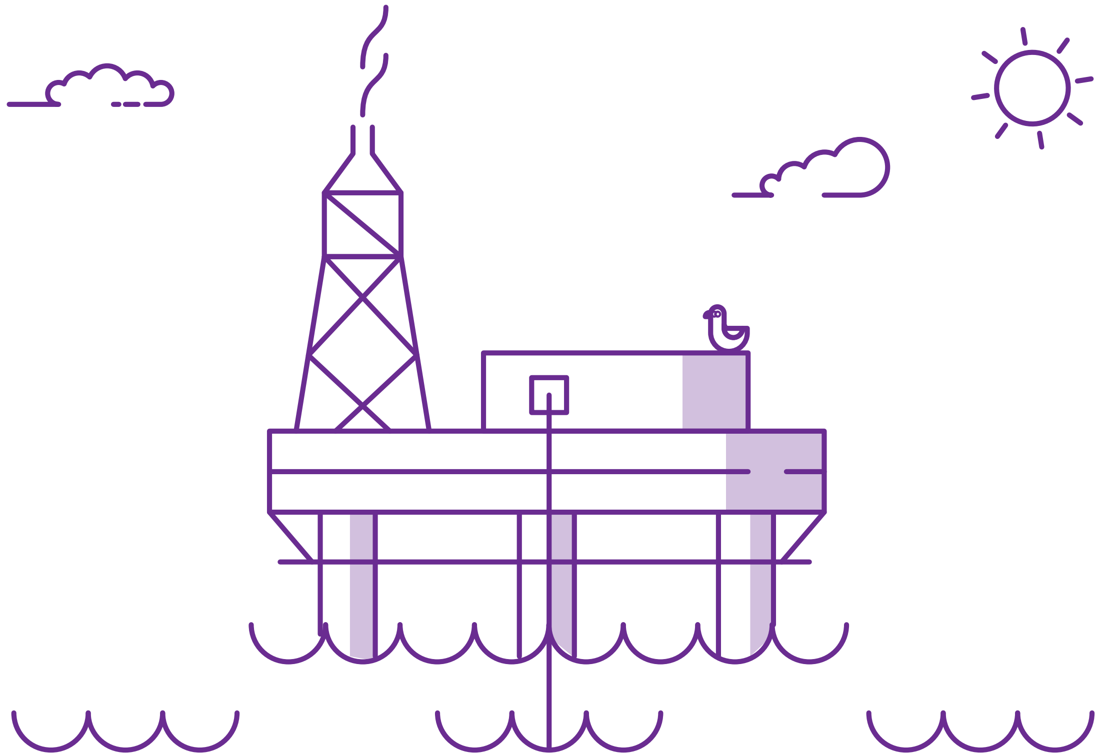
4 nationalgrid.com/gas-transmission/insight-and-innovation/gas-ten-year-statement-gtys
5 There is also c1.9 GW of conventional hydro power plant (i.e. not pumped hydro), which can provide flexibility by controlling when water is released through the turbines to generate power.

Where are we now?

Current sources of flexibility - oil

In the UK, the majority of oil demand is typically for transport. The UK has commitments to the International Energy Agency (IEA) to hold oil stocks to offset the impact of any significant disruptions to the global oil market. At the end of 2020 the UK had approximately 61 days of typical oil consumption held in reserve.

As the transport sector electrifies, the ability to maintain this level of reserve will reduce considerably. Electricity is much more difficult to store and, whilst some of this storage may be replaced, it is unlikely that the majority of it will be. While this means electrification increases the exposure of the transport sector to disruptions in the electricity market, the move to a more renewables-based UK energy system makes us less vulnerable to global commodities markets overall.



FES 2022 / Flexibility 311

Where are we now?

Current sources of flexibility - electricity

In the future there will be an increased need for electricity system flexibility, for two main reasons:

1. The increase in variable renewable electricity generation which requires additional flexibility to ensure supply and demand are balanced.

2. The electrification of other sectors such as heat and transport will increase total electricity demand, but especially peak demand. It will also expose the power sector to new variability trends (e.g. the increased charging of Electric Vehicles (EVs) prior to a bank holiday). To meet both these effects, additional flexibility is required.

Electricity system flexibility today is predominantly delivered on the supply side. As demand varies through the day, different sources of electricity can be turned up or down to varying degrees. Some like nuclear operate more as 'baseload' generation, running constantly although ramping up and down within pre-set limits, while others such as natural gas turbines are more flexible. There is also some demand side flexibility where demand can shift to meet an increasingly weather dependent supply. Some of this is due to residential consumers shifting demand but the majority is industrial and commercial consumers switching to onsite generation. This doesn't change total underlying demand but does reduce the level of demand seen at transmission level. See The Energy Consumer chapter for more details.

FES 2022 / Flexibility 312

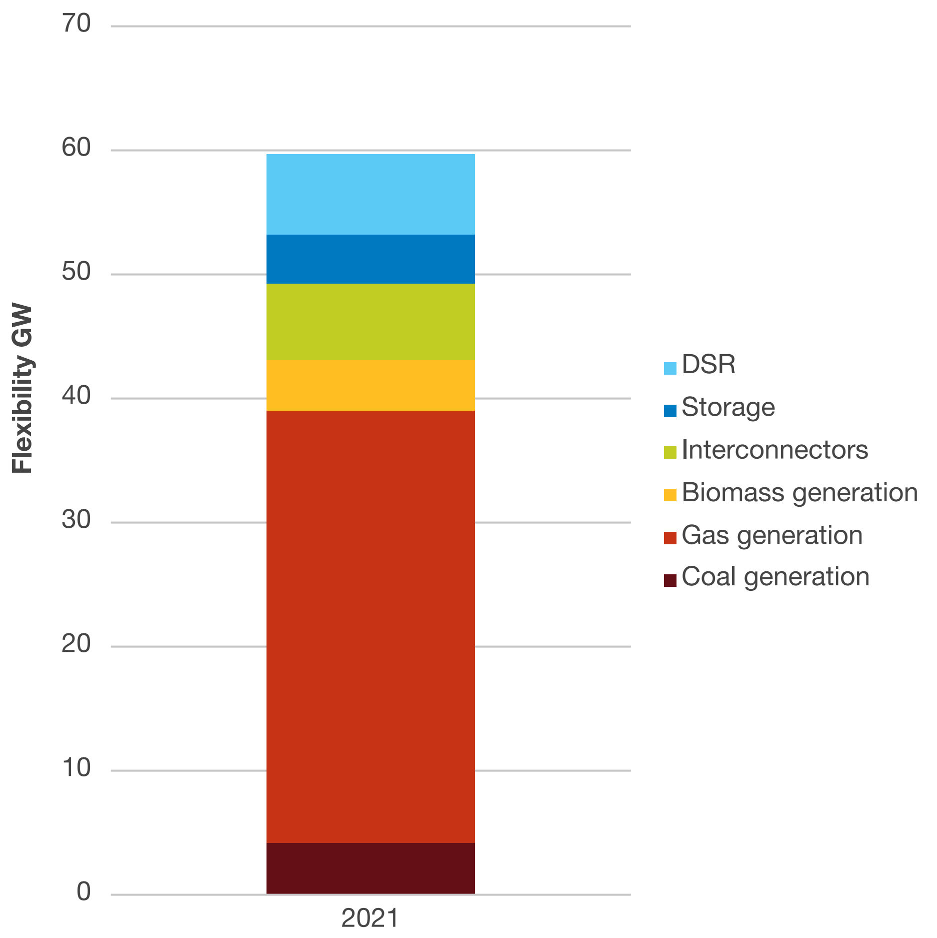
Where are we now? - Current sources of flexibility

Different sources of electricity flexibility are shown in Figure FL.02. This includes storage, but also dispatchable electricity generation, and is shown in terms of instantaneous power output: energy delivered per second as opposed to just energy stored as shown in Figure FL.01. It shows that demand side flexibility currently makes up a small proportion; the majority of electricity system flexibility today comes from fossil fuels, especially natural gas, with gas power stations able to modulate up and down, supported by gas network flexibility.

Although gas will remain important to the broader energy system as a transitionary fuel, by 2035 unabated gas usage in the power sector makes up no more than ~ 2% of domestic generation under all our Net Zero scenarios, and in Leading the Way all unabated gas generation capacity is phased out by the end of 2035. This reduction is required not only to achieve the 2035 Net Zero power sector target, but also to allow other sectors such as heat and transport to decarbonise through electrification.

This combination of an increasing need for electricity system flexibility and a reduced reliance on gas means additional sources of flexibility for the power sector need to be deployed. Strong market signals and the correct enabling conditions, such as increased digitalisation, are needed to ensure the right types of flexibility are in the right places, at the right time.

Figure FL.02: Power output of flexible electricity technologies in 2021



FES 2022 / Flexibility 313

Solutions flexibility can provide

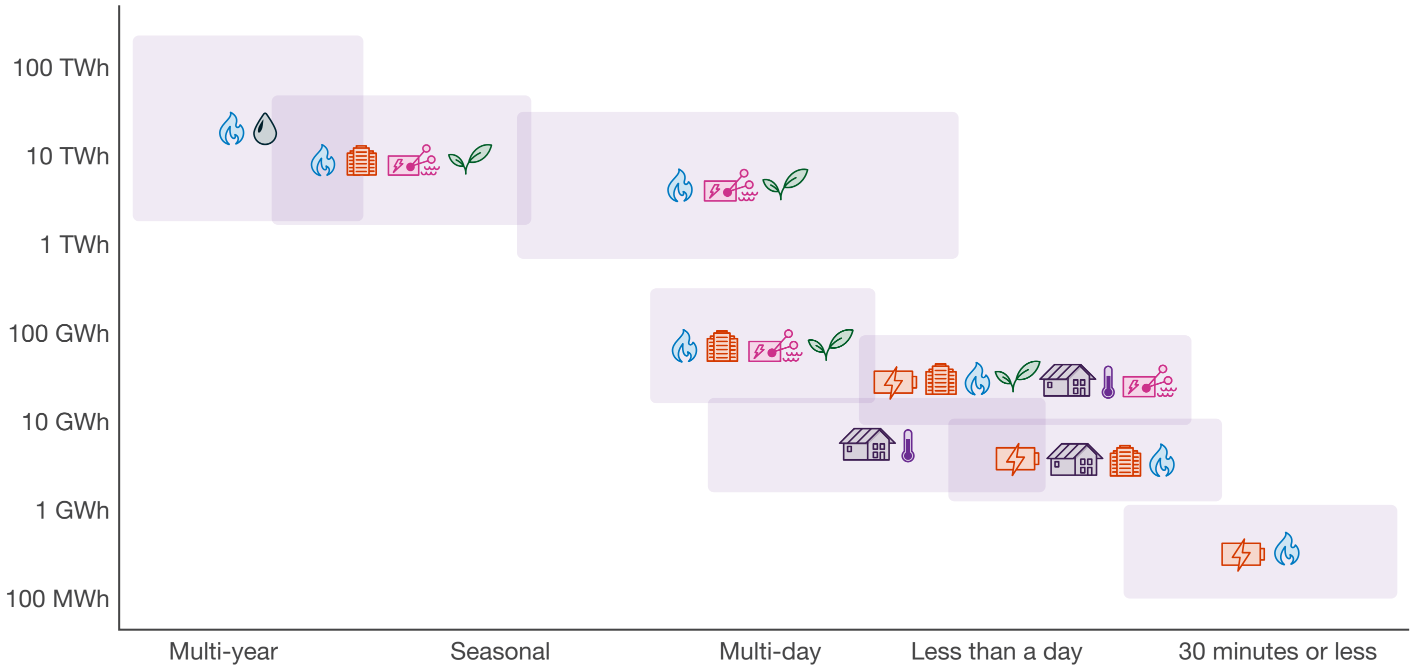
As the UK moves towards Net Zero, more renewable generation and increased electrification will increase the net requirement for flexibility, increasing its importance in ensuring a reliable and low-carbon energy system. Flexibility is needed for a range of roles, including: storing energy over years, covering extended periods of extremes in high demand or low supply, and charging and discharging over minutes or less to maintain operability of the electricity network. This increased need for flexibility over a range of durations and scales presents a challenge to future energy systems and, as the UK approaches Net Zero, it won't be able to use natural gas flexibility like in the past. However innovation is leading to a range of new technologies which can help provide this flexibility, often over a range of scales and durations.

The graphics on the next page highlights some of these technologies, the issues they can help manage, the duration over which they must act and the scale of requirement. The role of these technologies will be investigated further in the following sections.

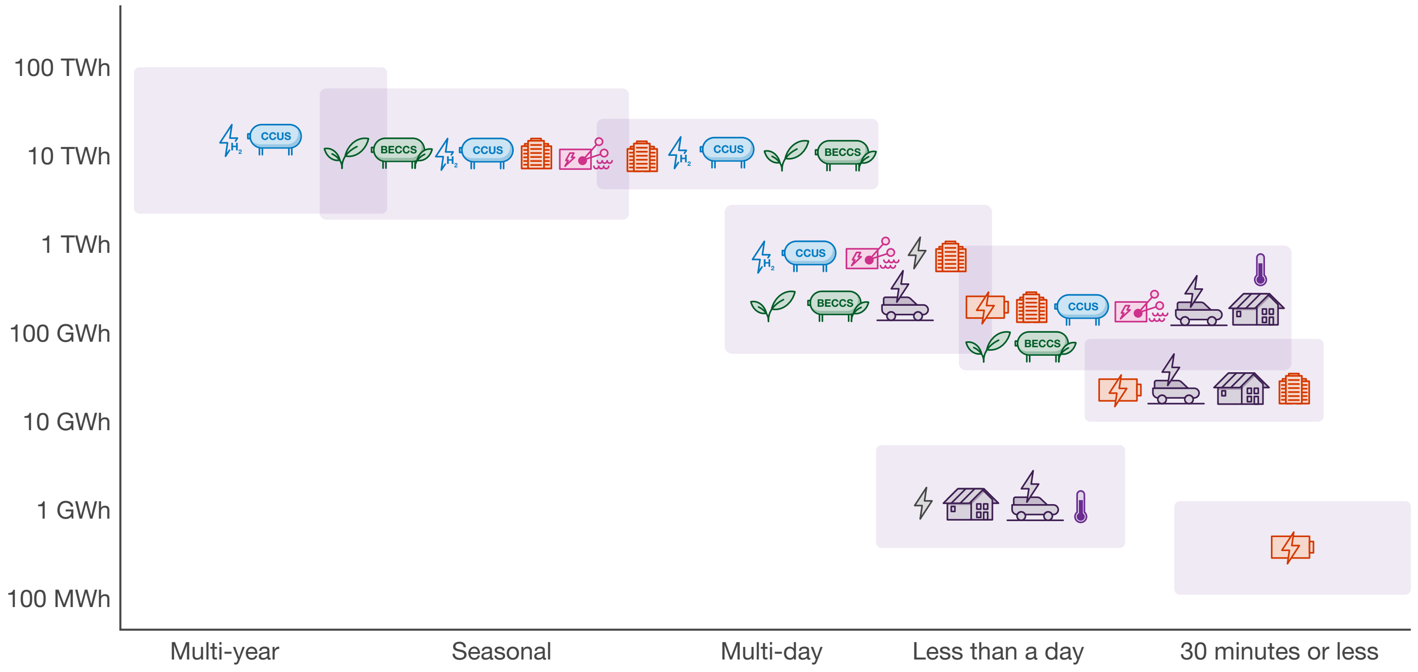
FES 2022 / Flexibility 314

Where are we now?

Flexibility requirements in 2020[6]



Flexibility requirements in 2050



Key:
Electricity storage: Batteries Long duration energy storage (e.g. pumped hydro, compressed air, liquid air) **Interconnectors:**
Electrolysis: **Thermal energy storage:** **Oil:** **Demand side response:** Domestic or industrial EV flexibility
Gas storage: Natural gas Natural gas with CCUS Hydrogen **Bioenergy:** Biomass BECCS

6 Our FES scenarios do not model specific flexibility services and model an unconstrained network, as such these graphics are indicative only and do not directly align to FES modelling and the Data Workbook.

Where are we now?

System resilience

System resilience generally refers to the system's ability to respond to sudden shocks, for example energy system resilience to global supply shocks is improved by storing fuels. Historically this has been fossil fuels but in the future it could be hydrogen.

Seasonal differences

Although supply and demand vary throughout the year, demand and to some extent supply, have seasonal trends. Whilst demand side flexibility and variation in wind generation throughout the year will lessen these trends, they will still be present. Demand is often high in the winter when cold weather and longer nights increase heating, lighting and car journeys. Wind generation is weather sensitive and solar generation will be greatest during summer. This means flexibility is often required to manage peaks in winter demand and summer lows, relative to supply.

Key:
Electricity storage: Batteries Long duration energy storage (e.g. pumped hydro, compressed air, liquid air) **Interconnectors:**
Electrolysis: **Thermal energy storage:** **Oil:** **Demand side response:** Domestic or industrial EV flexibility
Gas storage: Natural gas Natural gas with CCUS Hydrogen **Bioenergy:** Biomass BECCS

FES 2022 / Flexibility 316

Where are we now?

Extreme weather periods

Renewable generation is weather sensitive so periods of extreme, sustained weather can impact supply. Depending on the weather supply could be very high, for example a week of windy weather, or a (sunny) heat wave or very low wind and little solar generation (i.e. Dunkelflaute events). These events can also impact demand, for example whilst heat waves tend to result in higher solar generation it could also result in higher demand for air conditioning, and low wind periods can occur when it is overcast and cold and so demand is higher. These periods will require flexibility either to increase supply and lower demand or vice versa depending on the nature of the weather event. These events are different to seasonal differences in having a weaker seasonal trend, perhaps not even occurring each year. When they do occur, they often tend to be more severe than seasonal differences, although they may not last as long (i.e. a few weeks rather than throughout a whole season).

Variations in supply and demand (for several days)/ daily variations in supply and demand

Renewable generation can vary significantly within a single day or remain relatively high or low for several days. Similarly, demand varies within a day linked to people's activities (e.g. it tends to be lower overnight). Demand may also change for a day or days at a time due to weather (e.g. increased air conditioning when it is hot), or other events (e.g. demand tends to be lower during bank holidays when economic activity reduces). Flexibility is needed to ensure demand is met when it is high relative to supply, and to store or consume energy when supply is high relative to demand.

Key:
Electricity storage: Batteries Long duration energy storage (e.g. pumped hydro, compressed air, liquid air) **Interconnectors:**
Electrolysis: **Thermal energy storage:** **Oil:** **Demand side response:** Domestic or industrial EV flexibility
Gas storage: Natural gas Natural gas with CCUS Hydrogen **Bioenergy:** Biomass BECCS

FES 2022 / Flexibility 317

Where are we now?

Unplanned plant outages

On rare occasions power plants can unexpectedly shut down due to a fault. So, flexibility is needed to provide reserve for an unplanned outage.

Forecast errors

Renewable generation can be slightly different to forecast (typically around 5%) so flexibility is required to manage this difference.

Network constraints

Networks have a maximum capacity they can accommodate: if supply is higher than this and parts of the network become congested flexibility is needed to change the patterns of demand and generation to remove the constraint. Whilst flexibility technologies can help with network constraints that last for a few hours each day, energy storage is less helpful when the constraints are active most of the time or for very long periods. In this case the storage needs an unconstrained period to complete each charge-discharge cycle. See here for more detail.

Key:
Electricity storage: Batteries Long duration energy storage (e.g. pumped hydro, compressed air, liquid air) **Interconnectors:**
Electrolysis: **Thermal energy storage:** **Oil:** **Demand side response:** Domestic or industrial EV flexibility
Gas storage: Natural gas Natural gas with CCUS Hydrogen **Bioenergy:** Biomass BECCS

FES 2022 / Flexibility 318

Where are we now?

Real-time operability

The transmission network needs supply and demand to be balanced in real-time to ensure transmission system voltage and frequency are kept stable within operational limits. Flexibility is needed to ensure this balance is maintained in real-time.

Key:
Electricity storage: Batteries Long duration energy storage (e.g. pumped hydro, compressed air, liquid air) **Interconnectors:**
Electrolysis: **Thermal energy storage:** **Oil:** **Demand side response:** Domestic or industrial EV flexibility
Gas storage: Natural gas Natural gas with CCUS Hydrogen **Bioenergy:** Biomass BECCS

FES 2022 / Flexibility 319

Demand vs supply

Traditionally, risks to meeting electricity Security of Supply (i.e. meeting all electricity demand at any given time) have been at times of high demand, particularly peak demand.[7] Flexibility is used to help manage these periods, normally in the form of dispatchable gas plants being switched on, with relatively small contributions from pumped storage and (mainly industrial) Demand Side Response (DSR).

As we move away from gas generation to renewables, alternative methods for managing peaks in demand will be required; these could include replacing natural gas power plants with equivalent hydrogen power plants, longer duration energy storage, DSR, and batteries for shorter, less sustained peaks.

In the future high demand will not be the only risk to Security of Supply managed by flexibility as increased renewable generation will result in supply determining periods of risk. For example, high demand during periods of high renewable supply will pose less risk than periods of lower demand but with much lower levels of renewable generation. These periods of undersupply are typically short: hours or a few days and can be managed by options including several energy storage technologies: interconnectors, DSR and EV smart charging (or Vehicle-to-Grid (V2G)).

More extreme but rare extended periods of low renewable generation (often referred to as Dunkelflaute events) possibly lasting up to several weeks also have the potential to pose a Security of Supply risk. There is still considerable uncertainty around the length and regularity of these events. Their level of impact will be determined by how low renewable generation is and how much it fluctuates relative to demand.

To manage these Dunkelflaute events, dispatchable thermal power plants (gas and/or hydrogen), depending on the scenario and year, are likely to be required. There is also potential for some combination of long duration energy storage (e.g. compressed air energy storage, liquid air energy storage, pumped hydro storage) and interconnectors. We are working with academic partners to improve our understanding of the potential impact of Dunkelflaute periods in future FES iterations.

Oversupply can also be an issue as, at periods of high renewable generation and low regular demand, additional energy will need to be consumed (either by increasing demand or using energy storage) or generation will need to be constrained. As with undersupply, oversupply can occur daily or last for a longer period. Electrolysers may be particularly useful for managing longer periods of electricity oversupply as they can increase demand by using electricity to produce hydrogen which can then be stored for the duration of the period of oversupply.

Peak Demand

The maximum electricity demand in any one fiscal year. Peak demand typically occurs at around 5:30pm on a week-day between November and February. Different definitions of peak demand are used for different purposes. FES uses the Average Cold Spell (ACS) definition which is consistent with the treatment of demand in the electricity Capacity Market.

7 There are several definitions of peak demand, see the peak demand box here for those used in this section.

FES 2022 / Flexibility 320

Scenarios overview: flexibility

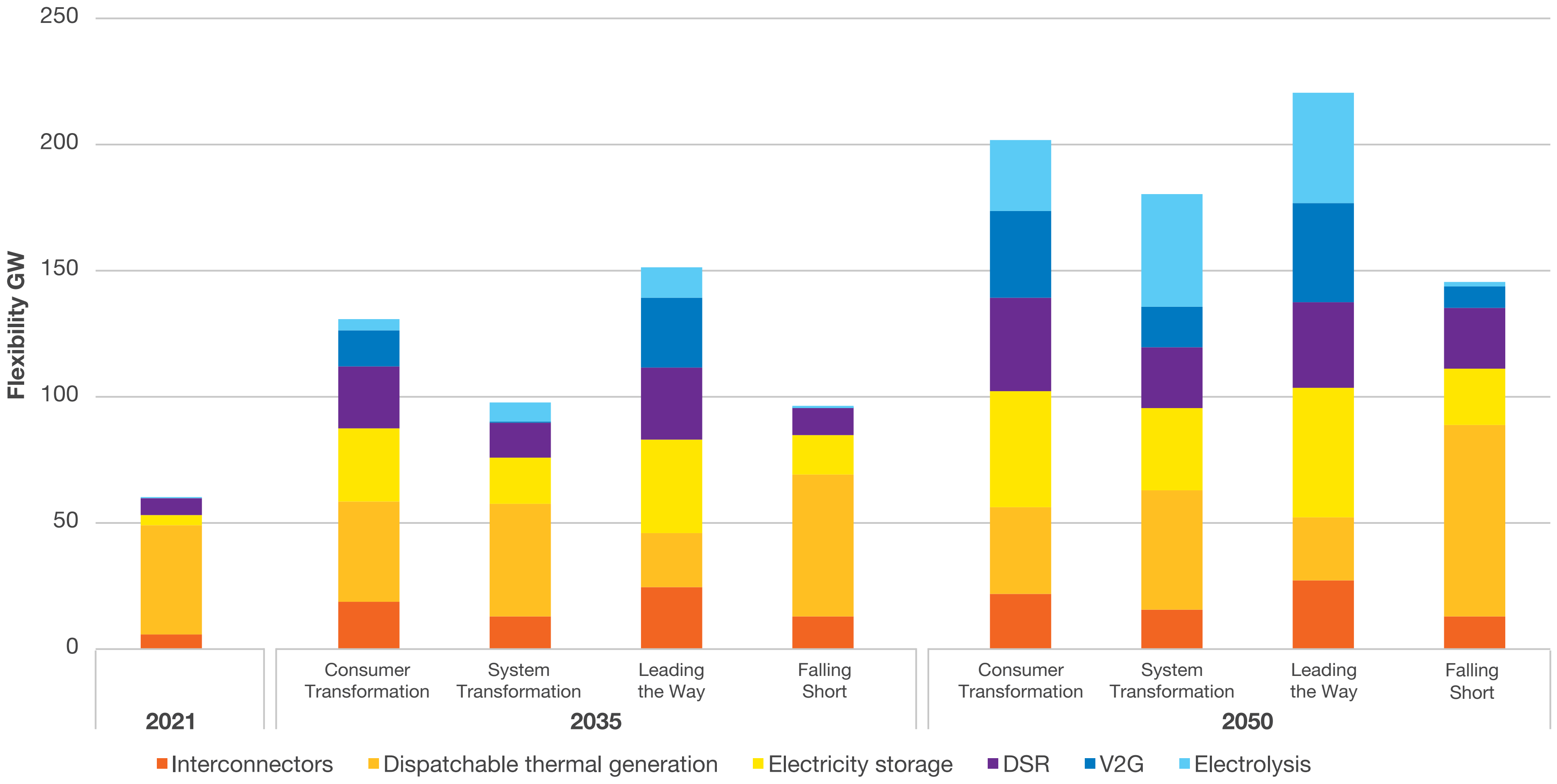
Consumer Transformation

System Transformation

Leading the Way

Falling Short

Figure FL.03: Supply and demand flexibility in 2021, 2035 and 2050



Supply side flexibility: Interconnectors, Dispatchable thermal generation, Electricity storage
Demand side flexibility: DSR, V2G, Electrolysis

What we've found

Smart automation

Smart automation is where EVs and smart appliances automatically change their demand (or in the case of V2G, even start supplying power), based on signals, usually market based which reflect the difference between supply and demand on the network at any given time. Although the process is automated consumers may still set parameters such as when an EV must be charged by.

Consumer Transformation

The road to 2050

- Peak electricity demand starts to increase from the mid-2020s as different sectors of the economy electrify.
- Through the 2020s, developments in flexibility are gradual; on the supply side it is made up primarily of growth in interconnection and storage and there is limited growth in Demand Side Response outside of the industrial sector.
- In the 2030s, Demand Side Response and consumer engagement rapidly increase, partly due to assumptions around high levels of societal change and lack of technical barriers in this scenario. This helps to mitigate demand growth.
- Some unabated natural gas electricity generation capacity remains well into the 2040s to provide security of supply, but generation is gradually reduced from the mid-2020s (supplying only ~2% of demand by 2035,) with other forms of dispatchable generation filling the gap.
- Hydrogen storage starts to support flexibility through the early 2030s with over 2.5 TWh of storage needed by 2035 amidst growth in electrolysis and hydrogen generation capacity, while natural gas demand falls sharply.

By the 2040s, domestic smart automation has become the norm, with demand side flexibility and Vehicle-to-Grid technology providing a maximum demand reduction capacity at peak of over 45 GW in 2040.

What does 2050 look like?

Flexibility capacity from demand side options is almost equal to that from supply side options. A combination of electrolysis, storage and hydrogen generation offer high levels of whole energy system flexibility and high net exports over interconnectors help to manage renewable generation output.

Supply side flexibility: Interconnectors, Dispatchable thermal generation, Electricity storage
Demand side flexibility: DSR, V2G, Electrolysis

FES 2022 / Flexibility 322

Scenarios overview: flexibility

System Transformation

The route to 2050

- Peak electricity demand increases only steadily until post 2030 where electrification of transport starts to accelerate.
- Contribution from Demand Side Response to mitigate this increase is limited (compared to Leading the Way and Consumer Transformation), with contributions from smart charging from the mid-2020s onwards and V2G post 2035. Together, these provide a maximum demand reduction capacity of around 12 GW by 2040.
- Hydrogen storage is developed at scale from the early 2030s, reaching almost 24 TWh by 2040; the gas network is repurposed to transport hydrogen.
- Throughout the 2030s, hydrogen and gas Carbon Capture Utilisation and Storage (CCUS) generation capacity is deployed reaching 22 GW in total by 2040, offsetting the decrease in unabated gas generation on the supply side.
- Interconnection capacity reaches just under 16 GW by 2040.

What does 2050 look like?

Supply side flexibility still outweighs demand side flexibility, although demand side flexibility still increases considerably from today. Widespread use of hydrogen for heat and industrial and commercial sectors keeps peak electricity demands relatively low, although lower consumer engagement limits the contribution of Demand Side Response. Dispatchable thermal generation from gas CCUS and hydrogen support Security of Supply. Net exports over interconnectors help manage renewable generation output. Hydrogen use across the economy is supported by high levels of hydrogen storage to move energy inter-seasonally.

Supply side flexibility: Interconnectors, Dispatchable thermal generation, Electricity storage
Demand side flexibility: DSR, V2G, Electrolysis

FES 2022 / Flexibility 323

Scenarios overview: flexibility

Leading the Way

The route to 2050

- Peak electricity demand increases post-2025 as the economy electrifies.
- Rapid early take-up of demand side response (residential and commercial plus EV smart charging) and V2G gives the potential for demand at peak times to be reduced by almost 20 GW in 2030 and 54 GW by 2040 compared to the counter factual demand with no Demand Side Response.
- Almost 2 TWh of hydrogen storage is needed by 2035 amidst growth in electrolysis and hydrogen generation, while natural gas demands fall sharply.
- Unabated natural gas generation capacity declines sharply from 2025 and is phased out completely by the end of 2035, in line with the Climate Change Committee (CCC) target of no unabated gas generation by 2035. This is mitigated by growth in interconnection, storage and hydrogen generation as well as additional demand reduction from Demand Side Response technologies.
- Interconnection capacity increases rapidly, reaching 10 GW by 2025 and almost 20 GW by 2030, and net exports are seen over the interconnectors from 2025.

What does 2050 look like?

Demand side flexibility provides slightly more capacity than supply side. High levels of energy efficiency and greater consumer engagement limit peak demands through Demand Side Response and V2G output. Electrolysis, hydrogen generation and hydrogen storage combine to offer high levels of whole energy system flexibility, with the high levels of electrolysis and load shifting able to maximise the use of local renewable generation. There are also high exports across the interconnectors.

Supply side flexibility: Interconnectors, Dispatchable thermal generation, Electricity storage
Demand side flexibility: DSR, V2G, Electrolysis

FES 2022 / Flexibility 324

Scenarios overview: flexibility

Falling Short

The route to 2050

- Peak electricity demand increases all the way to 2050 as electrification occurs (albeit slower than other scenarios) but with limited energy efficiency improvements.
- Demand Side Response and Electric Vehicle smart charging take-up is low due to low consumer engagement, providing only 8 GW of demand reduction capacity at peak by 2030 and 16 GW by 2040, with very minimal engagement in V2G.
- A limited role for hydrogen across the economy sees only slow growth in electrolysis and almost no large-scale storage.
- Unabated natural gas generation continues to play a significant role backing up renewable generation and meeting Security of Supply. From 2035, some of this generation is displaced by gas CCUS which reaches 11 GW by 2040.
- Growth in interconnection capacity is slow but still reaches 13 GW by 2030 before plateauing.

What does 2050 look like?

Supply side flexibility continues to dominate over demand side flexibility. Peak electricity demands rise to be as high as those in Consumer Transformation by 2050. Relatively low levels of consumer engagement in Demand Side Response alongside some electrification but limited deployment of energy efficiency is responsible. The natural gas network and storage continue to provide energy flexibility, meeting heat demands and supplying gas generation (with and without CCUS) which helps to meet Security of Supply. Levels of electrolysis and hydrogen usage across the whole system are small.

Supply side flexibility: Interconnectors, Dispatchable thermal generation, Electricity storage
Demand side flexibility: DSR, V2G, Electrolysis

FES 2022 / Flexibility 325

What we've found

Electricity peak demand

We expect electricity peak demands to increase in all scenarios as electrification of other sectors of the economy continues, particularly heat and transport.

Figure FL.04 shows the electricity demand as calculated for the Electricity Capacity Mechanism, which assumes the Average Cold Spell definition of demand (ACS[8], and includes peak demand reduction from EV smart charging and residential heat flexibility, but not from Industrial and Commercial DSR, non-heat residential DSR and Vehicle-to-Grid response).

Consumer Transformation is the most electrified scenario and the peak demand for electricity increases rapidly from the late 2020s and then plateaus through the early 2040s before stabilising out to 2050. This is slower in the other scenarios where many sectors, but particularly heat, experience lower levels of electrification.

Compared to FES 2021, this year's electricity peak and annual demands are marginally lower in the short term (out to 2030) due to the forecast higher energy prices and slower economic growth which impact demand. Post 2030, peak demand in System Transformation rises at a similar rate to last years results, but do not exceed last year's peak demand until 2047 due to the lower starting point (i.e. lower peak demands through the 2020s).

For the other scenarios, electricity peak and annual demands from the early 2030s up to 2049 are higher than last years, reflecting stakeholder feedback and policy announcements.

