July 2021

Future Energy Scenarios

nationalgridESO

Navigation

This version of the FES 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

Executive Summary

Introduction

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

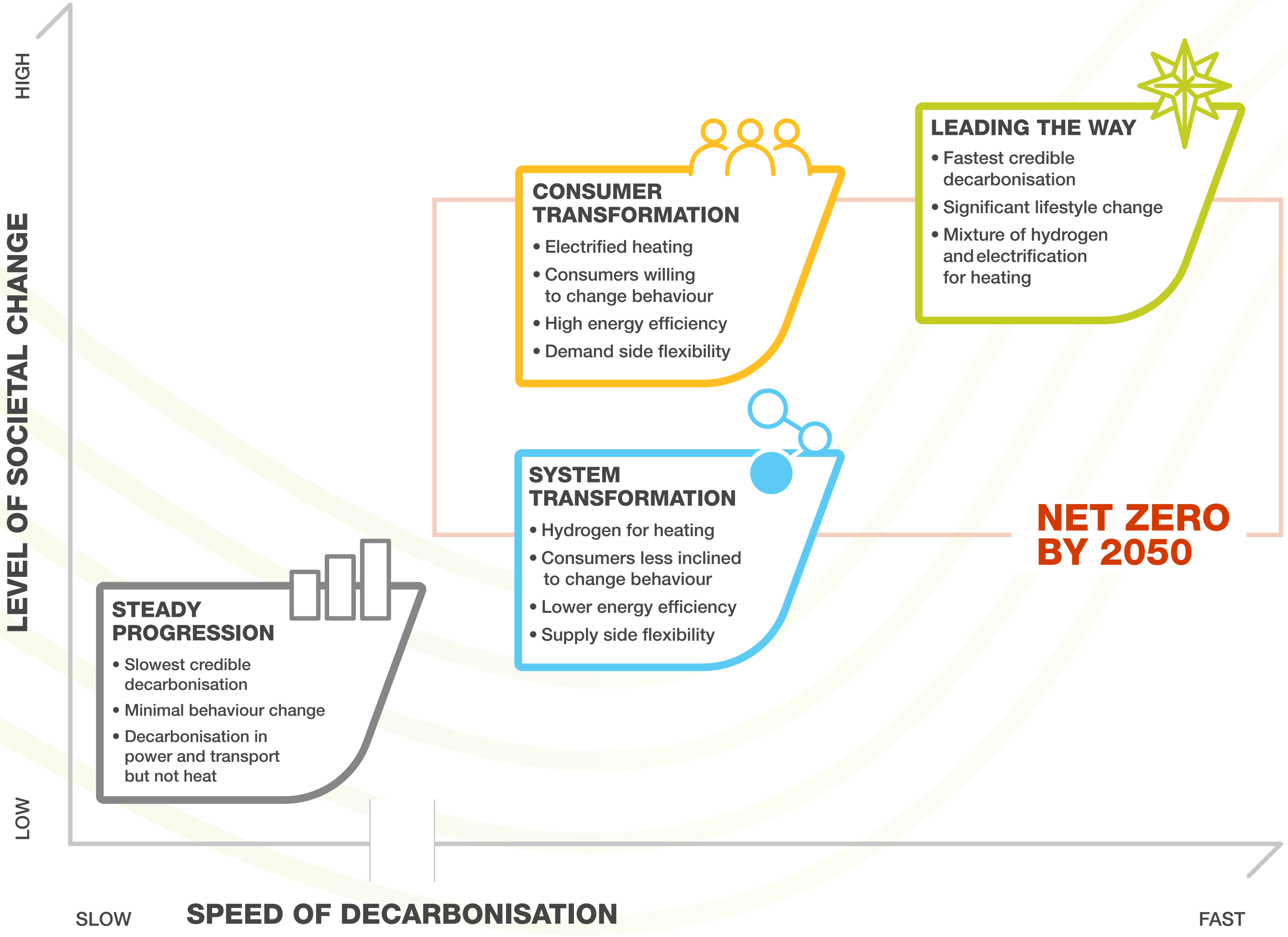
With an ambitious target for net zero emissions by 2050, our energy system will need to transform rapidly while continuing to deliver reliability and value for consumers. We believe decarbonising energy is possible but also that it will be complex, not least because there are many ways to reach net zero, each with their own trade-offs.

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. The overall scenarios remain consistent with those in FES 2020 but the details within them are new for 2021 following extensive modelling, research and stakeholder engagement.

FES can be used to inform a range of energy system activities including network operation, investment decisions and energy policy.

Learn more about how FES is used

The Scenario Framework



FES 2021 / Executive Summary 05

The Scenario Framework

Steady Progression

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 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.

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 solely from electrolysis powered by renewable electricity.

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.

Consumer Transformation

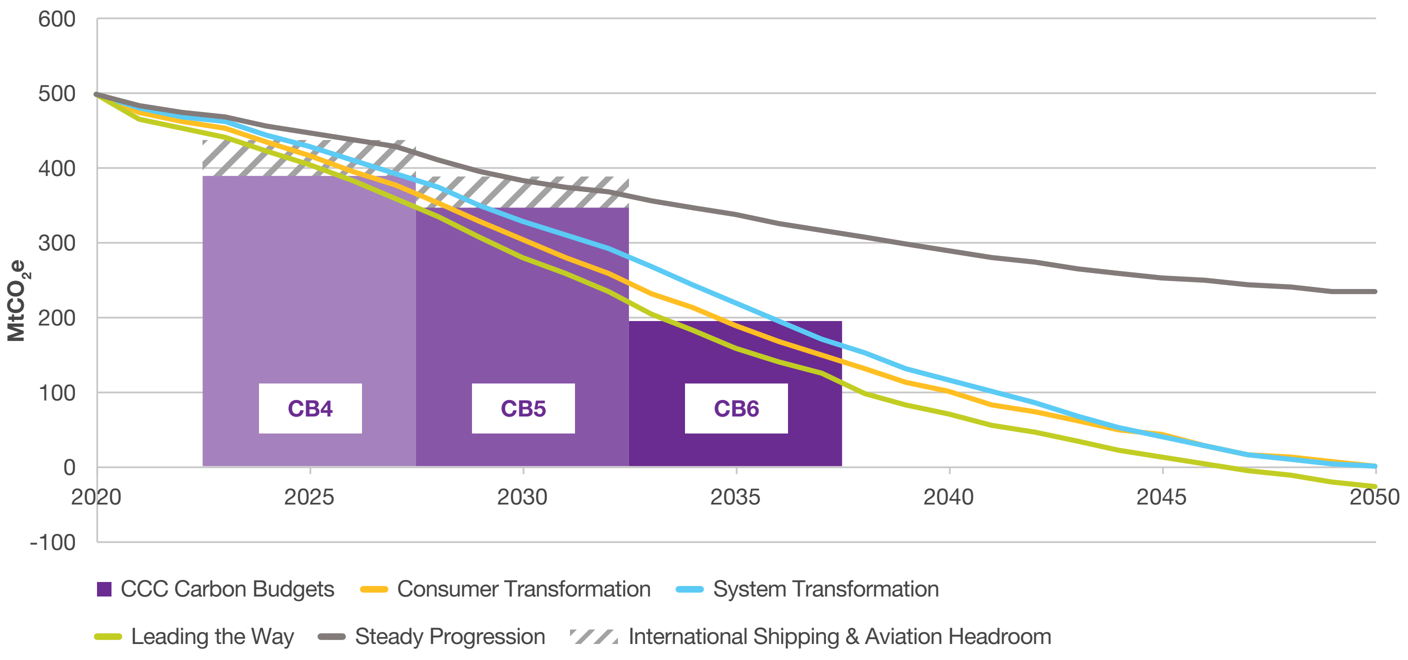
The 2050 net zero target is met with measures that have a greater impact on consumers and is driven by higher levels of consumer engagement. A typical homeowner will use an electric heat pump with a low temperature heating system and an electric vehicle. They will have made extensive changes to improve 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 and smart energy management.

FES 2021 / Executive Summary 06

29 years to net zero

All of our FES 2021 scenarios have lower emissions by 2030 compared to FES 2020. Three of those reach net zero by 2050.

Total net greenhouse gas emissions (including carbon budgets)



Consumer Transformation and System Transformation represent two different ways to get there - either by changing the way we use energy or by changing the way in which we generate and supply it. In Leading the Way, a combination of high consumer engagement and world-leading technology and investment help to enable our fastest credible decarbonisation journey. In this scenario, the UK reaches net zero in 2047 and goes on to reduce emissions by 103% by 2050 (compared to 1990 levels) - in other words, it is net negative. Decarbonisation happens slowest in Steady Progression, where 2050 emissions are reduced by 73% of 1990 levels.

Some sectors don't get to zero emissions by 2050 so any residual emissions must be offset by use of greenhouse gas removal (GGR) technology in other sectors.

COVID-19 impact

- Since the first COVID-19 lockdown, average daily electricity demand has reduced by around 5-10% compared to normal levels (as much as 18% at times during summer 2020).
- Reasons include less travel, reduced economic activity due to social restrictions and people spending more time at home rather than their normal place of work.
- Our analysis suggests long term impact is likely to be small. We will continue to monitor the impact of the COVID-19 restrictions and build our understanding into FES 2022.

FES 2021 / Executive Summary 07

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 the chart represent the average maximum annual emissions over a budget period required to meet the target.

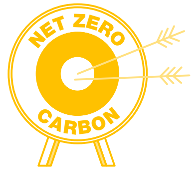
So while some scenario trajectories appear below a carbon budget by the end of a budget period, that does not mean they have met the budget target. For example, System Transformation reaches the average emissions required for the 6th Carbon Budget before the end of the period but its cumulative emissions are above the average for that period and so misses the budget target.

FES 2021 / Executive Summary 08

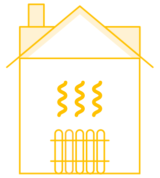
Key Message 1

Policy and delivery

Achieving net zero requires detailed policies and clear accountabilities, coupled with an immediate and sustained focus on delivery, to maintain the momentum provided by the Energy White Paper.

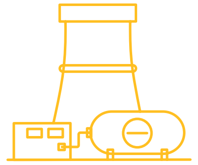


Leading the Way reaches net zero in **2047**



Thermal efficiency of buildings is as important for hydrogen boilers as it is for heat pumps

Close to zero unabated natural gas generation from **2035** in Leading the Way



Emissions from power sector net negative by **2034** in all net zero scenarios

What this means

- FES 2021 sets out different routes to net zero to capture uncertainty but, to support action on delivery, important policy decisions need to be made on:
  - Relative roles of electrification and hydrogen for residential heating
  - Level of support for energy efficiency measures
  - Timings for transitioning away from unabated gas
  - Extent to which natural gas is used in hydrogen production
- Competitive markets and strategic planning are both needed to meet net zero.

Coordination and collaboration are key when setting policy direction and parameters whereas competitive markets are the best tool to deliver that policy at least cost and to foster innovative solutions.

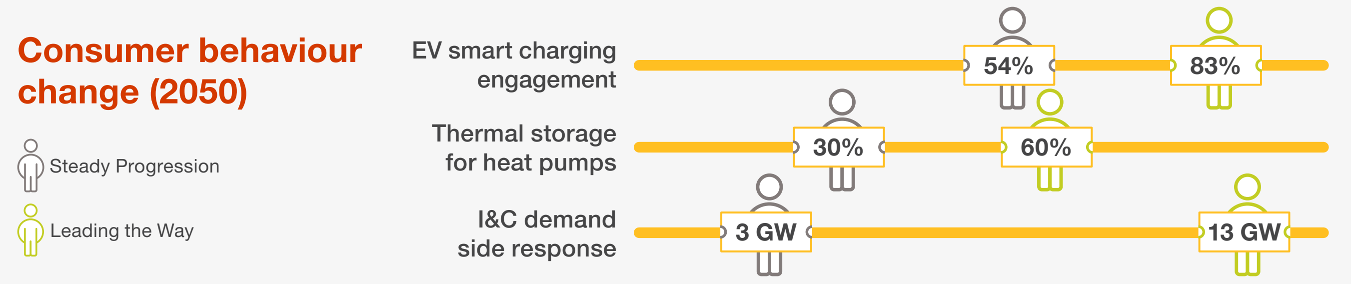
- Clear roles are needed between government, regulator and industry to facilitate efficient transitions and market changes whilst maximising value to end consumers.
- Improvements in energy efficiency of buildings, vehicles and appliances should be a 'no-regret' policy priority in all scenarios as reducing demand reduces the costs of energy security across the scenarios.

Key Message 2

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.

Every scenario sees some level of societal change compared to today, even Steady Progression, but the scale and type of change assumed varies significantly across them.



What this means

- Historically, changes to deliver decarbonisation have been on the supply side and largely invisible to consumers. However, to reach net zero there will need to be direct changes to consumer behaviour. What got us here, won't get us there!
- The journey to net zero by 2050 will involve multiple generations of consumers. Improved understanding of how we as consumers can help is required as polling currently suggests a significant gap.
- How consumers engage with energy balancing will often be through upfront investment in smart technology that then optimises demand on their behalf (e.g. EV charging patterns). Digital solutions are required to prevent swings in demand caused by multiple smart systems responding to the same price signal.
- As smart technologies and innovative business models develop, digitalisation and data will become increasingly important. A balance between open data and privacy must be found to promote trust and to unlock demand side flexibility – while embracing digitalisation.

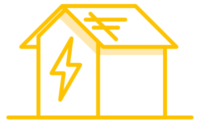
FES 2021 / Executive Summary 09

Key Message 3

Markets and flexibility

Holistic energy market reform is needed to drive the investment and behaviour changes needed to deliver net zero and ensure security of supply at a fair and reasonable cost for all consumers.

Between **34 GW** and **77 GW** of new wind and solar generation could be required to meet demand in **2030**



This could require as much as **13 GW** of new electricity storage in **2030** to help balance periods of high and low renewable output

6 GW of new flexible residential demand reduction is available in Leading the Way by **2030**

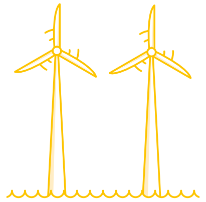
What this means

- Changes are needed to market and code designs to ensure that the right kind of flexibility can be harnessed to balance supply and demand across different locations and time periods – from "second by second" to "seasonal".
- To attract new market participants, especially from the demand side, and to drive efficient signals, the market design arrangements must prioritise accessibility and competition.
- A sustainable route to market is required to ensure financing of renewable electricity capacity when the majority of generation operates at zero marginal cost. Market rules, processes and data must be transparent to build trust from participants and investors.
- Whilst roll-out of 'time of use tariffs' (TOUTs) is required alongside appliance automation, protection must be put in place to ensure fairness and to shield potentially vulnerable consumers from extreme price volatility.
- Initiatives to incentivise new renewable or flexible capacity (e.g. Ofgem's work on full chain flexibility) must continue to consider the impact on system operability. Similarly, markets must be designed coherently to deliver efficient, interoperable and co-optimised investment signals across the whole energy system.

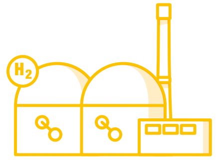
Key Message 4

Infrastructure and whole energy system

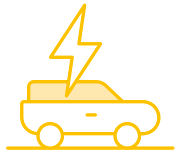
Significant investment in whole system infrastructure will be required over the coming decade – this should be optimised to ensure timely delivery and value for consumers.



Across the scenarios, between **31 GW** and **47 GW** of offshore wind is connected by **2030** – as well as at least **16 GW** of interconnector capacity



By **2035**, at least **2 TWh** of hydrogen storage is required in net zero scenarios to provide whole energy system resilience



Even Steady Progression (our slowest decarbonising scenario) sees **4.7 m** EVs and **1.9 m** heat pumps connected by **2030**

What this means

- Coordinated offshore network development is required to integrate the target level of offshore wind with the wider electricity system by 2030. This development will also include multi-purpose interconnectors and potentially hydrogen in the future and so may require changes to industry roles and processes.
- Onshore network reinforcement will also be required to avoid significant constraint costs caused by accelerated renewable connections, interconnectors and increased electrification of heat and transport – or to transition from natural gas to hydrogen. This can be minimised by deploying smart and innovative non-build solutions and integrated planning but remains a key challenge to delivering net zero fairly and at pace.
- Hydrogen storage is necessary to support whole energy system security of supply as well as to accommodate electrolysed hydrogen at times of excess wind or solar. A strategic approach to its development is required to bring forward investment given the likely lead times involved.
- Regional planning work across the electricity and gas transmission and distribution interfaces is required to ensure a fair and coordinated approach to network development and to minimise cost and disruption to end consumers.