Specifically the higher electricity peak and annual demands are due to a combination of:

- Increased fuel switching (both electrification and hydrogen which can be produced via electrolysis) in Industrial and Commercial sectors, reflecting the Industrial Decarbonisation Strategy.
- Increased electrification of Heavy Goods Vehicles (HGVs).
- For Falling Short an increased level of electrification compared to FES 2021 is seen, although without the efficiency measures seen in some of the other scenarios.

For a more in-depth discussion of the changes to this year's FES modelling, see our FES 2021/2022 comparison document.

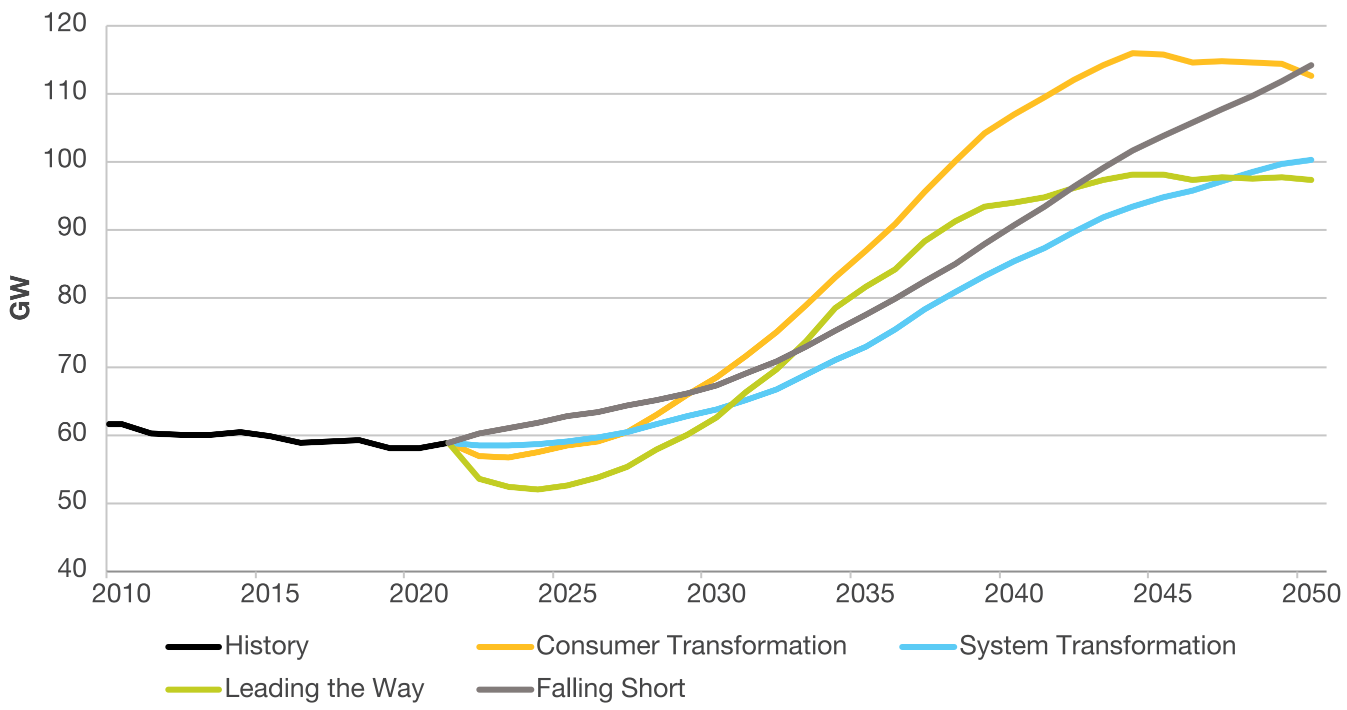
Electricity Capacity Mechanism

The electricity Capacity Market ensures sufficient levels of de-rated capacity are available to meet demand if and when required. In return, capacity providers are paid for the amount of capacity they are making available.

8 ACS demand for electricity is the maximum demand over an average winter and is consistent with the treatment of demand in the electricity Capacity Market. As an average it has a 50% chance of being exceeded in any given year.

Electricity peak demand

Figure FL.04: Electricity ACS peak demand



In the future, ACS peak demand[9] may not always represent the highest demands on the system. Electricity peak demands have historically occurred on winter weekday evenings, when demand for Industrial & Commercial premises overlaps heating and lighting in homes. As discussed in the **demand vs supply** spotlight, the nature and timings of peak demand are likely to change as the country decarbonises. As the share of renewable electricity supply increases, we may see peak demands at other times of the day or year. For example, in Leading the Way in 2050, a typical daytime demand could be increased by up to 58 GW from electrolysers alone. This could be encouraged to happen at times of high renewable output by low market prices or other incentives and would be in addition to 'ordinary' demands on the electricity system.

9 ACS demand for electricity is the maximum demand over an average winter and is consistent with the treatment of demand in the electricity Capacity Mechanism. As an average it has a 50% chance of being exceeded in any given year.

FES 2022 / Flexibility 327

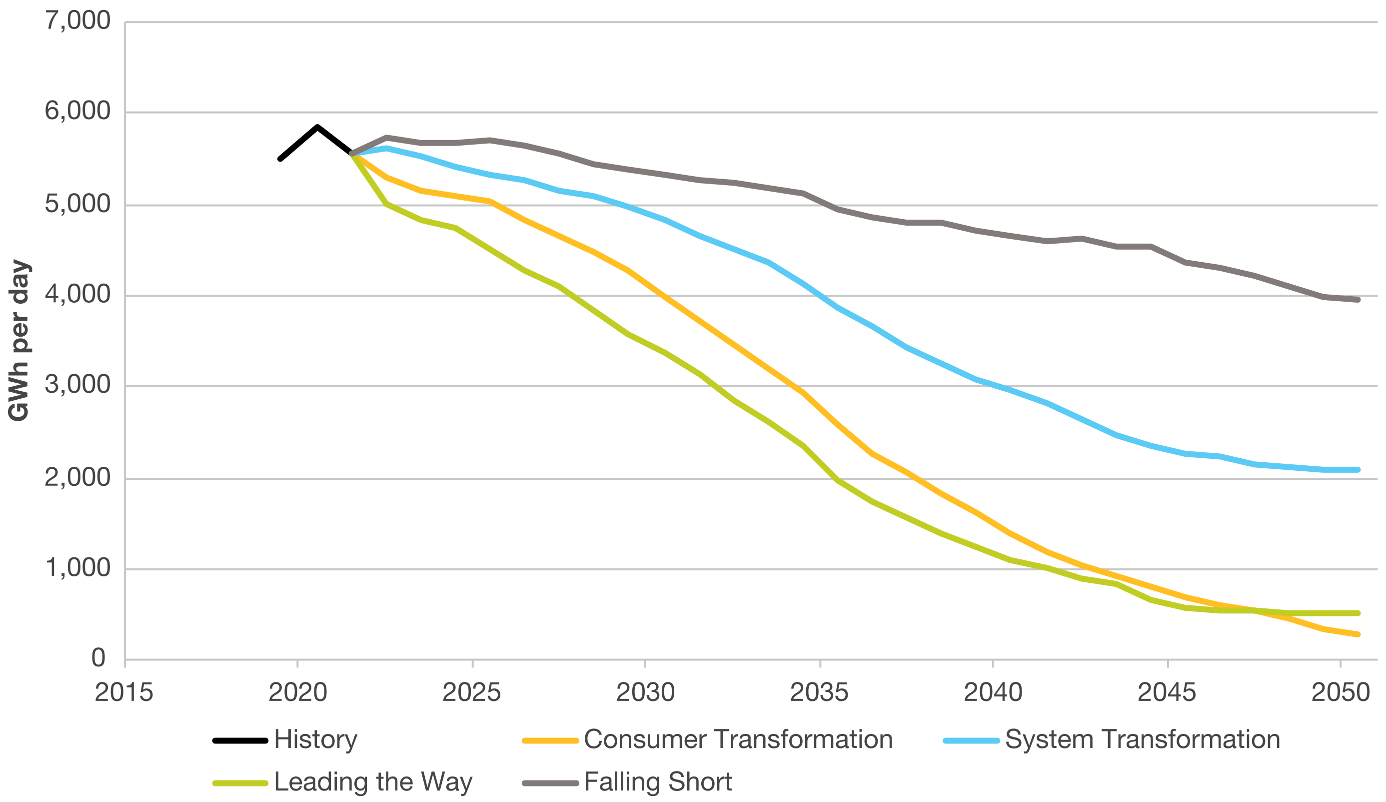
Natural gas peak demand

Natural gas peak demands[10] are expected to decline in line with the reduced use of natural gas in the Net Zero scenarios. Peak demand for natural gas is linked to annual demand, particularly driven by heat demand for residential homes. On cold winter evenings this will continue to be high while large numbers of homes still rely on gas boilers. As the heat sector decarbonises in the Net Zero scenarios, with greater use of heat pumps and hydrogen boilers, the peak demand for natural gas will reduce. Falling Short makes significantly more progress in decarbonising heat by 2050 than under FES 2021, with 142 TWh of natural gas being used for residential heating by 2050 in this year's results compared to 247 TWh last year. However, this still represents just over 50% of total residential heat demand. This, alongside some gas still being used in the power sector results in gas peak demands reducing more by 2050 than in last year's results but still remaining high.

In Consumer Transformation and Leading the Way, natural gas peak demand declines to nearly zero as unabated gas is phased out completely, with only limited residual uses in the energy system. Unlike FES 2021, in this year's results, natural gas peak demand in Leading the Way, whilst small, exceeds that in Consumer Transformation from 2048 onwards. This is due to some gas demand for methane reformation and a slight increase in gas CCUS power generation from 2040-2050 compared to a decline in Consumer Transformation.

In System Transformation natural gas is still used to produce hydrogen via methane reformation with CCUS. However, the peak demand is lower than today as methane reformation to produce hydrogen takes place throughout the year.

Figure FL.05: Natural gas peak demand



10 Peak demand for gas is the level that, in a long series of winters with connected load held at levels appropriate to the winter in question, would be exceeded in one out of 20 winters, with each winter counted only once.

What we've found

Annual demand

Trends in peak natural gas demand generally align to annual natural gas demand in each scenario as many of the factors which influence annual demand also influence peak demand, but the declines are not as rapid. For instance, if a property converts from a gas boiler to an electric heat pump, this will reduce both the annual and the peak demands. Similarly, energy efficiency measures impact peak demand, as well as annual demand, as a better insulated property would retain heat better during winter and require less gas in cold snaps.

FES 2022 / Flexibility 329

Hydrogen storage

Natural gas is both relatively easy to store and able to provide flexibility across the whole system, either used directly as a fuel, for example in gas boilers or for industry, or via gas turbines to produce electricity. As we move towards Net Zero, natural gas consumption, and consequently natural gas storage, reduces significantly. As another gaseous fuel, hydrogen can provide similar flexibility benefits across the whole system and is needed to replace some of the flexibility provided by natural gas.

In Falling Short we assume the continued (although slightly reduced) use of natural gas will lead to gas network storage (including linepack), and upstream supply variability continuing to play a leading role in terms of whole energy system flexibility and so hydrogen storage is negligible.

In the Net Zero scenarios in 2050, whole energy system flexibility is provided primarily through the use of electricity or gas to produce hydrogen, storing this hydrogen and then using this hydrogen in the power sector or to meet end user demand directly. Producing hydrogen through electrolysis offers demand side flexibility to the electricity system and converting it back to power offers supply side flexibility. If hydrogen is not used immediately for heat or transport, it can be compressed and stored, in potentially very large volumes. This allows energy generated in windy periods to be used in calm periods, or to be stored between summer and winter. The overall 'round cycle' efficiency of this process is low due to losses at the production, compression and combustion stages but has to be weighed up against the potential value of the electricity at times of low renewable output. Hydrogen storage will be important to support energy Security of Supply as well as to accommodate electrolysed hydrogen at times of excess wind or solar. Consequently, hydrogen storage is essential in all Net Zero FES scenarios, with between 11 TWh (CT) and 56 TWh (ST) by 2050 (see Figure FL.06). This dwarfs the total electricity storage capacity in the Net Zero scenarios (a maximum of 170 GWh by 2050) and is partly due to the relative ease of storing hydrogen compared to electricity. This demonstrates the value of hydrogen storage to the future whole energy system. Across all three Net Zero scenarios, hydrogen storage capacity begins to develop with between 0.6-2.5 TWh by 2030 and continues to increase all the way out to 2050, although at different rates for each scenario.

Roles for hydrogen storage flexibility:

- System resilience
- Managing seasonal differences in supply and demand
- Managing extreme weather periods
- Managing several days of oversupply or undersupply

FES 2022 / Flexibility 330

What we've found

Linepack

This is the amount of gas in the network at any given time. The acceptable range over which this can vary an the ability to further compress and expand this gas is called 'linepack flexibility'.

Throughout the day, gas supply and demand is rarely in balance. If demand exceeds supply, levels of linepack in the National Transmission System (NTS) will decrease, along with system pressures. The opposite is true when supply exceeds demand.

Hydrogen storage

One of the advantages of transporting hydrogen through pipelines is that the pipelines provide relatively low-cost storage. This will be useful for daily flexibility but will not meet all storage needs. For seasonal variations in demand much larger scale storage will be required.

Salt caverns are one of the most viable options for long-term, large-scale storage of hydrogen. The reuse of these facilities (previously used for natural gas storage) is a relatively well-proven commercial option. The amount of hydrogen lost through long-term storage in this way is believed to be minimal and not increase over time, but there may be some limitations on the rate of injection/discharge due to the geology of storage sites. Alternative larger scale hydrogen storage possibilities include decommissioned oil and gas fields. For smaller-scale storage, hydrogen can be kept as a gas in pressurised tanks.

To store hydrogen in liquid form it is best converted into ammonia, methanol or Liquid Organic Hydrogen Carriers. Options are also being investigated for solid-state storage. This would allow storage of a higher concentration of hydrogen and would involve solid materials that can either physically absorb the gas or chemically combine with it.

FES 2022 / Flexibility 331

Hydrogen storage

The storage capacity required is broadly in line with the hydrogen demand of each scenario. So by 2050:

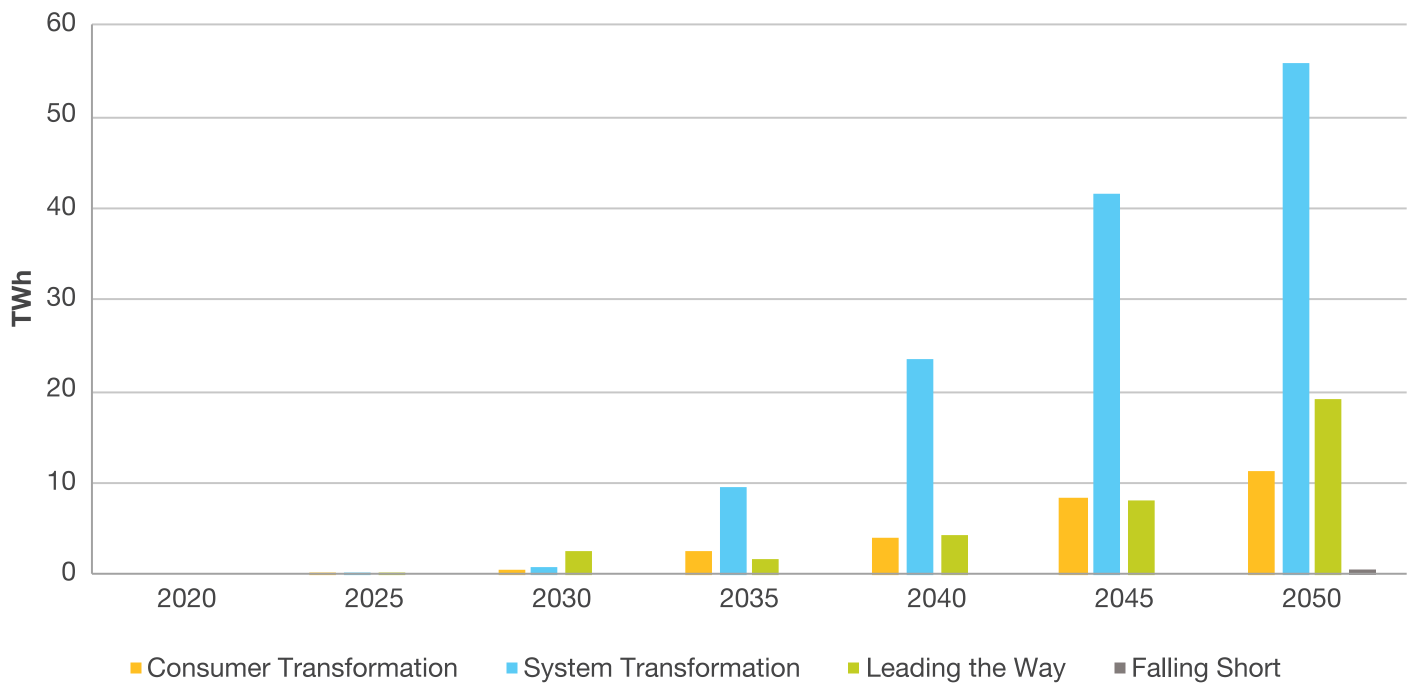
- Consumer Transformation which predominantly relies on electrification and energy efficiency to decarbonise has the lowest hydrogen storage at 11 TWh.
- Leading the Way which uses a combination of electrification and hydrogen, follows next with 19 TWh.
- System Transformation has the greatest volumes of hydrogen storage at 56 TWh as it has the greatest hydrogen demand.

The volumes of hydrogen storage in Leading the Way and System Transformation represent an increase in capacity compared to today's natural gas storage volume of ~16 TWh, and System Transformation is slightly higher than GB gas storage capacity of 51 TWh in 2015 prior to the closure of Rough.

Given its future importance to the energy system, urgent focus is needed to optimise the energy system infrastructure changes needed to support hydrogen storage and contribute to delivering zero-carbon energy to consumers. These changes include infrastructure for the production of the hydrogen as well as any repurposing of the current natural gas system or dedicated hydrogen network assets. A strategic approach to development of hydrogen storage is required to kick-start investment given the likely lead times involved. Hydrogen storage requirements will vary significantly by scenario and depending on how it is modelled. Levels of hydrogen storage will also depend on the future potential revenue streams for flexibility and the support available to develop hydrogen storage sites.

The UK Government has recognised the need to support hydrogen production and storage. In the recently published British Energy Security Strategy, the Government increased its 2030 ambition for hydrogen production from 5 GW to up to 10 GW, with at least half of this to be green hydrogen. It also recognised the value, particularly of green hydrogen, as a storage solution. Specifically on hydrogen storage, the strategy committed to designing hydrogen storage (and transport) business models by 2025 to be in place by 2030.

Figure FL.06: Hydrogen storage capacity requirements



Hydrogen storage

The way hydrogen storage is used also changes between scenarios. Figure FL.07 shows the daily level of hydrogen in storage over the year in 2050 for the Net Zero scenarios. System Transformation has the greatest inter-seasonal variation, with stored hydrogen peaking in mid-autumn, and declining through the winter as hydrogen heat demands increase. Stored energy reaches a minimum in early spring, before increasing. In Leading the Way the inter-seasonal relationship is still present but much weaker due to lower heating requirements, whilst in Consumer Transformation with no heating requirement there is almost no seasonal relationship. In summary, the requirement for hydrogen storage in System Transformation is largely demand-driven, whilst in Consumer Transformation it is mainly driven by supply and in Leading the Way it is a combination of both.

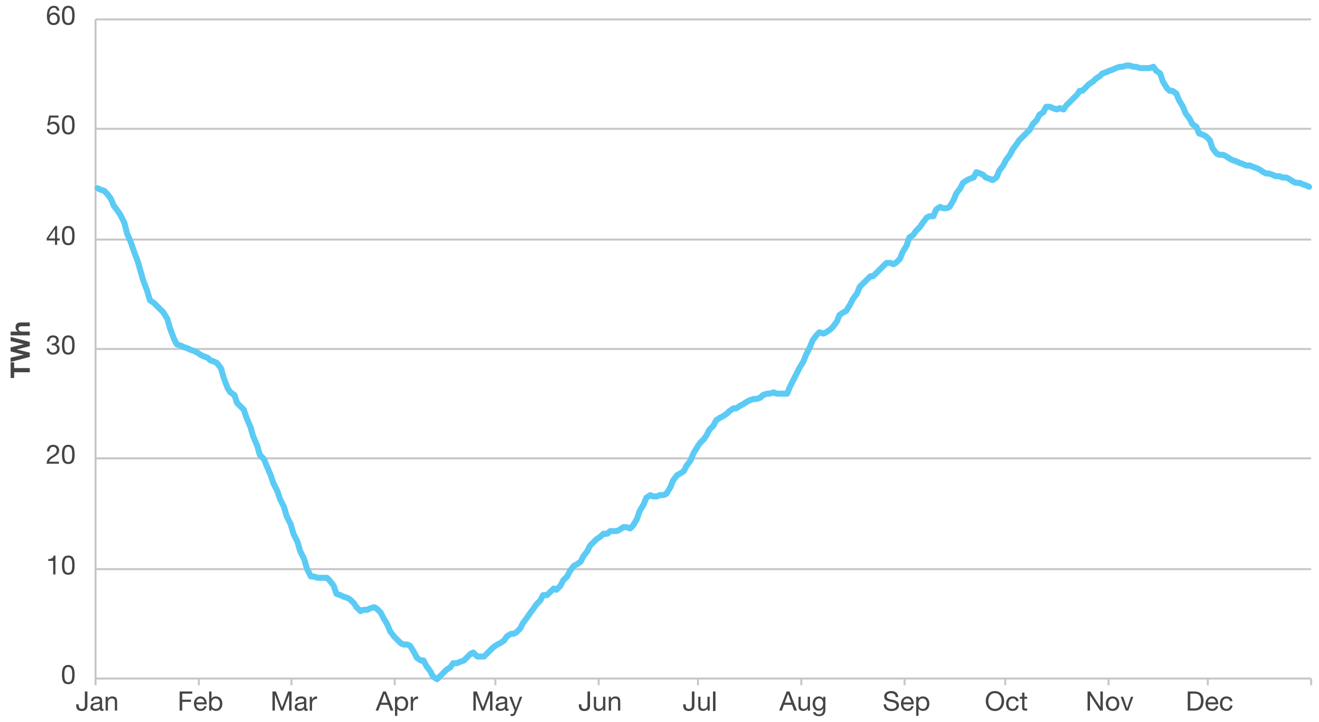
The level of storage needed, especially in System Transformation, is also affected by the use of methane reformation to produce hydrogen (see **Hydrogen Supply**), compared to electrolysis. Because methane reformation is not dependent on weather, it would be possible to ramp up production in the winter and reduce it in summer to lower the levels of inter-seasonal storage needed. The economic trade-offs between reducing the load factor of methane reformation hydrogen production and additional investment in hydrogen storage will need to be explored in more detail but FES 2022 assumes that use of hydrogen storage is preferable as methane reformers will operate most efficiently at baseload and hydrogen produced by electrolysis can also benefit from storage.

Figure FL.07: Levels of hydrogen storage in 2050 – Consumer Transformation

Note that Y axis is different between the charts.

Hydrogen storage

Figure FL.07: Levels of hydrogen storage in 2050 – System Transformation



Note that Y axis is different between the charts.

Figure FL.07: Levels of hydrogen storage in 2050 – Leading the Way

Note that Y axis is different between the charts.

FES 2022 / Flexibility 334

Figure FL.07: Levels of hydrogen storage in 2050 – Falling Short

Note that Y axis is different between the charts.

FES 2022 / Flexibility 335

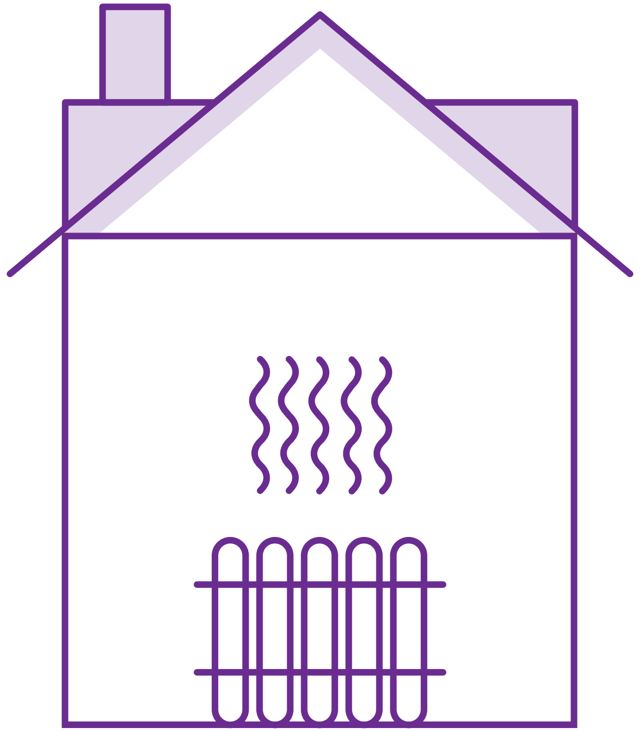
What we've found

Residential thermal energy storage

Thermal energy storage refers to a series of technologies which store heat energy and includes hot water tanks and solid storage (including storage heaters) as well as newer technologies.

The input to thermal energy storage can be heat, usually from a resistive heater or heat pump, or in the case of some new technologies (e.g. Sunamp, Caldera Warmstone), electricity directly. Domestic thermal energy storage can be used to reduce electricity demand at times of low supply or during peak times, or to increase it at times of higher supply. For example, a heat pump charges up a hot water tank or a dedicated thermal store when prices are low, this then supplies heat to the house for 3-4 hours over the peak evening period. Increased electrification of domestic heat demand occurs across all scenarios, and so thermal storage will become increasingly important.

Storage heaters were adopted in the 1960s and 70s to make the most of surplus electricity overnight, when demands were lower. Although use has declined, there were still around 1.6 million households using storage heaters in 2020. While storage heaters can shift electricity demand away from peak evening demand periods, providing over 4 GW of nominal peak shaving in 2021, they are mostly ‘dumb’ devices with only basic controls that cannot adjust according to system needs, and so their ability to balance supply and demand more broadly is limited. However, a new generation of ‘smart’ storage heaters is now available that could unlock greater flexibility in future.



FES 2022 / Flexibility 336

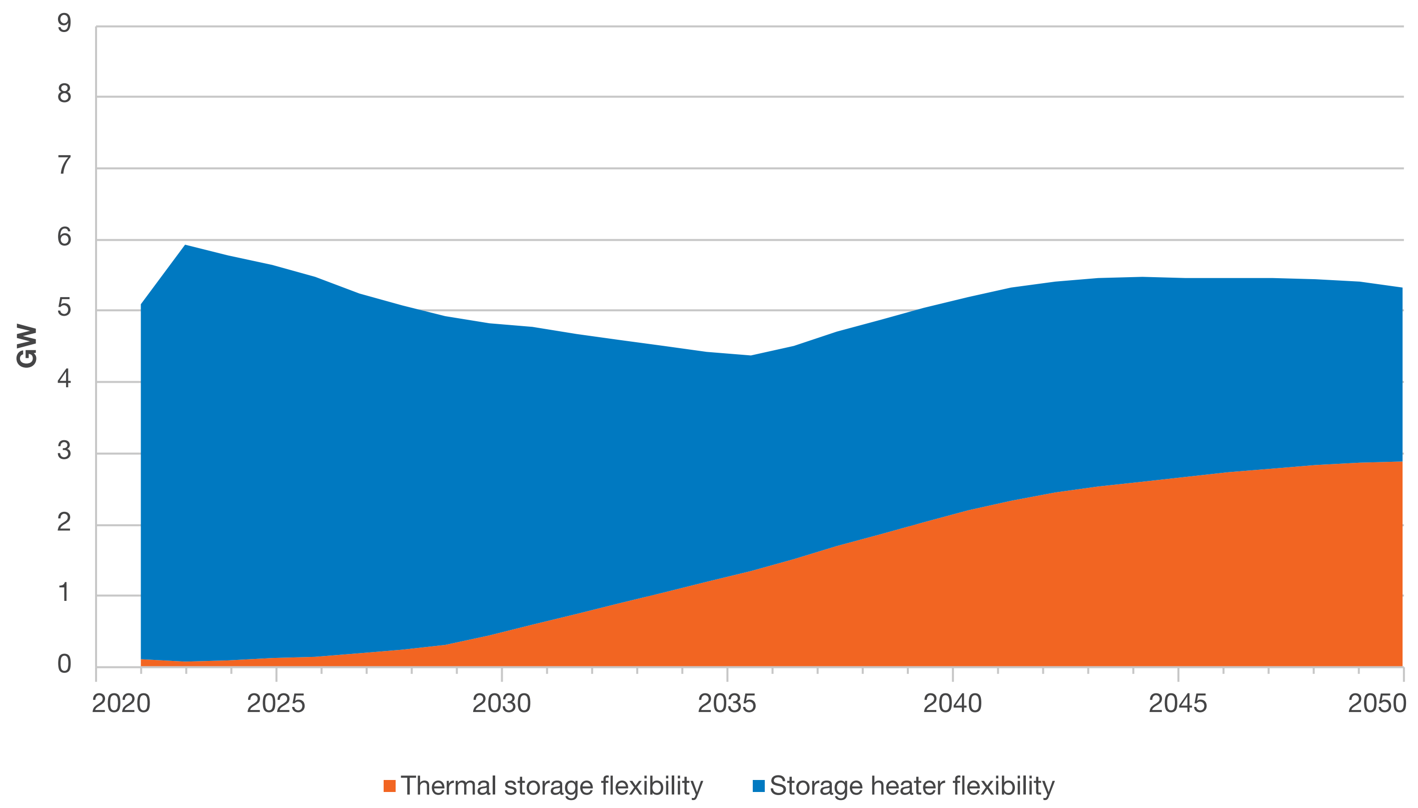
Residential thermal energy storage

Figure FL.08 shows residential thermal storage capacity, and storage heater capacity separately, in operation during ACS peak demand. This period was chosen as it represents the greatest utilisation of thermal storage capacity, however thermal energy storage could also be used to balance supply and demand within a day[11] more generally.

Across all scenarios, thermal energy storage (excluding storage heaters) increases from negligible levels today to between 1.2 GW and 3.8 GW by 2050. System Transformation deploys the least thermal storage out to 2050 as much of its future thermal flexibility is provided by hydrogen boilers and hybrid heat pumps. Leading the Way has the greatest deployment out to 2050 as barriers to thermal storage technologies are removed and engaged consumers look to manage their energy demand.

Storage heater capacity reduces across all scenarios continuing an ongoing trend, however they still provide between 1.5 GW (System Transformation) and 3.4 GW (Falling Short). Again, System Transformation has the least capacity by 2050 due to availability of other thermal flexibility. Falling Short has the greatest capacity of storage heaters, as minimal changes to consumer behaviour and slower decarbonisation lead to existing technologies being retained.

Figure FL.08: Domestic thermal energy storage at ACS winter peak Consumer Transformation



11 Thermal energy storage has typically operated within daily cycles, and this is how it is modelled in FES. However, some new technologies can store heat for longer, up to several days at a time.