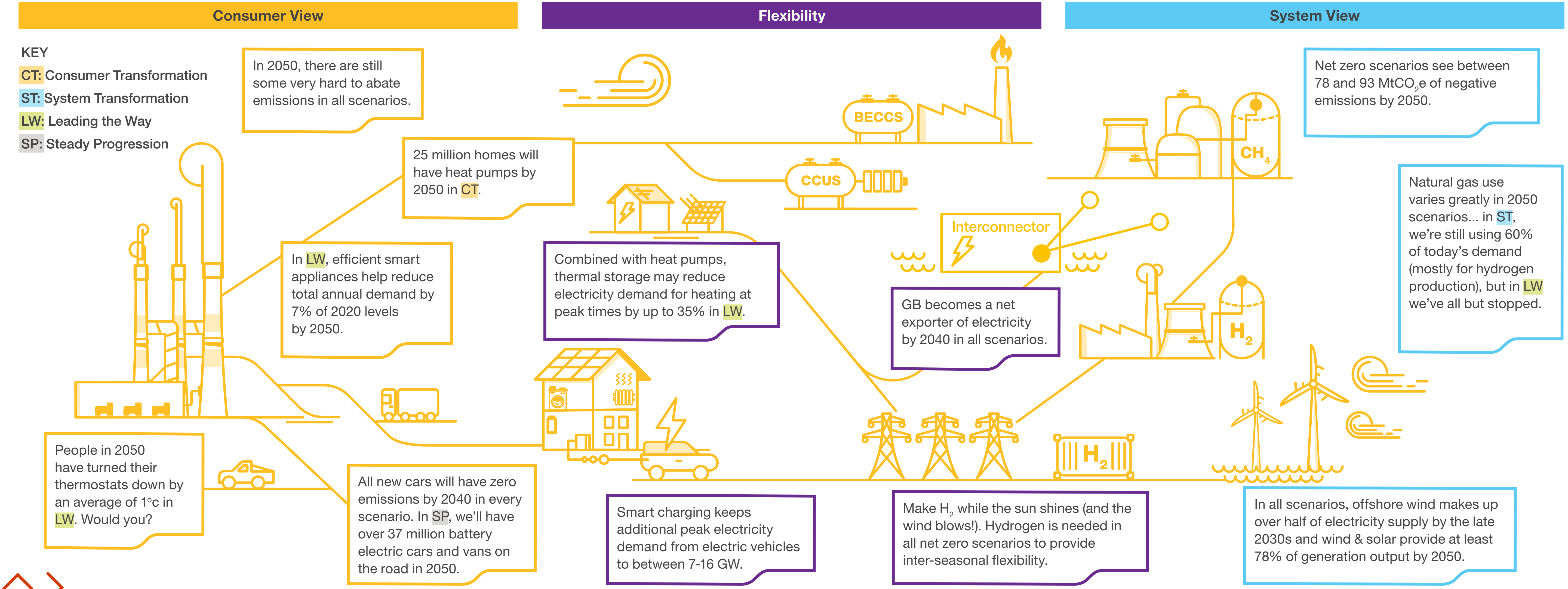
FES 2021 / Executive Summary 10

Whole energy system view

As well as a chapter on reaching net zero, FES 2021 has dedicated chapters on consumer view (residential, transport and industrial & commercial), system view (bioenergy, natural gas, hydrogen and electricity supply) and flexibility to explore these in detail. To create and operate an optimal whole energy system, the important links between demand, supply and flexibility must be clearly understood.

Today, the electricity system is designed and operated to ensure supply meets demand. However, the whole energy system of the future will be based more around supply, with demand adjusting to use or store energy as required. It will also involve increased interaction across fuels like natural gas, bio-resources and hydrogen.

The importance of flexibility increases with electrification in all scenarios – especially when the electricity comes from weather-driven renewables. Consumers and the energy system must support each other to manage peaks and troughs in supply and demand.

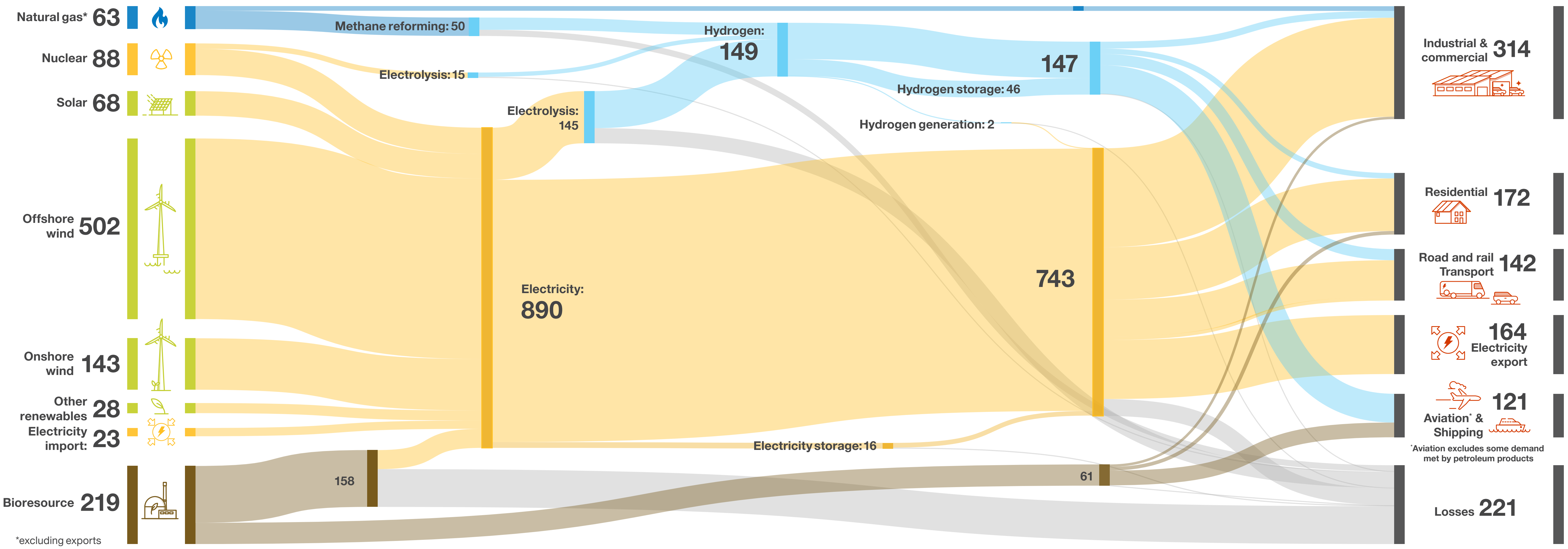


FES 2021 / Executive Summary 11

2050 energy flows

Consumer Transformation: energy demand and supply (TWh)

- Home heating, transport and industry largely electrified
- Hydrogen produced in the UK, primarily through electrolysis
- Electricity generation capacity and output is highest in this scenario to meet high annual electricity demands
- High levels of energy efficiency measures, lowest end user demand

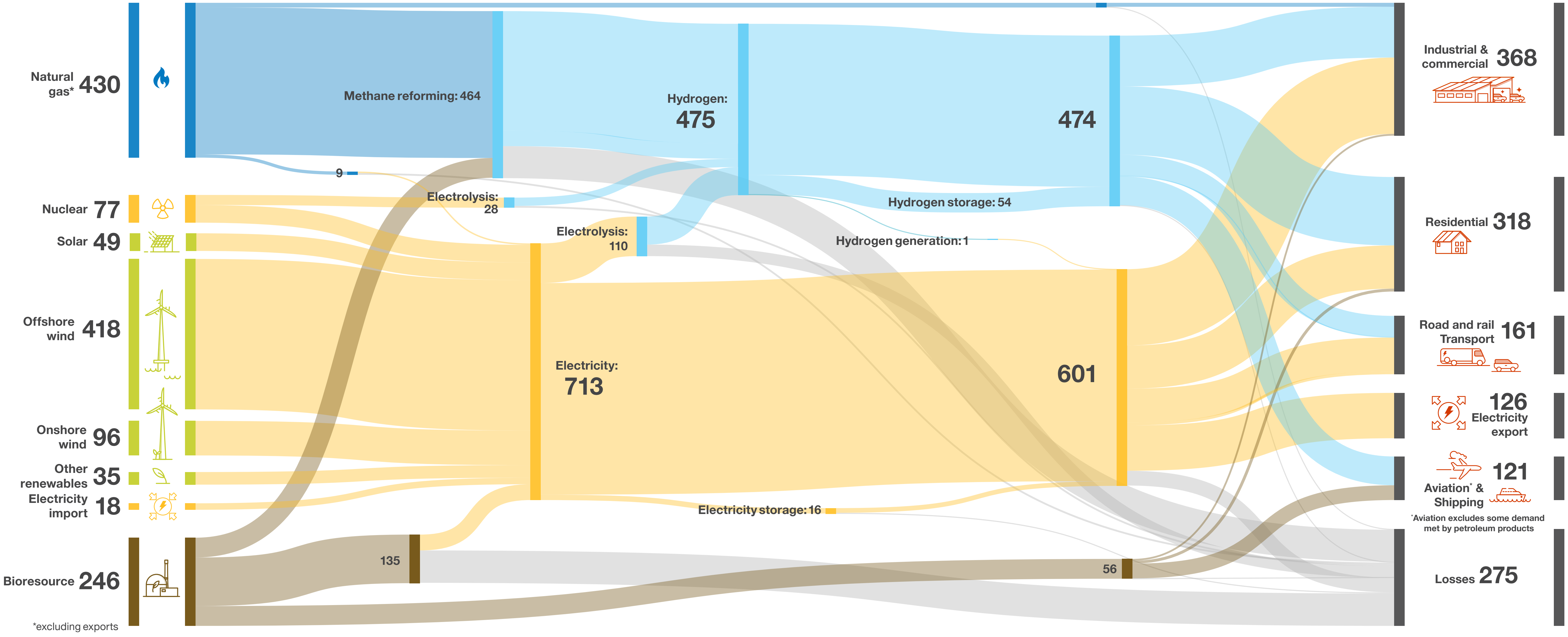


FES 2021 / Executive Summary 12

2050 energy flows

System Transformation: energy demand and supply (TWh)

- Highest proportion of hydrogen with widespread use for home heating, industry and HGVs
- Hydrogen produced in the UK, mainly through methane reforming, with large requirement for natural gas with CCUS
- Some negative emissions from hydrogen production from bioresources with CCUS
- Highest level of bioresource use, particularly for BECCS in the power sector

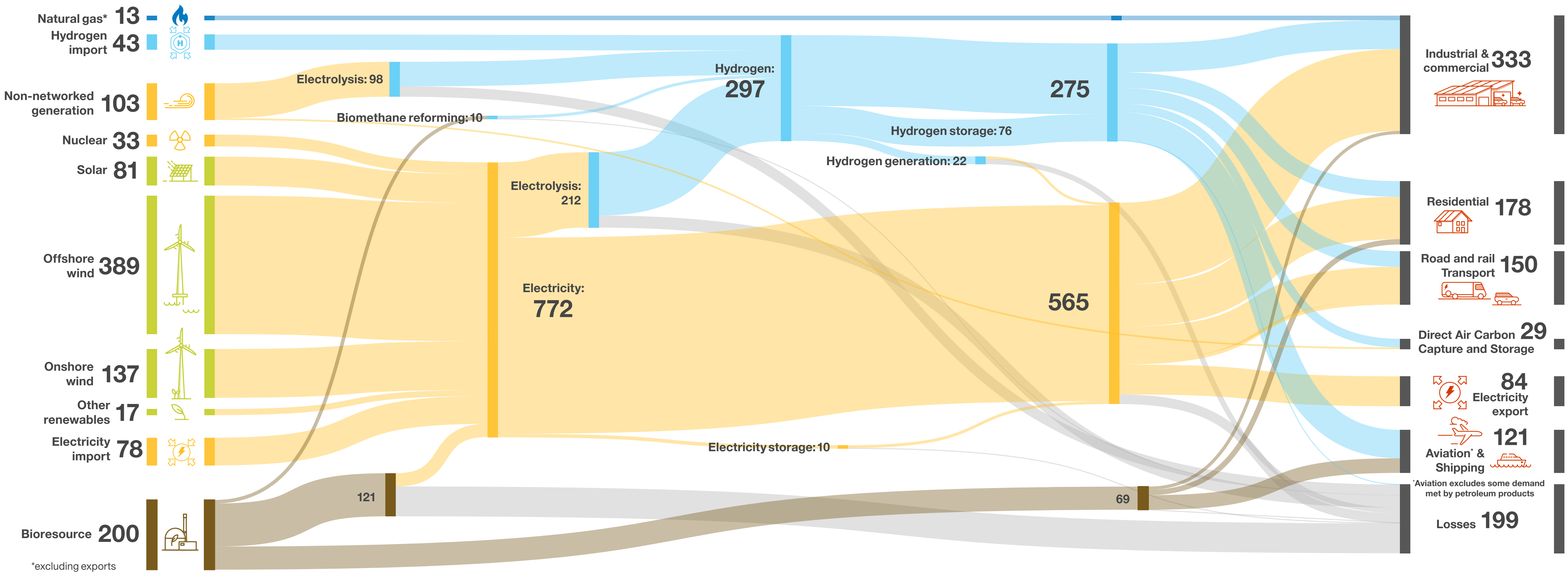


FES 2021 / Executive Summary 13

2050 energy flows

Leading the Way: energy demand and supply (TWh)

- Combination of hydrogen and electricity used in industry and to heat homes using hybrid heat pumps or hydrogen boilers
- No natural gas used to produce hydrogen
- Some use of direct air carbon capture and storage (DACCS) for negative emissions
- The only scenario to include non-networked electricity generation and hydrogen imports

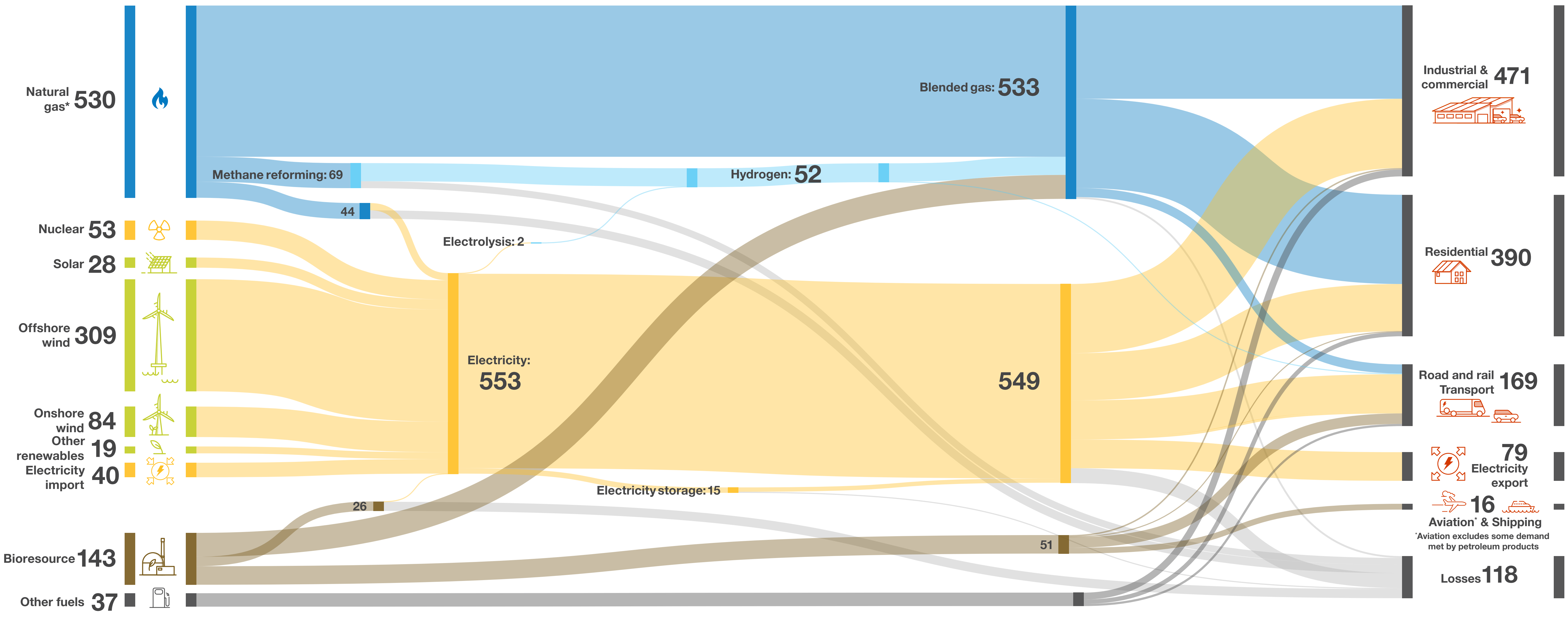


FES 2021 / Executive Summary 14

2050 energy flows

Steady Progression: energy demand and supply (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

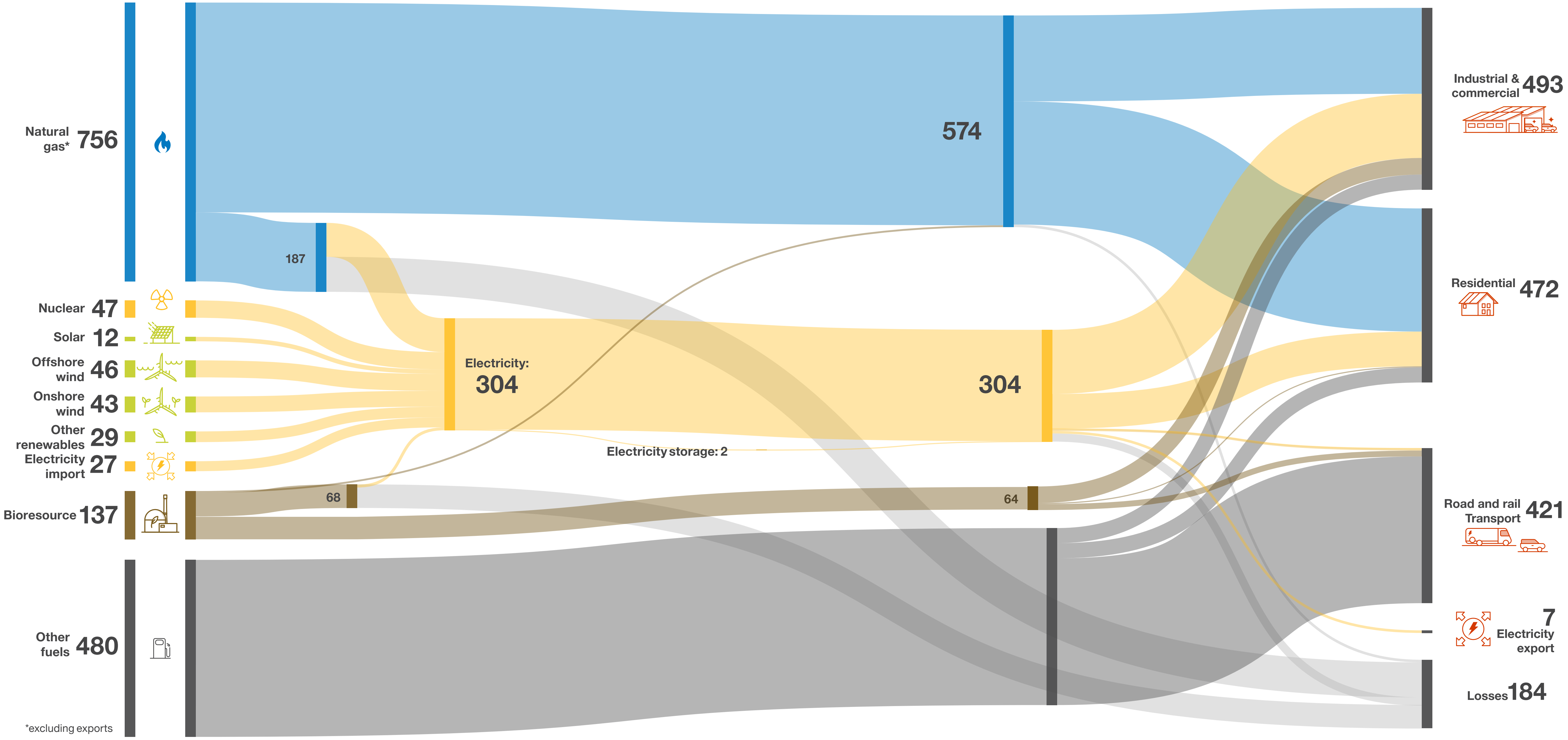


*excluding exports

FES 2021 / Executive Summary 15

2020 energy flows

- Relative to net zero scenarios energy demand is much higher today than in 2050
- Fossil fuels provide the majority of energy supply
- Energy demand for transport is much higher today than in 2050 due to the relative inefficiency of ICE vehicles compared to electric vehicles



FES 2021 / Executive Summary 16

Introduction to the FES

This is a pivotal year on our journey to net zero. Nations around the world are preparing to make firm commitments to tackle Climate Change at COP26. Since 1990, the UK has halved its greenhouse gas emissions, and has made a legal commitment to a 78% reduction by 2035.

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 is possible as long as we work together urgently to reduce our emissions and agree clear ways forward. That's where our **Future Energy Scenarios (FES)** come into play.

FES 2021 / Introduction to the FES 18

2021: A critical year for FES

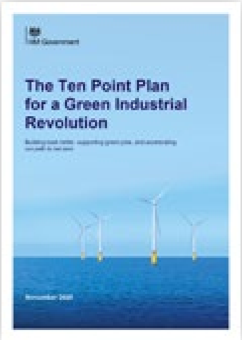
The first FES document was published in 2011, which means 2021 marks its tenth anniversary. Our scenarios have evolved over this time and while every year is an important step on the journey to net zero emissions, 2021 is arguably the most important year yet. At the United Nations' Conference of Parties (COP26) in November, the world will be watching as national leaders come together to make firm commitments to tackle climate change – with many countries, including the UK, striving for net zero by 2050.

PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

NOV 2015
UN COP21

Global agreement and call to action on limiting global warming and its impact

National Policies



NOV 2020
10 Point Plan

The UK's Net Zero ambitions

DEC 2020
Sixth Carbon Budget

Policy advice for UK decarbonisation

DEC 2020
Energy White Paper

Details supporting the 10 Point Plan

CO_2

JUN 2021
Legal Commitment

78% fewer emissions by 2035 (vs. 1990 levels)

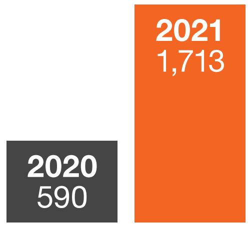
UN CLIMATE CHANGE CONFERENCE UK 2021
IN PARTNERSHIP WITH ITALY

NOV 2021
UN COP26

Global commitments on Climate Change

FES 2021 / Introduction to the FES 19

Purpose of FES 2021



Stakeholder Engagement

This year, we have had 3 times more stakeholder engagement than in FES 2020

Analysis & Insight

We use stakeholder engagement and market research to inform our analysis and insights into what the future may look like

Future Energy Scenarios 2021

In FES, we outline four pathways for the future of energy from now to 2050 – exploring the different ways we may use and generate energy alike. These scenarios are not forecasts or predictions, but they do represent a credible range of likely outcomes and are used by the National Grid ESO and other energy network owners / operators as a fundamental part of annual network planning and operability analysis. FES can also:

- Inform investment decisions
- Support policy development
- Help people understand the different ways we may supply and consume energy between now and 2050

FES 2021 / Introduction to the FES 20

FES 2021 scenarios

Scenario Framework

FES 2021 uses the same scenario framework as last year. This is in response to stakeholder requests for consistency and because we believe it still allows us to explore the credible range of uncertainty. The 'Societal Change' axis combines changes in innovation, understanding and behaviour.

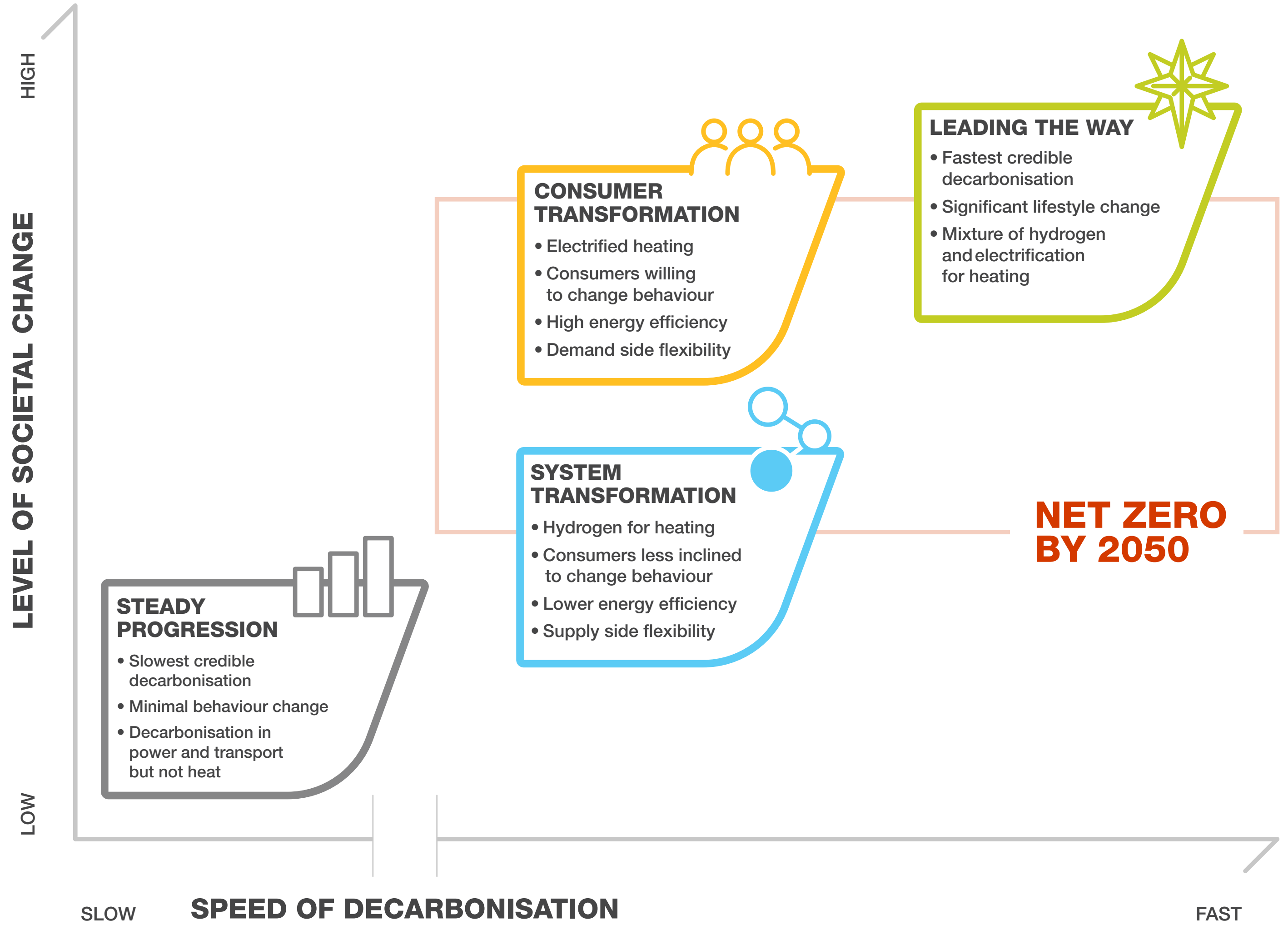
Consumer Transformation and System Transformation represent two different ways to reach net zero by 2050 – either by changing the way we use energy or by changing the way in which we generate and supply it.

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.

Steady Progression represents our slowest credible speed of decarbonisation and does not reach net zero, although it has accelerated relative to FES 2020.

FES 2021 explores what these scenarios mean for the consumer and for the energy system in detail.

Learn more about the Scenario Framework



FES 2021 / Introduction to the FES 21

FES 2021 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 and smart energy management.

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 solely from electrolysis powered by renewable electricity.

Steady Progression

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 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.

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.

FES 2021 / Introduction to the FES 22

What's new for FES 2021?

As ever, FES 2021 reflects recent policy publications e.g. the Energy White Paper

Dedicated chapter on emissions and reaching/living in a net zero world

Dedicated chapter on flexibility including how we manage peaks and troughs in supply and demand

Accessibility: more of our content is available directly on our new **website**

FES 2021 / Introduction to the FES 23

What impact will COVID-19 have on our future energy scenarios?

In this section, we aim to summarise the effect that the COVID-19 pandemic, and the associated restrictions, has had on our scenarios. This effect has been built into the analysis that underpins the results presented later in the document and so isn't referenced explicitly in each individual section.

We are continually learning more about the impact of the COVID-19 pandemic, and the associated restrictions and lockdowns, on energy. There are many ways the pandemic has affected our energy usage since the early months of 2020. For instance:

- Lockdowns changed the balance of residential and industrial & commercial demand as people spent much more time at home and some businesses were forced to close.
- There has been significantly less travel, both domestically and internationally.
- Rules like social distancing continue to affect economic activity both directly and indirectly.

Impact so far

In the early days following the first lockdown, demand on the electricity system dropped by as much as 18% and we also saw some of the lowest ever transmission demands over the summer of 2020. These low demands meant a significantly changed generation mix, with zero carbon renewables like wind and solar taking up their largest ever share. Not only did this result in some of the lowest carbon intensity electricity seen on the system, the characteristics of this generation mix, namely low inertia and low flexibility, also provided a unique opportunity to experience some of the operability challenges that will be increasingly common in the zero-carbon grid of the future.

Since then, the pandemic's impact on electricity demand has fluctuated with the different degrees of restriction on the economy. There was a similar reduction in gas demand compared to historic levels between April and June 2020 before returning to more normal levels once lockdown controls were eased – including minimal impact on gas demand during winter 2020/21[1].

Our analysis, using our experience of the pandemic to date, has shown how the reduction in demand is correlated to the lockdown restrictions. However, over winter we also saw that peak electricity demands were not as affected as at other times of the day or year.

More generally across the economy (i.e. not just energy), COVID-19 has also impacted UK greenhouse gas emissions with a fall of around 10% in 2020 compared to 2019. As the global economy begins to recover from COVID-19 there are signs of carbon emissions rebounding strongly, with the International Energy Agency stating that global energy-related emissions were 2% higher in December 2020 than in December 2019[2]. The UK economy is also expected to recover significantly in 2021 and 2022 suggesting emissions will increase as well, however it's too early to say by how much, this is something we will report on in next year's FES.

1 COVID-19 Webinars - National Grid Gas Operational Data Community

2 https://www.iea.org/news/after-steep-drop-in-early-2020-global-carbon-dioxide-emissions-have-rebounded-strongly

FES 2021 / Introduction to the FES 24

What impact will COVID-19 have on our future energy scenarios?

Short-term outlook

Our modelling has been informed by our experience of how COVID-19 has impacted energy use to date - with the following trends being considered in our analysis against metered demands:

- timings of lockdowns and associated restrictions
- vaccination rates
- working patterns
- levels of industrial activity
- employment / financial support.

We do not predict there to be a significant impact on demand in the short to mid-term due to the lockdown easing.

However, the most relevant input into our scenarios is the wider impact of economic growth. While its correlation with energy continues to weaken due to factors such as energy efficiency, this remains a key component for several industrial and commercial (I&C) sub-sectors modelled by us.

We procure independent third-party economic data to inform our analysis alongside publicly available OBR (Office of Budgetary Responsibility) and ONS (Office for National Statistics) information.

Based on this analysis, and combined with our experience to date, we see a slight dip in I&C demand in the very short term followed by a prompt return to pre-pandemic as the lockdown restrictions are lifted. We have not included any assumptions specifically on further outbreaks or lockdowns.

Longer term impacts

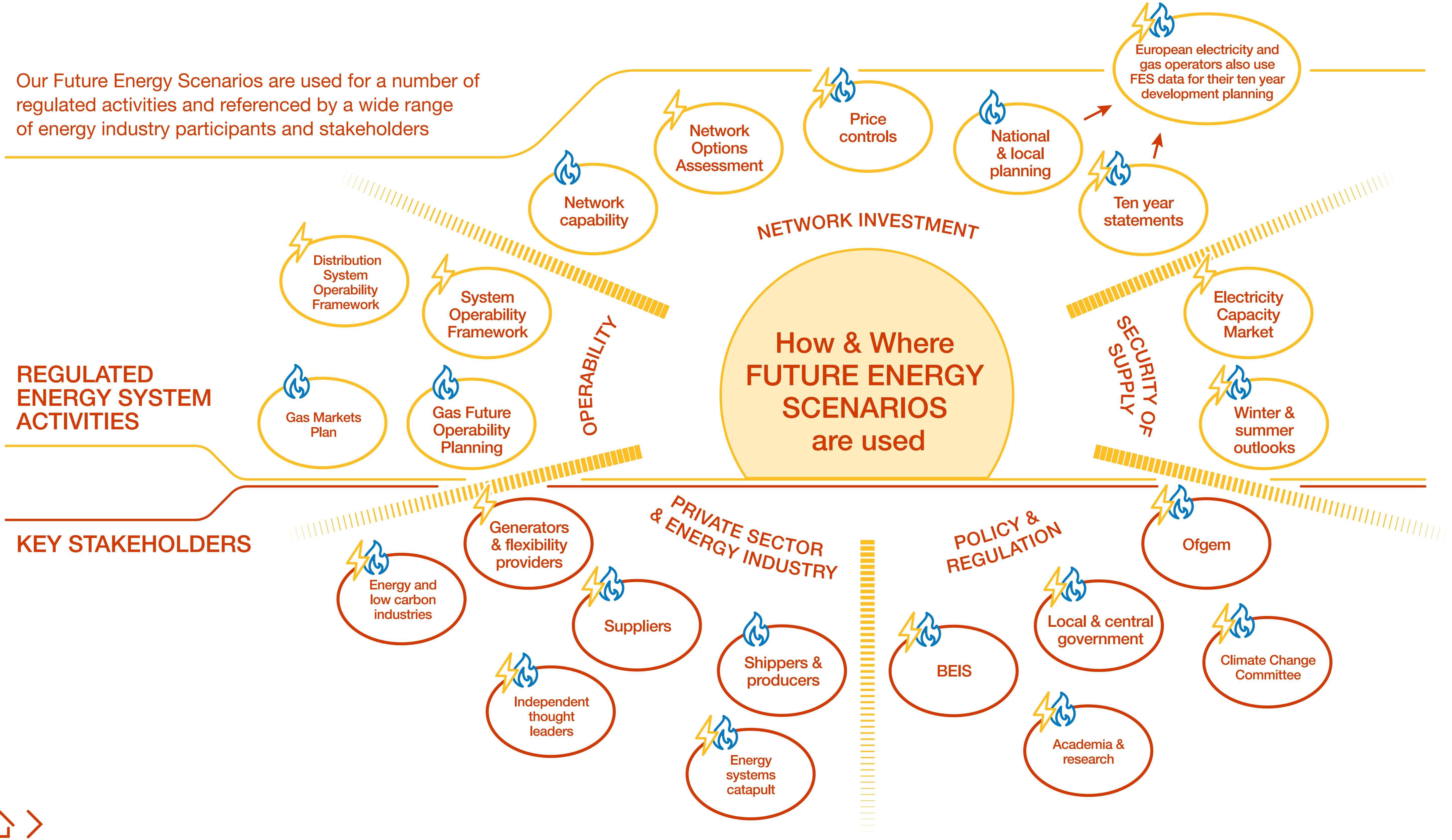
Based on experience to date, our modelling for FES 2021 shows that the long-term impact of COVID-19 on energy demand (both peak and annual) is likely to be small. Changes to economic output, and its effect on industrial demand, are reflected in our modelling using updated economic forecasts.

However, as the pandemic's impact on society becomes clearer, we will be able to reflect our observations of the post-lockdown impacts in FES 2022 and beyond.
We are particularly interested in:

- Potential changes to commuting/working patterns and how they affect demand;
- How amenable consumers are to lifestyle change now compared to how they felt pre-COVID;
- The degree of change our society and infrastructure can cope with; and
- How any longer-term impacts to businesses and the economy impact decarbonisation efforts.

An important insight to draw from the country's response to COVID-19 is how willing and able consumers are to make significant adaptations to their behaviour when called on, for example, to go into lockdown. This willingness to change behaviour, and how long-lasting it is, aligns well to the "level of societal change" axis of the FES Framework - a key area of uncertainty that we explore across our scenarios.

FES 2021 / Introduction to the FES 25



FES 2021 / Introduction to the FES 26

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.

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 2021 / Introduction to the FES 27

Regionalisation

We believe that there are aspects of decarbonising the whole energy system that are driven mainly by local factors. These cannot be fully understood using only a top-down assessment framework and we are increasingly focusing on more granular regional outputs. This is both as part of our modelling and through the insights we provide to the industry.

The spatial heat model we have used in this year's analysis is a first stage in this capability which we will be developing further as we move beyond FES 2021 – both in relation to heat but also more broadly across the energy sector.

Regional analysis will also be used to support discussions with local Transmission and Distribution network companies who are well-placed to explain any differences at this more granular level which will enhance our understanding at a GB level.

We are hopeful that the drive for regionalisation in our National Grid ESO Future Energy Scenarios will support understanding of future energy policy at a local level.

We are also hopeful it will simplify and optimise the interface with the more bottom-up 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. This will build upon and enhance the information we currently produce and publish such as the regional datasets that are used in the Electricity Ten Year Statement process.