Residential thermal energy storage

Figure FL.08: Domestic thermal energy storage at ACS winter peak
System Transformation

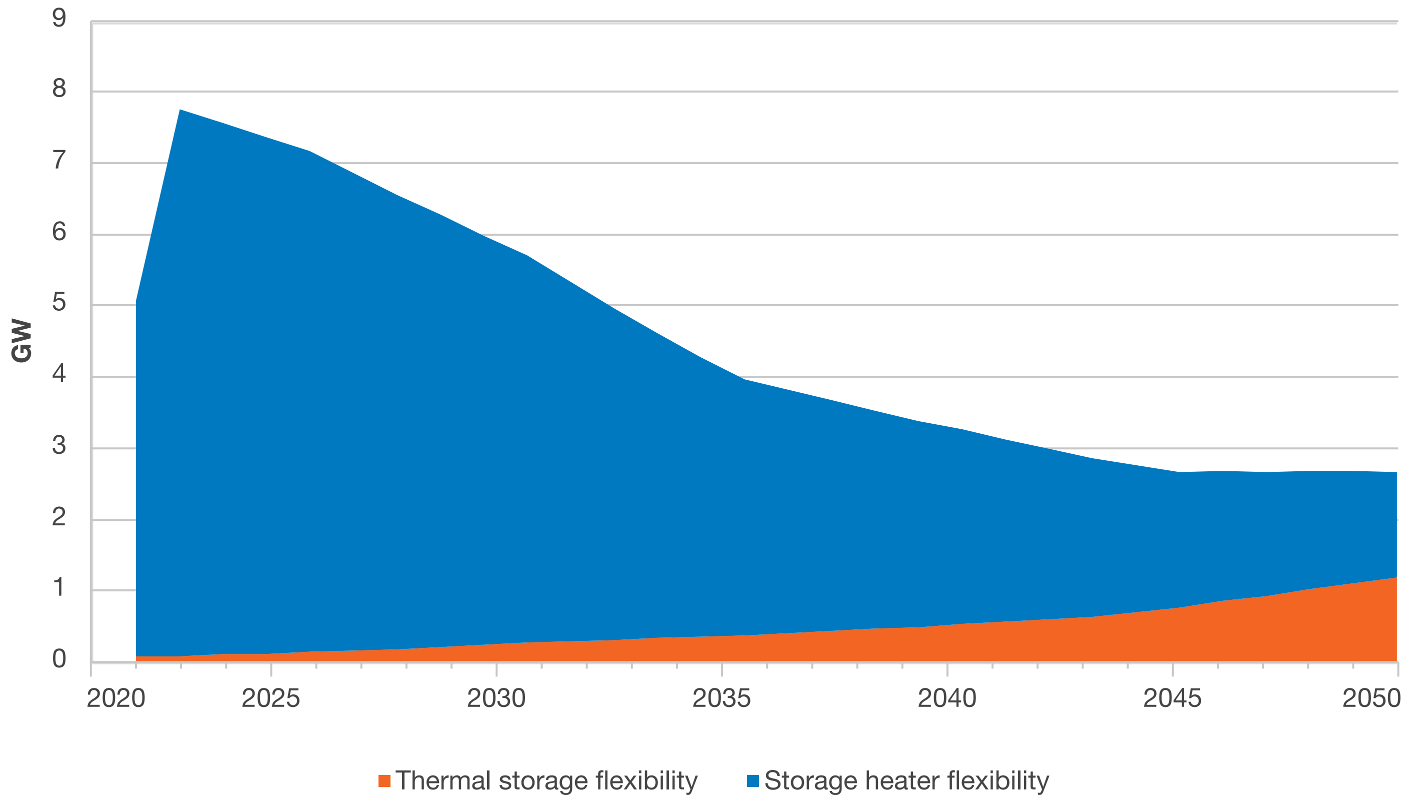
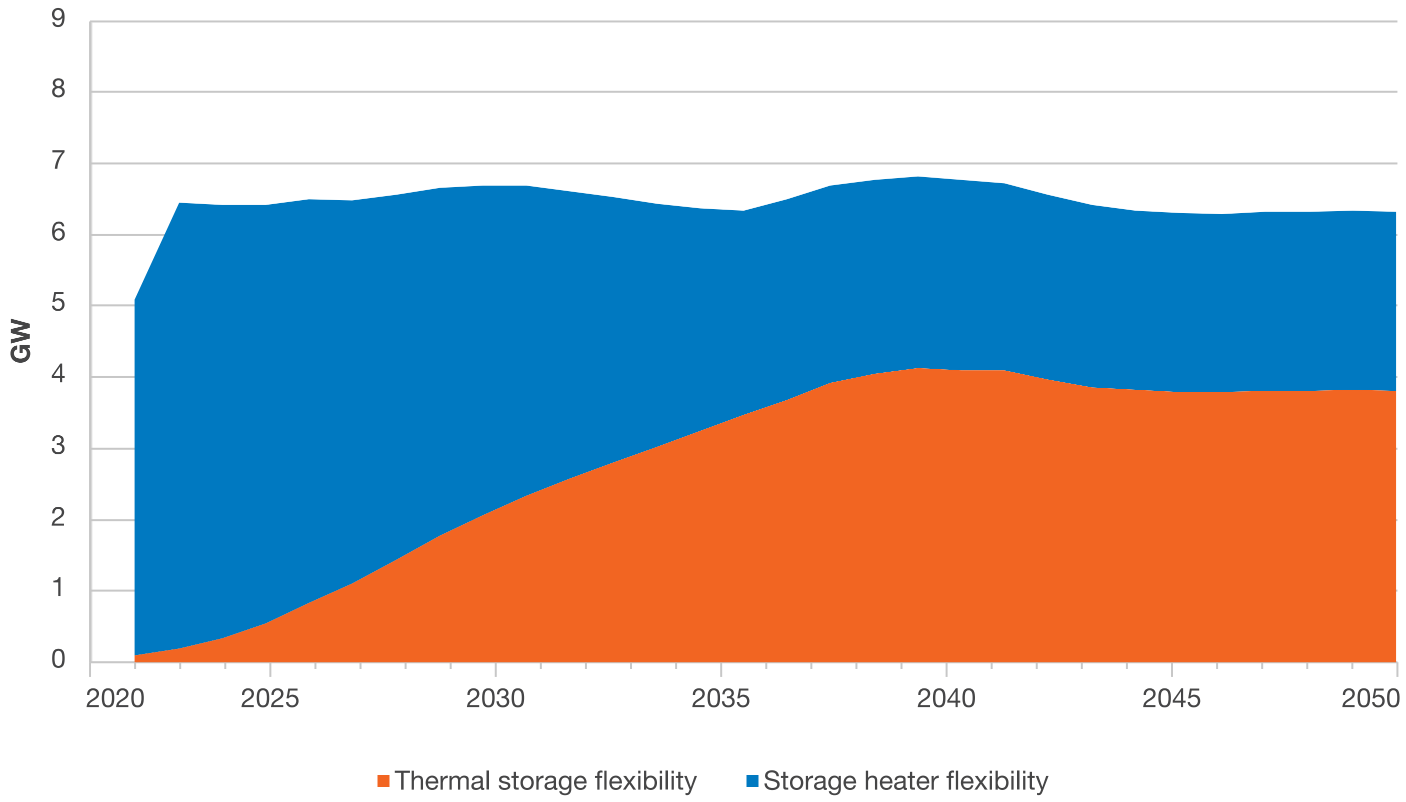
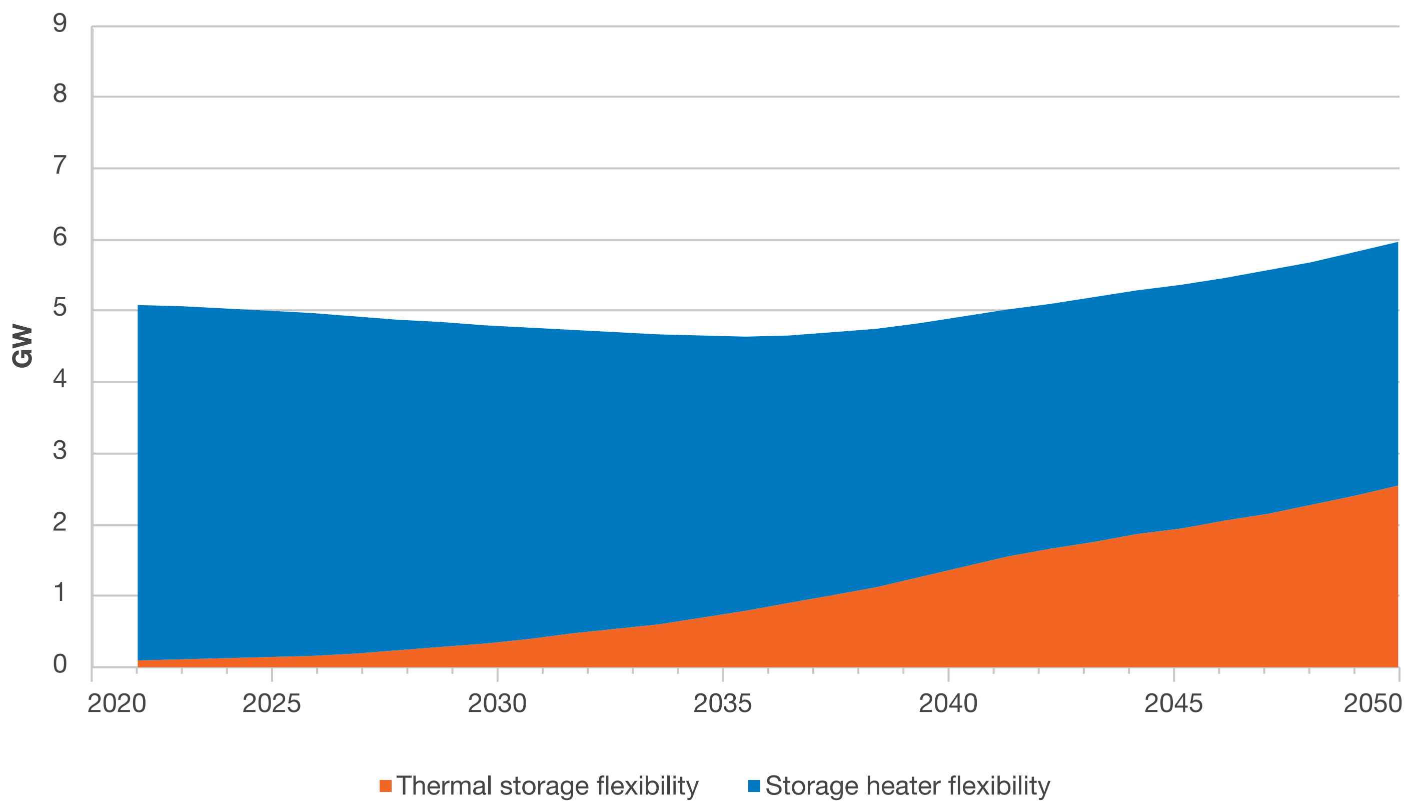


Figure FL.08: Domestic thermal energy storage at ACS winter peak
Leading the Way



FES 2022 / Flexibility 338

Figure FL.08: Domestic thermal energy storage at ACS winter peak Falling Short



FES 2022 / Flexibility 339

What we've found

Demand side flexibility

Electrification across sectors leads to increasing peak demands from the mid to late 2020s in all scenarios, before plateauing in the mid-2040s in the case of Consumer Transformation and Leading the Way. Demand side flexibility, including contracted Demand Side Response and price related load shifting, will play an important role in balancing supply and demand and mitigating peak demand increases. However, it should be recognised that some demand cannot be moved and this still needs to be met.

It should also be recognised that if demand side flexibility is to be deployed at scale, market changes and a demand side strategy are required. These changes must facilitate flexible tariffs, support innovation and reduce barriers to participation for new market entrants from the Industrial & Commercial sector or in the form of aggregated residential demand. See here for more detail on our Net Zero Market Reform work. A demand side strategy should identify strategic priorities and incentivise more flexible electricity consumption, as well as long duration storage and early hydrogen uptake.

Figure FL.09 shows the demand side flexibility options available and their impact in reducing peak demand for each scenario in 2050. The central bar in Figure FL.09 represents the ACS peak demands[12] shown in Figure FL.04.

Unmanaged peak demand is reduced by up to 18% to get to the ACS peak figure through EV smart charging, and residential heat flexibility. Industrial & Commercial DSR, non-heat residential DSR[13] and Vehicle-to-Grid (V2G) response are not included in the ACS peak calculation and can reduce the peak demand by up to 29% below this. It should be noted that demand side flexibility options may not necessarily all be utilised at once (although they have the potential to be) and so Figure FL.09 shows maximum potential demand side flexibility per scenario. While all these flexibility options are important, across the scenarios the take-up of different flexible technologies varies, as does consumer engagement with smart tariffs. The uptake rates and the relative impact of each technology are explored in more detail in the following sections.

Comparing Figure FL.09 to last year's results, Consumer Transformation and Leading the Way have the potential for around 10 GW less demand side flexibility by 2050 as our assumptions on EV smart charging and industrial DSR have reduced based on new trial data and changes to modelling methodology respectively (see I&C demand side flexibility for more details on this assumption). Total demand side flexibility for System Transformation and Falling Short have stayed similar to last year as our EV assumptions didn't change for the less consumer engaged scenarios, and I&C DSR plays a smaller role in these scenarios. A noticeable difference is how much higher ACS peak demand is in Falling Short – this is not due to lower levels of demand side flexibility in FES 2022 but rather because of higher peak electricity demands.

Consumer Transformation and Leading the Way see consumers increasingly using energy in a smart, flexible way, which helps reduce total peak demands by up to 38% and 42% respectively due to demand side flexibility by 2050.

Unmanaged peak demand

Unmanaged peak demand is demand at peak prior to the use of any flexibility to reduce it, including DSR.

12 ACS demand for electricity is the maximum demand over an average winter and is consistent with the treatment of demand in the electricity Capacity Mechanism. As an average it has a 50% chance of being exceeded in any given year.
13 Non-heat residential DSR refers to demand from domestic appliances which can be aggregated across many households and then shifted as a cumulative demand by third party aggregators.

Demand side flexibility

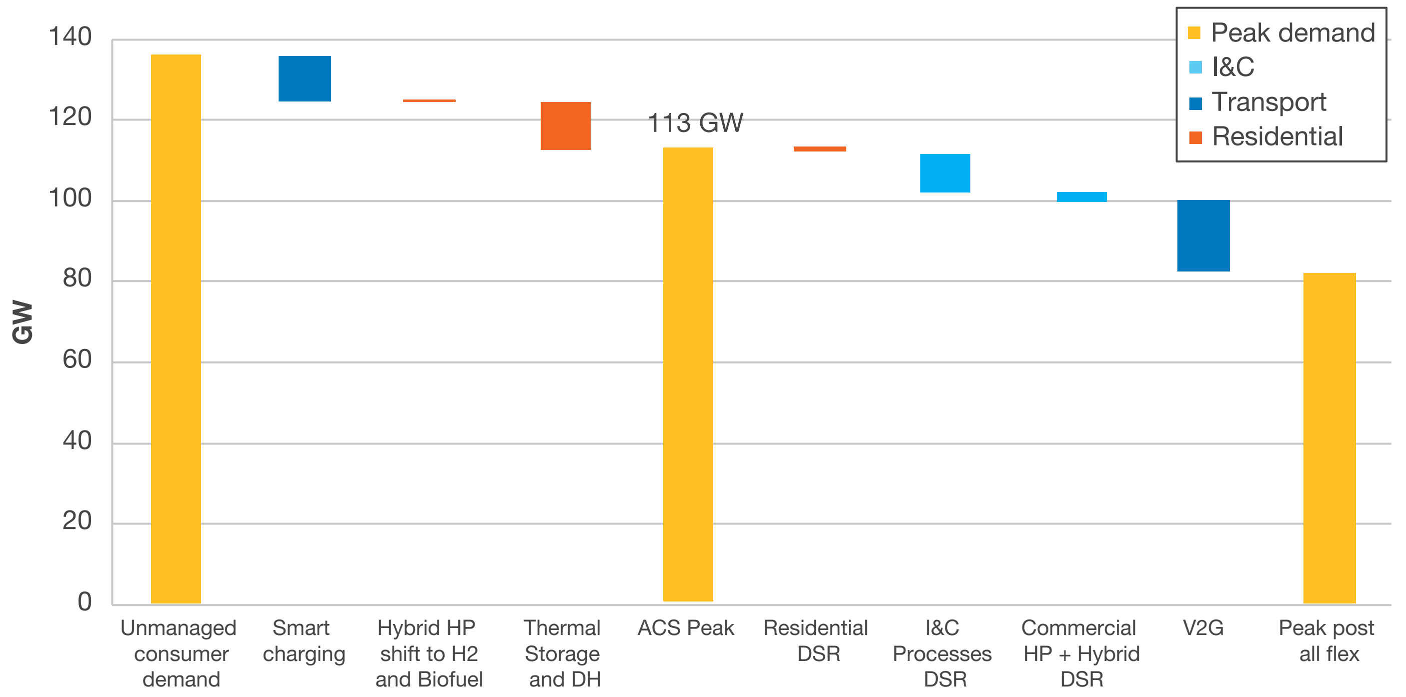
Demand side flexibility take-up is lower in System Transformation and Falling Short which have lower levels of consumer engagement, however they still see over 26% and 19% total peak demand reduction respectively from demand side flexibility.

Whilst electrolysis is considered a flexible demand side technology, it will typically not be operating during winter network peak demand, due to higher electricity prices, unless there is excess renewable generation on the system. It is therefore not included with Figure FL.09 showing the impact of flexible demand side technologies at peak. Winter peak demands will continue to be a challenging time for system operation, however in future they may not represent the highest periods of demand on the network. There are likely to be times of very high renewable output that see flexible sources of demand such as electrolysis and EV charging on top of normal consumer demands when there is excess generation available at low prices. These time periods will present a different challenge to the electricity system, and may see very high flows on transmission and/or distribution networks and consequent congestion on the network.

Roles for demand side flexibility:

- Balancing daily variations in supply and demand
- Reserve for unplanned outages/forecast error
- Reducing network constraints

Figure FL.09: Impact of flexible DSR technologies on peak demands in 2050
Consumer Transformation



Demand side flexibility

Figure FL.09: Impact of flexible DSR technologies on peak demands in 2050
System Transformation

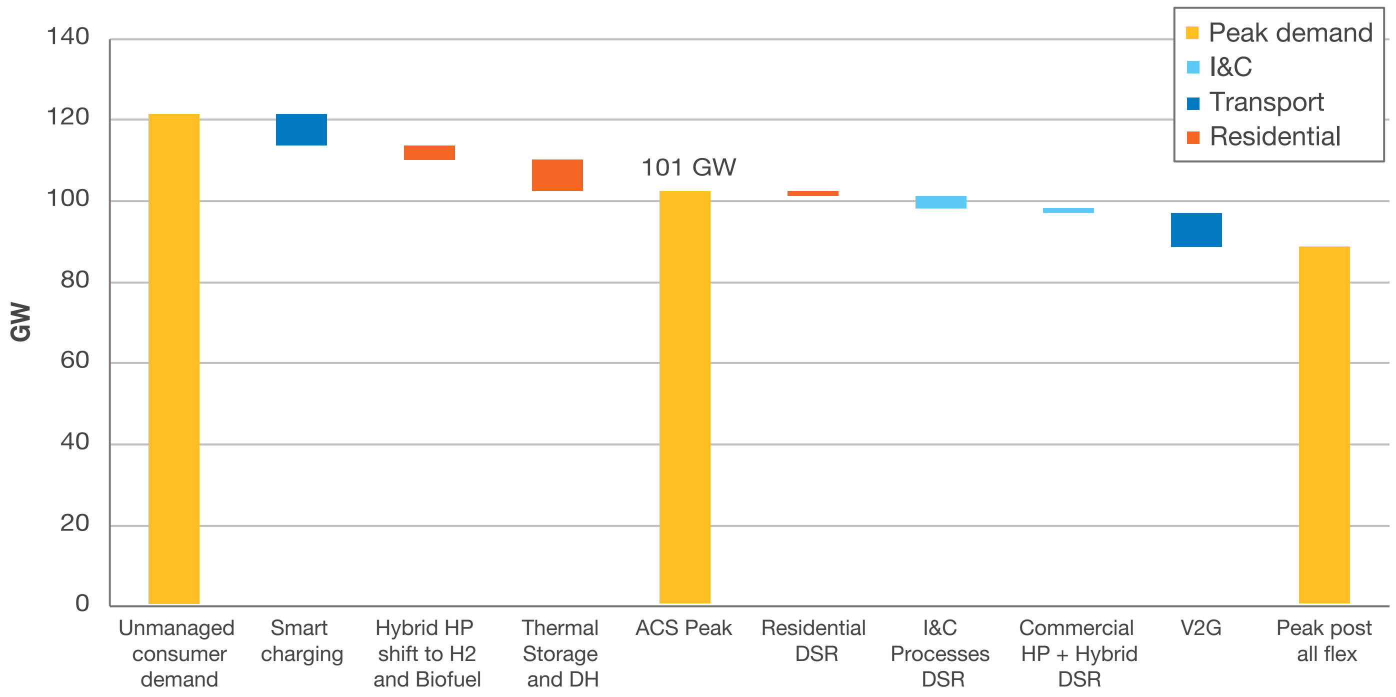
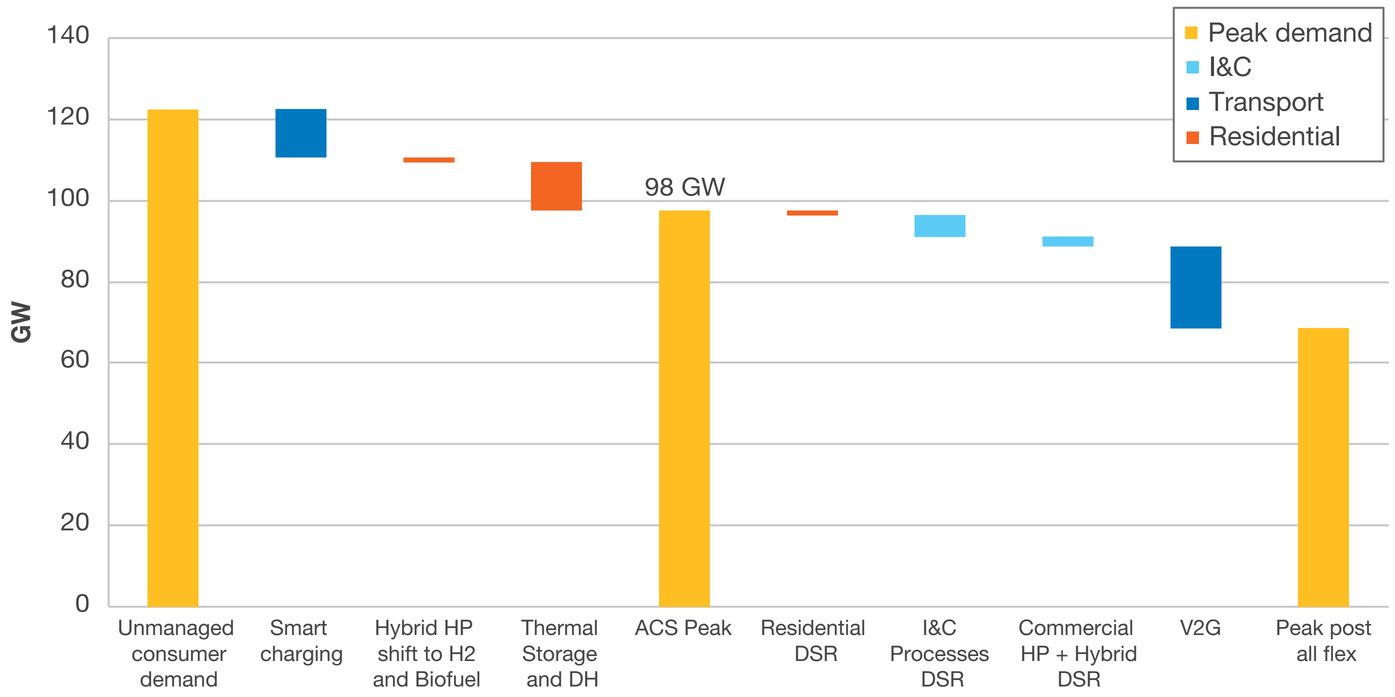
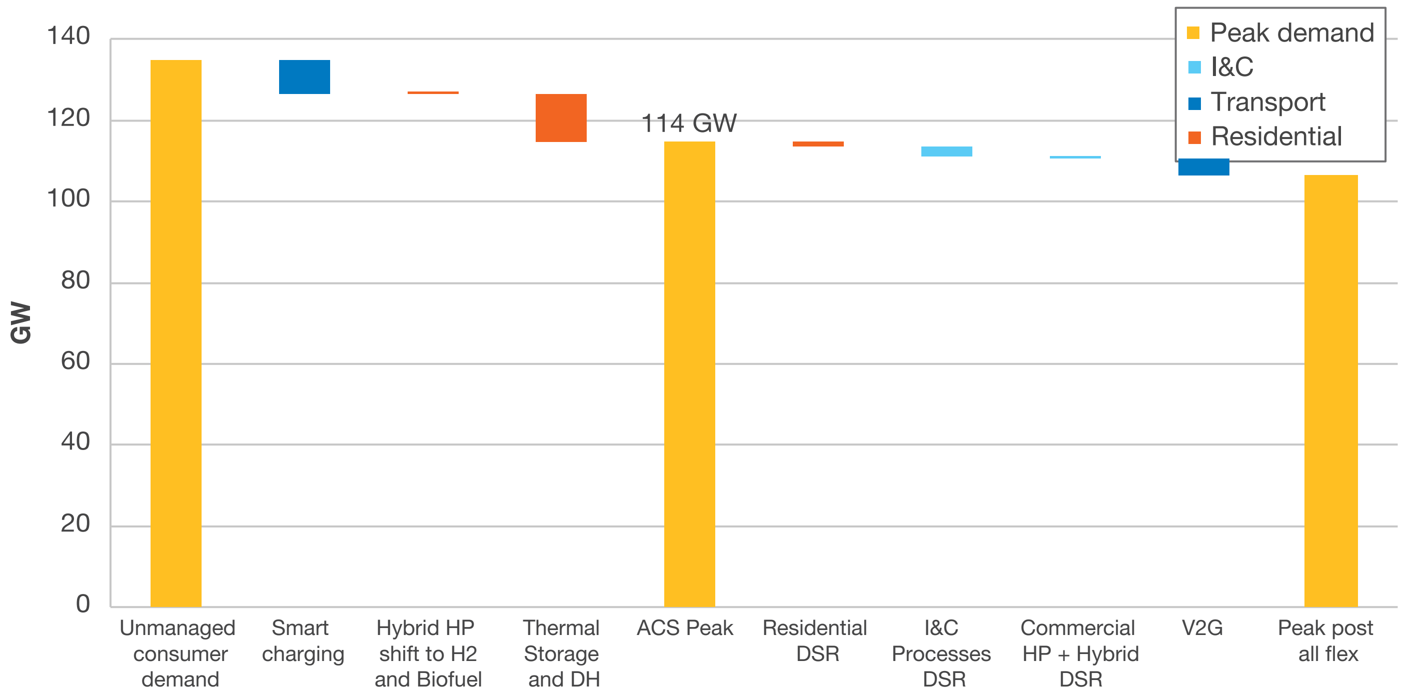


Figure FL.09: Impact of flexible DSR technologies on peak demands in 2050
Leading the Way



What we've found

Figure FL.09: Impact of flexible DSR technologies on peak demands in 2050
Falling Short



FES 2022 / Flexibility 343

I&C demand side flexibility

The Industrial & Commercial sectors are expected to offer increased levels of demand flexibility in the future. However, whilst there is growth in demand side flexibility across all scenarios, this has been reduced compared to last year's results where relatively high proportions of industrial peak demand were being shifted using demand side flexibility.[14]

Industrial and commercial demand side flexibility can be split into two broad categories:

- Demand side flexibility from processes: an industrial process is carried out earlier or later to shift its energy demand.
- Demand side flexibility from heat: as industrial and commercial heat is electrified, heating demand can be moved to match supply using either smart storage heaters or thermal storage alongside heat pumps.

We expect load shifting of demand for industrial processes to increase across all scenarios, with greater acceleration from the mid-2020s for the Net Zero scenarios. The rise of smart technology, and the developing market for demand side flexibility, see the rewards for participating increase while the barriers to entry are eased. Scenarios with high industrial electrification and a preference for a smarter, more efficient energy system see the greatest uptake of I&C demand side flexibility. In Falling Short, in 2024-25 there is an increase of around 1 GW which then returns to close to today's level by 2026 and is to ensure the electricity Security of Supply standard is still met following nuclear plant closures. This short-term increase before falling back reflects the fact that industrial demand side flexibility currently has higher costs relative to other options, and so is incentivised when other generation options are not available, and then drops off as alternative, cheaper plant become available. In the longer term, with less deployment of smart technology, the industrial demand side flexibility market develops more slowly in Falling Short.

FES 2022 / Flexibility 344

14 Demand side flexibility is an area which is continuously developing and has undergone several policy changes over the last few years (e.g. the targeted charging review and its impact on triad avoidance). These factors create uncertainties which our modelling assumptions have to factor in, and on revisiting last years assumptions and based on current evidence, we have revised our assumptions for FES 2022 resulting in the drop in industrial demand side flexibility.

I&C demand side flexibility

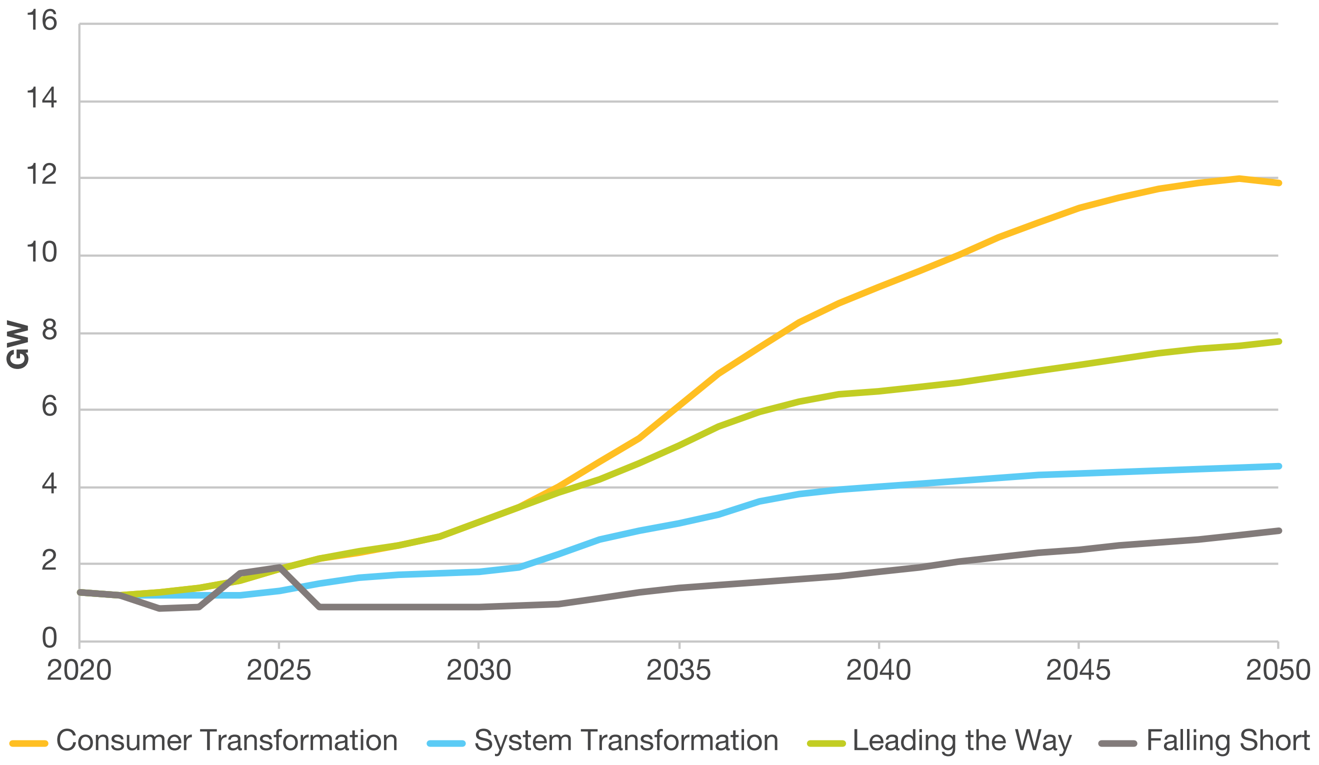
In System Transformation, a significant proportion of I&C demand moves away from natural gas to hydrogen rather than electricity. This results in low electricity demand relative to the other Net Zero scenarios and less potential for demand side flexibility. This is further reduced by lower relative consumer engagement in System Transformation, leading to the lowest levels of industrial demand side flexibility of the Net Zero scenarios.

In Consumer Transformation, as hydrogen is a premium fuel, I&C demand electrifies as much as possible, particularly in the areas of space heating, with commercial heat pumps and other secondary systems potentially available to provide demand side flexibility.

Consumer Transformation has the highest customer electricity demand of this year's scenarios and therefore the highest levels of industrial demand side flexibility out to 2050. Although lower than Consumer Transformation, Leading the Way also has relatively high levels of demand side flexibility as this scenario reflects a rapid drive to as efficient and smart a system as possible.

Across the Net Zero scenarios we expect increased electrification of heat to lead to increased opportunity for heat demand to be shifted to match supply; from very low levels today to over 2.5 GW by 2050. This shifting of demand is enabled by a combination of thermal storage alongside heat pumps, as well as a larger contribution from smart storage heaters. There is very little growth in thermal flexibility in Falling Short due to limited consumer engagement and lower levels of electrification of heat.

Figure FL.10: Industrial and commercial demand side response, total



I&C demand side flexibility

Figure FL.10: Industrial and commercial demand side response from processes

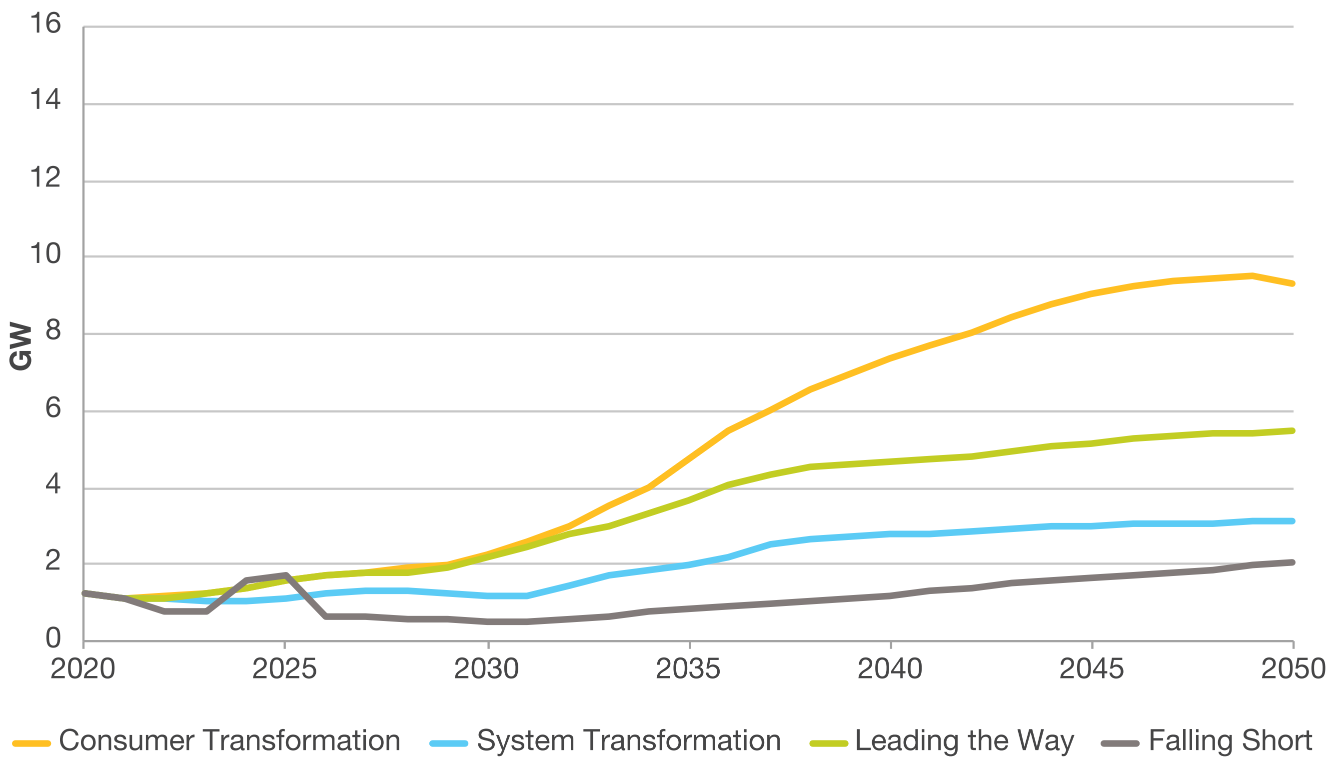
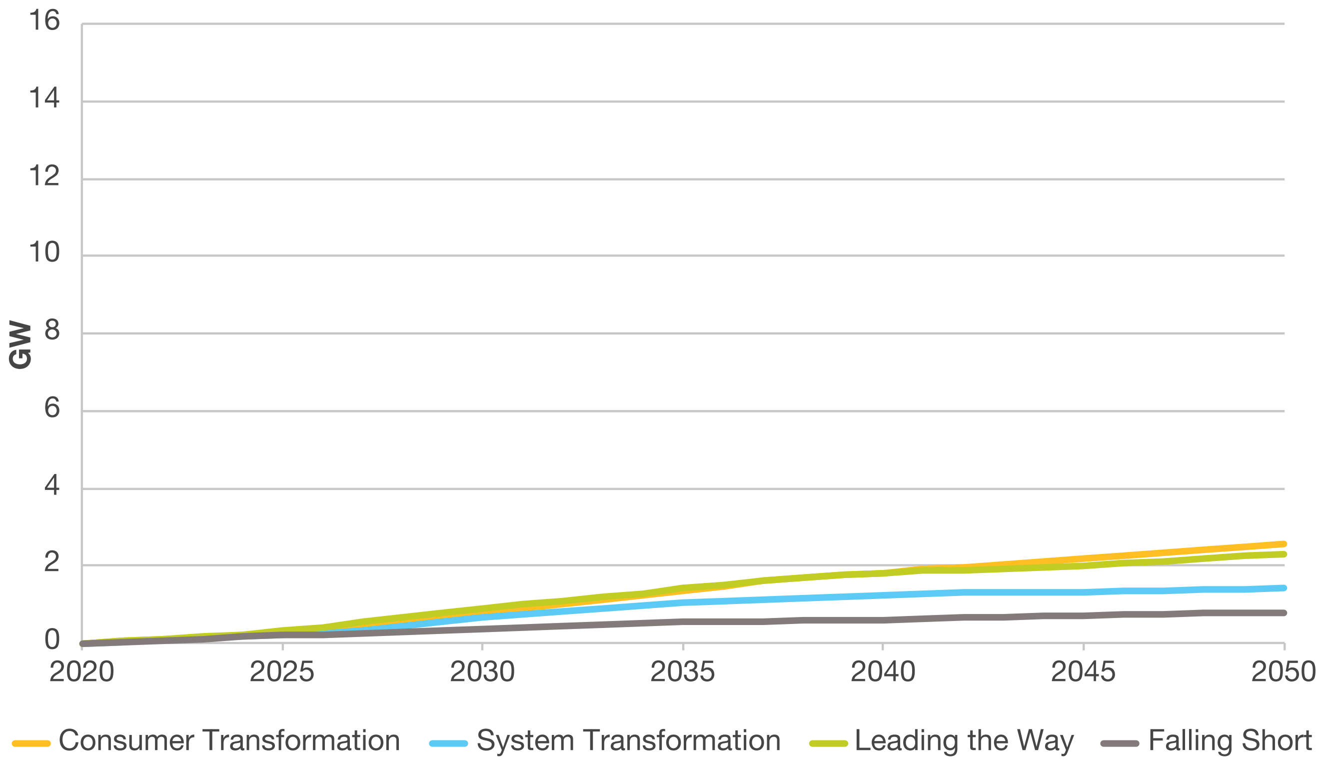


Figure FL.10: Industrial and commercial demand side response from heat



FES 2022 / Flexibility 346

Residential flexibility

Flexibility from residential consumers is increasingly important in a Net Zero world.

There are several avenues for consumers to provide demand side flexibility, from appliances, electric heating or Electric Vehicle charging. EVs and smart charging demand are covered in the Transport flexibility section later in the document. Much of this flexibility will be delivered without direct consumer involvement – consumers would simply opt in to a smart tariff, and use smart devices in their homes. These devices would then turn on and consume power in the background when supply is high relative to demand, within any parameters pre-set by the consumer. Smart technology can minimise the impact on the consumer experience.

Flexibility from appliances presents a smaller but still significant opportunity. Smart appliances automatically responding to price signals from smart tariffs could shift electricity demand away from peak periods for appliances such as washing machines, dishwashers and, even for short periods of time, refrigerators or freezers. Up to 1.4 GW of peak demand could be shifted away from peak times in this way. We expect the move to flexible EV charging to act as a trigger point for consumers to begin to engage in this type of demand shifting as elements such as time varying EV tariffs are already available in the current market.

Across all scenarios we expect increased electrification of heat, primarily from greater use of heat pumps. In 2050 Consumer Transformation sees the highest level of electrification of heat, followed by Leading the Way and Falling Short. This results in Consumer Transformation having the highest electricity peak heat demands followed by Falling Short. Greater energy efficiency and improved standards in new builds helps to reduce peak demand in Leading the Way.

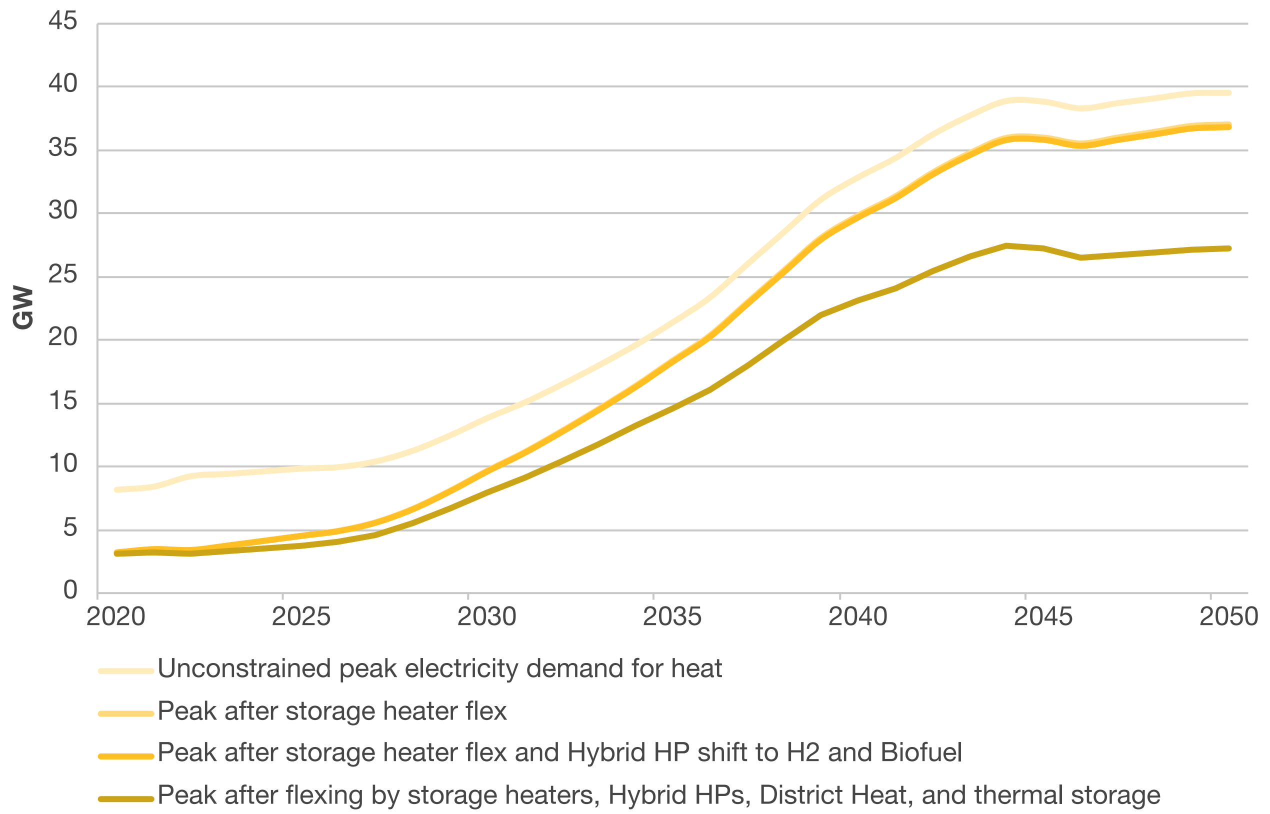
Domestic heat flexibility has an important role to play in shifting some of this heat demand away from peak times. As well as thermal storage technologies (including storage heaters) discussed here, there are a number of other thermal flexibility options. At times of peak demand, hybrid heat pumps can switch from electricity to hydrogen or biofuels for heating. On very cold days some households using Air Source Heat Pumps (ASHPs) without thermal storage may switch to a resistive heating mode, operating at less than half their usual efficiency and increasing their electricity demand. In highly insulated homes the heating can be switched off completely for short periods, reducing demand over peak times without leading to a loss of temperature.

District heat networks can also have centralised thermal storage attached, allowing them to shift demand. Figure FL.11 shows the net demand reduction effect of thermal flexibility after taking account of these options.

FES 2022 / Flexibility 347

Residential flexibility

Figure FL.11: Residential winter peak electricity demand for heating and flexibility from heating technologies Consumer Transformation



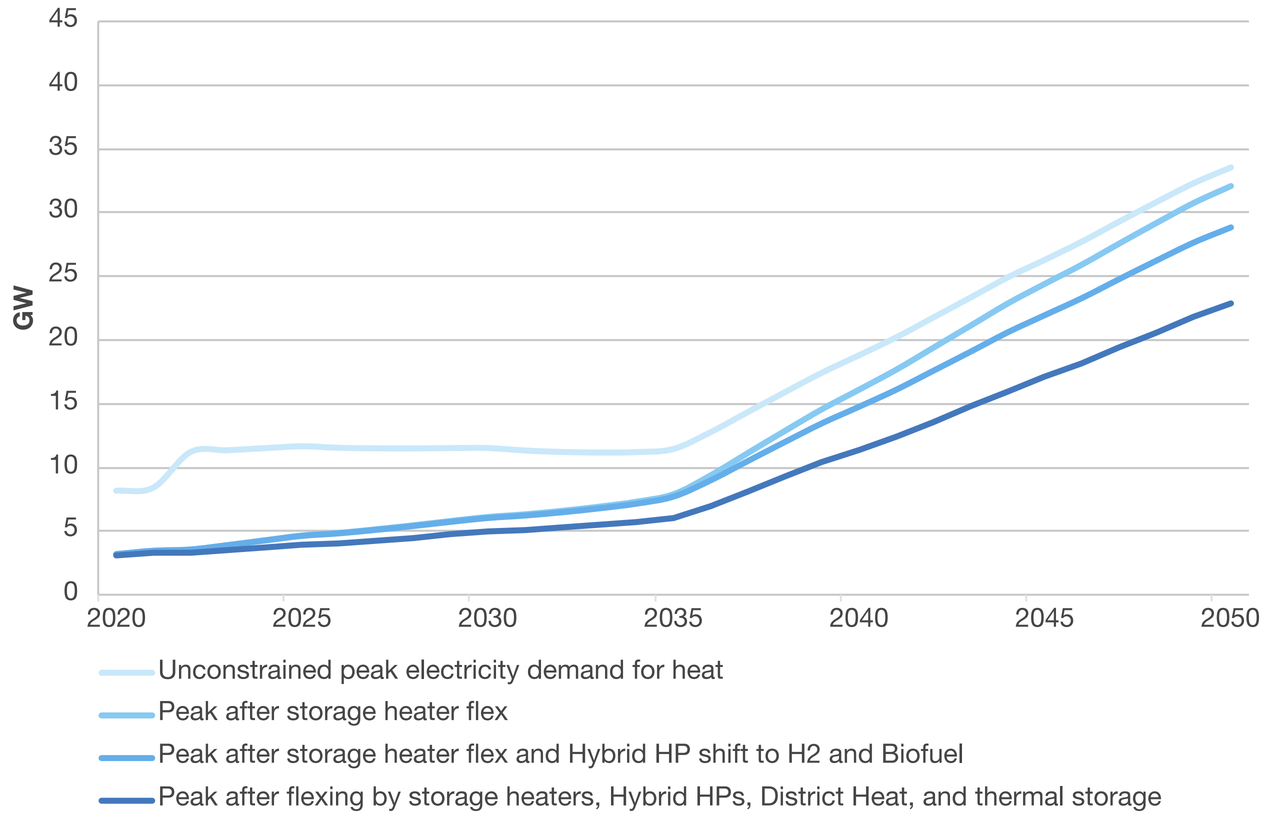
Consumer Transformation

High levels of electrification of heat from 2027 increase peak demand, with load shifting from thermal storage playing a large role in reducing peak demand from 2030 onwards. There is over 9.5 GW of thermal storage load shifting, partly from thermal storage from homes (2.9 GW) but mainly from heat networks (6.7 GW). Total reduction in peak demand reaches 12.3 GW / 31% in 2050.

FES 2022 / Flexibility 348

Residential flexibility

Figure FL.11: Residential winter peak electricity demand for heating and flexibility from heating technologies System Transformation



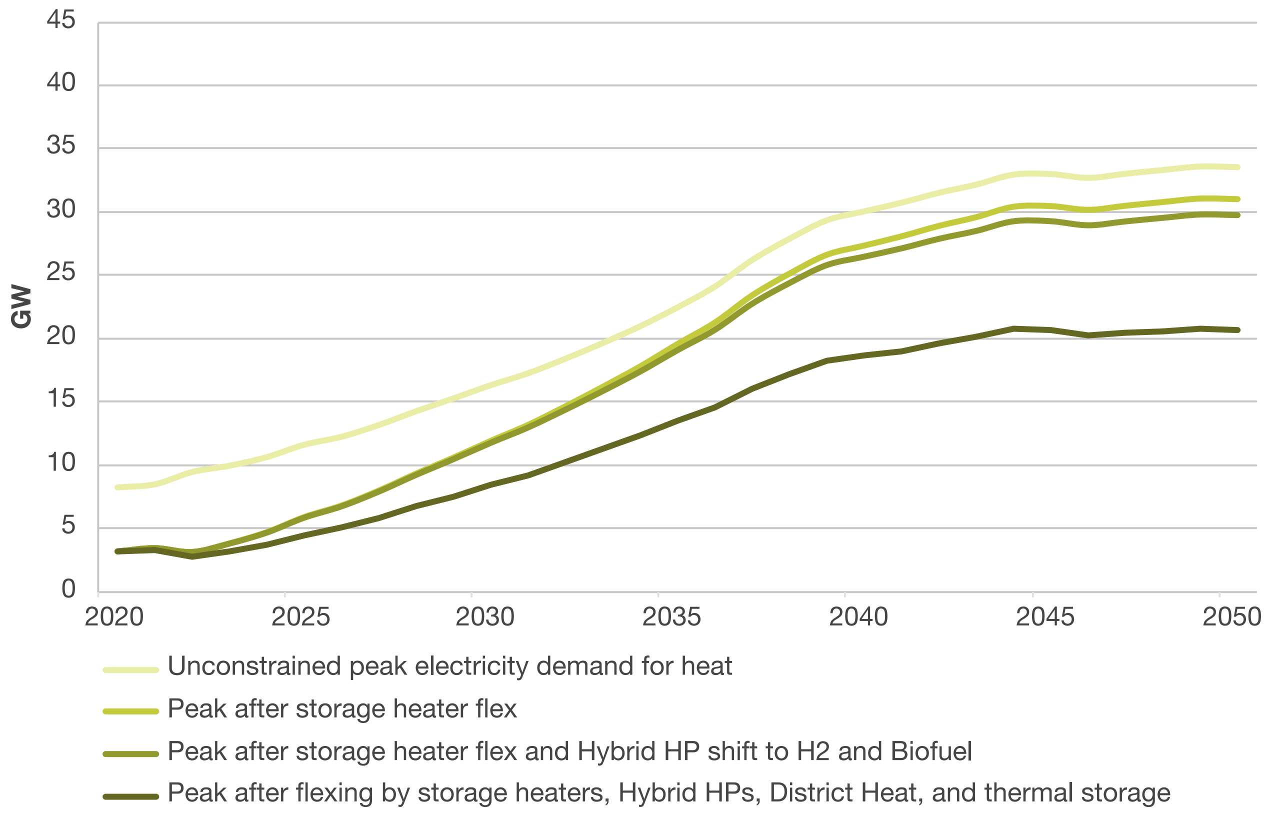
System Transformation

Slower take-up of heat pumps leads to a lower residential peak demand for heat, with flexible demand reduction mainly split between hybrid heat pumps and thermal storage in heat networks. Total reduction in peak demand reaches 10.7 GW / 32% in 2050.

FES 2022 / Flexibility 349

Residential flexibility

Figure FL.11: Residential winter peak electricity demand for heating and flexibility from heating technologies Leading the Way



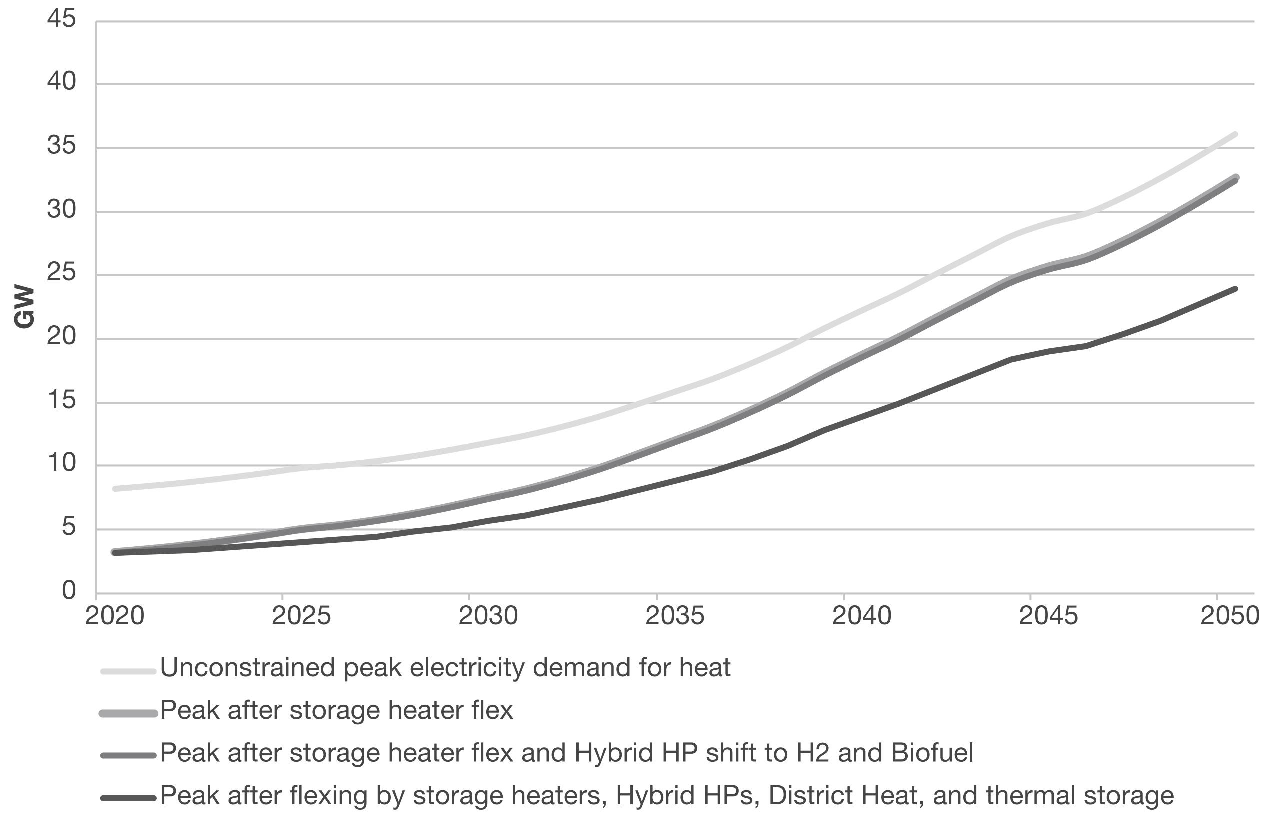
Leading the Way

Peak electricity for heat climbs from the early 2020s to late 2030s where it begins to plateau as most electrification has occurred. Total reduction in peak demand reaches 12.9 GW / 38% in 2050.

FES 2022 / Flexibility 350

Residential flexibility

Figure FL.11: Residential winter peak electricity demand for heating and flexibility from heating technologies Falling Short



Falling Short

Peak electricity demand for heat rises in 2050 and is higher than last years results due to the increased electrification assumed this year. Peak electricity demand in 2050 is also higher than both Leading the Way and System Transformation as, whilst there is less electrification, there is also fewer energy efficiency improvements to reduce peak demand. By 2050 peak demand is reduced by storage heater flexibility (3.4 GW by 2050) and thermal storage from homes (2.6 GW) and heat networks (5.6 GW). Total reduction in peak demand reaches 12.2 GW / 34% in 2050.

FES 2022 / Flexibility 351

Transport flexibility

Smart charging and Vehicle-to-Grid behaviour will play an important role in the future energy system. Across all scenarios, cars are primarily electrified, increasing electricity demands and requiring strategies to manage how they are charged, and how system costs are distributed. However, this presents an opportunity to increase system flexibility, integrate renewables and better match supply and demand. With suitable incentives and automation, drivers will be able to reduce their transportation costs at the same time as reducing the costs of operating the energy system. Figure FL.12 shows EV charging demand both before (unmanaged charging) and after smart charging is applied at times of evening peak demand. The reduction from unmanaged charging to smart charging is the electricity flexibility provided by smart charging.

Smart chargers and automation will make the transition to smart tariffs simple for consumers; both in relation to domestic chargers and centralised charging hubs. We expect the flexibility from smart charging to keep additional peak electricity demand from EVs to between 7 and 12 GW lower than it would otherwise be by 2050. It is important that we have the right market design.

Market reform is required to give granular price signals by time and location, accurately reflecting system conditions near real time. This will help to avoid unintended consequences such as many EVs (or other demand side technologies) responding to a price signal at the same time, leading to big fluctuations in frequency which can cause system operation issues. See Digitalisation section for more detail.

Most of the flexibility value provided by EVs comes from vehicles charging at home overnight; although commercial vehicle fleets or workplace EV chargers can play a greater role at other times of day. During the daytime we expect some commuters to plug in their cars at work. Smart optimisation of EV chargers can benefit consumers and the energy system, ensuring that vehicles maximise the use of low carbon and low-cost electricity. Commercial fleet operators are also incentivised to keep running costs low and providing flexibility from smart charging and V2G can support this. Increasing demand through smart charging at times of high renewable output could be as valuable to the energy system as reducing peak demands.

We expect high take-up of smart charging in households with off-street parking and their own home chargers. In Leading the Way and Consumer Transformation, widespread innovation also allows most households with on-street parking to charge, although Consumer Transformation also assumes near-home rapid charging hubs. In System Transformation, most households without off-street parking use these centralised rapid charging hubs, whilst in Falling Short these households charge opportunistically (e.g. at work, or at destination). These charging behaviours contribute to Leading the Way and Consumer Transformation, where there is better access to chargers, having greater smart charging flexibility during peak times. This is despite assumptions around the level of residential smart charging being reduced compared to FES 2021 based on increased trial data availability.

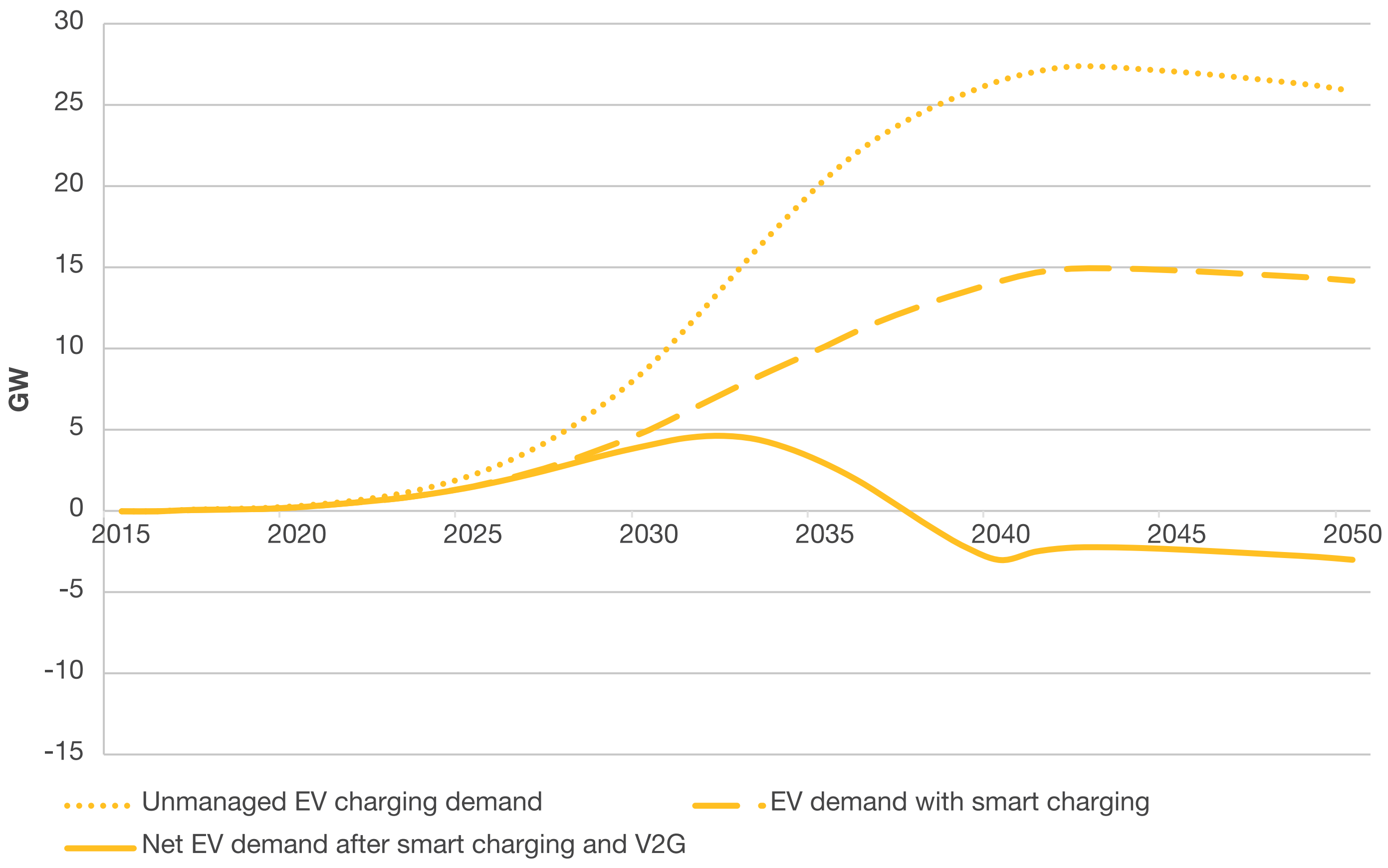
Transport flexibility

The scale of V2G's deployment and its consequent ability to provide flexibility to the electricity system is uncertain, with a wide range of outcomes across our scenarios. System Transformation and Falling Short see limited take-up of V2G, however by 2050 this still represents a potential peak shaving of up to 8 GW in System Transformation. In Consumer Transformation and Leading the Way, high levels of consumer engagement see net EV demands at peak times become negative from the mid-2030s, with more power being fed back to the grid from EVs than is used to charge them at that particular moment. This impact is limited somewhat in the 2040s as Autonomous Vehicles (AVs) start to increase market share and individual car ownership falls. While we would not expect AVs to be typically charging at times of tight system margins, neither are they as likely to be plugged in and able to respond to a V2G signal.

Roles for Electric Vehicle flexibility:

- Managing several days of oversupply or undersupply
- Balancing daily variations in supply and demand
- Reserve for unplanned outages/ forecast error
- Reducing network constraints

Figure FL.12: Electric vehicle charging behaviour at ACS winter peak system demand
Consumer Transformation



FES 2022 / Flexibility 353

Figure FL.12: Electric vehicle charging behaviour at ACS winter peak system demand
System Transformation

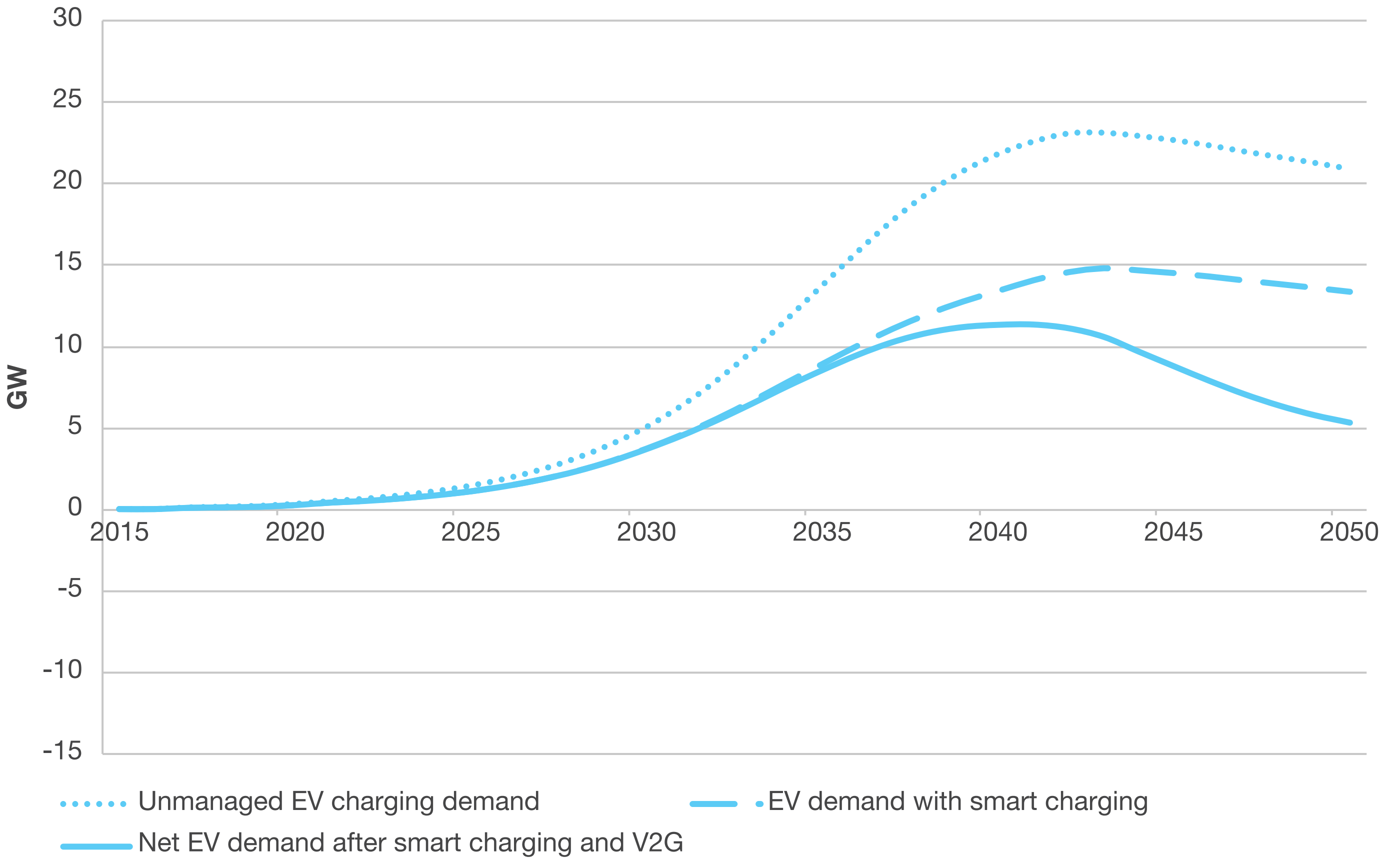
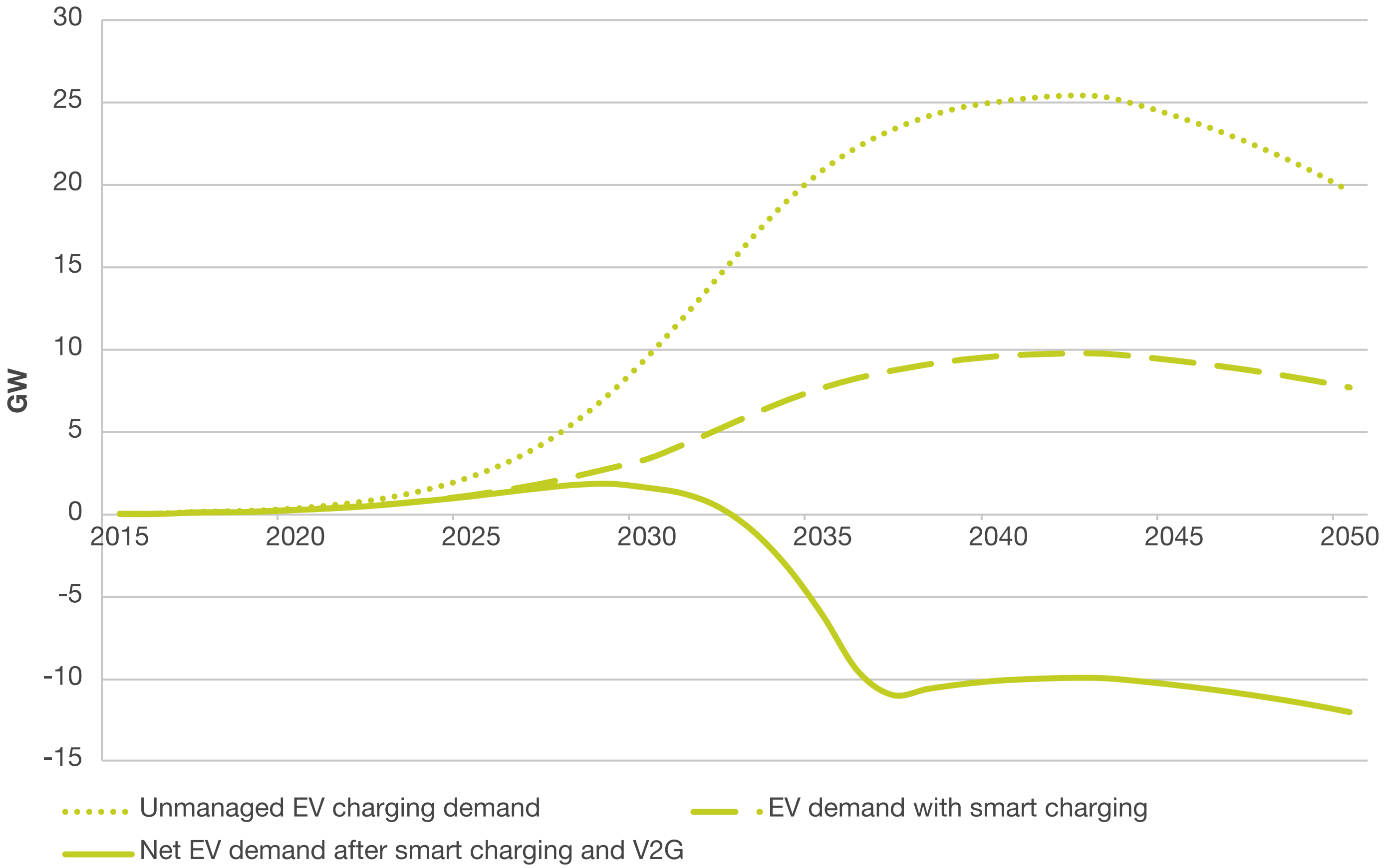
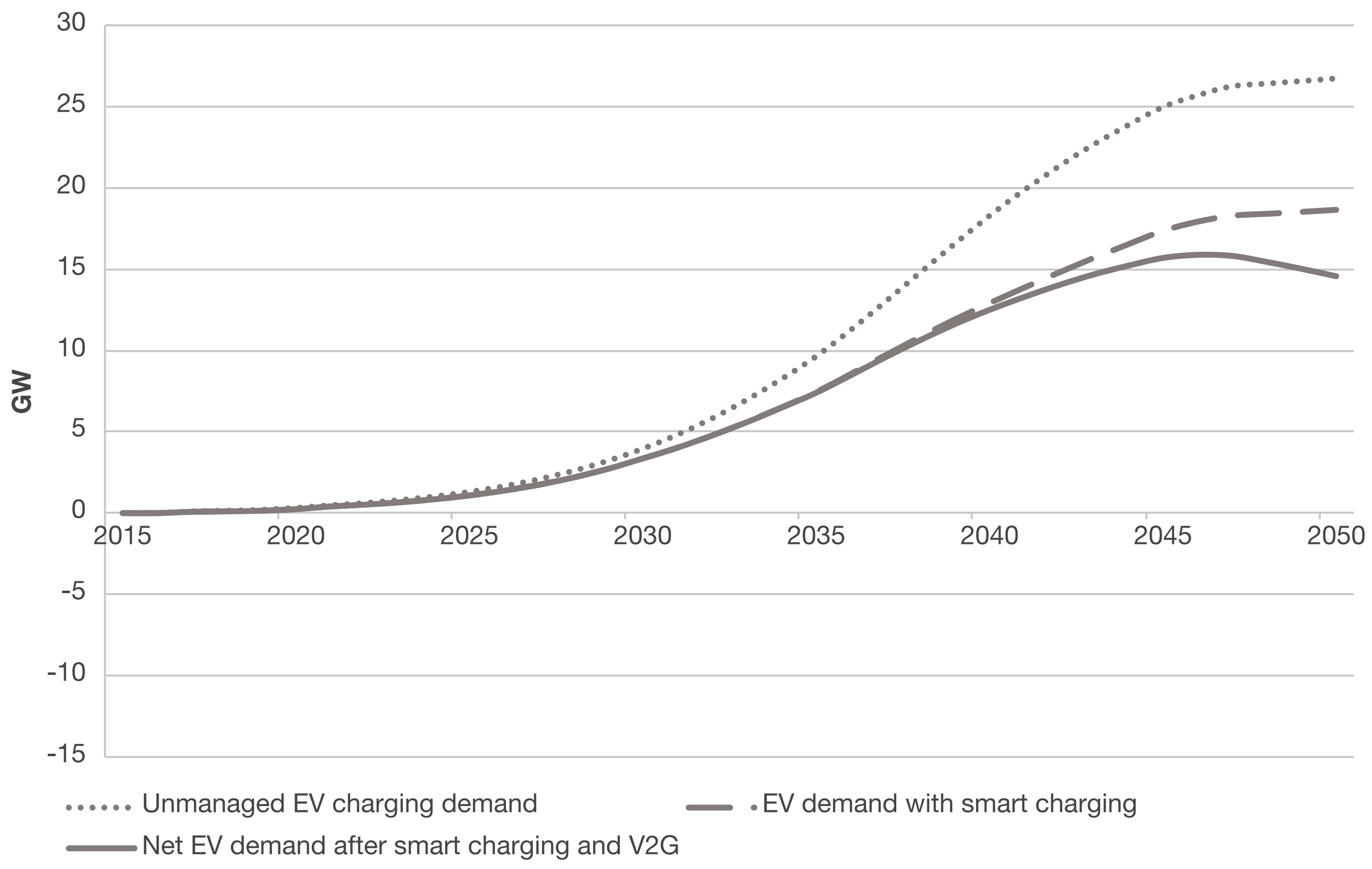