Interaction between FES and DFES

Through the Open Networks project run by the Energy Networks Association (ENA), networks have been working closely to align process and provide clarity on the purpose of Distribution Future Energy Scenarios (DFES) and Future Energy Scenarios (FES) activities to stakeholders.

FES is an annual process undertaken by National Grid ESO. It provides a set of scenario projections for Great Britain and focuses on the whole energy system, through the lens of how the energy system can be decarbonised. FES utilises information, insight and data from all sectors of the energy industry and is used as a fundamental part of annual transmission network planning and national system operability analysis. It also provides insight to members of the energy industry and beyond.

DFES is an annual forecasting activity undertaken by Distribution Network Operators across Great Britain. They provide granular scenario projections that incorporate regional factors and can be used at a local level for strategic planning of distribution networks. These projections are informed by local stakeholder engagement to understand the needs, plans and delivery progress of local authorities and other stakeholders. The DFES provides an evidence base for DNOs to develop the business case necessary to support future investment, including regulated business plans.

Both FES and DFES use a common scenario framework and definition of technologies, to allow for comparison of datasets for all network and system operators. Whilst a common scenario framework is used, regional variations in projections mean that the summation of DFES forecast ranges may not have identical alignment to the GB FES forecast range.

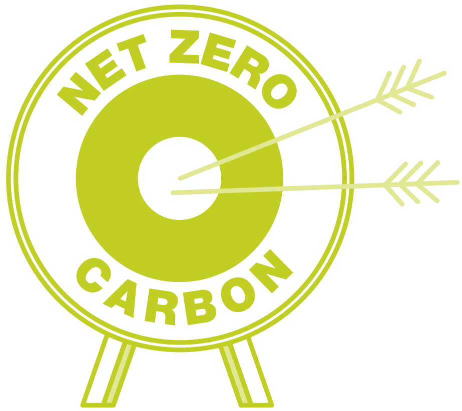
Any discrepancies are investigated as part of an ongoing cycle to improve forecasting accuracy. DNOs can also include additional scenarios to reflect sensitivities to the existing framework where necessary. National Grid ESO will also be improving their regional analysis and assumptions to better account for regional variations which includes using the DFES to enrich future iterations of FES and further development of the regional breakdown of the GB scenarios.

FES 2021 / Introduction to the FES 28

Net Zero

Introduction

Reaching net zero is now almost universally recognised as critical to the future of our society and is a focal point for policies relating to all sectors of the economy. It has changed the focus of FES and will continue to heavily influence decisions made in the energy sector for many years to come. In this chapter, we explain what net zero really is, examine the results of our FES modelling and discuss what they mean for the consumer.



Key insights:

- Leading the Way, Consumer Transformation and System Transformation reach net zero by 2050. Leading the Way and Consumer Transformation also meet the sixth carbon budget.
- Leading the Way reaches net zero by 2047 and results in net annual emissions of -28 $MtCO_2e$ by 2050 (i.e. the equivalent of 28 million tonnes of carbon dioxide are removed from the atmosphere).
- Steady Progression doesn't get to net zero, diverging from carbon budgets around 2025 resulting in 243 $MtCO_2e$ of residual annual emissions by 2050.
- The power sector gets to net negative emissions by 2032 in Leading the Way and Consumer Transformation and by 2034 in System Transformation.
- Heat and road transport reach zero or almost zero emissions by 2050 across all scenarios except Steady Progression.
- Some sectors such as waste and aviation do not reach zero emissions by 2050, so we need solutions which remove their emissions from the atmosphere.
- Bioenergy with Carbon Capture and Storage (BECCS) is the largest provider of negative emissions in all scenarios that reach net zero, but nature-based solutions like afforestation, reforestation and peat restoration all feature heavily with Direct Air Carbon Capture and Storage (DACCS) also playing a role in Leading the Way.
- Lifestyle changes will be needed to reach net zero. Early engagement with consumers is critical.

FES 2021 / Net Zero 30

Context for net zero

The phrase net zero is now commonly used. While we all understand it relates to reducing our carbon emissions, for the purposes of our FES work, it is worth explaining in a bit more detail what net zero actually means.

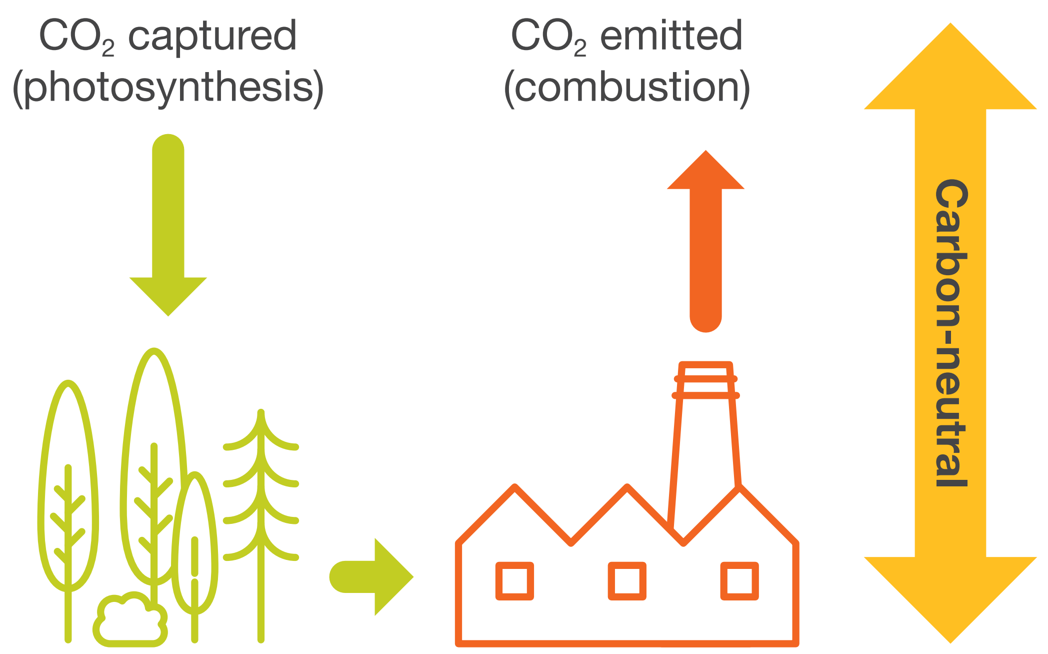
Net zero is closely linked to the natural carbon cycle, which is the emission and absorption of carbon from animals and plants. Human use of fossil fuels and deforestation has upset this balance, so that more carbon is emitted than absorbed. Net zero acknowledges that we might not be able to stop all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

Besides reducing our emissions through lowering demand and moving to zero-carbon energy, there are three ways we can support net zero greenhouse gas emissions:

1. Using bioenergy so that emissions are offset by biomass growth
2. Continuing to produce fossil emissions but capturing the greenhouse gases before they are released into the atmosphere
3 Actively removing greenhouse gases from the atmosphere (negative emissions)

Using bioenergy so that emissions are offset by biomass growth

Trees naturally pull CO_2 out of the atmosphere (absorbing it during photosynthesis). This results in carbon being stored in forests, in vegetation and in the soil. When we burn sustainably sourced wood or other sustainable bioenergy crops instead of fossil fuels like natural gas, oil and coal, the CO_2 emitted can be offset by the CO_2 they have absorbed over their life.



Context for net zero

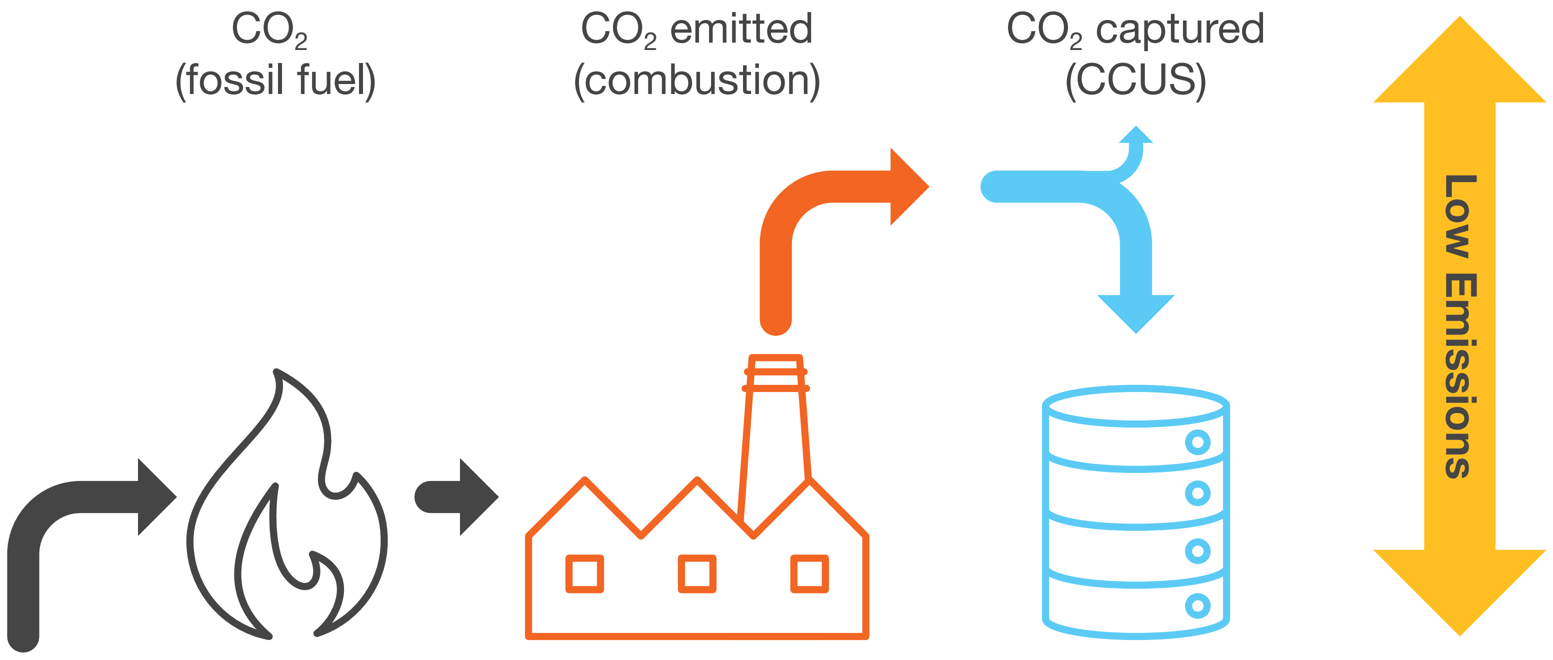
Greenhouse gas emissions

When discussing net zero, ‘carbon dioxide’ or even ‘carbon’ emissions are often referred to but in fact 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 (CO_2), methane, nitrous oxide, and the fluorinated or F gases (hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride and nitrogen trifluoride). The UK net zero target covers all greenhouse gas emissions, not just CO_2, but UK emissions are currently dominated by CO_2 which made up 80% of UK GHG emissions in 2019.

FES 2021 / Net Zero 32

Continuing to produce fossil emissions but capturing the greenhouse gases before they are released into the atmosphere

The CO_2 produced from fossil fuel combustion or other industrial processes can be captured before it is released into the atmosphere. This is known as Carbon Capture Usage and Storage (CCUS), however there remains a certain level of CO_2 leakage. Capture rates are expected to range between 90 and 98% by 2050 across the FES 2021 scenarios. So, using this approach results in low, but not zero, emissions.

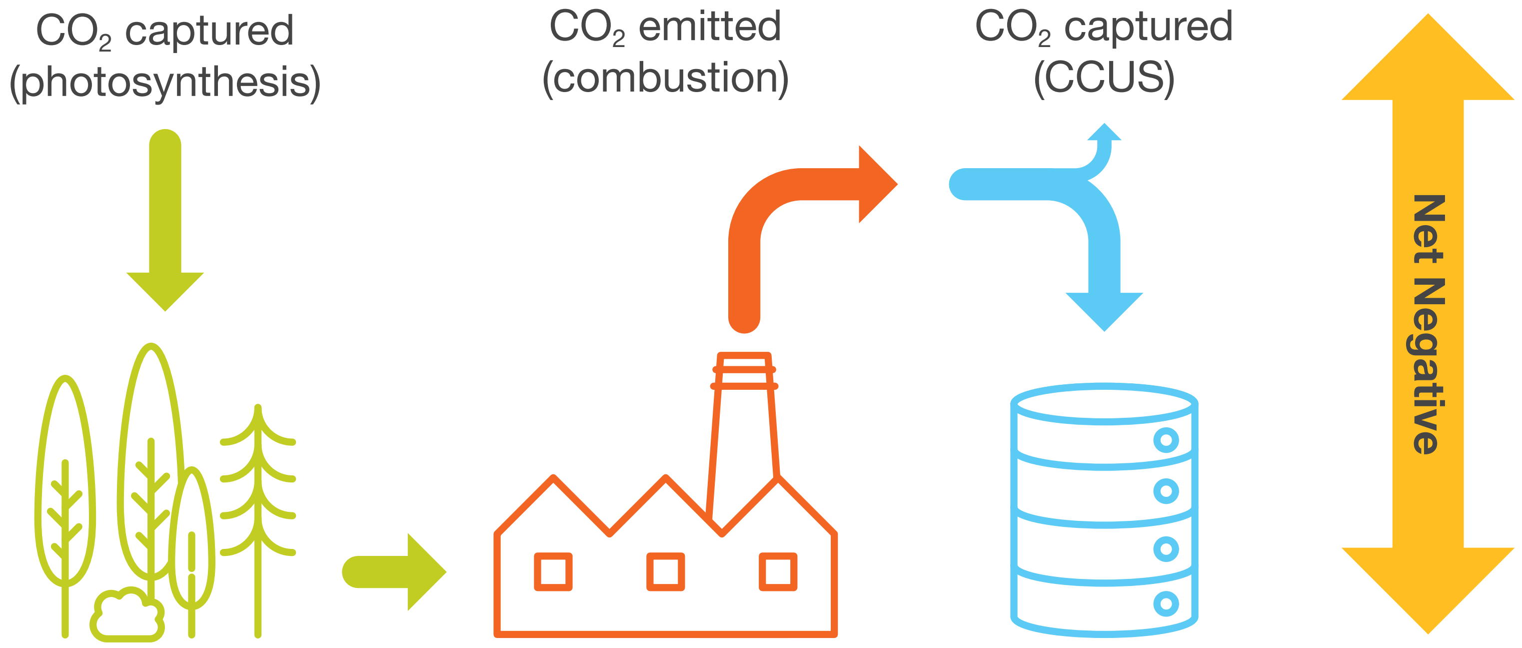


FES 2021 / Net Zero 33

Actively removing greenhouse gases from the atmosphere (negative emissions)

‘Negative emissions’ are the removal of greenhouse gases from the atmosphere. This can be done using natural options such as creating new forests/woodland areas (afforestation), replanting trees in old forests (reforestation) and peatland restoration. Another approach is to combine CCUS with the use of bioenergy, to store away recently absorbed CO_2. For example, electricity generated by burning organic matter (biomass) rather than coal or gas, with the resultant CO_2 emissions being captured using CCUS, will result in negative emissions. This process is known as Bioenergy with Carbon Capture and Storage (BECCS). Bioenergy can play a key role in meeting net zero, but it is important to use sustainable feedstocks and there are also important land use considerations - see the dedicated Bioenergy supply section for more information.

New technology is also under development to capture CO_2 directly from the atmosphere. Direct Air Carbon Capture and Storage (DACCS) involves a chemical process which absorbs CO_2 from a flow of air. However, this remains in the early stages of development.



FES 2021 / Net Zero 34

Context for net zero

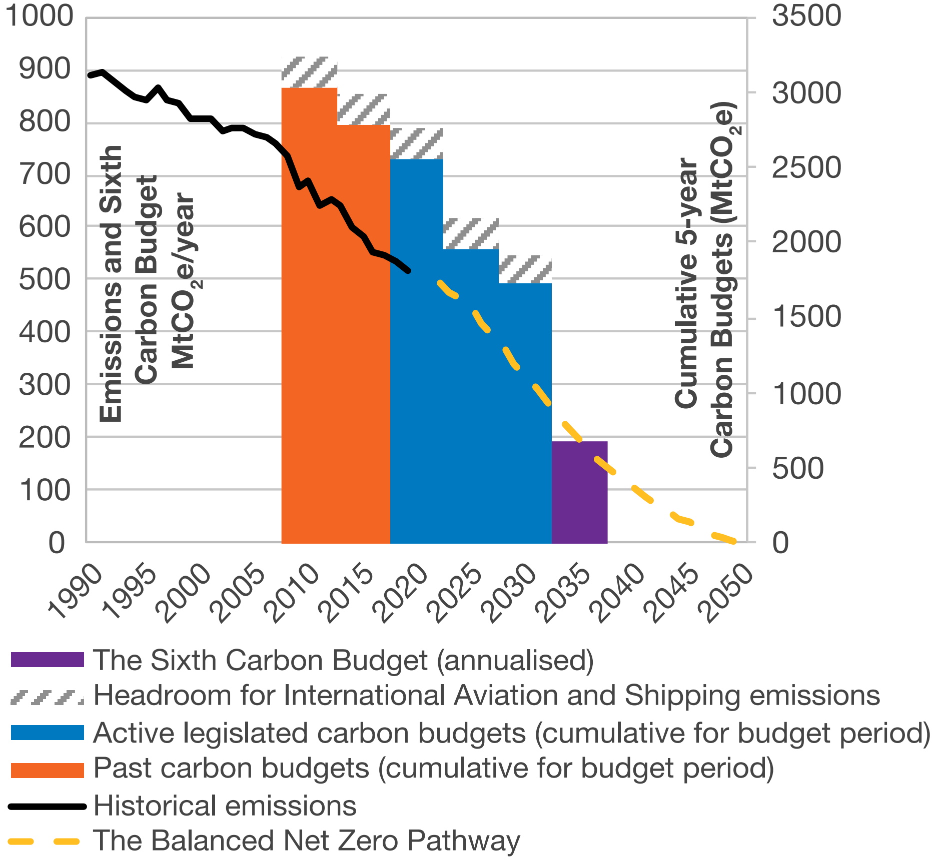
Net zero has become a more well-known concept since the United Nations Climate Change Conference in 2015 in Paris, where an agreement was signed to limit global warming to well below 2°C compared to pre-industrial levels. To do this, man-made greenhouse gas emissions need to be at net zero by the second half of the 21st century. Signatories of the agreement also agreed to pursue efforts to limit the temperature increase to 1.5°C, which will require net zero emissions by 2050 at the latest.

Net zero is important because it is now well known 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 consequences for life on the planet should warming exceed 1.5°C are severe and details of what might happen are set out in the Intergovernmental Panel on Climate Change's special report.

According to the Met Office, the planet has already warmed by 1°C and the consequences of this have been felt globally in the form of fires, droughts, hurricanes and flooding. This first-hand experience is helping to focus the world's attention. This includes the EU's Climate Law, committing the block to climate neutrality by 2050. Net zero commitments now cover over half the world's GDP.

In 2019, the UK Government was the first major economy to put a net zero commitment into law. The Climate Change Committee (CCC) advises the UK and devolved governments on emissions targets and reports to Parliament on progress made in reducing greenhouse gas emissions. In its most recent report, setting out our sixth carbon budget, it showed the UK has made significant progress in reducing emissions, largely due to the power sector switching away from coal towards renewables. However, while the UK has achieved a lot to date, the continuing trajectory for emissions reductions must now reach across all sectors including those where little progress has so far been made such as transport and heating buildings.

NZ.1: Historical emissions and carbon budgets



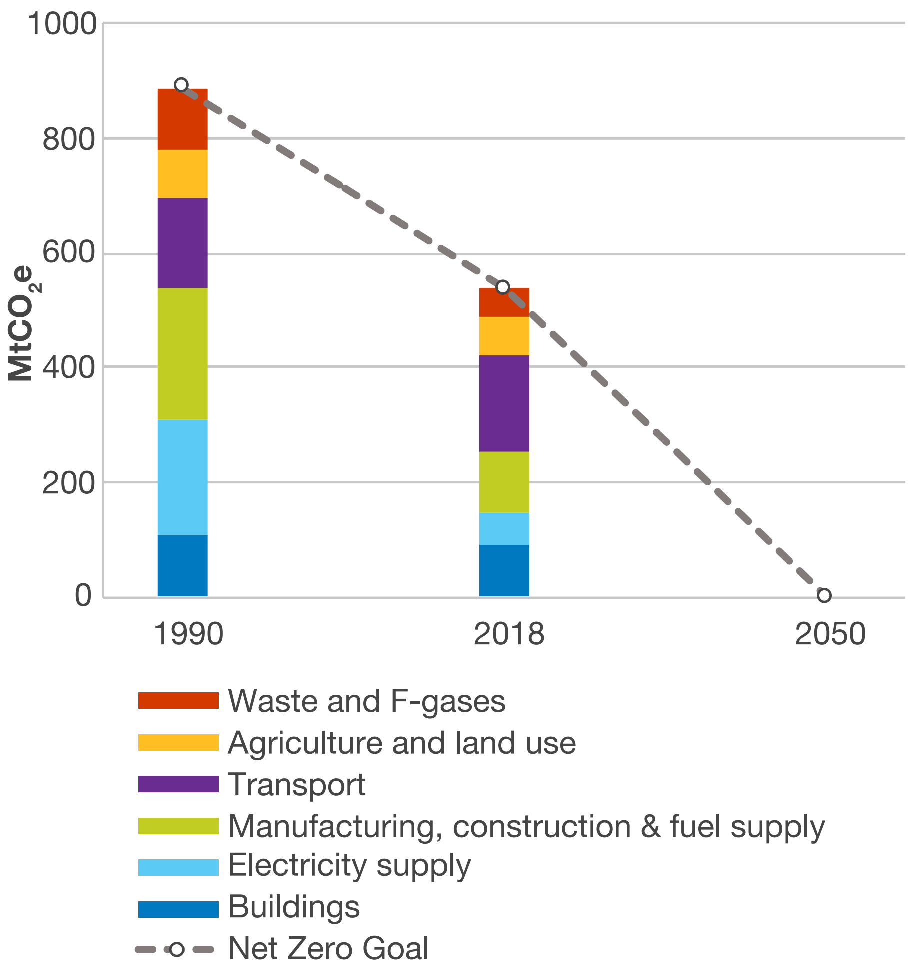
Source: CCC 6th Carbon Budget - Charts and data in the report, **https://www.theccc.org.uk/publication/sixth-carbon-budget/**

Context for net zero

GDP

Gross Domestic Product (GDP) is the monetary value from the production of all goods and services within a country. The global economy is still largely powered by fossil fuels, so higher GDP's are usually linked to a higher carbon footprint. Consequently, measuring global net zero commitments in terms of the percentage of global GDP they cover, instead of the number of countries, is a useful metric.

NZ.2: Historical emissions by sector, and trajectory



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

FES 2021 / Net Zero 36

COP26 Spotlight

What is COP?

The United Nations has been coordinating annual global climate summits, known as the Conference of the Parties or COP, for nearly three decades. COP refers to the decision-making body of the United Nations Framework Convention on Climate Change (UNFCCC). The summit provides an opportunity for heads of state, climate experts and negotiators to come together, share ideas and agree coordinated actions to fight climate change. Since the first 1995 COP in Berlin, stand-out summits include the 1997 COP3 in Kyoto, famous for agreeing the Kyoto Protocol which commits industrialised nations to reduce greenhouse gas emissions, and the 2015 COP21 in Paris where the Paris Agreement was achieved.

COP21 in Paris is globally significant in terms of climate change, as almost every nation committed to limit global warming to well below 2°C, with the aim of 1.5°C. Nationally Determined Contributions (NDCs) were also set out; NDCs are plans for how much each country will reduce its carbon emissions.

It was agreed that the plans would be reviewed and updated every five years, reflecting the highest possible ambition at the time of review. This makes the delayed COP26, which should have been in 2020, the first opportunity following the Paris Agreement where nations will revisit their NDCs.

Why is COP26 Important?

So COP26 is a particularly significant COP as nations will discuss and strengthen their NDCs set out following Paris, and together aim to avoid the worst potential effects of climate change. Following the COVID-19 postponement of the 2020 summit, the UK is now hosting COP26 in November 2021 in Glasgow. Before the event, countries attending are expected to set out their revised NDCs.

The UK, for example, set its NDC at a 68% reduction by 2030 (in comparison to 1990 levels) in accordance with the Climate Change Committee's advice. Also, the now legally-binding 6th Carbon Budget sets out a target average greenhouse gas emissions reduction of 78% on 1990 levels by 2035 (over the budget period of 2033-2037[1]). COP26 provides the platform to review, challenge and revise these emission targets set out by nations after the Paris Agreement, ensuring there is accountability and action to reduce global emissions.

UN CLIMATE CHANGE CONFERENCE UK 2021

IN PARTNERSHIP WITH ITALY

FES 2021 / Net Zero 37

1 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

How is National Grid ESO supporting the UK's NDC target?

National Grid ESO has a key role in the decarbonisation of the energy system allowing the UK to achieve its 2030 NDC emission targets set out in advance of COP26. The UK is currently one of the global leaders amongst major economies in the decarbonisation of electricity supply, recording a reduction in carbon intensity (the level of carbon emitted for each unit of energy generated) of 66% between 2013 and 2020. Other stand-out milestones include the first coal-free electricity generation day on Friday 21st April 2017, followed in 2020 by the longest run without coal since the industrial revolution of 68 days (see Figure NZ.3). More recently, the UK set a new wind power record providing 62% of the energy mix on Friday 21st May 2021. As new records are set, National Grid ESO has an important role to share knowledge and expertise with other system operators, regulators, legislators, and policy makers across the world through forums such as:

- Powering Past Coal Alliance (PPCA), a body working to advance the transition from coal power generation to clean energy
- GO15, a voluntary initiative of the world's 19 largest power grid operators that represent more than 70% of global electricity demand; and
- Global PST (G-PST), a body to discuss the challenges associated with rapidly transforming power systems to low carbon.

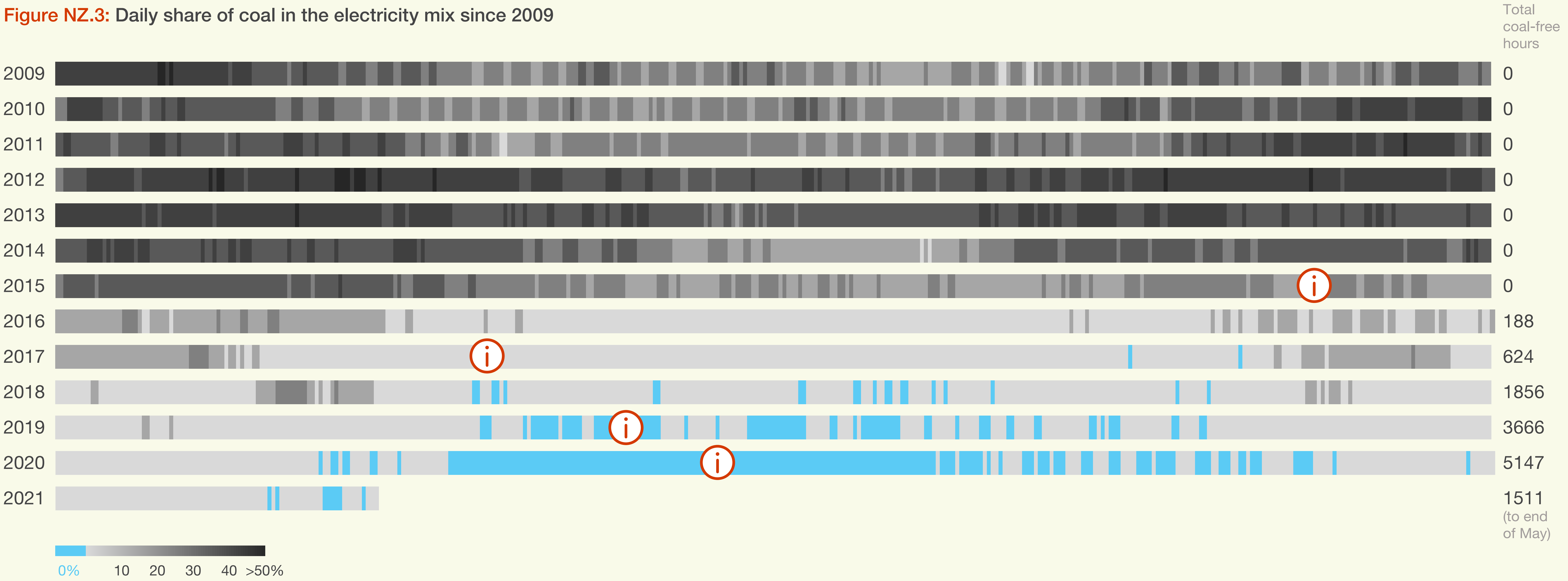
For more information about our international cooperation please see here.

The challenges discussed in these organisations and bodies centre around the operational complexities associated with replacing fossil fuel generation with renewables. This conversation is fundamental for system operators, including National Grid ESO, as by having a grid that can support zero carbon supply, the growth in renewables that is key for facilitating decarbonisation and allowing the UK to achieve its NDC targets, can happen. Through our transformational work at National Grid ESO, where we are aiming to operate a zero-carbon grid by 2025; we are enabling the continued growth of renewables that is key for achieving the wider UK goal of net zero by 2050.

For more information on the challenges National Grid ESO has encountered as we transition to a zero-carbon grid, and the supporting role the ESO has at COP26 with National Grid group as a principal partner, read our 'Road to Zero Carbon' report here.

FES 2021 / Net Zero 38

Figure NZ.3: Daily share of coal in the electricity mix since 2009



The following notes relate to the (i) icons on Figure NZ.3.

November 2015

The UK government announces plans to close all coal-fired power stations by 2025, and restrict their use by 2023.

April 21 2017

First consecutive 24 hours of coal-free generation on Britain's electricity system.

April 9–28 2019

Britain's electricity system sees its first coal-free fortnight, which turns into a run of 18 days, six hours and ten minutes.

April 10–June 16 2020

The longest ever coal-free run on Britain's electricity system – 67 days, 22 hours and 55 minutes – is interrupted when a coal station powers on for routine maintenance. Britain would run coal-free for a further 54 days.

FES 2021 / Net Zero 40

Context for net zero

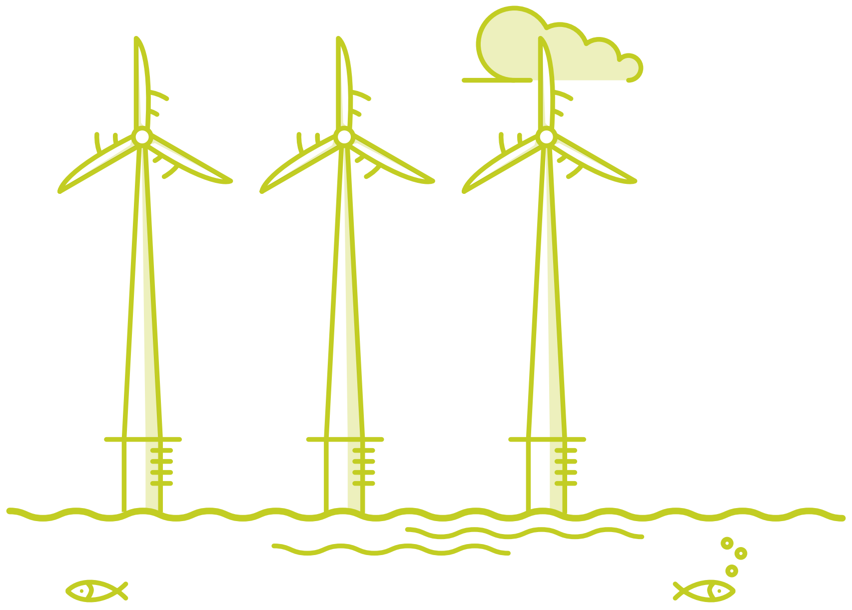
Whilst decarbonisation is increasingly in the public consciousness, to date, it has largely happened in the background for consumers as most changes have related to how energy is generated and not how it is consumed. From here on, a more conscious effort will be required from consumers if net zero is to be achieved, with at least moderate levels of societal change for all three scenarios which reach net zero. However, there are signs that consumers are increasingly up for the challenge, for example the support for Greta Thunberg and movements such as veganism citing reducing emissions as a key driver.

In January 2020 the UK Climate Assembly was formed to explore the question 'How should the UK meet its target of net zero greenhouse gas emissions by 2050?'. Rather than ask 'experts', the UK Climate Assembly aimed to gather views across the whole of the UK. The Climate Assembly consisted of 108 members representative of the UK population in terms of age, gender, ethnicity, educational level, location, and their level of concern about climate change.

The assembly members agreed on underpinning principles for the path to net zero which are detailed in the Climate Assembly report. Some of these principles relate to consumers and include:

- Informing and educating everyone
- Fairness within the UK
- Local community engagement
- Transparency and honesty
- Equality of responsibility (for individuals, government and business)
- Everyone should have a voice
- Enabling and not restricting individual choice
- Compromise about changing lifestyles

While many consumers expect to play an important role in reaching net zero, and accept change will be required, they still expect choice. So, and again aligned to these principles, it is important that consumers are engaged with and informed about the choices they have and the impact of these choices on net zero.



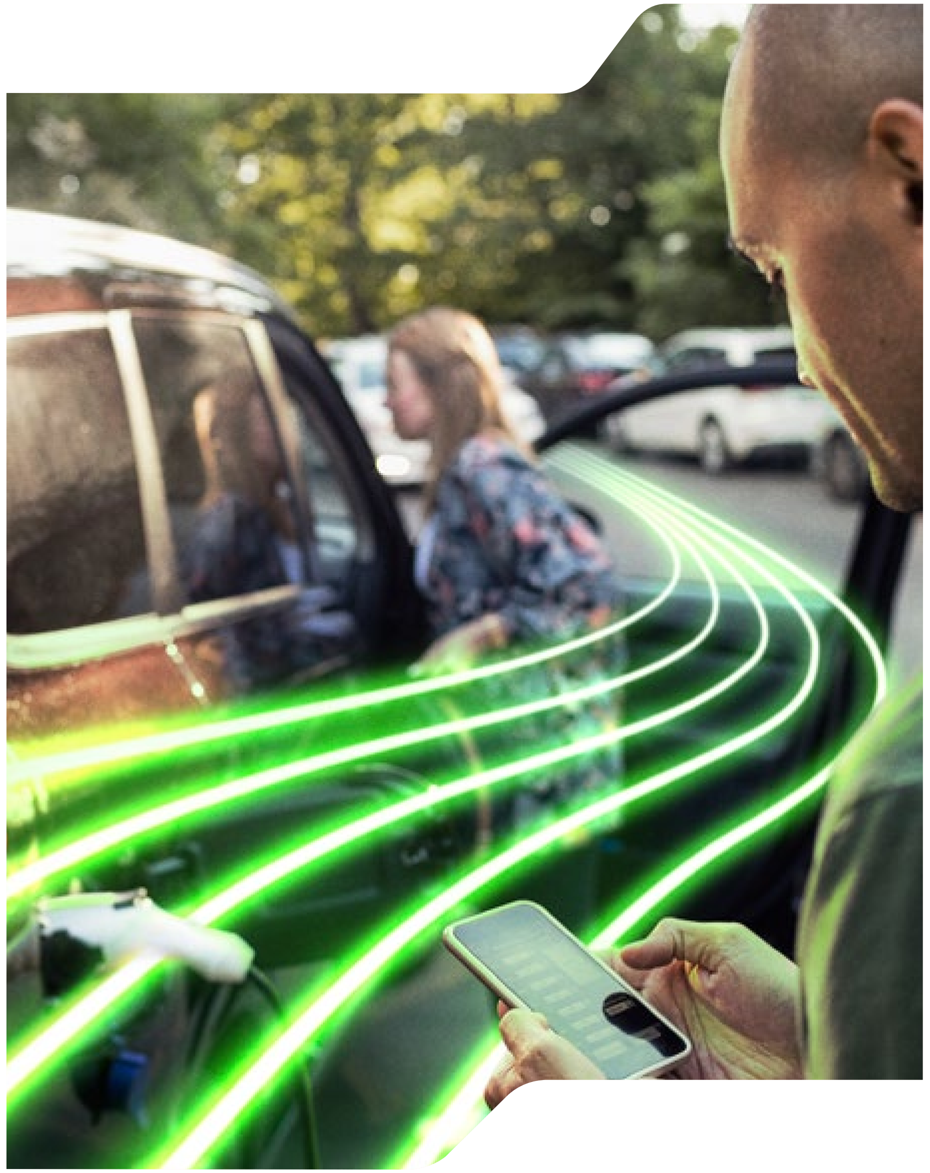
FES 2021 / Net Zero 41

How do we get to net zero?