Figure FL.12: Electric vehicle charging behaviour at ACS winter peak system demand
Leading the Way



FES 2022 / Flexibility 354

Figure FL.12: Electric vehicle charging behaviour at ACS winter peak system demand
Falling Short



FES 2022 / Flexibility 355

FES 2022 / Flexibility 356

What we've found

Electrolysis

Electrolysis plays an important role as a source of flexibility in the Net Zero scenarios. It can ramp up demand rapidly to match renewable output, producing hydrogen that can be stored until it is needed.

Leading the Way sees the earliest development of significant electrolysis capacity, reaching over 9 GW by 2030 and exceeding the Government target of at least 5 GW by 2034. This target is met by the other Net Zero scenarios in 2037 (System Transformation) and 2036 (Consumer Transformation). There is minimal electrolysis production in Falling Short due to limited demand for hydrogen and, because the electricity sector is not fully decarbonised, hydrogen produced from electrolysis is not zero carbon.

By 2050, System Transformation has the greatest total capacity of grid-connected electrolysis at 45 GW, compared to 44 GW in Leading the Way. However, Leading the Way deploys electrolysers quicker and so has the greatest capacity until 2045. Consumer Transformation, which generally has less hydrogen demand or high renewable output, has less total grid-connected electrolyser capacity, reaching 28 GW by 2050.

In Consumer Transformation and System Transformation, some electrolysis capacity developed in the late 2020s (System Transformation) and 2030s is connected directly to new nuclear generation.

At times of low electricity demand, or high renewable output, nuclear-connected electrolysis increases to absorb excess power while allowing the reactor to continue to operate at baseload (i.e. providing electricity flexibility). This makes up a relatively small proportion of total grid-connected[15] electrolysis capacity in these scenarios in 2050; 4.1 % in Consumer Transformation and 6.4 % in System Transformation.

High levels of renewable generation, particularly offshore wind, are needed in this year's Net Zero scenarios to meet annual electricity demands. Its variable nature means we will often see times when renewable output exceeds demand. If demand cannot be increased via one or more of the sources of flexibility discussed in this chapter then more generation will be curtailed. Electrolysis in particular can reduce curtailment as the hydrogen produced is easier to store than electricity, and can, if needed, be stored across seasons. Electrolysis will be incentivised to operate and respond to electricity prices and market conditions, including times of potential curtailment. For more detail on curtailment and the role of flexibility see here. Similarly, we don't expect electrolysis to be incentivised to run at times of peak demand other than at times of high levels of renewable generation.

This is a key part of the transformation of our electricity system from being demand-led to being supply-led, with demands shifting to make use of available electricity.

15 While there is electrolysis capacity that is not grid-connected (see Hydrogen Supply), this section is about electricity flexibility and so focuses solely on grid-connected.

Electrolysis

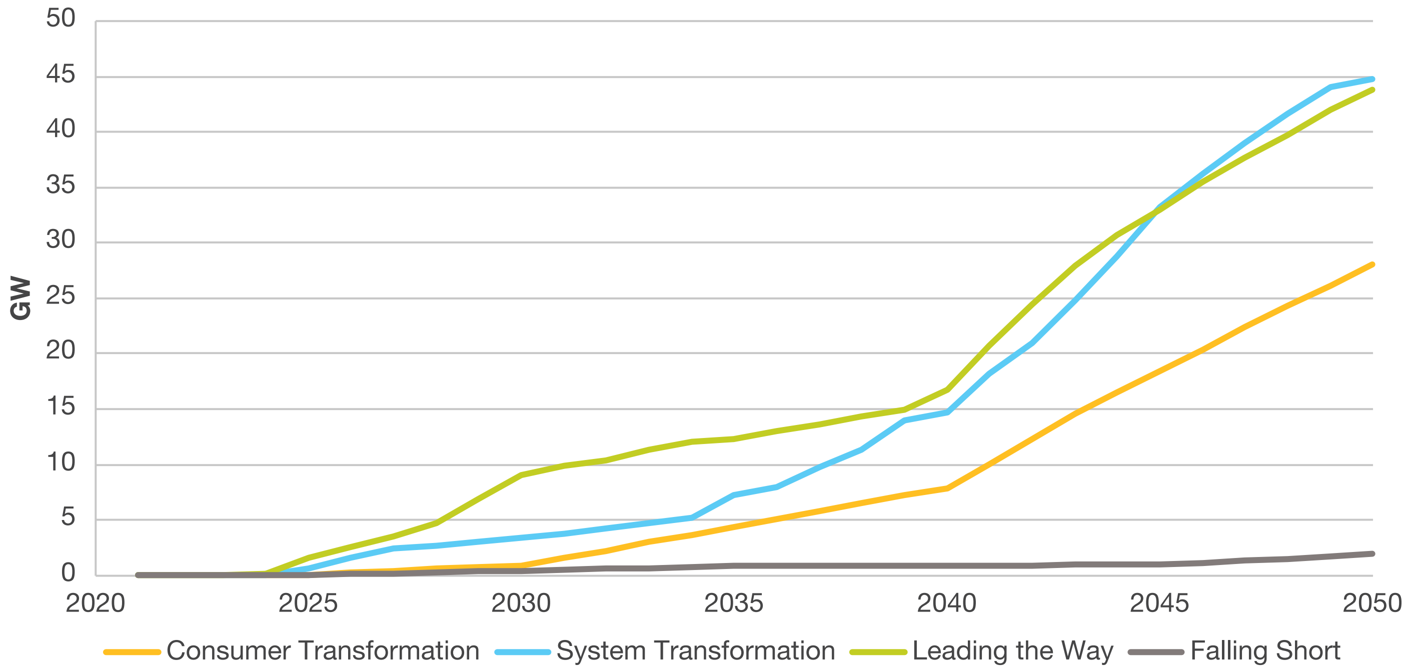
The locations of electrolysers are also key and must be considered to maximise value to the energy system. There must be hydrogen storage nearby or a connection to a network or infrastructure to transport the hydrogen. Locating electrolysers close to renewable generators could also minimise the need for electricity network reinforcement to transport this energy. However, sub-optimal siting could potentially increase network costs and constraints.

Efficient price signals will be important to not only ensure that electrolysers are incentivised to run when we want them to and not when we don't (i.e. to run when supply is high relative to demand), but also to ensure they are optimally sited in locations where flexibility can provide the most benefit to the system. To do this efficient market design is needed, for example the introduction of locational pricing. Our Net Zero Market Reform work looks at this and is discussed in more detail here.

Roles for electrolysis flexibility:

- Managing several days of oversupply or undersupply
- Balancing daily variations in supply and demand
- Reducing network constraints

Figure FL.13: Total electrolysis capacity: all network-connected electrolysers (including nuclear)[16]



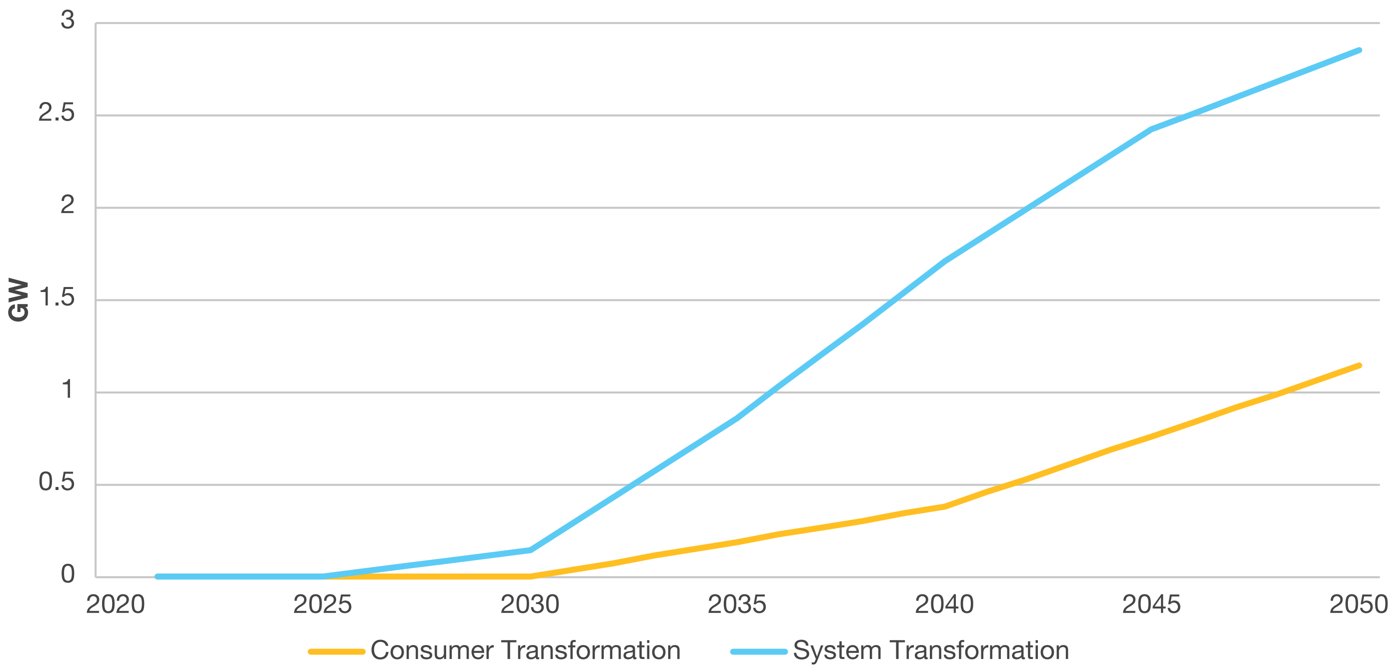
Note that Y axis is different between the charts.

16 Non-network connected electrolysis capacity (e.g. offshore) is not included in Figure FL.13.

FES 2022 / Flexibility 357

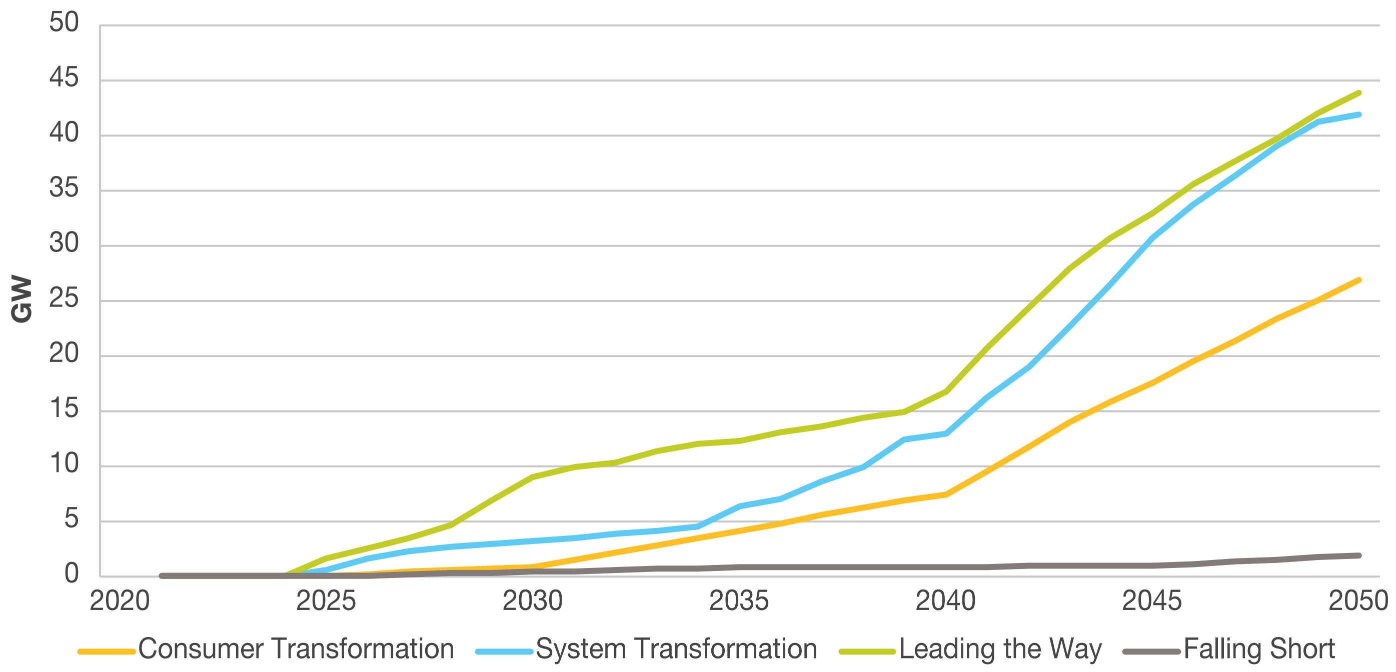
What we've found

Figure FL.13: Nuclear electrolysis capacity: Electrolysers directly connected to nuclear power plants[16]



Note that Y axis is different between the charts.

Figure FL.13: Network-connected electrolysis capacity: Electrolysers connected to the GB distribution and transmission systems either directly or via generation plant (excluding nuclear)[16]



Note that Y axis is different between the charts.

16 Non-network connected electrolysis capacity (e.g. offshore) is not included in Figure FL.13.

FES 2022 / Flexibility 358

What we've found

Regional flexibility spotlight

Flexibility can deliver more value to the energy system in some locations than others which reduces the costs of balancing the energy system. Flexibility options should be sited to maximise this value whilst still considering other siting requirements. But the most suitable locations will vary by flexibility option, typical siting considerations for specific flexibility options include:

- Energy storage (typically batteries) may be co-located alongside renewable generation.
- Longer duration energy storage often has geological siting constraints which limit their location (i.e. Pumped Hydroelectric Storage (PHS) and Compressed Air Energy Storage (CAES)).
- Domestic and industrial demand side flexibility will be most concentrated in larger residential and industrial demand centres respectively.
- Interconnectors need to consider the route between the two connected countries to minimise cable distance and ensure adequate grid connection.
- The optimal placement of some flexibility option could defer or remove the need of costly network reinforcements.
- In general, all flexibility options connecting to the electricity network will have to ensure they are suitably placed on the network: that there is an adequate grid connection, and they are not limited by network constraints.

Hydrogen production from electrolysis is one flexibility option where location can really impact its value. As discussed in the Energy System chapter, there must be hydrogen storage on site or nearby unless there is a connection to a network or infrastructure to transport the hydrogen. A water supply is also needed (although sea water can potentially be desalinated if offshore).

If these siting requirements can be met then electrolysers can be sited on areas of the network with potential constraints. These constraints are caused when more electricity is trying to flow across the network than it has the capacity to manage, often due to high levels of renewable generation. Electrolysers can convert electricity into hydrogen, so diverting it from the electricity network, helping manage the constraint, reducing network reinforcement and integrating renewable generation into the network. More generally, electrolysis can also help to balance oversupply and undersupply across a network. Whilst it is not necessary, being closer to areas of renewable generation can reduce the network costs of providing this flexibility.

FES 2022 / Flexibility 359

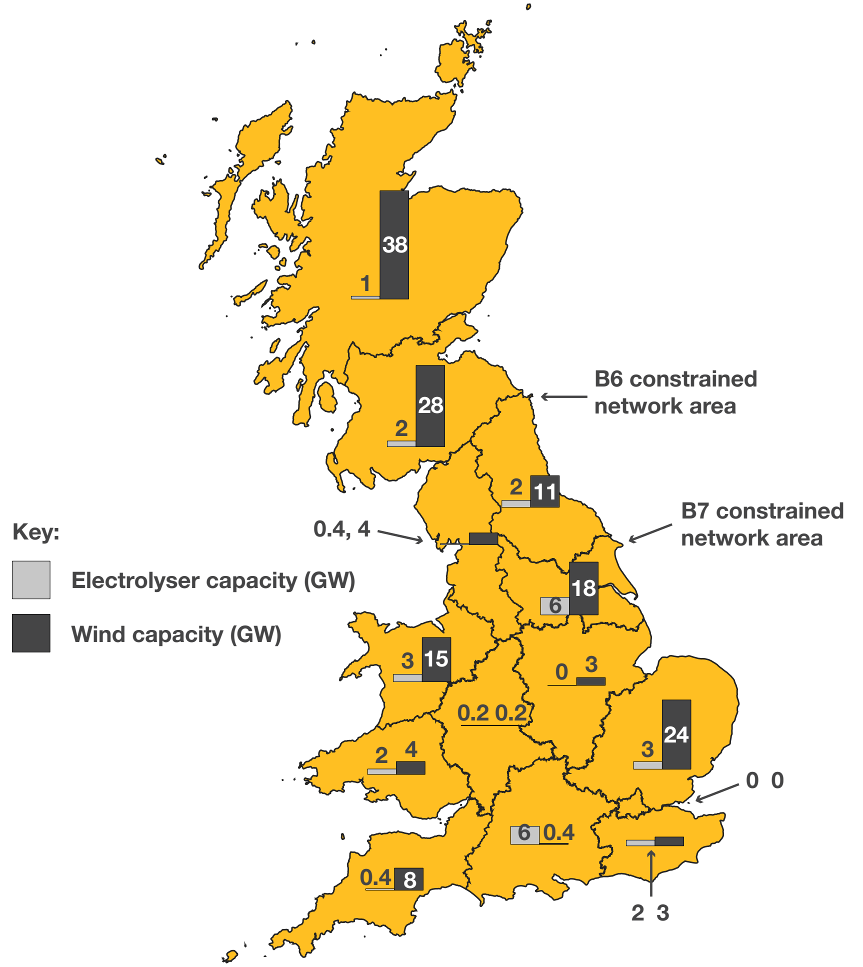
What we've found

Figure FL.14 shows the electrolyser capacity and total wind capacity[17] per Distribution Network Operator (DNO) region for each Net Zero scenario in 2050. For System Transformation and Leading the Way the regions with the greatest wind capacity also have the greatest electrolyser capacities, this is most noticeable in Scotland where over 35% and 45% of total electrolyser and wind capacity is located in both scenarios. Areas with high deployment of wind capacity also have the potential to lead to network constraints; the B6 and B7 constrained network areas in Scotland and the Northeast of England are current examples and these may get worse as additional wind capacity is deployed. There is significant deployment of electrolysers in both these regions which can help mitigate these constraints.

For Consumer Transformation the link between electrolyser and wind capacity is less clear with Scotland still having high levels of wind but only a small deployment of electrolysers, while Southern England has the higher deployment of electrolysers but only a small wind capacity. Consumer Transformation has a relatively small hydrogen demand compared to Leading the Way and System Transformation largely because it mainly electrifies demand rather than using hydrogen. This means that as well as having less electrolyser capacity it also has a much more limited hydrogen network. Consequently, electrolysers are focused in demand centres such as the South of England so a smaller network is needed to transport the hydrogen to where it is needed.

Siting electrolysers in a way similar to that in Leading the Way and System Transformation will not only ensure they provide the maximum benefit in terms of flexibility, but also boost the business case of electrolysers. This is because placing electrolysers next to constrained areas of the network may increase the demand to run them (i.e. increase their load factor). If electrolysers are to be optimally sited then there needs to be the right market arrangements to incentivise this which will require market reform. This is likely to include locational price signals which can reflect the varying need for flexibility in different regions at different times. This is discussed in more detail in the Markets section.

Figure FL.14: Electrolyser and wind capacity by DNO region in 2050 - Consumer Transformation



17 This refers to all offshore and onshore transmission and distribution connected wind. It does not include non-networked wind.

Figure FL.14: Electrolyser and wind capacity by DNO region in 2050 - System Transformation

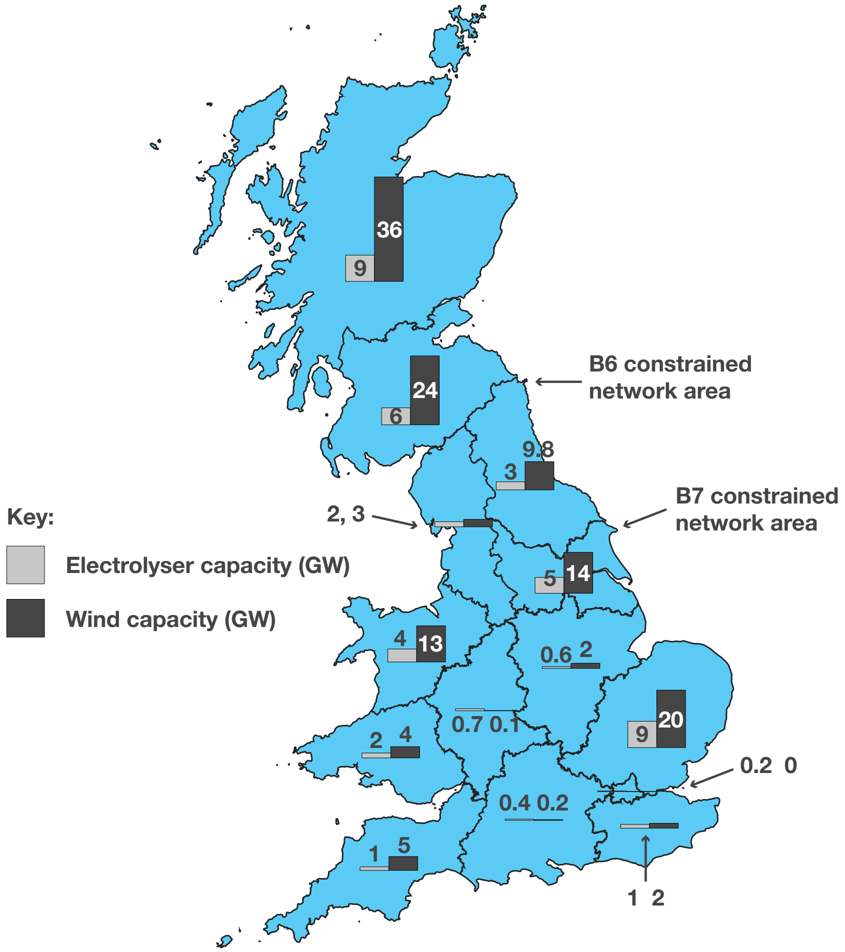
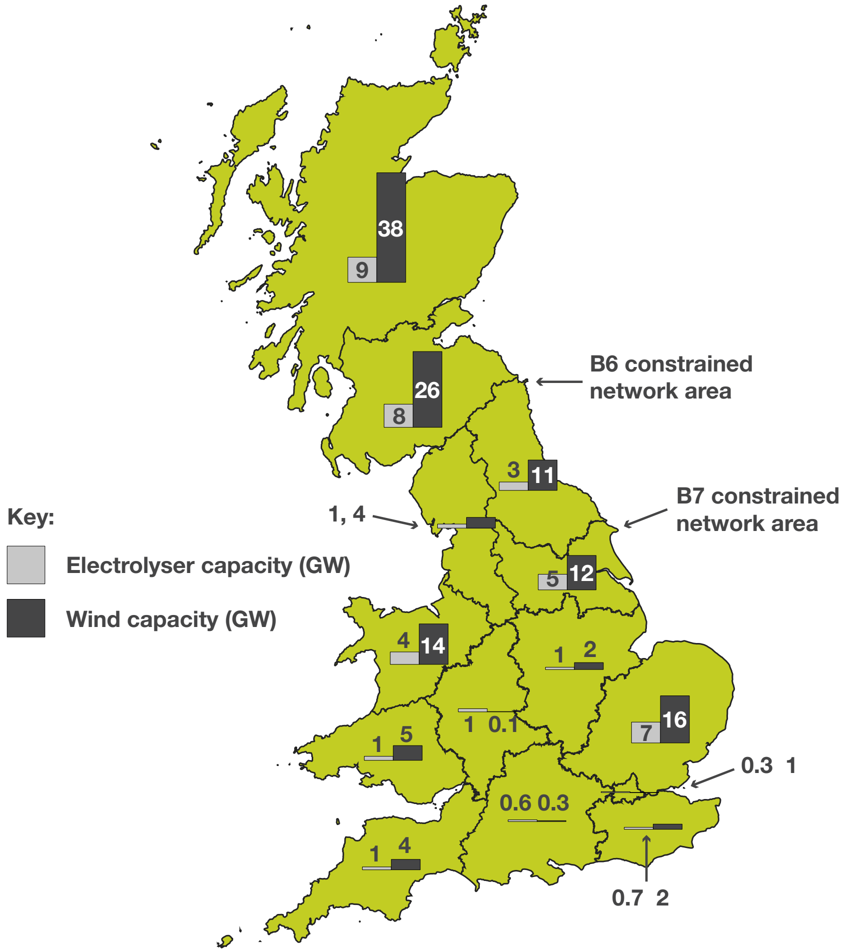


Figure FL.14: Electrolyser and wind capacity by DNO region in 2050 - Leading the Way



FES 2022 / Flexibility 361

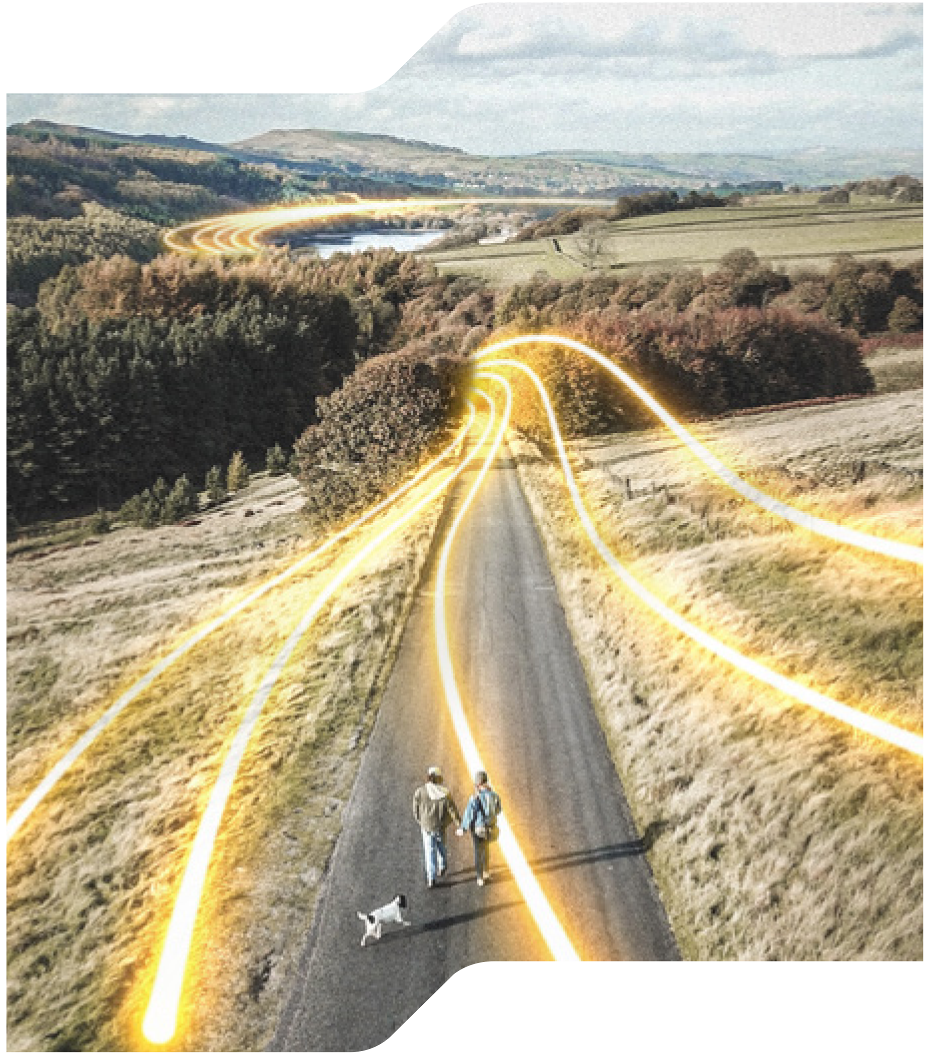
Dispatchable sources of supply

We see increased dispatchable sources of supply across all scenarios compared to FES 2021 as a consequence of increased peak demands.

Demand Side Response will be crucial to help manage peak demands, as shown in Figure FL.04, but some demand is inflexible and needs to be met by sources of supply under all conditions, even when renewable generation output is low. Today the bulk of dispatchable capacity comes from natural gas generation. In the future a much greater share will come from other sources, such as electricity storage and interconnection with other countries and electricity markets.

Unabated gas generation declines to zero ahead of 2050 in the Net Zero scenarios and load factors begin to reduce earlier still; however some level of capacity needs to be retained to meet Security of Supply and provide resilience, although this is less so in Leading the Way. In the Net Zero scenarios, hydrogen generation capacity increases through the 2030s, providing a new source of flexible thermal generation capacity. Beyond this, however, significant increases in other technology types are also needed. In Leading the Way, although unabated gas generation capacity is phased out by the end of 2035, there is only a small and temporary reduction in net dispatchable sources of supply as increased levels of energy storage and interconnectors are deployed. As renewable generation capacity is rising sharply over this period, this dispatchable supply may be required to run for a number of hours at a time, potentially over several days and so it is important that the energy storage deployed includes a suitable capacity of longer duration technologies (see storage page). More broadly, this highlights the importance of ensuring these alternative dispatchable technologies are supported now so they are deployed at the required scale in the future.

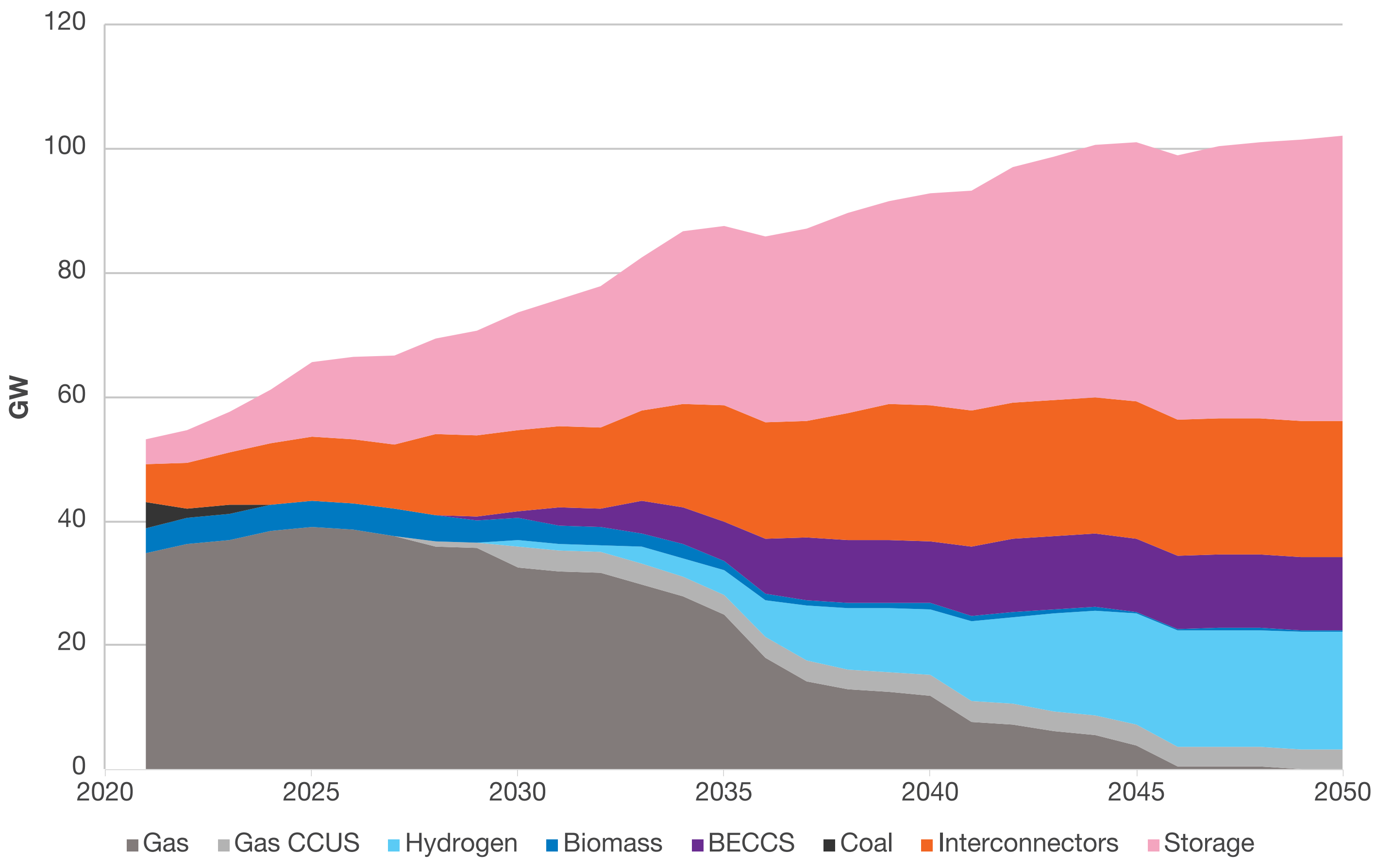
In System Transformation and Consumer Transformation, the slightly slower closure of unabated gas generation means there is less reliance on other technologies for resilience until post-2040, although unabated gas generation is providing almost no energy production. In Falling Short, gas generation, both unabated and gas CCUS, plays the biggest role in ensuring Security of Supply all the way to 2050.



FES 2022 / Flexibility 362

Dispatchable sources of supply

Figure FL.15: Dispatchable electricity supply sources Consumer Transformation



Roles for dispatchable (thermal) supply flexibility

- System resilience
- Managing seasonal differences in supply and demand
- Managing extreme weather periods
- Managing several days of oversupply or undersupply
- Balancing daily variations in supply and demand
- Reserve for unplanned outages/forecast error
- Real-time operability

Dispatchable sources of supply

Figure FL.15: Dispatchable electricity supply sources System Transformation

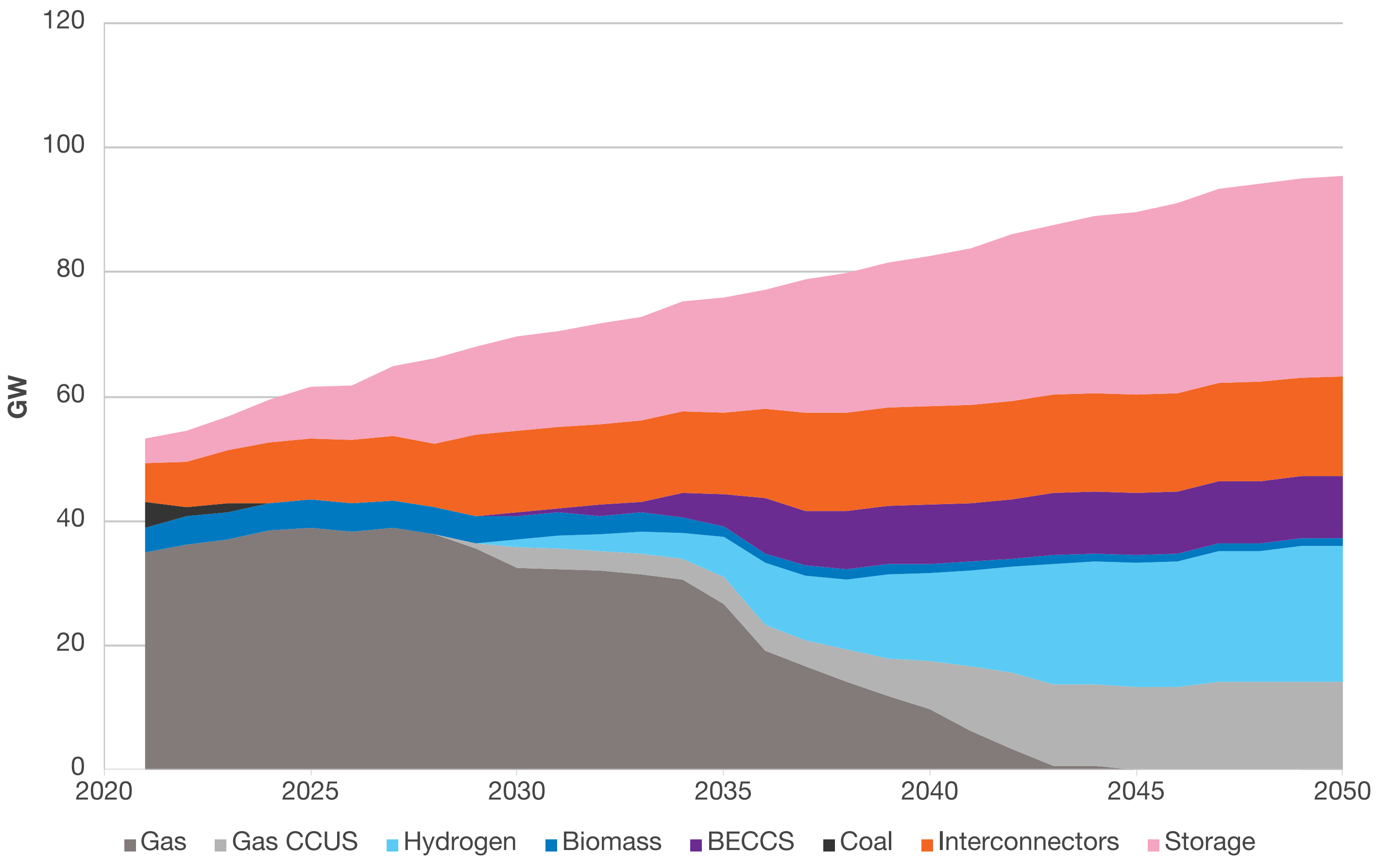
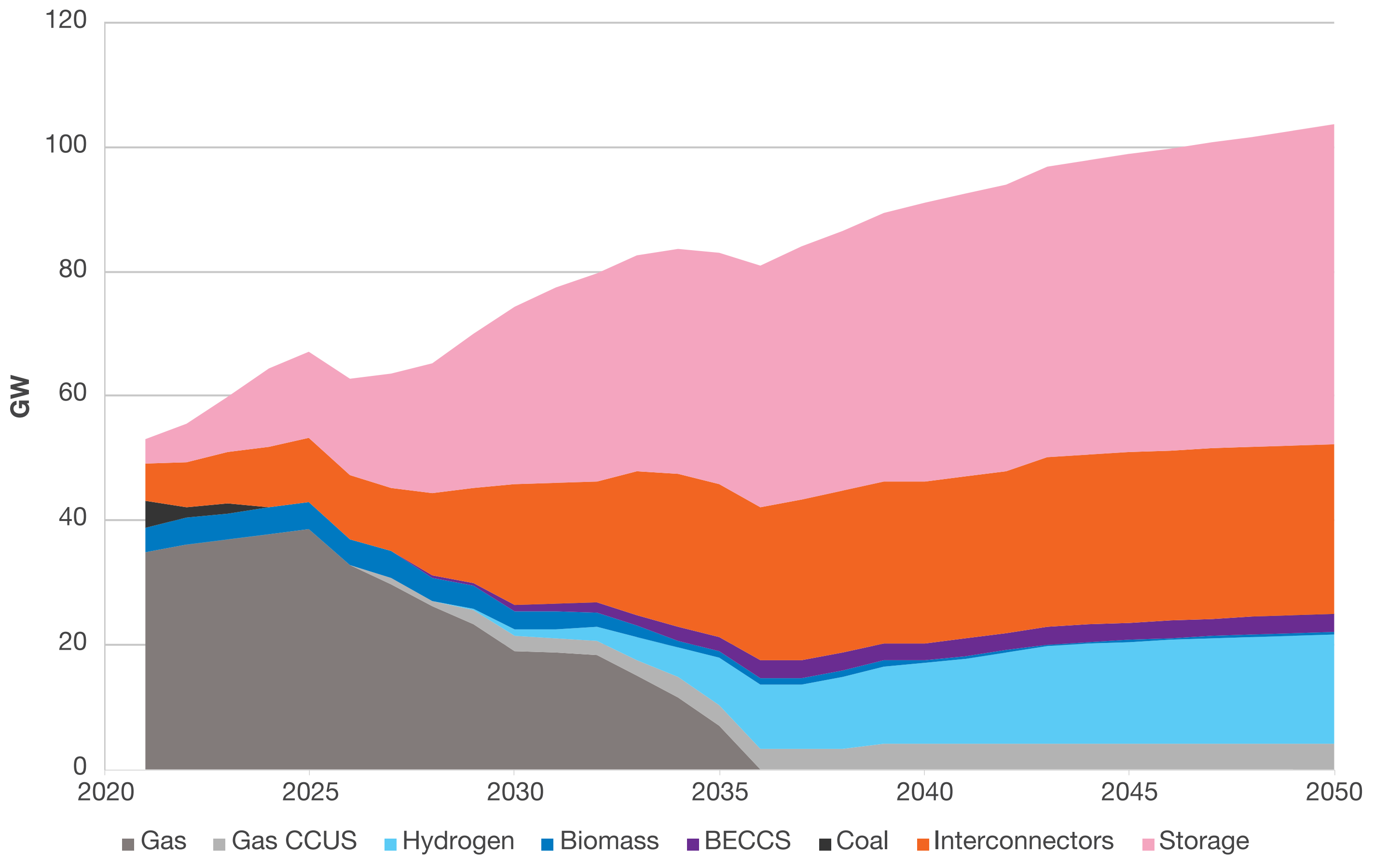
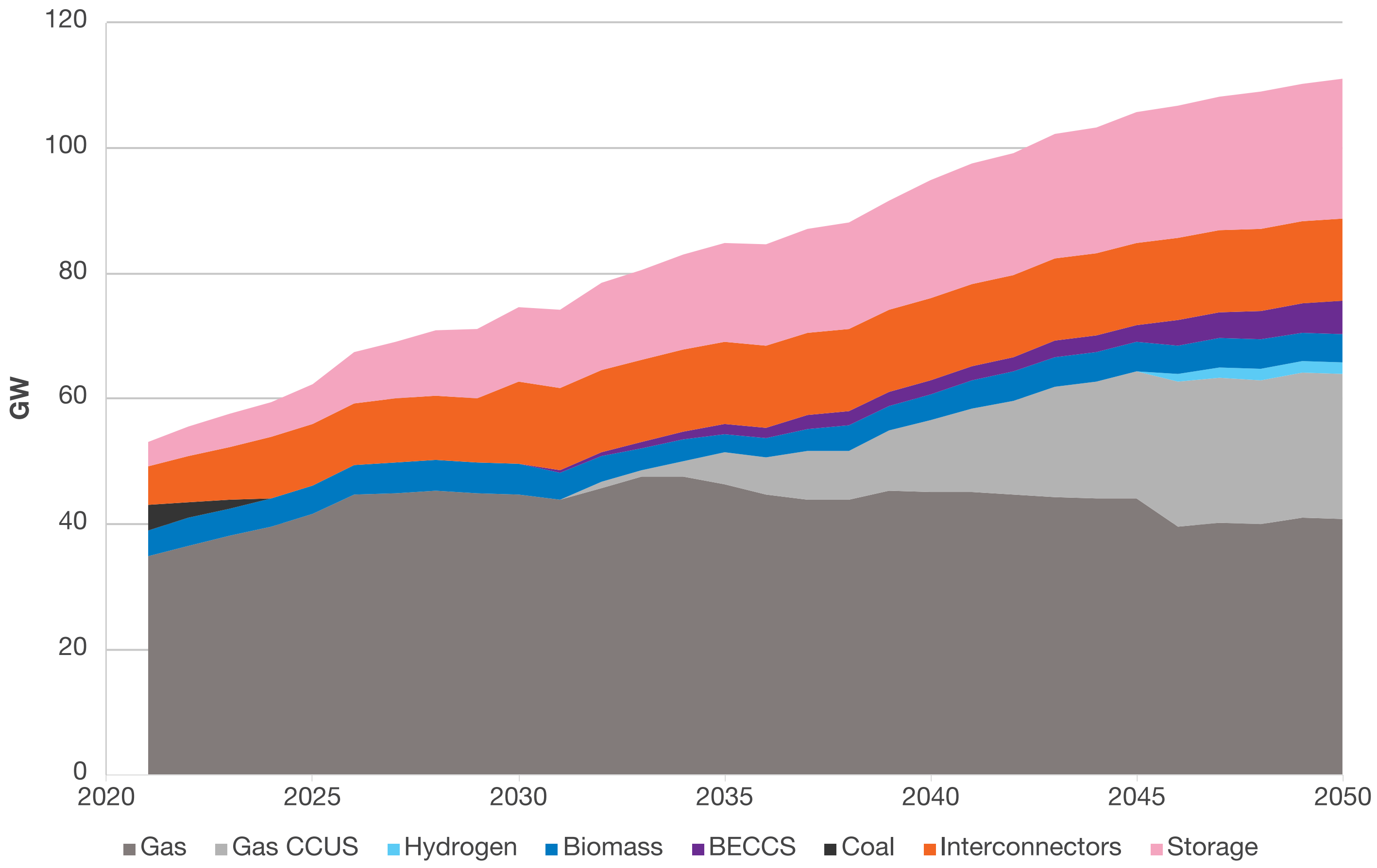


Figure FL.15: Dispatchable electricity supply sources Leading the Way



What we've found

Figure FL.15: Dispatchable electricity supply sources Falling Short



FES 2022 / Flexibility 365

Electricity storage

Electricity storage will need to increase significantly to support the decarbonisation of our electricity system, with as much as twelve-fold and seven-fold increases in capacity (GW) and volume (GWh) respectively from 2021 to 2050.

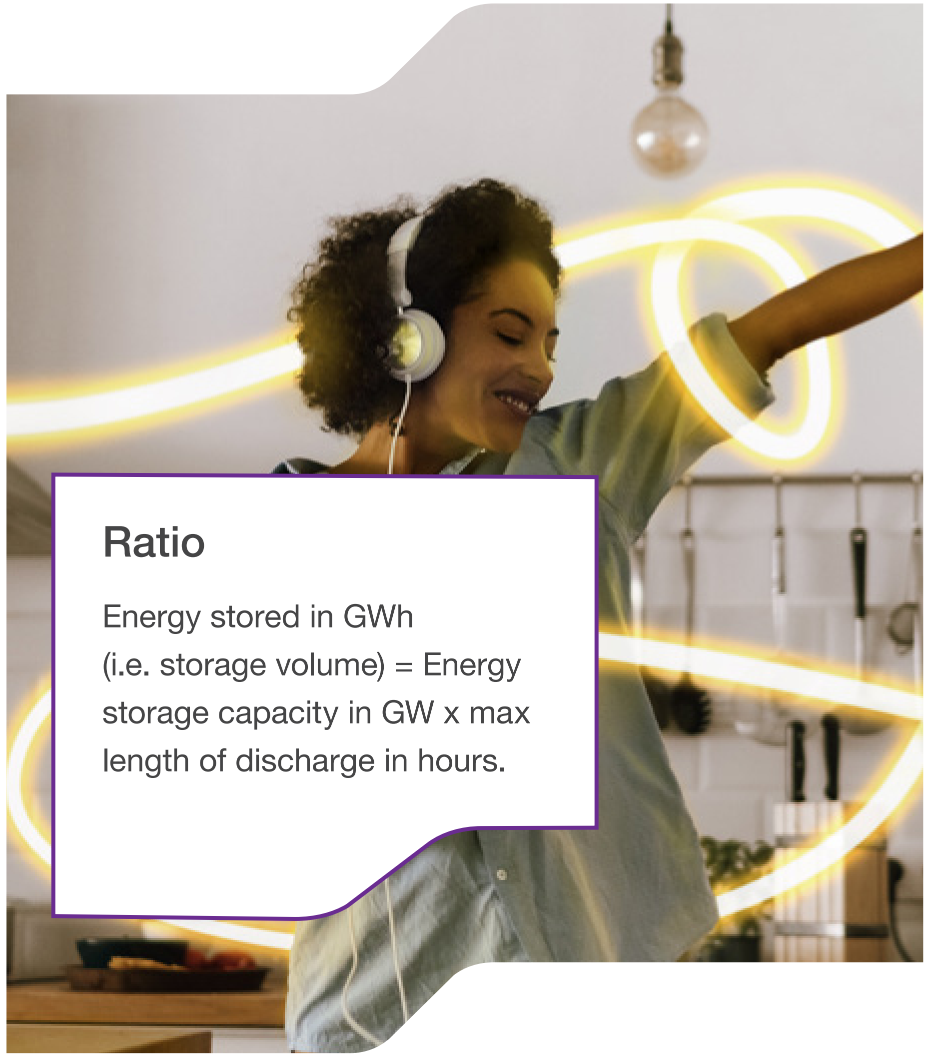
We see a combination of electricity storage technologies being deployed out to 2050 (Figure FL.16):

- pumped hydro,
- large-scale, residential and industrial behind-the-meter batteries, and
- Compressed Air Energy Storage (CAES) and Liquid Air Energy Storage (LAES).

Energy storage is a rapidly developing sector and there are a number of emerging technologies such as gravitational storage[18] and flow batteries which are not included as there is very limited information on future sites. However, as they develop, it is possible they may displace some of the capacity and volume we currently allocate to other technologies. We will continue to review our modelling assumptions and update future FES iterations as more market information becomes available.

Battery storage sees the greatest increase in capacity, increasing from 1.6 GW in 2021 to as much as 20 GW by 2030 and 35 GW by 2050 (Leading the Way). This in part reflects the very large pipeline of battery storage sites. The greatest increase in storage volume is for pumped hydro storage which increases from 25.8 GWh in 2021 to as much as 65 GWh in 2030 and 84 GWh in 2050.

The ratio between storage capacity (GW) and volume (GWh) dictates the amount of time a technology can discharge for at full power, and this in turn influences the type of flexibility the technology can provide. Batteries typically have a 1:1 or 1:2 ratio of capacity to volume, although stakeholder feedback suggests this is partly market driven and could increase to at least 4 hours. Pumped storage, CAES and LAES all typically see much more energy stored compared to power output (up to a ratio of around 1:14 in FES scenarios) and are able to charge or discharge at maximum output for a longer period of time.



Ratio

Energy stored in GWh (i.e. storage volume) = Energy storage capacity in GW x max length of discharge in hours.

18 Storing energy by raising weights. The energy is then released by lowering the weights.

FES 2022 / Flexibility 366

Electricity storage

Different durations of energy storage provide different benefits to the energy system (see **"Flexibility requirements" infographics on pg 315**). Two to four-hour storage typically helps meet short intra-day variations in demand and supply, provide short term reserve or help manage the real-time operability of the network. Longer duration storage can help secure the system over longer periods of high or low renewable generation output. However, non-electrical storage in other fuels such as hydrogen or gas is better suited to very long term or inter-seasonal storage.

We also see storage technologies being positioned at different locations on the network. Consumer Transformation and Leading the Way see a relatively larger share of storage connected to distribution networks or co-located with renewable generation, while System Transformation and Falling Short see higher levels of projects connected to the transmission network. For more detail on the importance of locating flexibility correctly see **here**.

The policy, regulatory and market environment for storage will need change to bring forward the levels of energy storage we expect to need on the system. This could involve changes to how storage is treated by electricity codes, removal of planning permission barriers and market change to allow greater revenue stacking of different services to improve the business case for storage projects. This is most needed for longer duration storage; The Department for Business, Energy and Industrial Strategy (BEIS) recently announced the winners of their **Longer Duration Energy Storage Demonstration Competition**[19] which aims to accelerate the commercialisation of innovative longer duration energy storage projects. This includes compressed air and electrolysis projects, whilst Liquid Air Energy Storage has previously received government funding.

19 BEIS refer to longer duration energy storage as greater than 4hours.

FES 2022 / Flexibility 367

Electricity storage

Figure FL.16: Varying power and energy outputs of electricity storage types in 2030 and 2050 Consumer Transformation

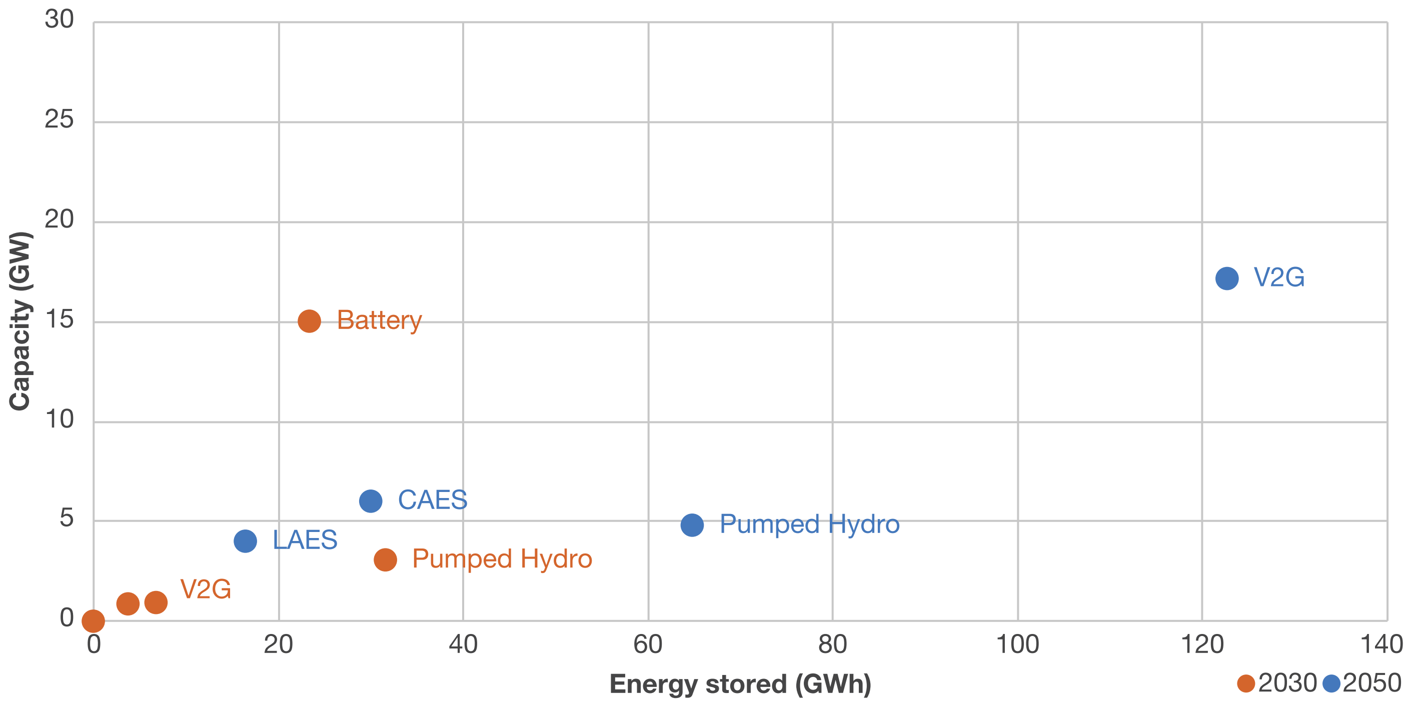
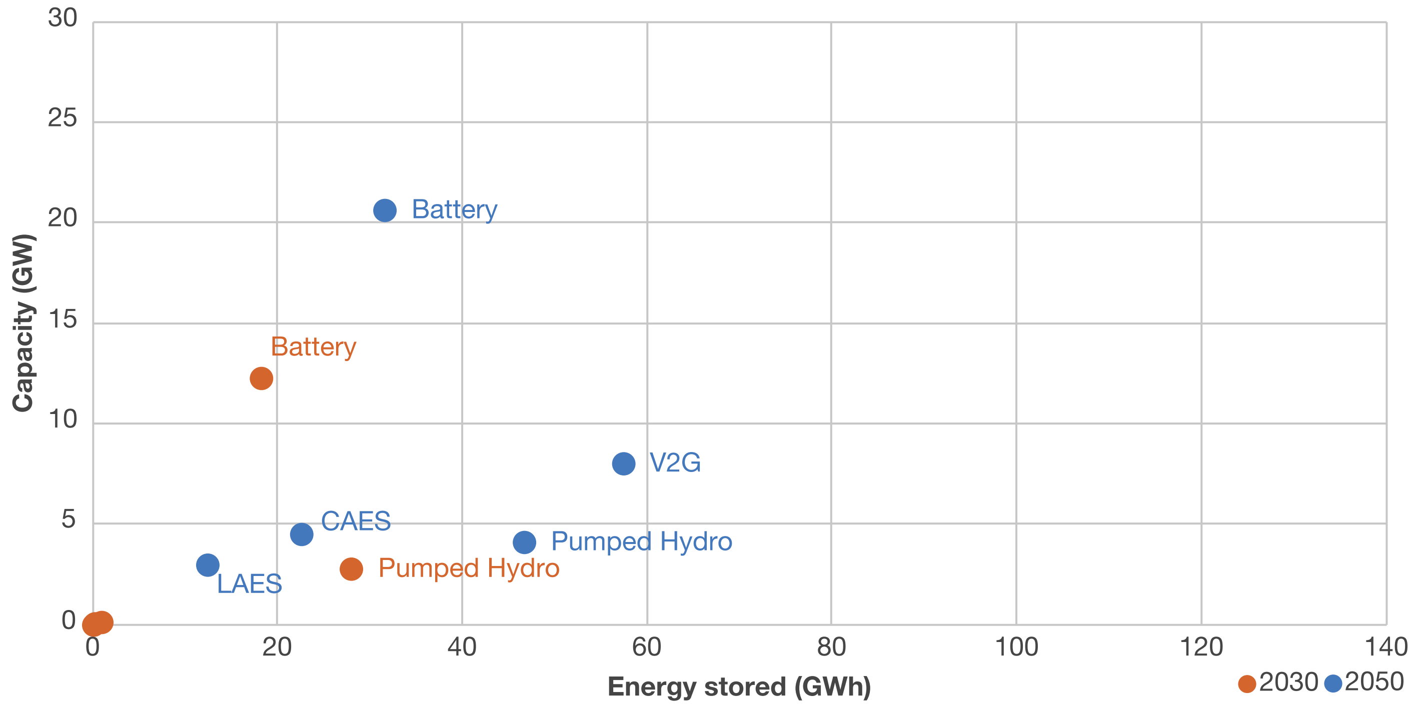


Figure FL.16: Varying power and energy outputs of electricity storage types in 2030 and 2050 System Transformation



FES 2022 / Flexibility 368

Electricity storage

Figure FL.16: Varying power and energy outputs of electricity storage types in 2030 and 2050 Leading the Way

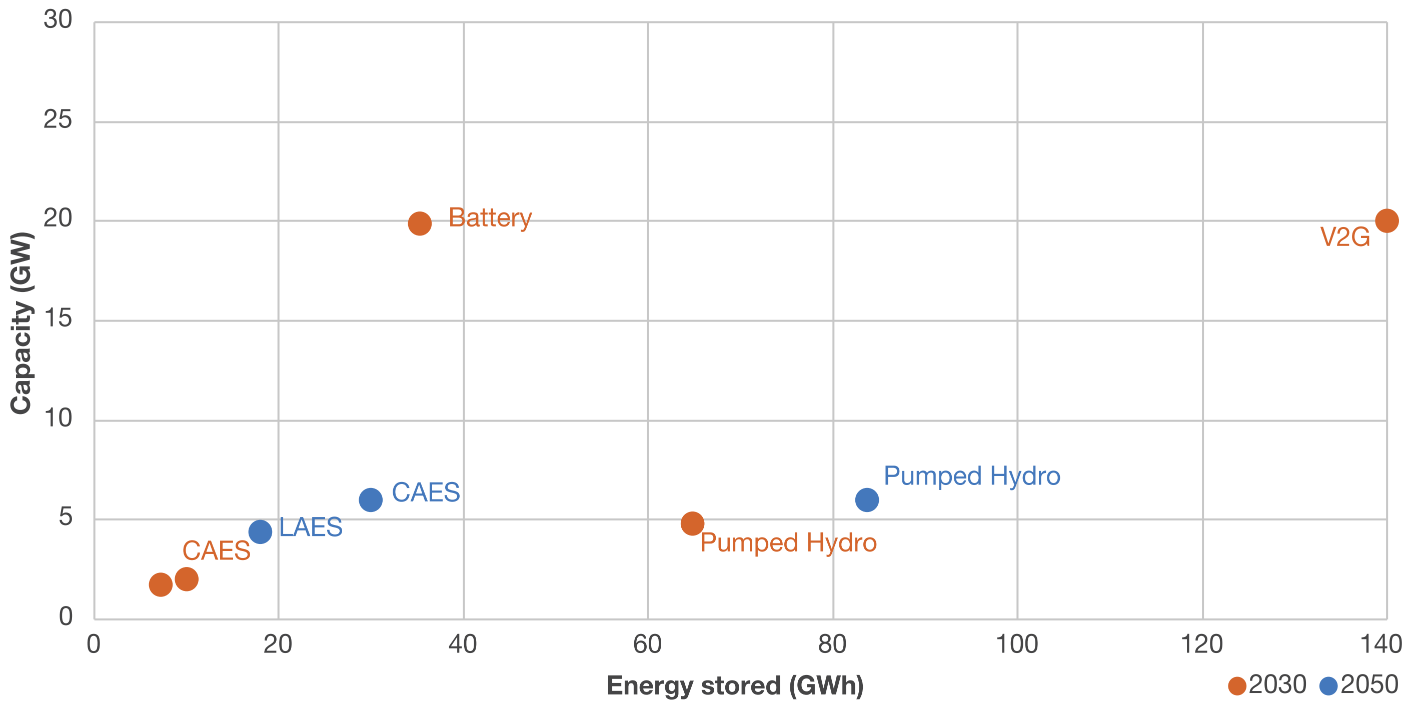


Figure FL.16: Varying power and energy outputs of electricity storage types in 2030 and 2050 Falling Short