Reaching net zero will mean a fundamental shift in how many things are done, both in the UK and across the globe. Net zero has implications for all aspects of the way we live. Change doesn't necessarily have to be bad and many aspects of a lower carbon way of living will be beneficial to individuals, communities and biodiversity.

Our Future Energy Scenarios describe in detail what net zero might be like for the UK in 2050. At a high level, we know that this challenge will need all the following activities and tools in varying extents:

- Energy needs to be used efficiently, however that may be – transport, heating, appliances or processes. Reducing the initial demand for energy makes decarbonisation easier.
- Fossil fuels used without any sort of abatement on their emissions is no longer possible. We need to use low or zero carbon energy sources (renewable electricity, hydrogen, bioresources, nuclear) or ensure that carbon capture and storage technology is fitted and functional wherever fossil fuels are burned.
- Lifestyles will need to change and individual contributions will count, whether relating to travel, heating, food or waste. Individuals need to be informed about the changes they can make but transitions must be fair; enabling and incentivising those who can engage but not penalising those who can't.
- Carbon capture usage and storage of emissions, either from the atmosphere or at source, will be needed. CCUS can be fitted to industrial processes where there are no alternatives to fossil fuels. It can also be fitted to processes which use biomass as a fuel, creating 'negative' emissions, as carbon has been removed from the atmosphere twice. DACCS is still in its infancy but has potential to help by taking carbon dioxide out of the atmosphere. Finally, more trees will be needed, as well as restoration and protection of carbon sinks such as peatland.
- Although all sectors do reduce emissions, not every one will reach zero emissions by 2050. Negative emissions in some sectors will be required to offset remaining emissions in others.

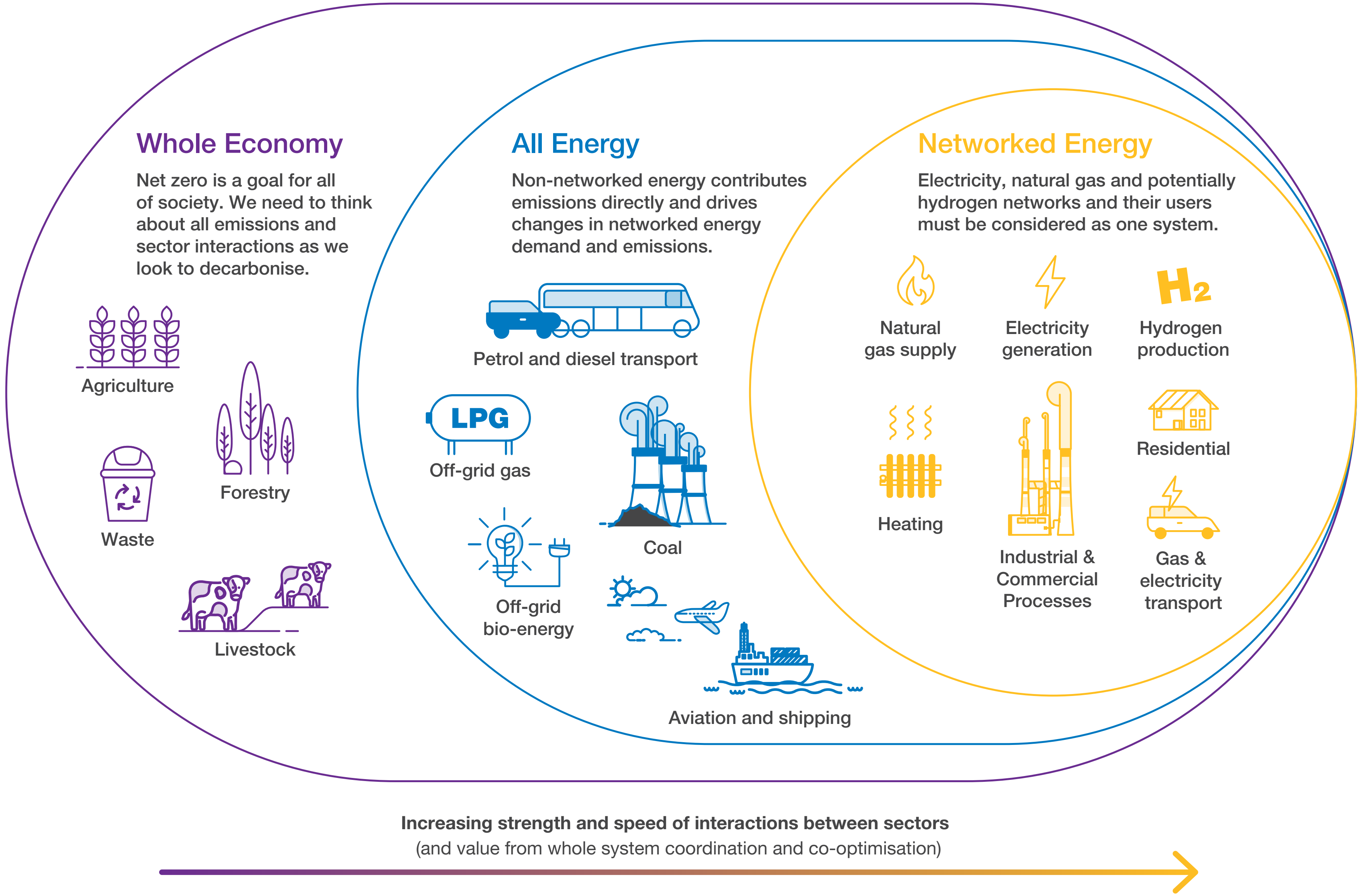


FES 2021 / Net Zero 42

How do we get to net zero?

- 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 is already debating how to introduce a carbon 'import tax', to avoid carbon leakage. This is where cheaper but more carbon intensive methods are used to produce goods outside of the EU but then imported for sale. In our net zero scenarios, we have assumed a carbon cost would be applied to the use of fuels like natural gas to encourage consumers to use lower carbon alternatives. This same mechanism also means that payments are made to those industries storing carbon. This makes bio-gasification for the production of hydrogen financially attractive in System Transformation.
- Policy, market and regulation decisions needed to meet 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 impacts right across markets, infrastructure and consumers. For example, as electric vehicles are rolled out there must, at the same time, be adequate support to ensure charging can be shifted away from peak demand periods and towards periods of high renewable output.

Towards Net Zero: Whole System Interactions



FES 2021 / Net Zero 43

How do we get to net zero?

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. There is no single solution for net zero.

Our FES analysis directly models the UK energy sector, but other sectors (for example aviation, maritime and land use) emit greenhouse gases so a whole economy view is needed when assessing net zero. For these 'other' sectors we've used the CCC pathways in their sixth carbon budget analysis as our basis. For System Transformation and Consumer Transformation, we have generally followed the Balanced Pathway and, for Leading the Way, we have largely used Widespread Innovation.

Ammonia

Hydrogen reacts with nitrogen, producing ammonia which can be transported as a liquid below -33°C (much warmer than liquefied hydrogen), or at a high pressure. 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 a potential option for powering ships, although care has to be taken as it is a toxic substance.

Assumptions taken from CCC

	System Transformation	Consumer Transformation	Leading the Way
Aviation	• 41% emissions reduction (compared to 2018) due to slower demand growth (only 25% increase compared to forecast 65%), improvements in plane efficiency and a modest share of sustainable aviation fuels at 25% **(from CCC Balanced Pathway)**		
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 **(from CCC Balanced Pathway)**		• Widespread adoption of low carbon fuels over the 2030s, so that by 2040 close to zero emissions **(from CCC Widespread Innovation)**
Agriculture	• 35% reduction in emissions from agriculture by 2050 (compared to 2018) • By 2050, reduction by just over a third for weekly meat consumption and 20% reduction for dairy **(from CCC Balanced Pathway)**		• 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 **(from CCC Widespread Innovation)**
Land Use	• 30,000 hectares of trees planted annually by 2035 • All peatland restored by 2050 • 700,000 hectares of perennial energy crops by 2050 **(from CCC Headwinds)**	• 50,000 hectares of trees planted annually by 2035 • All peatland restored by 2045 • 700,000 hectares of perennial energy crops by 2050 **(from CCC Balanced Pathway)**	• 50,000 hectares of trees planted annually by 2030 • All peatland restored by 2045 • 1.4m hectares of perennial energy crops by 2050 **(from CCC Widespread Innovation)**
Waste	• 51% fall in edible food waste by 2030 and 61% by 2050 (compared to 2007) • Emissions fall just over 75% from today's levels to reach 7.8 MtCO_2e/year by 2050 **(from CCC Balanced Pathway)**	• Same as System Transformation but also 50% fall in inedible food waste by 2050 • Emissions fall just over 80% from today's levels **(from CCC Widespread Innovation)**	

FES 2021 / Net Zero 44

Results in FES 2021

Overview

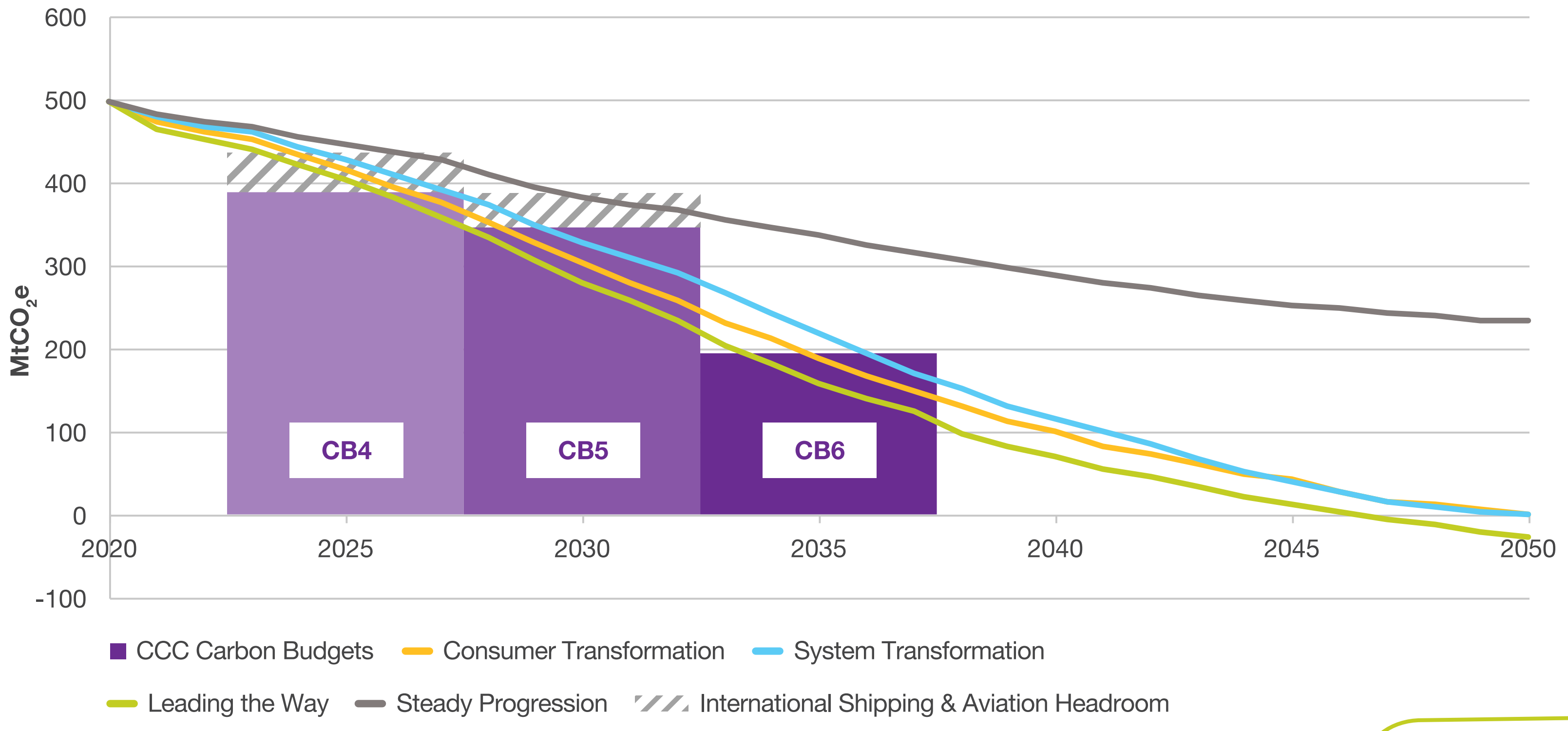
Leading the Way, System Transformation and Consumer Transformation all meet net zero by 2050. Leading the Way reaches net zero by 2047 and goes on to achieve annual net emissions of -28 $MtCO_2e$ by 2050, a removal of 28 million tonnes of greenhouse gas (GHG) emissions from the atmosphere annually. To put this into context, total UK emissions in 2018 were 537 $MtCO_2e$, and in the same year, the UK power sector emitted 66 $MtCO_2e$ whilst surface transport emitted 115 $MtCO_2e$.[2] System Transformation and Consumer Transformation also meet net zero by 2050 but result in greater net emissions than Leading the Way of around -1 $MtCO_2e$ each. Steady Progression is significantly higher than net zero at 243 $MtCO_2e$, having diverged from the trajectory needed to meet net zero at around 2025.

FES 2021 emissions compared to FES 2020

In FES 2021 three scenarios reach net zero by 2050, just like in FES 2020. However, in FES 2021 decarbonisation happens faster with all three scenarios reaching lower emissions in 2030 than last year. Leading the Way also decarbonises further with net annual emissions by 2050 of -28 $MtCO_2e$ compared to -10 $MtCO_2e$ in the equivalent FES 2020 scenario. This is due to increased government ambition highlighted by recent policies including the acceptance of the updated, more challenging sixth carbon budget target and the Government's Energy White Paper.

All three scenarios which meet net zero meet the fourth and fifth carbon budgets when international aviation and shipping (ISA) headroom are accounted for, but System Transformation misses the sixth carbon budget. An acceleration in emissions reduction from the mid to late 2030's for System Transformation, partly due to a relatively quick transition from natural gas to hydrogen for residential heating and negative emissions from hydrogen production, means that it still meets net zero by 2050.

Figure NZ.4: Total net greenhouse gas emissions (including carbon budgets)



2 This data came from the 6th Carbon Budget Analysis.

FES 2021 / Net Zero 45

Results in FES 2021

International aviation and shipping (ISA) headroom

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

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 the chart represent the average maximum annual emissions over a budget period required to meet the target. So while some scenario trajectories appear below a carbon budget by the end of a budget period, that does not mean they have met the budget target. For example, System Transformation reaches the average emissions required for the 6th Carbon Budget before the end of the period but its cumulative emissions are above the average for that period and so misses the budget target.

FES 2021 / Net Zero 46

Scenario breakdown

Although System Transformation and Consumer Transformation both reach net zero by 2050, they get there in different ways. System Transformation uses more hydrogen to meet demand, including for heating, as well as BECCS for hydrogen production. Consumer Transformation mainly electrifies demand and includes negative emissions from BECCS in the power sector, although this is present in both scenarios. There are also different levels of societal change, with Consumer Transformation assuming higher levels of change in consumer behaviour, 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, although it produces hydrogen from electrolysis rather than from methane reformation combined with CCUS. It also assumes some direct air carbon capture and storage, as well as the highest levels of societal change.

Across all scenarios, the sectors which are most difficult to decarbonise are those not directly modelled by FES. These relate mostly to emissions from activities such as agriculture, shipping and aviation, waste and land use. In these areas there are either very few technical options available meaning most emission reductions come from potentially unpopular lifestyle changes (e.g. further reduction in meat/dairy consumption, reduction in waste), or the technical options which do exist are at an early stage with considerable challenges (e.g. new fuels for aviation and shipping).

For Consumer Transformation and System Transformation these emissions reduce by 79% and 75% respectively from 2020 to 2050 with around 43 $MtCO_2e$ and 51 $MtCO_2e$ remaining. The deeper and quicker decarbonisation in Leading the Way is partly due to a slightly quicker transition to decarbonised domestic heat. However, most of the additional emissions reductions in this scenario are due to a greater reduction in the difficult to decarbonise sectors, with only 17 $MtCO_2e$ remaining by 2050.