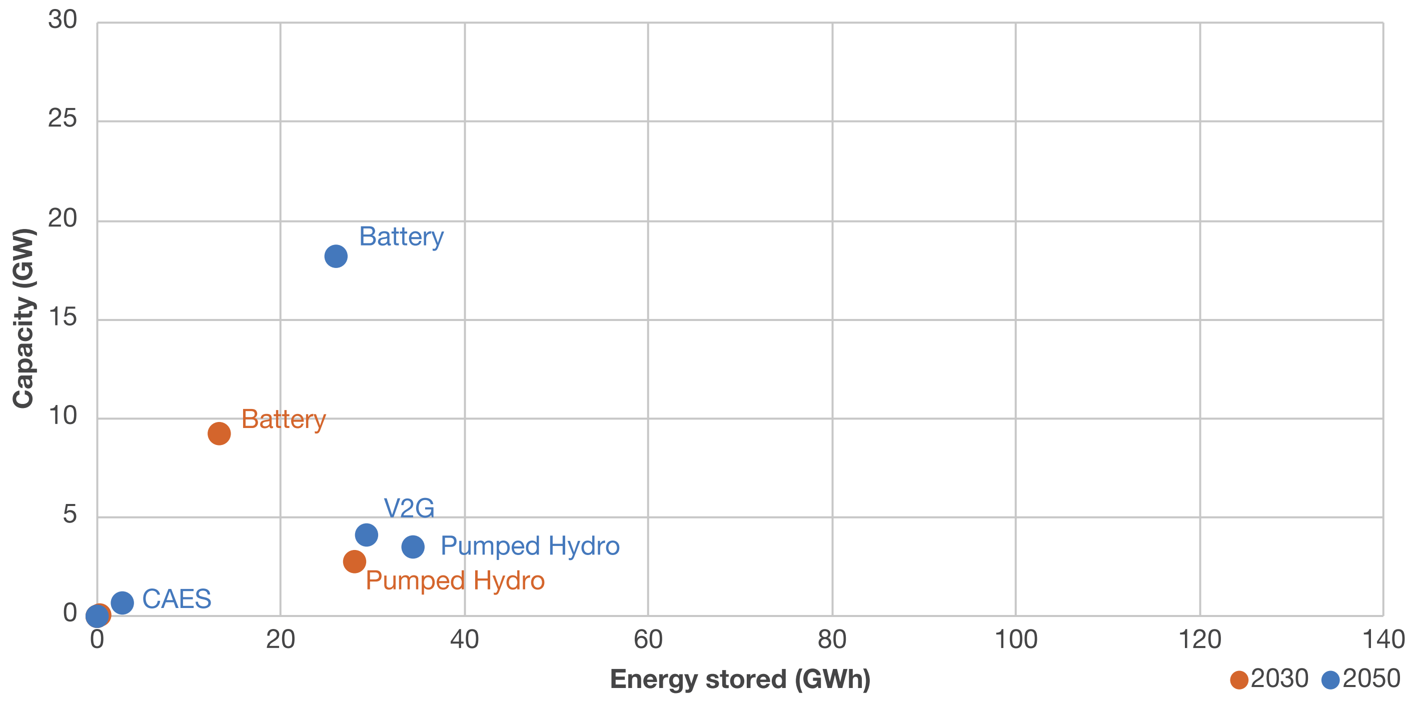
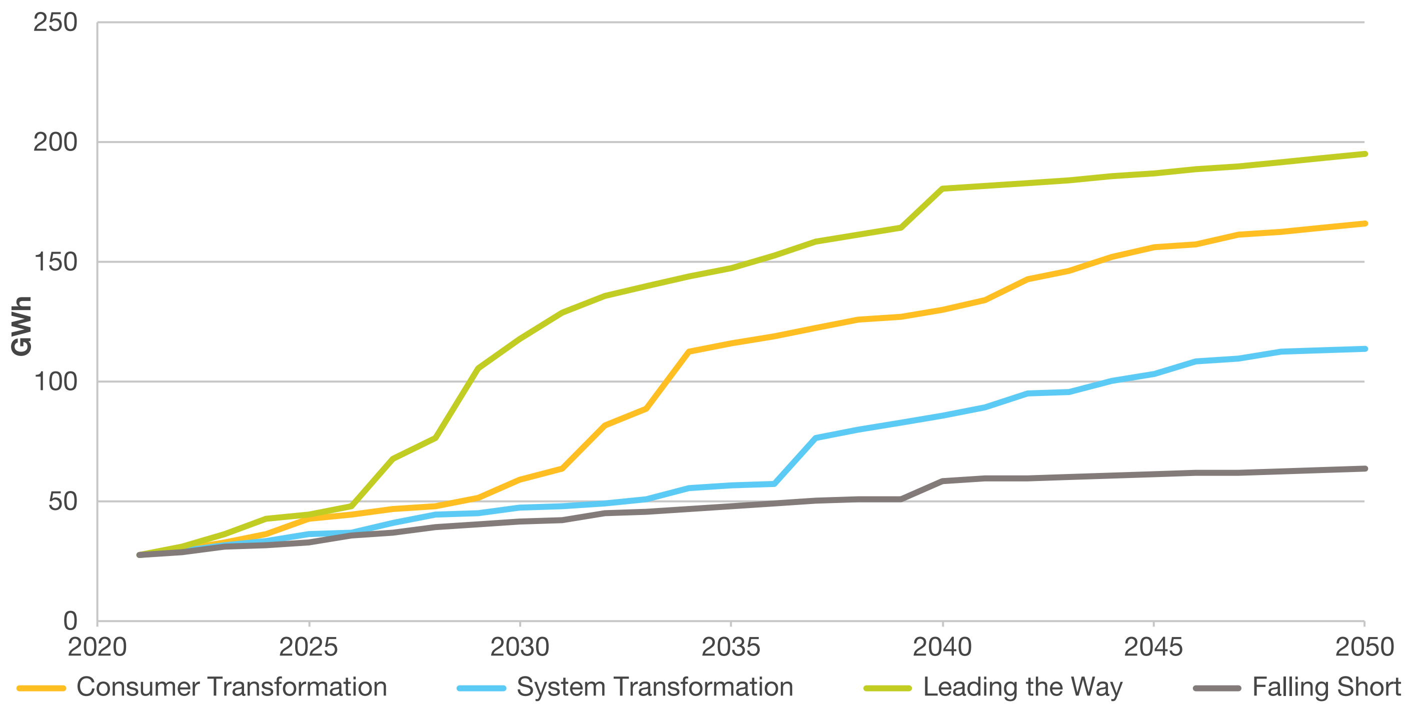


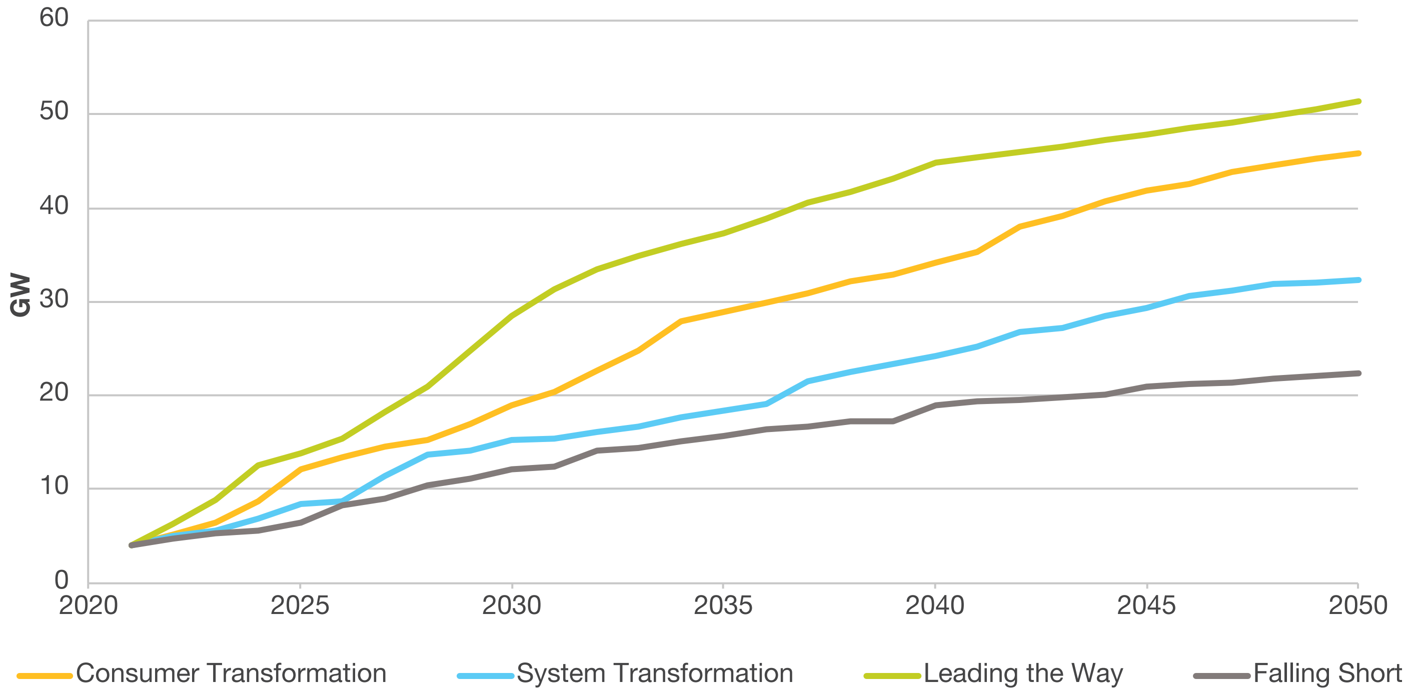
Figure FL.17: Total electrical energy storage volume (GWh)



FES 2022 / Flexibility 370

What we've found

Figure FL.18: Total electrical energy storage capacity (GW)



Roles for electricity storage flexibility

- Managing seasonal differences in supply and demand (longer duration storage)
- Managing several days of oversupply or undersupply (longer duration storage)
- Balancing daily variations in supply and demand (longer and shorter duration storage)
- Reserve for unplanned outages/forecast error (shorter duration storage)
- Real-time operability (shorter duration storage)

FES 2022 / Flexibility 371

What we've found

Interconnectors

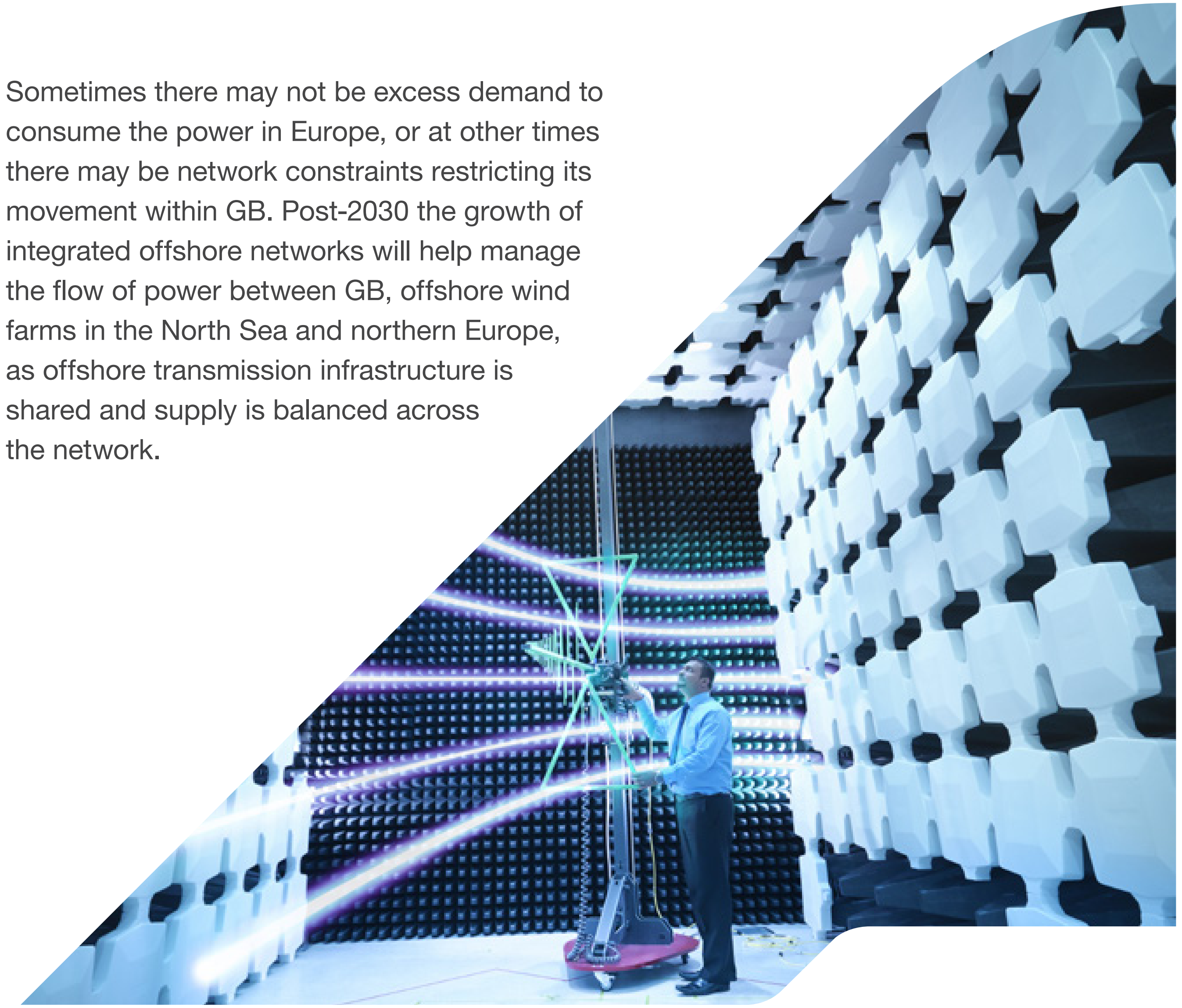
Figure FL.19 shows electricity interconnector flows at peak (the hour with the highest peak winter demand). Positive values represent interconnector imports, indicating that imports are expected at peak even out to 2050 under all Net Zero scenarios. In Consumer Transformation and Leading the Way, peak flows see a large increase in the early to mid 2030s as interconnector capacity continues to rise, fossil fuel capacity is phased out and peak electricity demands grow as the economy electrifies. Our modelling considers the Security of Supply implications of relying on interconnectors to meet peak demand in the same way as in our Capacity Market modelling, more details of which can be found here.

Aside from importing at peak, interconnectors are also used to move energy between GB and its neighbours throughout the year. In recent years there are typically net imports over our interconnectors with continental Europe throughout the year, particularly at peak times, although this is partially offset by export to Ireland and Northern Ireland.

When there is excess renewable generation in GB, between almost 16 GW (System Transformation) and 27 GW (Leading the Way) of interconnection to other electricity markets can be used to export this excess power in the Net Zero scenarios by 2050 (see ES.E.25). While operation over the year varies, we do see changing trends in net flows. From 2025 to 2040, all scenarios see an increasing annual export of electricity with annual net exports from 2030. The high levels of variable renewable generation, particularly offshore wind, in these scenarios often exceed demand and so power is exported to the continent.

The movement of power over the interconnectors will continue to be primarily driven by price differentials between electricity markets (see Markets for more detail on how suggested market reforms may impact Interconnector flows). However, exporting over the interconnectors is not a solution for all excess power.

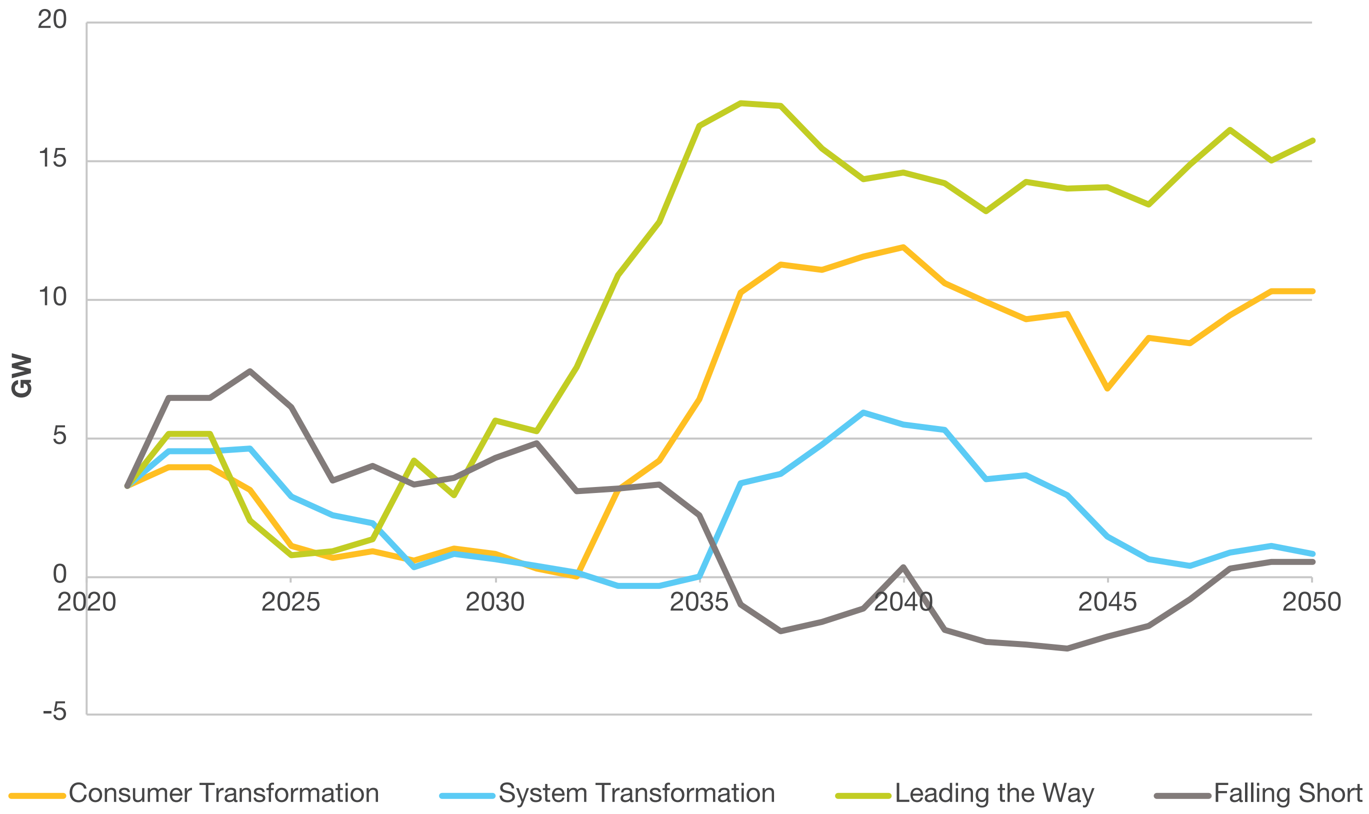
Sometimes there may not be excess demand to consume the power in Europe, or at other times there may be network constraints restricting its movement within GB. Post-2030 the growth of integrated offshore networks will help manage the flow of power between GB, offshore wind farms in the North Sea and northern Europe, as offshore transmission infrastructure is shared and supply is balanced across the network.



FES 2022 / Flexibility 372

What we've found

Figure FL.19: Interconnector peak flows



Roles for interconnector flexibility

- Managing seasonal differences in supply and demand
- Managing extreme weather periods
- Managing several days of oversupply or undersupply
- Balancing daily variations in supply and demand

FES 2022 / Flexibility 373

What we've found

Figure FL.20: Interconnector imports and exports

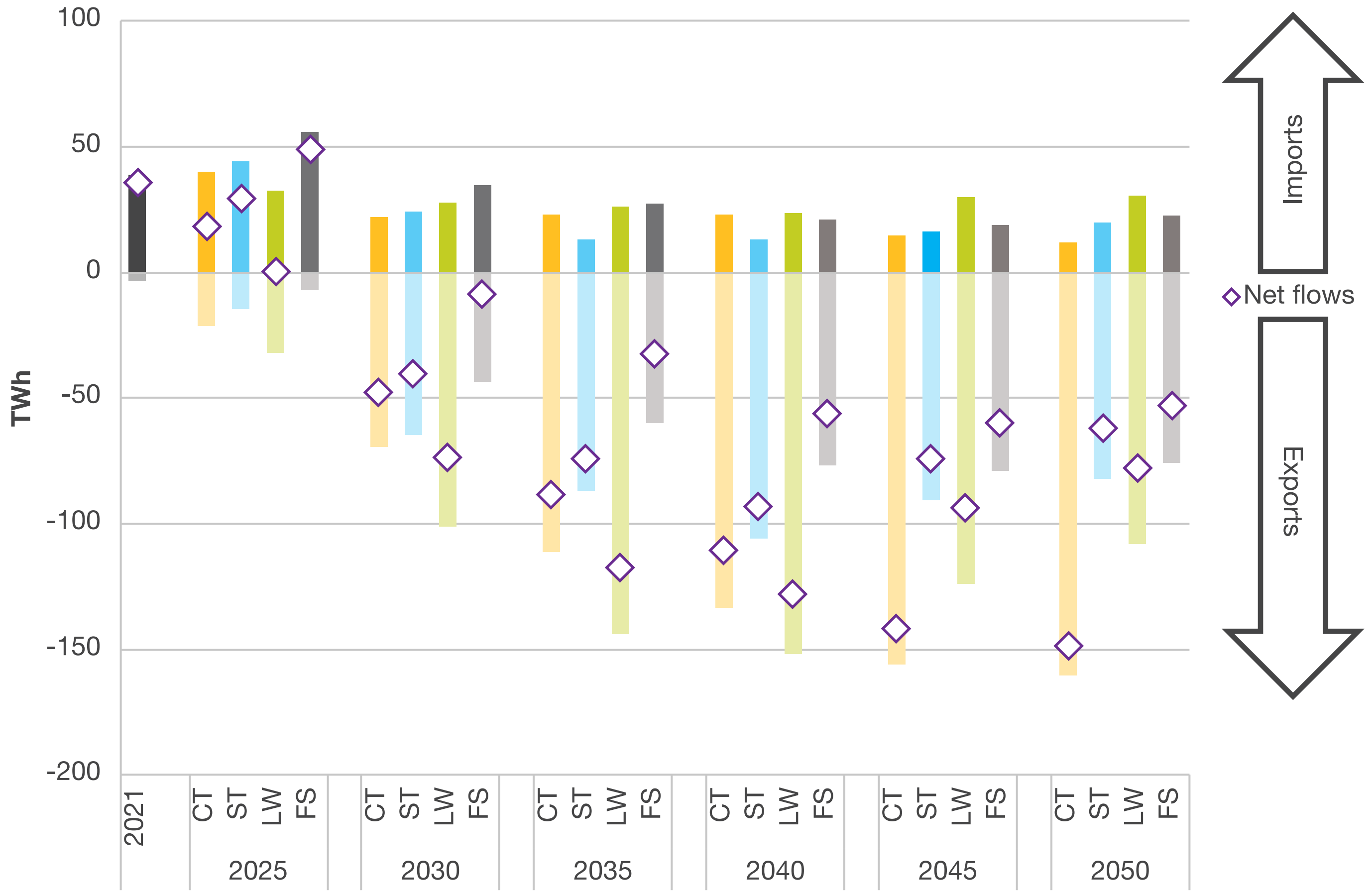
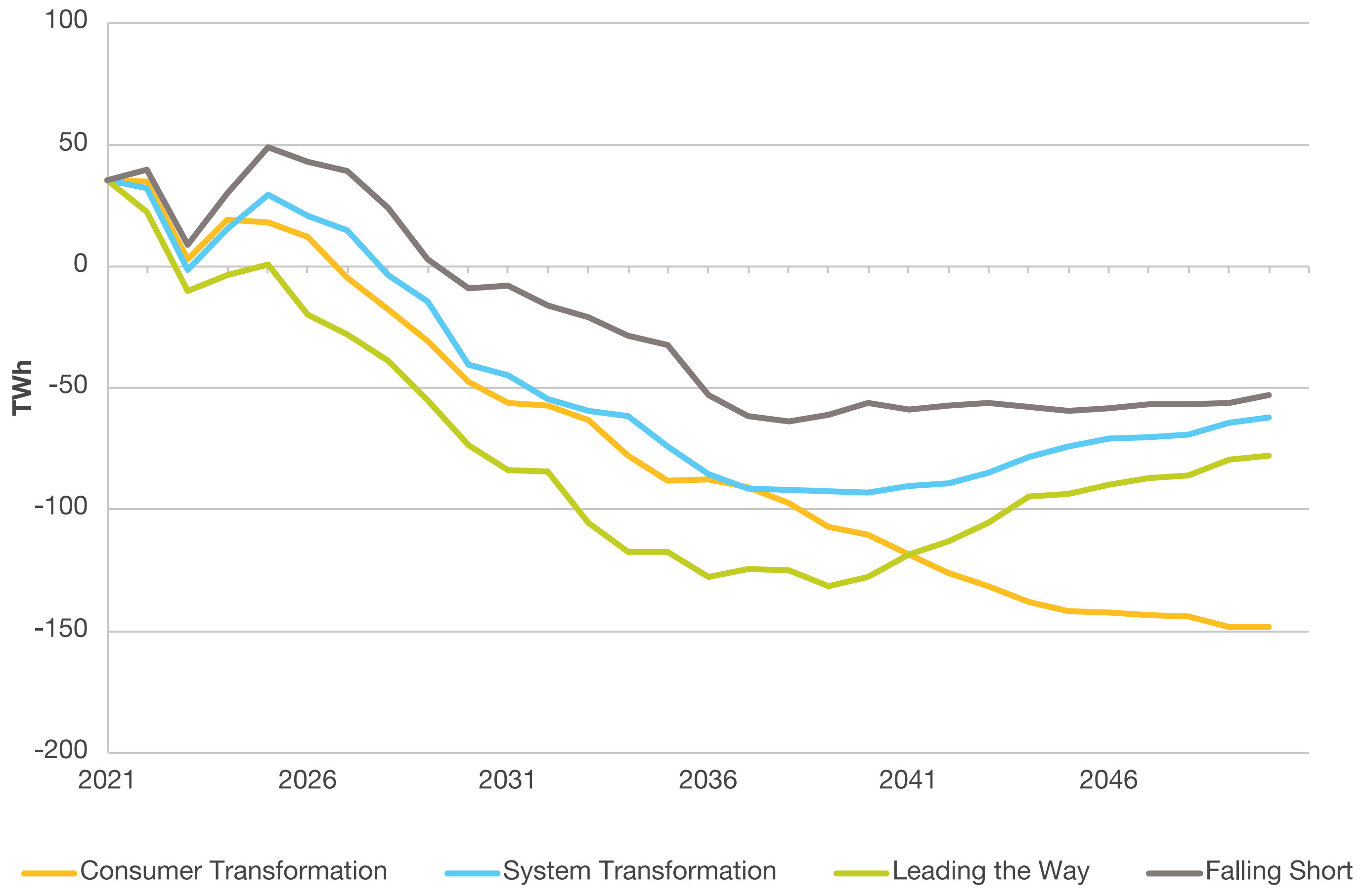


Figure FL.20: Interconnector net annual flows



Curtailment

As increasing levels of renewable generation are deployed, particularly wind, there will be times (i.e. windy days) when supply is significantly higher than demand.

As discussed throughout this chapter, flexibility can be used to store some of this supply, or to shift demand to consume it. After flexibility options have been utilised, if supply still exceeds demand, then some generation will be asked to stop generating (curtailment); this could be any generation type and tends to be the cheapest to turn of at the time. Generation can also be curtailed due to network constraints but isn't included here as FES models energy flows on unconstrained networks. The impacts of network constraints on energy flows are analysed in other ESO and industry publications, for example our Network Options Assessment and Electricity Ten Year Statement.

Whilst several flexibility technologies (e.g. interconnectors or demand side flexibility) can help to reduce curtailment to some extent, electrolysis is particularly useful in this respect. This is because hydrogen is much easier to store than electricity and so can hold significant volumes of curtailed energy for long times, potentially across seasons.

Figure FL.21 shows curtailment for each scenario out to 2050. System Transformation has the most curtailment, peaking at almost 86 TWh by 2036. To put this in context this is equivalent to 22% of total UK electricity demand in that year. However this then decreases sharply through the 2040's as electrolysis capacity and the potential to export hydrogen increases. Leading the Way is generally a well-balanced system, with greater energy efficiency measures and flexibility, which lowers peak demand and therefore maximum generation capacity. It also deploys electroylsers at scale the fastest and has the greatest capacity until 2045. These factors, alongside the highest level of interconnector capacity and a quicker build out of renewable generation, results in the smallest peak in annual curtailment, of 40 TWh, which occurs early (i.e. in 2033) but then rapidly reduces.

FES 2022 / Flexibility 375

Curtailment

Although Falling Short has minimal levels of electrolysis, it also has the least renewable generation. This leads to greater curtailment in 2050 than under Leading the Way and System Transformation but less than Consumer Transformation, with peak annual curtailment of 51 TWh in 2038.

Consumer Transformation sees peak annual curtailment occur in 2045 at 78 TWh. This is later than the other scenarios and is due to a slower and smaller deployment of electrolysis but the greatest wind generation capacity from 2040 onwards. Whilst curtailment reduces by 2050 to 53 TWh it is still more than double the next scenario.

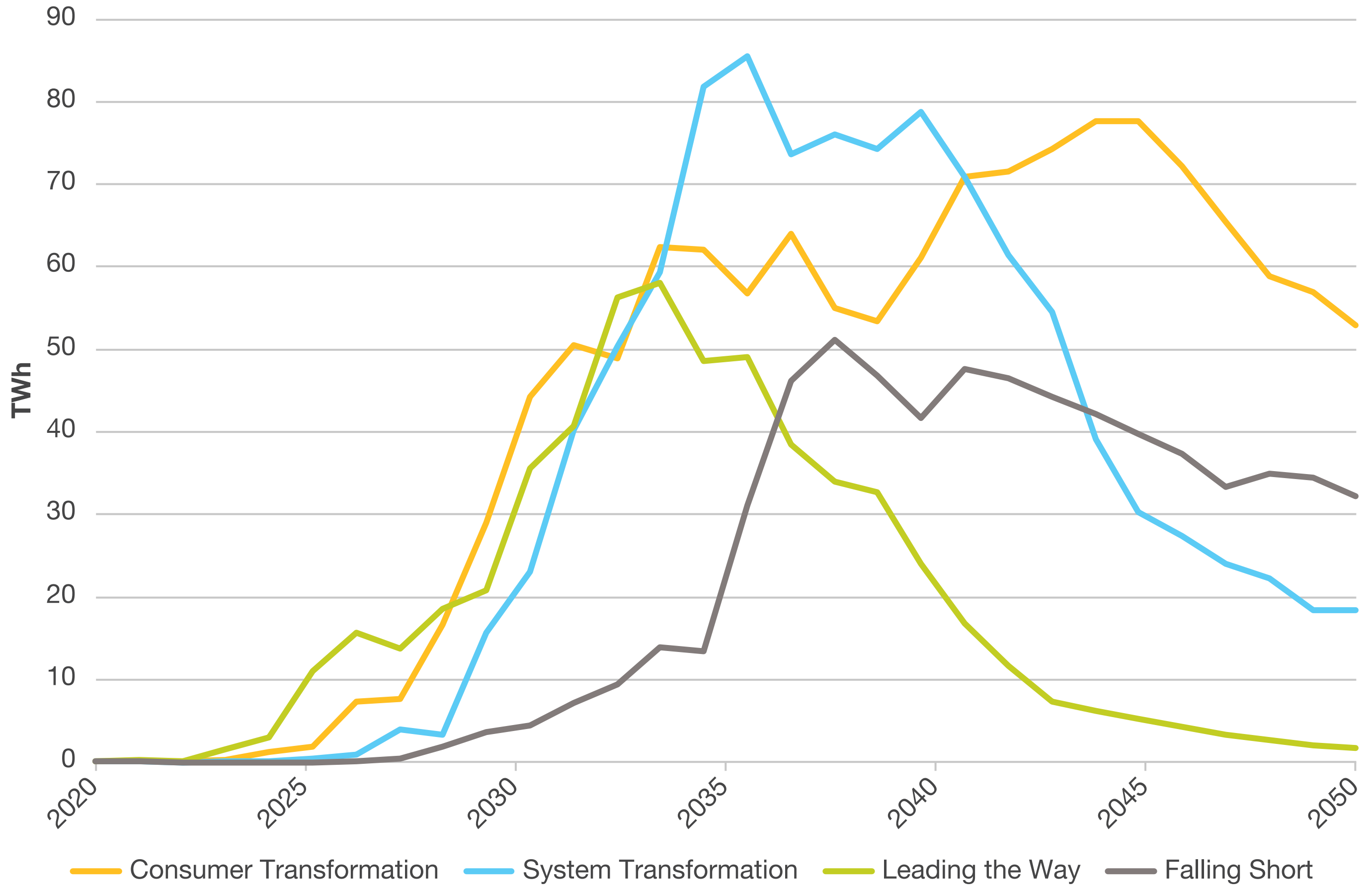
The high levels of curtailment shown in Figure FL.21 during the 2030s and 40s before reducing highlight the need for co-ordinated future energy planning. As renewable capacity is rapidly increased, flexibility options such as interconnectors, electrolysis and demand side flexibility should be developed simultaneously as much as possible, rather than in later years.

When supply is high compared to demand we would then expect these flexibility options to respond to low electricity prices and market conditions and begin operation.

Whilst this occurs in our scenarios there is still significant curtailment - opportunities to utilise this curtailed energy through earlier and additional deployment of these flexibility options should be investigated and where appropriate incentivised. This may include additional demand side flexibility, increased interconnector export, or potentially the development of a hydrogen export market.

Looking across the scenarios from a whole energy perspective, it seems clear that higher levels of hydrogen demand to support more electrolysis would be beneficial in Consumer Transformation. Similarly for System Transformation, a greater share of electrolysis compared to methane reformation could deliver whole energy system benefits that should be considered in policy development.

Figure FL.21: Annual Curtailment



What we've found

Digitalisation

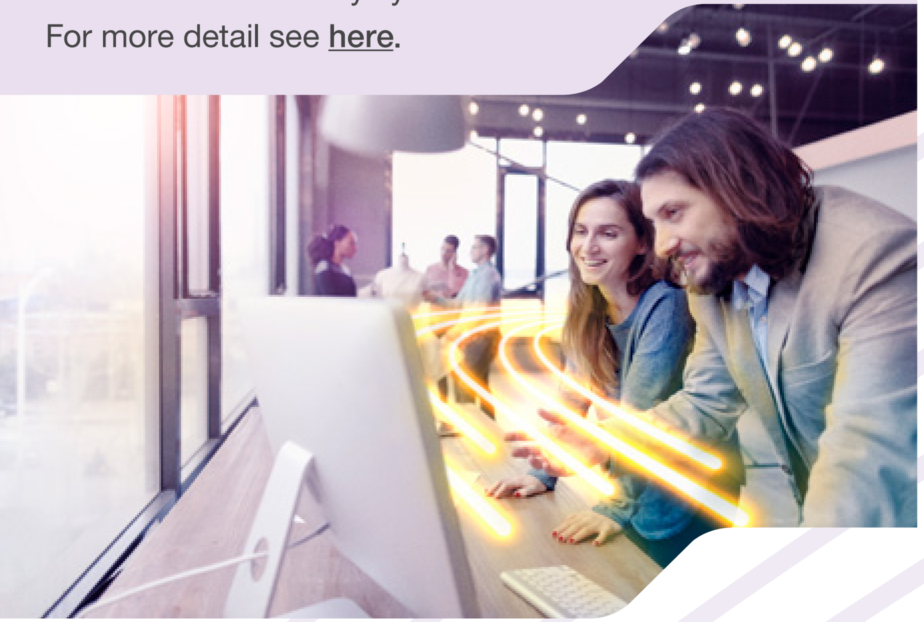
This section has emphasised that, increasingly, flexibility will have to come from the demand side which will need to be enabled to respond to changing supply. Electric Vehicles will need to charge when demand is lowest compared to supply and, in the case of V2G, provide supply to the network when demand is high. This means that consumers have to be able to increase or decrease their consumption in line with the price signals driven by differences between supply and demand.

Digitalisation is essential to enabling these actions, sending real-time signals between assets and networks to allow the integration of renewables and balancing of the energy system. Since publication of FES 2021, the Energy Digitalisation Strategy has been released which sets out a series of actions to digitalise the energy system, including ensuring energy network operators comply with best practice and guidance on data and digitalisation and the launch of a new independent Energy Digitalisation taskforce.

There are also challenges to the energy system from smart flexible demand which require digitalisation to manage. Without careful control of assets, aggregated demand side technologies responding directly to half hourly price signals could cause big fluctuations in frequency. More granular control, including randomisation of response times, will be needed to avoid causing system operation issues. This is not just nationally but also at a regional and local level across distribution networks and right down to street level. For example, a whole street of EVs all drawing power from or feeding power back to the grid at maximum output could cause local network issues. However, if managed correctly the flexibility provided from EVs could provide large benefits to the electricity system (see Figure FL.12). The right incentives need to be in place to manage this, with National Grid ESO working closely with Distribution System Operators to ensure a coordinated response. Our 2021/22 Bridging the Gap programme explored what the energy system in 2035 might look like and how we can make sure we have the flexibility required. It found digitalisation will be integral to all aspects of the future energy system.

National Grid ESO's Virtual Energy System

One example of using digitalisation to help the energy system move towards Net Zero is our Virtual Energy System. This is a world first, real-time replica of our entire energy landscape and will work in parallel to our physical system. It will improve our simulation and forecasting abilities to support the long-term vision to operate a zero-carbon electricity system.
For more detail see here.



FES 2022 / Flexibility 377

What we've found

Markets

As discussed throughout this chapter, to deliver higher levels of flexibility we need improved market signals to incentivise the right outcomes. We see up to 51 GW of electricity storage across our scenarios in 2050, compared to 4 GW in 2021, 54 GW of demand side response, compared to 6 GW today and 55 GW of electrolysis from close to zero today. These high levels need to be incentivised and supported by appropriate market signals. Currently, investment signals for flexibility are largely driven by revenues for ancillary services that support system operation and the capacity market which provides Security of Supply. However in future, signals should primarily come from the wholesale market to support balancing of energy flows. We must also identify the optimal market signals to unlock flexibility, ensuring they complement, rather than conflict with, other markets such as adequacy (capacity market) and decarbonisation (carbon pricing).

Our Net Zero Market Reform (NZMR) work examines the holistic changes to current GB electricity market design that will be required to achieve a fully decarbonised electricity system by 2035. A key finding to come out of this work is the need for more locational pricing in the wholesale market. The single GB price for electricity we currently have does not always incentivise flexibility to flow to where it's needed and can at times exacerbate constraints. For example if one area of the UK is experiencing high wind generation but the rest isn't, the current single price may incentivise unhelpful behaviour from flexible assets like interconnectors or storage across the whole of the UK including the area with high wind generation, potentially making network constraints worse. The next phase of the NZMR work will focus on investment (as market design also influences siting of renewable and flexible assets) and flexibility markets to complement locational pricing. See here for more detail on our Net Zero Market Reform work.

FES 2022 / Flexibility 378

Glossary

Advanced Nuclear Fund
Government support scheme launched alongside the 2020 Ten Point Plan to support nuclear technology development including small modular reactors and next generation advanced modular reactor demonstrator projects.

Afforestation
Planting new forests in places which haven't been forested before.

Air Source Heat Pump (ASHP)
Heat pump which absorbs heat from the outside air. This heat can then be used to produce hot water or heating.

Ammonia
A chemical compound made of nitrogen and hydrogen.

Anaerobic
A chemical reaction which takes place without oxygen, for example anaerobic digestion which produces methane from biomass.

Anaerobic Digestion (AD)
Anaerobic digestion is a process through which bacteria break down organic matter – such as animal manure, wastewater biosolids, and food wastes – in the absence of oxygen.

Ancillary Services
Services procured by the ESO to support operation of the electricity system.

Arbitrage
In an energy context, this usually refers to the practice of buying energy when the price is low, storing this energy and then selling it when the price has risen.

Autonomous Vehicle (AV)
A vehicle which is able to drive without human involvement.

Average Cold Spell (ACS)
A measure of hypothetical maximum demand over some period (usually an entire winter period) based on all the possible weather variation that could have occurred over the period. The ACS out turn is the value that, based on all the hypothetical weather variation, had a 50% chance of being exceeded. It is the average value of the maximum demand.

Baseload Generation
An electricity generator that tends to operate at constant output for 24 hours a day throughout the year.

Battery Electric Vehicle (BEV)
A vehicle which uses a battery as its sole means of propulsion and is recharged by plugging in to the electricity network.

Bi-directional Charger
A charger for an Electric Vehicle that, once plugged in, can support flows from the electricity grid to the EV and vice versa.

Billions of Cubic Metres (BCM)
A unit of volume used in the gas industry. 1 bcm = 1,000,000,000 cubic metres. For gas, in GB, a good guide for converting from energy in watt hours to gas volume in cubic metres is to divide by 11.

Bioenergy
Energy produced from bioresources.

Bioenergy with Carbon Capture and Storage (BECCS)
The coupling of bioenergy with carbon capture and storage to capture the CO2 produced during combustion. This process delivers negative emissions.

Bioethanol
Ethanol which is made from biomass. Ethanol can be used as a fuel for a number of applications, including in vehicles.

Biogas
A naturally occurring gas that is produced from organic material and has similar characteristics to natural gas. We use biogas to refer to gas that is not of pipeline quality.

FES 2022 / Glossary 379

BioLPG
LPG is liquefied petroleum gas, which can be in the form of propane or butane. BioLPG is propane made from biomass.

Biomass
Plant or animal material used for energy production, heat production or in various industrial processes as a raw material.

Biomass Gasification
A process that generates hydrogen from biomass. When combined with CCUS technology this can produce hydrogen while also delivering negative emissions.

Biomethane
Biogas that has been further processed to make it suitable for injection into gas transmission or distribution networks.

Bioresources
Organic feedstocks like energy crops, forestry and agricultural waste and biological materials that can be used to produce energy.

BioSNG
The transformation of the carbon content of household waste (including contaminated and unrecoverable plastics) into bio-substitute natural gas (BioSNG), a green and sustainable copy of natural gas.

Blended Gas
Gas supplied to homes and businesses, which contains hydrogen and/or biomethane blended in with natural gas.

Blue Hydrogen
Hydrogen created via methane reforming using natural gas as an input, plus CCUS.

Cap and Floor
This is a form of revenue regulation applied to electricity interconnectors in GB. Where interconnector revenue falls within a specified range it can be retained by the interconnector operator. Any revenue over and above the top of this range (cap) is returned to customers and if any revenue is below the bottom of the range (floor) it is supplemented from customers.

Capacity
The power output of an electricity generation technology - usually measured in Watts (or kW, MW or GW).

Capacity Market (CM)
The Capacity Market is designed to ensure security of electricity supply. This is achieved by providing a payment for reliable sources of capacity, alongside their electricity revenues, ensuring they deliver energy when needed.

Carbon Capture, Usage and Storage (CCUS)
A process by which the CO_2 produced in the combustion of fossil fuels is captured and transported to a storage location and isolated from the atmosphere. Capture of CO_2 can be applied to large emission sources like power plants used for electricity generation, production of hydrogen from methane reforming and industrial processes. The CO_2 is then compressed and transported for long-term storage in geological formations or for use in industrial processes.

Carbon Dioxide (CO_2)
The main greenhouse gas. The vast majority of CO_2 emissions come from the burning of fossil fuels.

Carbon Footprint
The amount of carbon dioxide released into the atmosphere as a result of the activities of a particular individual, organisation or community.

Carbon Intensity
A way of examining how CO_2 is emitted in different processes. Usually expressed as the amount of CO_2 emitted per km travelled, per unit of heat created or per kWh of electricity produced.

Carbon Neutral
When applied to bioenergy, indicates that the carbon dioxide given off from combustion is offset by carbon dioxide absorbed during the plant matter's lifetime.

Carbon Price Floor (CPF)
A UK Government policy which sets a target for the minimum price of carbon that is applied to carbon polluters to encourage low carbon investment. It consists of the EU ETS (EU Emissions Trading Scheme) allowance price and the Carbon Price Support (CPS).

Carbon Price Support (CPS)
The CPS is effectively a carbon tax that tops up the EU ETS (EU Emissions Trading Scheme) allowance prices, as projected by the Government, to the UK Carbon Price Floor target.

FES 2022 / Glossary 380

Carbon Pricing
Applying a cost to the emission of each tonne of carbon dioxide.

Carbon Sinks
A location where carbon is absorbed from the atmosphere. Often this refers to forests or the ocean.

Climate Assembly Report
In 2020, the first UK Climate Assembly met. People from all walks of life were invited to be part of the assembly. They heard balanced evidence on the choices the UK faces, discussed them, and made recommendations about what the UK should do to become Net Zero by 2050. Their final report was published on Thursday 10 September 2020.

Combined Heat and Power (CHP)
CHP is a technology that produces electricity and thermal energy at high efficiencies using a range of technologies and fuels.

Climate Change Committee (CCC)
An independent, statutory body established under the Climate Change Act 2008. Its purpose is to advise the UK and devolved governments on emissions targets and to report to Parliament on progress made in reducing greenhouse gas emissions and preparing for and adapting to the impacts of climate change.

Compressed-Air Energy Storage (CAES)
Compressed-Air Energy Storage is a way to store energy for later use using compressed air.

Compressed Natural Gas (CNG)
Compressed Natural Gas is a fuel gas made by compressing natural gas to less than 1% of the volume it occupies at standard atmospheric pressure.

Contract for Difference (CfD)
A contract between the Low Carbon Contracts Company (LCCC) and a low carbon electricity generator, designed to incentivise low carbon generation and reduce its exposure to volatile wholesale prices.

COP26
Annual conference held by the United Nations to accelerate global action to reduce climate change and mitigate its impacts. The 26th Conference of Parties was hosted by the UK and Italy in 2021.

Crown Estate
Awards seabed rights, incentivises innovation, builds evidence and shares data to support the responsible and sustainable development of Offshore Wind, Wave and Tidal and Carbon Capture Usage and Storage (CCUS) opportunities.

Data Centres
High electricity demand sites where computing and networking equipment is concentrated to store and process digital data for online services.

Decarbonisation
The process of removing carbon emissions (e.g. generated by burning fossil fuels) from our economic and social activities.

Decentralised Generation
Electricity generation that is connected to power networks below the high voltage transmission system. Includes distributed generation and onsite generation.

Demand Side Flexibility
The ability of energy users to adjust demand in response to market signals.

Demand Side Response (DSR)
A deliberate change to a consumer's natural pattern of metered electricity or gas consumption, brought about by a signal from another party.

De-rated Generation Capacity
When a reduction factor is applied to the installed capacity of generation to best reflect what is expected to be available in real time.

De-rated Plant Margin
The sum of de-rated generation capacity declared as being available during times of peak demand plus support from interconnection minus expected demand at that time and basic reserve requirement.

Direct Air Carbon Capture and Storage (DACCS)
Direct air capture is a process of capturing carbon dioxide directly from the ambient air and generating a concentrated stream of CO_2 for sequestration or utilisation or production of carbon-neutral fuel and windgas.

FES 2022 / Glossary 381

Dispatchable Generation
Dispatchable generation refers to sources of electricity that can be dispatched on demand and modulated up and down as required, at the request of power grid operators, according to market needs.

District Heating
A community based heating solution, which uses a single central hub to heat water, which is then pumped around a number of different homes and buildings.

Electric Vehicle (EV)
A vehicle driven by an electric motor. It can either be driven solely off a battery, as part of a hybrid system, or have a generator that can recharge the battery but does not drive the wheels. We only consider EVs that can be plugged in to charge in this report.

Electricity Codes
Industry codes underpin the electricity and gas wholesale and retail markets. Licensees are required to maintain, become party to, or comply with the industry codes in accordance with the conditions of their licence.

Electricity Ten Year Statement (ETYS)
The Electricity Ten Year Statement (ETYS) is the ESO's view of future transmission requirements and the capability of Great Britain's National Electricity Transmission System (NETS) over the next 10 years. To find out more visit https://www.nationalgrideso.com/research-publications/etys.

Electrolysis
Electrolysis is the process of using electricity to split water into hydrogen and oxygen.

Embedded Generation
Embedded generation is electricity generation which is connected to the Distribution network rather than to the high voltage National Grid. Embedded generation is typically smaller generation such as renewables: small hydro, wind or solar power.

Energy as a Service
A concept whereby consumers subscribe to 'energy packages' which can include all of their energy assets and services. Consumers benefit from the end-to-end management of areas like their energy consumption, without making any upfront investment.

Energy Crops
Crops grown specifically for use as an energy source, rather than food for people or animals.

Energy Density
Energy contained in a fuel per unit of mass or volume.

Energy Performance Certificate (EPC)
An EPC gives a property an energy efficiency rating from A (most efficient) to G (least efficient).

EU Emissions Trading Scheme (EU ETS)
An EU wide system for trading greenhouse gas emission allowances which effectively sets an EU carbon price.

The scheme covers more than 11,000 power stations and industrial plants in 31 countries.

Feed-In Tariff (FIT)
A government scheme that ran from 2010 to 2019 whereby consumers can sell electricity generated from on-site generation to the grid.

Feedstock
Feedstock, in the context of bioenergy use in FES, is defined as any renewable and biological material that can be used directly as a fuel e.g. wooden pellets.

Flexibility
The ability to adjust energy supply and demand to keep them balanced.

Floating Wind
Offshore wind turbines that are attached to a floating structure in the sea rather than tethered directly to the sea bed. The floating structure is then tethered to the sea bed to prevent it drifting into a shipping lane or a beach.

Fuel Cell Electric Vehicle (FCEV)
A vehicle which uses a fuel cell to generate electricity to move, instead of using a battery. These vehicles typically use hydrogen.

FES 2022 / Glossary 382

Future Homes Standard (FHS)
Government policy that requires new homes, built during and after 2025, to meet certain energy standards. This includes the installation of energy efficiency measures, as well as low carbon heating technologies.

Gigawatt (GW)
1,000,000,000 watts, a unit of power.

Gigawatt hour (GWh)
1,000,000,000 watt hours, a unit of energy.

Great Britain (GB)
A geographical, social and economic grouping of countries that contains England, Scotland and Wales. FES analysis largely covers energy supply and demand on a GB-basis but the Net Zero Emissions Target is on a UK basis (i.e. includes Northern Ireland as well).

Green Gas
In our scenarios, this is used to cover both biomethane and bioSNG (i.e. biomethane which is created by larger, more industrial processes).

Green Hydrogen
Hydrogen produced via electrolysis using zero carbon electricity.

Greenhouse Gas (GHG)
A gas in the atmosphere that absorbs and emits radiation within the thermal infrared range.

Greenhouse Gas Removal (GGR)
Greenhouse gas removals (GGRs) is the name given to a group of methods that directly remove greenhouse gases from the atmosphere. There are a range of approaches that may be counted as GGRs, which fall into two categories:

- Nature-based approaches: such as afforestation, forest management and soil carbon sequestration.
- Engineering-based approaches: such as Direct Air Carbon Capture and Storage (DACCS), Bioenergy with Carbon Capture and Storage (BECCS), wood in construction, biochar and enhanced weathering.

Grid Curtailment
This is when the output from a generation unit connected to the electricity system is reduced due to operational balancing.

Ground Source Heat Pump (GSHP)
Heat pump which absorbs heat from the ground. This heat can then be used to produce hot water or space heating.

Halogen Bulbs
High luminosity incandescent light bulbs, sale banned within the EU in September 2018.

Heat Pump
A device that transfers heat energy from a lower temperature source to a higher temperature destination. Can include ground source or air source varieties.

Heating, Ventilation, and Air Conditioning (HVAC)
Heating, ventilation, and air conditioning (HVAC) is the use of various technologies to control the temperature, humidity, and purity of the air in an enclosed space. Its goal is to provide thermal comfort and acceptable indoor air quality.

Heavy Goods Vehicle (HGVs)
A truck weighing over 3,500 kg.

Hybrid Heat Pump
An integrated heating system using an electric heat pump alongside a traditional installation such as a gas or hydrogen boiler.

Hydrogen (H2)
Hydrogen is the lightest chemical element and is gaseous at room temperature. It can be used as a fuel or store of energy and, during combustion, the only by-product is water.

Hydrogen Blending
When hydrogen is injected into the gas network and mixed with natural gas.

Hydrogen Boiler
Home heating technology which burns hydrogen (rather than natural gas) for heating and hot water.

Hydrogen Combined Cycle Turbine Hydrogen (CCGT)
Combined cycle turbine that burns hydrogen (rather than natural gas) to generate electricity.

FES 2022 / Glossary 383

Industrial Cluster
Hub for industry all using the same local infrastructure e.g. hydrogen supply or carbon capture and storage plant.

Industrial Decarbonisation Strategy (IDS)
UK Government strategy published in March 2021 setting out how industry can decarbonise in line with Net Zero.

Inertia
Inertia helps support the stability of the electricity system. Higher levels of inertia help to slow the rate of change of frequency and aid system operation. It has traditionally been provided by spinning turbines from fossil fuel generators.

Interconnector
Transmission assets that connect the GB market to Europe and allow suppliers to trade electricity or gas between markets.

Intergovernmental Panel on Climate Change (IPCC)
The IPCC is the United Nations body for assessing the science related to climate change.

Internal Combustion Engine (ICE)
Traditional engine used in transport sector which is powered by fossil fuels such as petrol or diesel.

International Energy Agency (IEA)
The International Energy Agency works with countries around the world to shape energy policies for a secure and sustainable future.

Interoperability
The ability for digital systems to seamlessly exchange information.

Interseasonal Energy Storage
Interseasonal energy storage is the storage of energy for periods of up to several months. This is most commonly in the form of gas, hydrogen, or thermal energy. The energy can be collected whenever it is available and be used whenever needed, such as in periods of high energy demand.

Kilowatt Hour (kWh)
1,000 watt hours, a unit of energy.

Land Use, Land-Use Change, and Forestry (LULUCF)
Net carbon emissions related to changes in land use and tree planting.

Less Flexible Generation
Types of generation that require longer notice periods to change their output or have obligations that influence when they can generate.

Levelised Cost of Heat (LCOH)
A parameter that assesses the costs of heat produced by the various solar thermal energy technologies and helps to compare the various technologies for process heating and power generation.

Light-Emitting Diode (LED)
Electric light with higher efficiency and longer lifetime than conventional bulbs.

Linepack
The amount of gas stored within the gas network at any time.

Liquefied Natural Gas (LNG)
Formed by chilling natural gas to -161˚C to condense as a liquid. Its volume reduces 600 times from the gaseous form.

Liquefied Petroleum Gas (LPG)
A mix of propane and butane, used for heating homes in off gas grid areas as well as a number of other uses.

Liquid Air Energy Storage (LAES)
Liquid Air Energy Storage (LAES) uses electricity to cool air until it liquefies, stores the liquid air in a tank, brings the liquid air back to a gaseous state (by exposure to ambient air or with waste heat from an industrial process) and uses that gas to turn a turbine and generate electricity.

Load Factor
Load factors are an indication of how much a generation plant or technology type has output across the year, expressed as a percentage of maximum possible generation. These are calculated by dividing the total electricity output across the year by the maximum possible generation for each plant or technology type.

FES 2022 / Glossary 384

Loss Of Load Expectation (LOLE)
Used to describe electricity security of supply. It is an approach based on probability and is measured in hours/year. It measures the risk, across the whole of winter, of demand exceeding supply under normal operation. This does not mean there will be loss of supply for 3 hours per year. It gives an indication of the amount of time, across the whole winter, which the Electricity System Operator (ESO) will need to call on balancing tools such as voltage reduction, maximum generation or emergency assistance from interconnectors. In most cases, loss of load would be managed without significant impact on end consumers.

Mega Joule (MJ)
A Mega Joule is a unit of work or energy, equal to one million joules.

Mega Tonnes of CO_2 Equivalent ($MtCO_2e$)
The equivalent of 1,000,000 tonnes of carbon dioxide, standard unit for measuring national and international greenhouse gas emissions.

Megawatt (MW)
1,000,000 watts, a unit of power.

Megawatt Hour (MWh)
1,000,000 watt hours, a unit of energy.

Methane Reformation
A method for producing hydrogen, ammonia, or other useful products from hydrocarbon fuels such as natural gas. In addition to Steam Methane Reforming (SMR), this could include Autothermal Reforming (ATR) which uses a pure stream of oxygen to drive the reaction and increase the hydrogen production and CO_2 capture.

Million Cubic Metres (MCM)
A unit of volume used in the gas industry. 1 mcm = 1,000,000 cubic metres. For gas in GB, a good guide for converting from energy in watt hours to gas volume in cubic metres is to divide by 11.

National Transmission System (NTS)
The network of high pressure gas pipelines that connect coastal terminals and interconnectors to major industrial users, power stations and the distribution network operators who supply commercial and domestic users.

Nationally Determined Contributions (NDC)
NDCs are plans for how much each country will reduce its carbon emissions. NDCs are at the heart of the Paris Agreement and the achievement of the long-term goal of Net Zero.

Natural Gas
A mixture of gases, primarily methane, suitable for transport through gas transmission and distribution networks.

Negative Emissions
When more carbon is removed from the atmosphere and stored by a process than is emitted into the atmosphere, this is termed negative emissions. For example with BECCS, carbon is removed from the atmosphere by the growth of the biomass as well as then being captured by CCUS.

Net Carbon Intensity
The amount of greenhouse gas emissions for each unit of energy produced. Measured in grams of carbon dioxide equivalent per kilowatt hour (gCO_2e/kWh).

Net Negative Emissions
When negative carbon emissions are greater than positive emissions in a process or sector.

Net Zero
When the total amount of greenhouse gases emitted in a year reaches zero, after all emissions and all carbon sequestration has been accounted for. This is the current UK target for 2050.

Network Options Assessment (NOA)
The Network Options Assessment (NOA) is our recommendation for which reinforcement projects should receive investment. These projects are major electricity transmission network reinforcements as defined in the NOA methodology. To find out more please visit https://www.nationalgrideso.com/research-publications/network-options-assessment-noa.

Networked Energy Systems
The current gas and electricity transmission and distribution networks (included connected supply and demand) as well as potential future networks such as hydrogen.

FES 2022 / Glossary 385

Non-Networked Energy
Energy supply or demand not connected to the networked energy systems.

Non-Networked Offshore Wind
Offshore wind that is not connected to the GB electricity network.

Offshore Hub
Coordinated development of an offshore location that can connect to multiple offshore generation sites and provide a link between them and surrounding countries via electricity or gas interconnectors.

Peak Demand, Electricity
The maximum electricity demand in any one fiscal year. Peak demand typically occurs at around 5:30pm on a week-day between November and February. Different definitions of peak demand are used for different purposes. FES uses the Average Cold Spell (ACS) definition which is consistent with the treatment of demand in the electricity Capacity Mechanism.

Peak Demand, Gas
The level of natural gas demand that, in a long series of winters, with connected load held at levels appropriate to the winter in question, would be exceeded in one out of 20 winters, with each winter counted only once.

Peaking Plant
Electricity generators that operate only at times of peak demand when electricity prices are high.

Peat Restoration
Peat can store high levels of carbon, and so restoration is an important element of Net Zero. While degraded peatland emits carbon, when restored it can be an effective way of drawing carbon from the atmosphere.

Plug-in Hybrid Electric Vehicle (PHEVs)
A vehicle which has a battery which can be charged by plugging it in, as well as a petrol or diesel engine.

Prosumers
Individuals, who have chosen to install small-scale, renewable electricity generation in their home. They produce electricity for their own consumption and can also sell it back to the grid when it's not needed.

Pumped Storage (PS)
Pumped storage is a type of hydroelectric energy storage used by electric power systems for load balancing. The method stores energy in the form of gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation. During periods of high electrical demand, the stored water is released through turbines to produce electric power.

Reforestation
Planting trees in places which used to forested.

Reforming Methane
Changing methane gas into hydrogen.

Renewable Transport Fuel Obligation (RTFO)
A EU regulation, which requires a certain proportion of fuel used in transport to be made from renewable sources.

Renewables Obligation (RO)
The Renewables Obligation is designed to encourage generation of electricity from eligible renewable sources in the UK.

Residual Emissions
Remaining positive emissions in a given year that need to be offset by negative emissions to meet Net Zero.

Resistive Heating Mode
A mode of operation an electric heat pump can switch to provide heat when it is very cold, providing one unit of heat output for every unit of electricity input, compared to two or three units of heat in normal heat pump operating mode.

Retrofit
In an energy context, to install energy efficiency measures to a building after its construction.

Road to Zero Strategy
The Road to Zero Strategy outlines how government will support the transition to zero emission road transport and reduce emissions from conventional vehicles during the transition.

Seasonal Flexibility
Storing energy in one season for use later in the year.

Security of Supply (SoS)
Energy Security of Supply is a general term used to describe how required energy flows to consumers (e.g. gas or electricity) are maintained at all times. There are specific criteria used across these different fuels and security of supply can cover network resilience as well as adequacy more generally.

FES 2022 / Glossary 386

Shale Gas
Natural gas that is found in shale rock. It is extracted by injecting water, sand and chemicals into the shale rock to create cracks or fractures so that the shale gas can be extracted.

Shrinkage
Total losses of gas from the gas network.

Small Modular Reactors (SMR)
Small modular reactors offer an alternative approach to delivering nuclear power generation. A traditional nuclear power plant provides around 1-3 GW of capacity. SMRs are closer to half that at 300-500 MW but at this size, they are roughly equal to a gas generation plant, so can be deployed as like for like replacements in terms of capacity.

Smart Appliances
These can reduce, as well as shift, demand. For example lights only turn on when needed and heating is more easily configurable.

Smart Charging
Smart charging usually refers to Electric Vehicles that have two way communication ability and can react to external signals such as price tariffs to schedule EV charging.

Smart Home Energy Management Systems
Smart controls that schedule and optimise energy consumption from appliances, heating and electric vehicles within the home.

Smart Meter
New generation gas and electricity meters which have the ability to broadcast secure usage information to customers and energy suppliers, potentially facilitating energy efficiency savings and more accurate bills.

Societal Change
The extent of future change to the behaviour and lifestyle of energy consumers across domestic, industrial and commercial sectors.

Solar Photovoltaics (PV)
The conversion of energy from the sun into electricity using photovoltaic panels (solar panels).

Supply Side Flexibility
Electricity generators or market participants adjusting electricity supply to meet demand.

Sustainable Aviation Fuel (SAF)
SAF is produced from sustainable feedstocks and is very similar in its chemistry to traditional fossil jet fuel. Using SAF results in a reduction in carbon emissions compared to the traditional jet fuel it replaces over the lifecycle of the fuel.

Synfuels
Synthetic fuel is a liquid fuel, or sometimes gaseous fuel, obtained from syngas, a mixture of carbon and hydrogen, in which a syngas is first derived from gasification of solid feedstocks such as coal or biomass or by reforming of natural gas and then using a catalyst, can be converted into the required end product.

Synthetic inertia
System inertia is how resilient an electricity system is to frequency change. System inertia will depend on what types of generation are connected to the system. Typically, generators with large moving parts have high inertia – because their moving parts continue to move even after they are switched off or turned down. Synthetic inertia aims to mimic this and keep frequency stable by calling on rapid response from assets such as batteries.

System Operability Framework (SOF)
The SOF combines insight from FES with technical assessments to identify medium-term and long-term requirements for operability.

System Operator (SO)
An entity entrusted with transporting energy in the form of natural gas or electricity on a regional or national level, using fixed infrastructure. The SO may not necessarily own the assets concerned. For example, National Grid ESO operates the electricity transmission system in Scotland, which is owned by Scottish Hydro Electricity Transmission and Scottish Power Transmission.

Terawatt Hour (TWh)
1,000,000,000,000 watt hours, a unit of energy.

Thermal Generation
Generation that uses a temperature difference produced by burning fuel to produce electricity.

FES 2022 / Glossary 387

Thermal Storage
A store of heat, for example in a hot water tank or phase change material, that allows heat to be stored and then released when it is needed.

Time Of Use Tariff (TOUT)
A charging system that is established in order to incentivise residential consumers to alter their consumption behaviour, usually away from high electricity demand times.

Total Primary Energy Demand
Total input energy that is required to meet end consumer demand including conversion and transportation losses.

UK Clean Growth Strategy
The government's comprehensive set of policies and proposals that aim to accelerate the pace of clean growth by delivering increased economic growth and decreased emissions.

UK Continental Shelf (UKCS)
Comprised of those areas of the sea bed and subsoil beyond the territorial sea over which the UK exercises sovereign rights of exploration and exploitation of natural resources.

UK Emissions Trading Scheme (UK ETS)
A UK system, implemented from January 2021, that establishes the trading of greenhouse gas emission allowances which effectively sets a UK carbon price.

Ultra-Low Emission Vehicles (ULEV)
Vehicles that use low carbon technologies and emit less than 75g of CO2/km from the tailpipe - includes BEVs, PHEVs and FCEVs.

Unabated Fossil Fuel Combustion
Burning fossil fuels without CCUS (e.g. for heat or power).

United Kingdom of Great Britain and Northern Ireland (UK)
A geographical, social and economic grouping of countries that contains England, Scotland, Wales and Northern Ireland. FES analysis largely covers energy supply and demand on a GB-basis but the 2050 Net Zero Emissions Target is on a UK basis (i.e. includes Northern Ireland as well).

Used Cooking Oil (UCO)
The dominant biodiesel feedstock for biodiesel consumed in the UK is Used Cooking Oil (UCO), defined as the purified oils and fats of plant and animal origin that have been used to cook food.

Vehicle-to-Grid technology (V2G)
Enables energy stored in electric vehicles to be fed back into the national electricity network (grid) to help supply energy at peak times of demand. Sometimes referred to as vehicle to home if only used to meet domestic load rather than export to the grid.

Weather-variable Generation
Types of generation that can only produce electricity when their primary energy source is available. For example, wind turbines can only generate when the wind is blowing.

Wet Waste
Waste which is a by-product from wet processes such as sewage treatment or brewing.

Whole Electricity System
A collective term that is used to cover, but is not strictly limited to, transmission and distribution systems for electricity.

Whole Energy System
A collective term that is used to cover, but is not strictly limited to, transmission and distribution systems for both gas and electricity.

Whole Gas System
A collective term that is used to cover, but is not strictly limited to, transmission and distribution systems for gas.

Whole System
A collective term that is used to cover all interdependent systems associated with provision of energy and the emission of greenhouse gases; including systems such as transport, water, waste, hydrogen.

Whole System Flexibility
The management of energy demand and supply across fuels, for example the interaction between the natural gas and electricity systems due to the operation of gas-fired generation.

FES 2022 / Glossary 388

Thanks for your time, we hope you found FES 2022 interesting and useful

Continuing the Conversation

In terms of next steps, we now move into our main stakeholder engagement stage of the FES cycle, using your comments and questions about FES 2022 to inform our analysis and insights. We're also increasing the regional focus of our work, so particularly welcome your local insights.

Similar to previous years, we will be using FES 2022 as a basis for the next iteration of 'FES - Bridging the Gap to Net Zero'. If you'd like to know more, please click here.

Ways to connect and stay in touch

Keep an eye out for any surveys, thought pieces and engagement opportunities via our FES newsletter. If you are not already subscribed, you can do so via https://subscribers.nationalgrid.co.uk, the ESO website www.nationalgrideso.com/ or use the FES email address opposite.

Email us with your views on FES or any of our future of energy documents at: fes@nationalgrideso.com and one of our team members will be in touch.

Access our current and past FES documents, data and multimedia at: www.nationalgrideso.com/future-energy/future-energy-scenarios.

Get involved in the debate on the future of energy and join our LinkedIn group Future of Energy by National Grid ESO.

For further information on ESO publications please visit: https://nationalgrideso.com.

Write to us at:
Energy Insights & Analysis
Electricity System Operator
Faraday House
Warwick Technology Park
Gallows Hill Warwick
CV34 6DA

FES 2022 / 389

Legal Notice

Pursuant to its electricity transmission licence, National Grid Electricity System Operator Limited is the system operator of the national electricity transmission system.

For the purpose of this outlook document, the terms “we”, “our”, “us” etc. are used to refer to the licensed entity, National Grid Electricity System Operator Limited.

National Grid Electricity System Operator Limited has prepared this outlook document pursuant to its electricity transmission licence in good faith, and has endeavoured to prepare this outlook document in a manner which is, as far as reasonably possible, objective, using information collected and compiled from users of the gas and electricity transmission systems in Great Britain together with its own forecasts of the future development of those systems.

While National Grid Electricity System Operator Limited has not sought to mislead any person as to the contents of this outlook document and whilst such contents represent its best view as at the time of publication, readers of this document should not place any reliance on the contents of this outlook document.

The contents of this outlook document must be considered as illustrative only and no warranty can be or is made as to the accuracy and completeness of such contents, nor shall anything within this outlook document constitute an offer capable of acceptance or form the basis of any contract.

Other than in the event of fraudulent misstatement or fraudulent misrepresentation, National Grid Electricity System Operator Limited does not accept any responsibility for any use which is made of the information contained within this outlook document.

FES 2022 / 390

nationalgridESO