FES 2021 / Net Zero 47

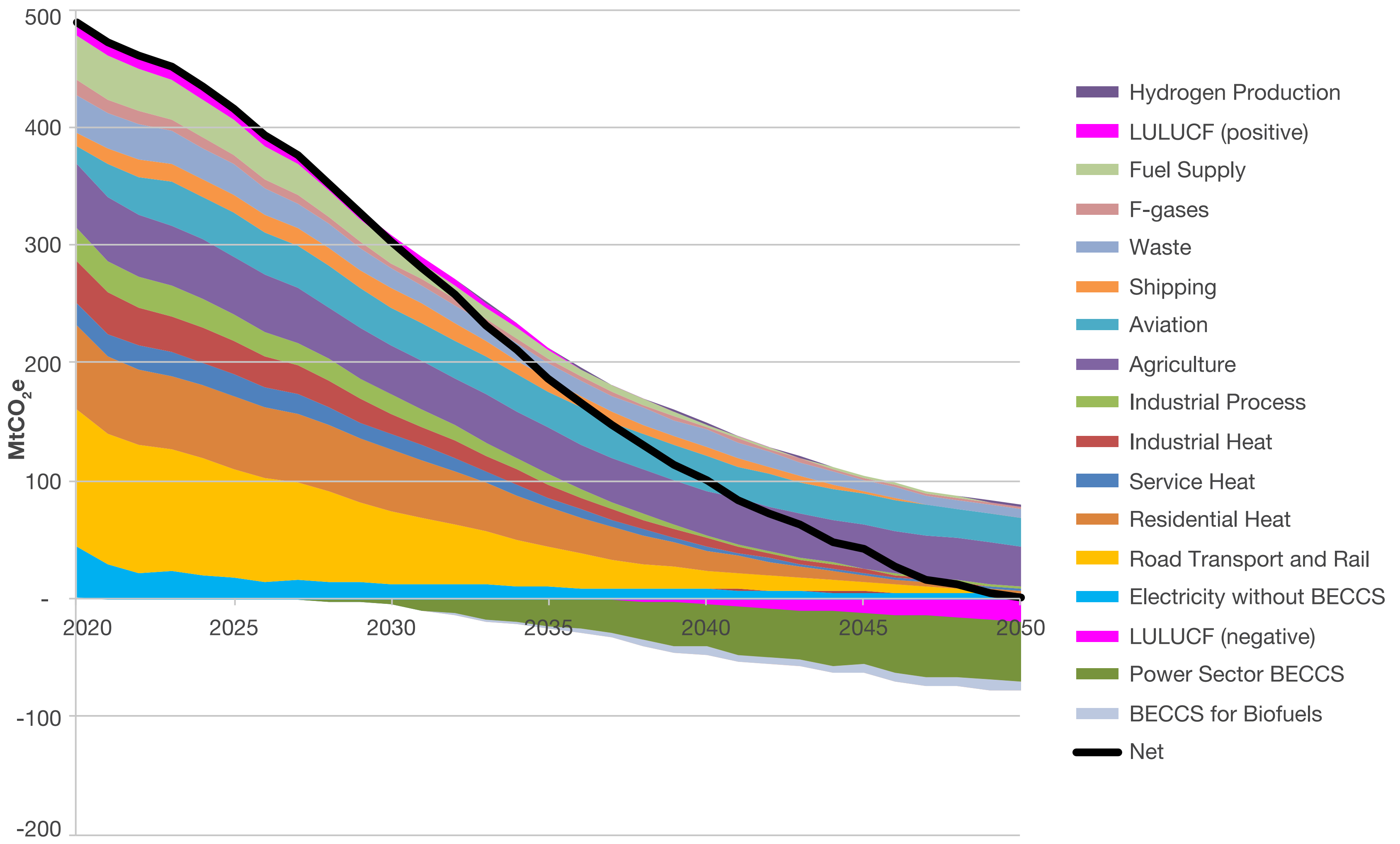
Results in FES 2021

The assumptions on emission reductions in those sectors not directly modelled by FES are detailed here, but will require a combination of technical innovation (e.g. development of low-carbon fuels), policy decisions (e.g. increased tree planting, peatland restoration) and further changes to consumer behaviour (e.g. reduction in meat and dairy consumption, reduction in food waste, reduction in flights compared to business as usual). For Leading the Way these assumptions are based on more ambitious yet 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 non-energy emissions to reduce as modelled in Consumer Transformation and System Transformation, extensive policy support will be required to drive innovation and deliver changes. As individuals, we will all be required to make changes to our lifestyles. Achieving the non-energy emission reductions under Leading the Way will require a doubling down of these efforts.

Even with this support, none of the non-energy sectors reach zero emissions by 2050 in any scenario, even 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, DACCS, or changes to land use such as increased forestation.

Figure NZ.5: Total net greenhouse gas emissions (Consumer Transformation)



FES 2021 / Net Zero 48

Results in FES 2021

Figure NZ.5: Total net greenhouse gas emissions (System Transformation)

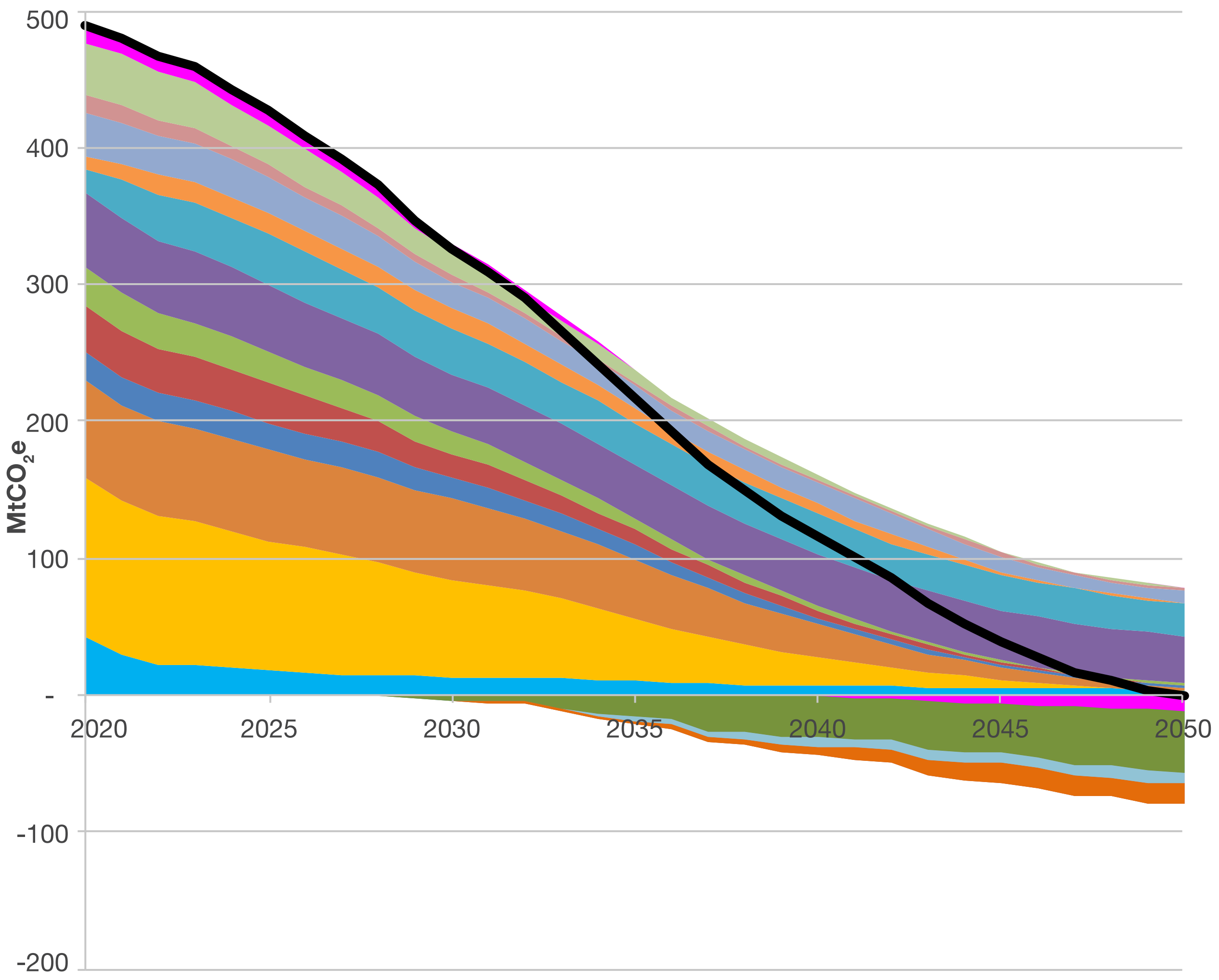


Figure NZ.5: Total net greenhouse gas emissions (Leading the Way)

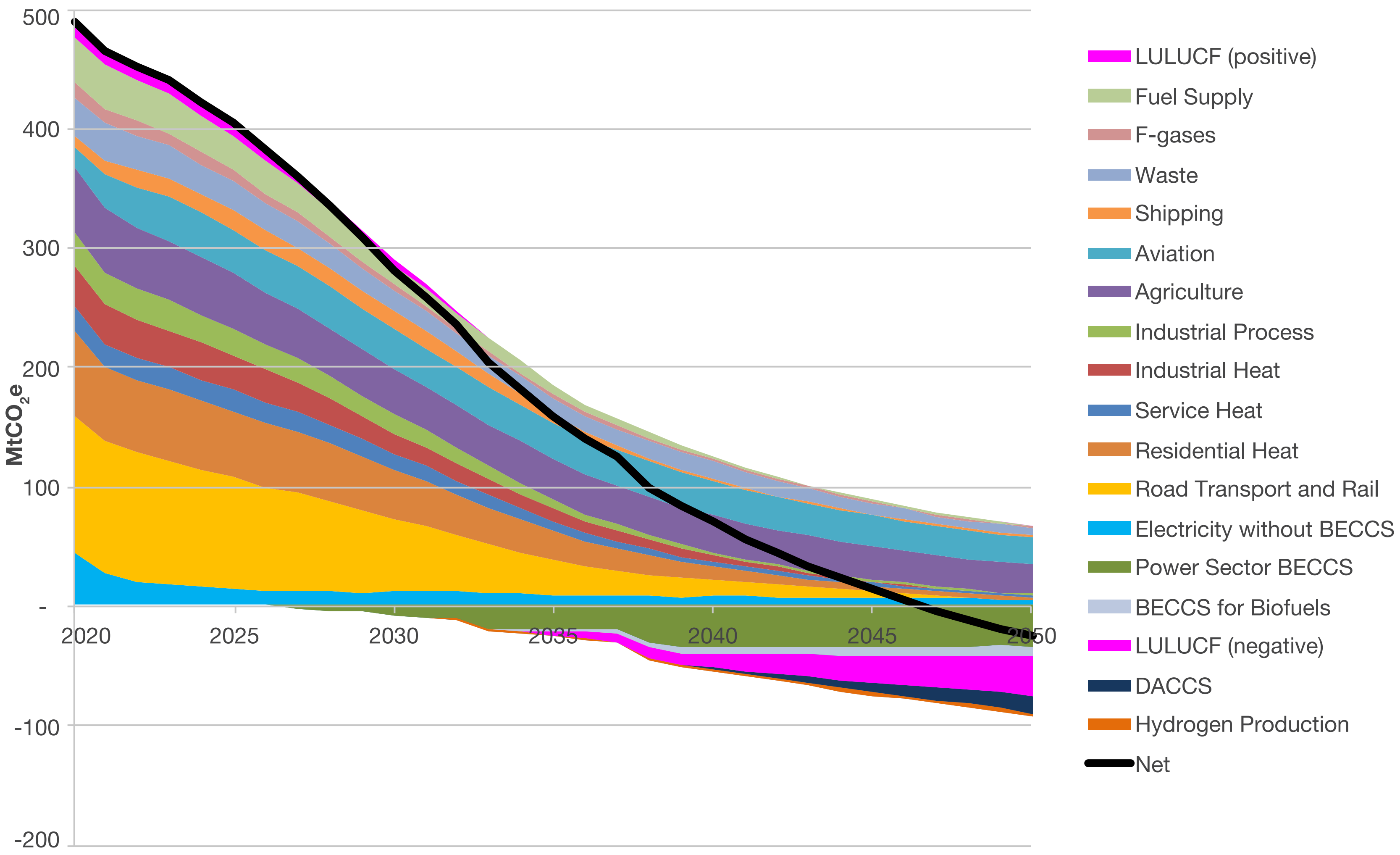
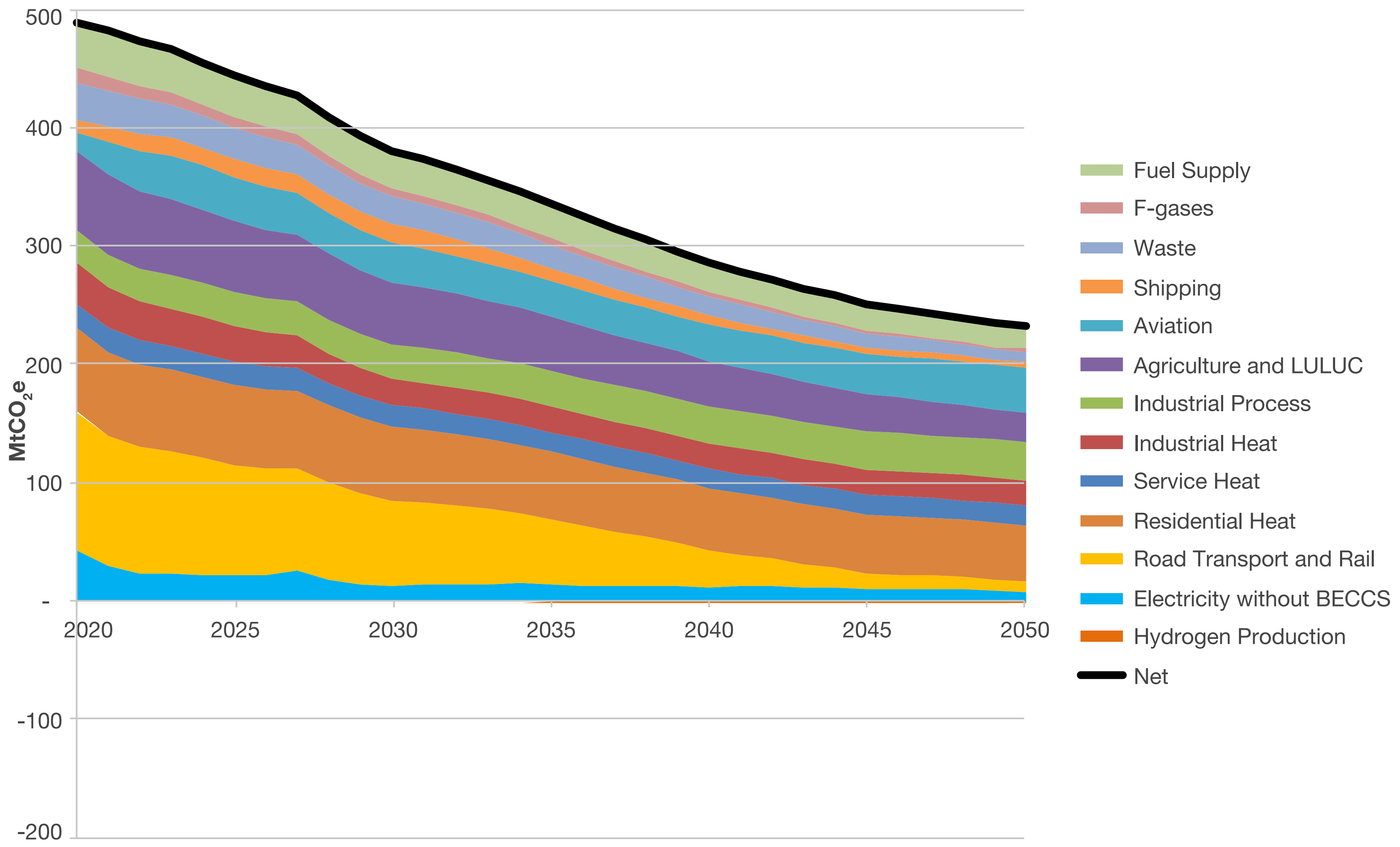


Figure NZ.5: Total net greenhouse gas emissions (Steady Progression)



FES 2021 / Net Zero 50

Negative emissions

Leading the Way has the most negative emissions by 2050 at -93 $MtCO_2e$. BECCS for the power sector and changes to land use (LULUCF) are responsible for the majority of negative emissions providing -34 $MtCO_2e$ and -33 $MtCO_2e$ respectively. DACCS also makes a notable contribution of -15 $MtCO_2e$ with the remainder (-11 $MtCO_2e$) coming from BECCS for hydrogen and biofuel production. DACCS is an emerging technology which will require significant demonstration and scale-up before large scale commercial use. So we only assume it is available in Leading the Way and then only to remove 15 $MtCO_2e$ of emissions in line with the CCC's Tailwinds pathway.

Consumer Transformation and System Transformation have fewer negative emissions by 2050 with -78 $MtCO_2e$ and -80 $MtCO_2e$ respectively. In the case of Consumer Transformation BECCS for power makes the largest contribution at -51 $MtCO_2e$, with LULUCF (-19 $MtCO_2e$) and BECCS for biofuels (-8 $MtCO_2e$) making up the remainder. In System Transformation BECCS for biofuels again contributes -8 $MtCO_2e$, while BECCS for power makes a slightly lower contribution of -43 $MtCO_2e$ and LULUCF also makes a smaller contribution of -12 $MtCO_2e$. However, in addition, BECCS for hydrogen production also contributes -17 $MtCO^2e$.

LULUCF

LULUCF represents the emissions from Land Use and 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

Although negative emissions will be critical to reaching net zero, the UK climate assembly report suggests consumers are not entirely supportive of all options for removing emissions from the atmosphere. The majority of assembly members 'strongly agreed' or 'agreed' that the three greenhouse gas removal methods which relate to LULUCF, as well as using wood in construction should be part of how the UK gets to net zero. However, assembly members were less supportive of bioenergy with carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS). Only 42% of assembly members 'strongly agreed' or 'agreed' that each of these methods should be part of how the UK gets to net zero, while 36% (BECCS) and 39% (DACCS) 'strongly disagreed' or 'disagreed'. Given the level of BECCS required under FES to get to net zero, further consumer engagement is required.

FES 2021 / Net Zero 51

Results in FES 2021

Figure NZ.6: Negative emissions (Consumer Transformation)

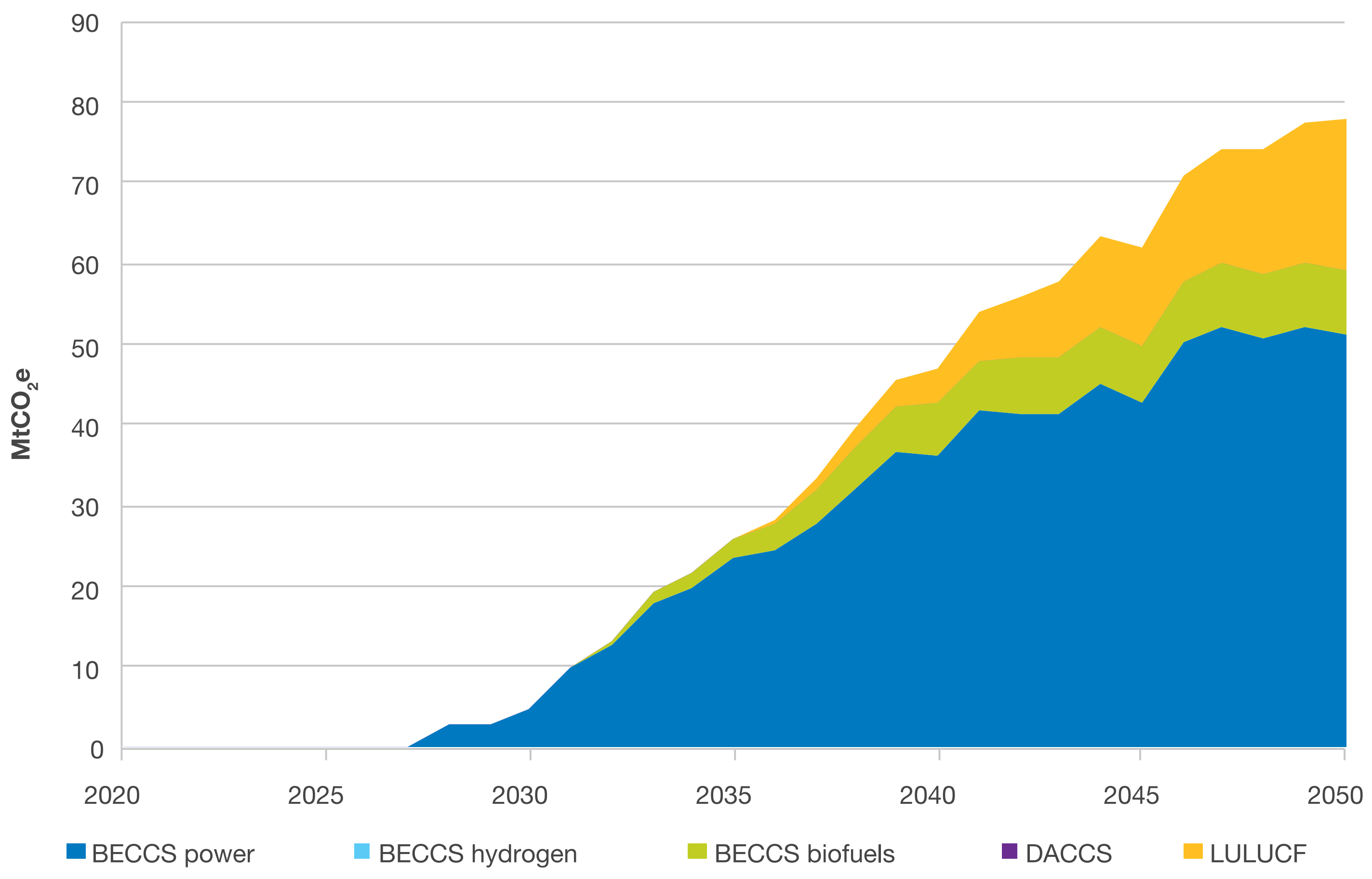
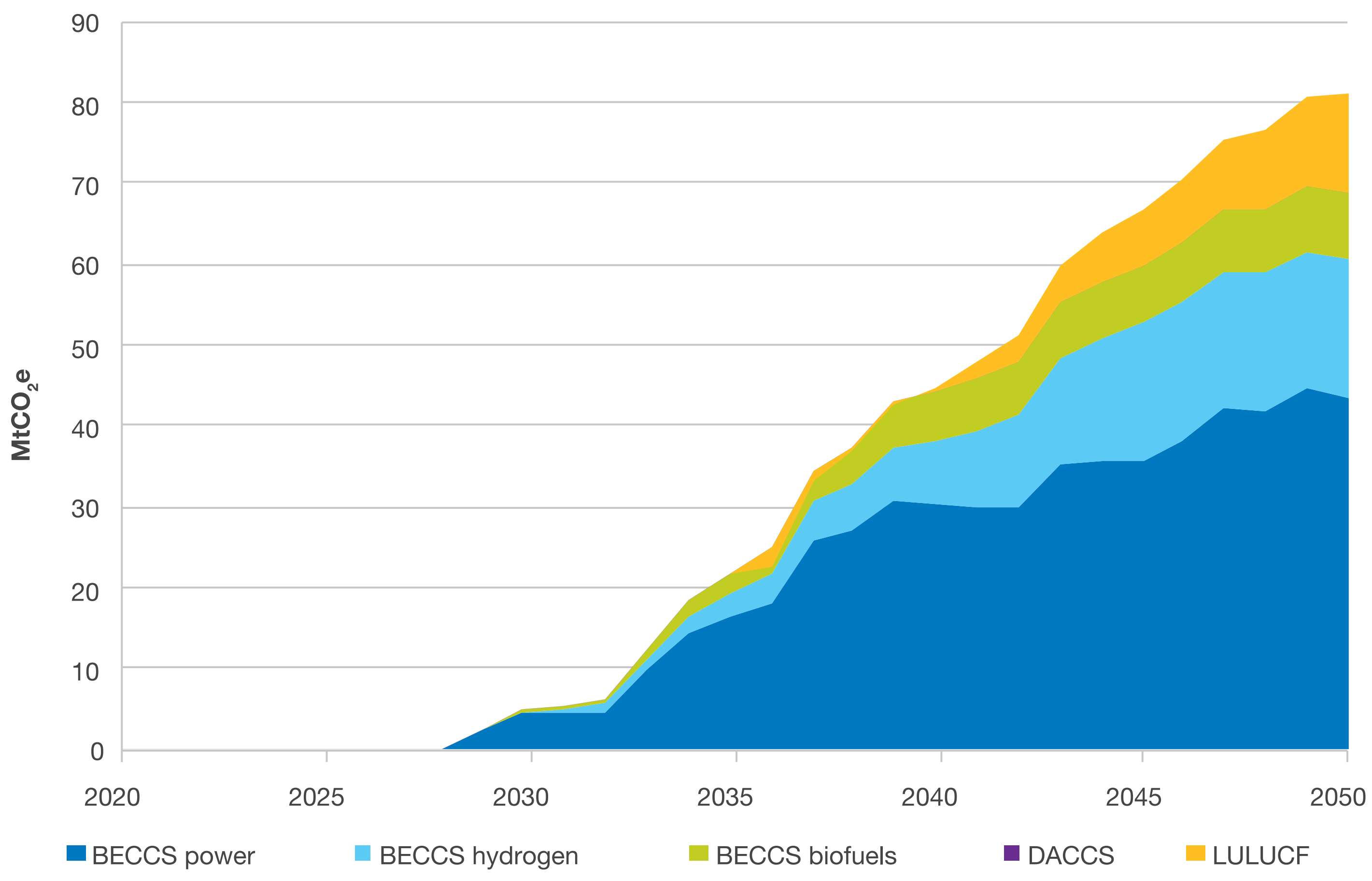
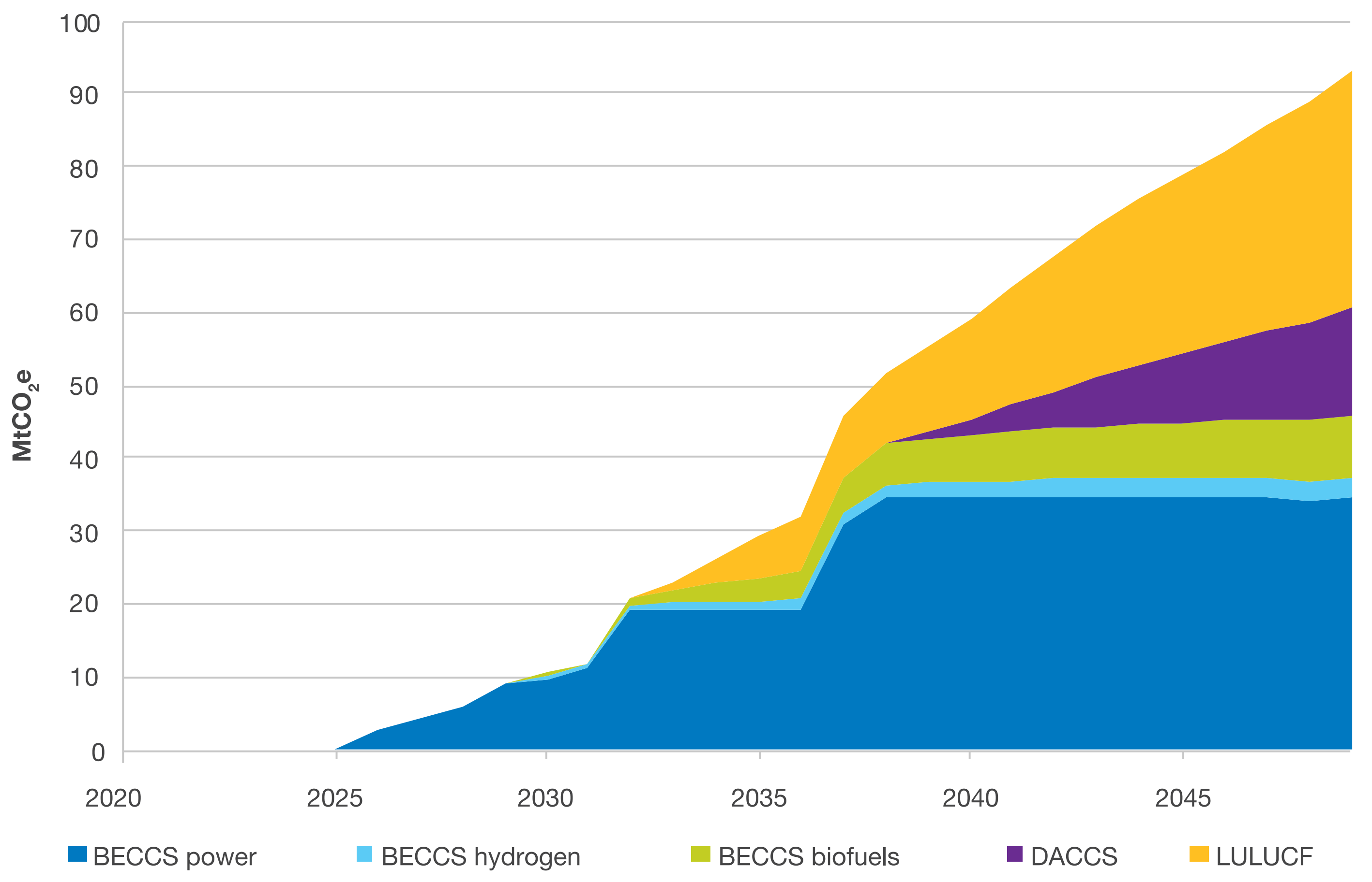


Figure NZ.6: Negative emissions (System Transformation)



FES 2021 / Net Zero 52

Figure NZ.6: Negative emissions (Leading the Way)



FES 2021 / Net Zero 53

Results in FES 2021

Changes for net zero

Net zero will only be possible if we start implementing measures now. We can't wait until 2050. 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.

All three scenarios that meet net zero see the power sector, led by wind and solar, reaching zero emissions in the early 2030's. A zero carbon electricity supply then contributes to decarbonising heat and transport sectors via electrification (even under System Transformation). Heat, road transport and hydrogen production all see zero or almost zero emissions by 2050, with meaningful emission reduction by 2030 for all scenarios but especially Leading the Way. Decarbonisation on the scale and rate seen by any of these three scenarios will require changes not only at a national scale but also on a business and individual level.

These changes will include government policy to promote mass consumer uptake of energy efficiency measures and to drive the transition from petrol and diesel vehicles. Within the industrial and commercial sectors, businesses will need to invest in energy efficiency measures whilst industry will need to apply a combination of fuel switching (electricity and hydrogen) and CCUS for those processes which still require natural gas. At an individual level, consumers will need to be more engaged with their energy use, both how they consume it (e.g. switching to low carbon heating technologies and EVs) and when they consume it (using Time of use Tariffs when possible without penalising those who can't).

Previous analysis has shown that the total costs of the energy system out to 2050 vary very little between our scenarios, including between the net zero compliant and non-compliant scenarios. This indicates that technology choices do not vary costs significantly. However, the analysis did find costs are kept lower when consumers are engaged, energy efficiency is pursued, and we have negative emissions in the energy sector.

Time of use Tariffs

A charging system that is established in order to incentivise residential consumers to alter their consumption behaviour, usually away from high electricity demand times.

FES 2021 / Net Zero 54

Consumer View

Introduction

The contribution of consumers to net zero – in terms of their behaviour and lifestyle choices – is crucial to meeting the legally binding target by 2050. The scale of change impacting consumers over the next three decades will be far-reaching. It is very hard to imagine how the future world of energy will impact our lives compared with today, from new heating systems, cars, and appliances, to new technologies providing clean fuels for homes and businesses.

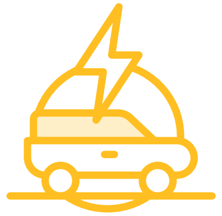
Consumers

A consumer is an end user (from individuals to large industrial and commercial consumers) who consumes energy for their own use, rather than for wholesale or retail purposes.

However, one big question remains: how far are consumers prepared to change their behaviours and lifestyles to support the transition to net zero emissions? To reflect this uncertainty, we have retained the 'level of societal change' axis on our scenario framework this year. This chapter considers the end consumption of energy from three different perspectives:

Residential

Including domestic heating and electrical appliances



Transport

Including road, rail, aviation and shipping

Industrial and Commercial

Including energy demand from heat and power use in businesses and heavy industry

We've seen lots of change in these sectors over the past 30 years, moving from energy as a basic requirement for everyday needs to being at the heart of our 21st century technology-based lifestyles. This transformation started from the 1990s when the popularity of TVs and games consoles began to increase, as well as car ownership.

FES 2021 / Consumer View / Introduction 56

Introduction

Today, consumer's carbon emissions (either increasing or decreasing) are driven by a number of factors, including:

1. Choice and value, as new goods and services have entered the mass market. For example:

- Lots of appliances and new technologies with short shelf lives, from fridges and freezers to games consoles, computers and mobile phones. These are typically on charge overnight or on standby
- More international flights with the rise of affordable package holidays

2. Increased consumer awareness of their impact on the planet. For example:

- Changing to plant-based diets
- Shopping in plastic-free shops and sections of some national supermarkets

3. Government policy. For example:

- Smart meters
- The domestic and non-domestic renewable heat incentive, encouraging residential and commercial installations of low carbon heating

And, of course, this does not include the imposed behavioural and lifestyle changes that have arisen from the global pandemic. See our main introduction for further detail about how this has been included in FES analysis this year. However, at a high level, the response to the pandemic has supported the view that consumers are generally willing and able to make changes to their lifestyle when 'how' and 'why' this is required is clearly set out.

Energy as a service

Energy as a service is 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.

But to return to our question, how far are consumers willing to change their lifestyles to ensure that we as a country meet net zero emissions in the next 30 years?

This will vary depending on people's circumstances – from the most engaged 'prosumers' who have the means to make lifestyle changes to the most vulnerable in society who have less choice about their energy and carbon usage.

To achieve net zero, consumers need to be fully engaged with both what needs to change and when - as well as why. The emissions reductions that we've seen so far have sometimes happened in the background, without us realising, such as improvements to the energy efficiency of white goods. Future change will be driven by a range of factors, from government policy that bans or discourages high-carbon activity to new innovative technologies and business models like 'energy as a service' or ride-hailing apps for autonomous vehicle (AV) taxis. This will be against the backdrop of changing generations, with today's environmentally-aware children leading the charge against climate change over the next three decades.

FES 2021 / Consumer View / Introduction 57

Introduction

Policy timeline compared to this year's scenarios[1]

Consumer Transformation

Key: ✗ Misses ✓ Meets ✓✓ Surpasses

Recent Government policy	Year	FES
Proposal to end gas grid connection for new homes	2025	✓
Two CCUS industrial clusters deployed	2025	✗
Future Homes Standard – All new homes to be 'zero carbon ready'	2025	✗
600,000 heat pumps installed per year	2028	✓
Two more CCUS industrial clusters	2030	✗
Ban on sale of new petrol and diesel cars and vans	2030	✓
First Hydrogen Town	2030	✗
Scotland: 1 million zero emission homes	2030	✗
Sale of Plug-in-Hybrid cars and vans banned	2035	✓
78% emissions reduction compared to 1990 levels	2035	✓
One fully net zero industrial cluster	2040	✓

1 This is not an exhaustive list as we expect additional policy announcements this year in the run up to the UK's hosting of international climate summit COP26 in November 2021. However, it highlights some of the most relevant and current government policy that relates to the Consumer View chapter. Sources include: BEIS Energy White Paper 2020 - https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future and Ten point plan for a green industrial revolution 2020 - https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution
2 Leading the Way and System Transformation just miss this policy date by 1 year, with two CCUS industrial clusters deployed in this scenario by 2026.
3 This is met in 2024 in Leading the Way.
4 Sale of plug-in hybrid cars and vans banned takes place in 2032 in Leading the Way.

FES 2021 / Consumer View / Introduction 58

Introduction

Policy timeline compared to this year's scenarios[1]

System Transformation

Key: ✗ Misses ✓ Meets ✓✓ Surpasses

Recent Government policy	Year	FES
Proposal to end gas grid connection for new homes	2025	✗
Two CCUS industrial clusters deployed[3]	2025	✗
Future Homes Standard – All new homes to be 'zero carbon ready'	2025	✗
600,000 heat pumps installed per year	2028	✗
Two more CCUS industrial clusters	2030	✓
Ban on sale of new petrol and diesel cars and vans	2030	✗
First Hydrogen Town	2030	✓
Scotland: 1 million zero emission homes	2030	✗
Sale of Plug-in-Hybrid cars and vans banned	2035	✓
78% emissions reduction compared to 1990 levels	2035	✗
One fully net zero industrial cluster	2040	✓

1 This is not an exhaustive list as we expect additional policy announcements this year in the run up to the UK's hosting of international climate summit COP26 in November 2021. However, it highlights some of the most relevant and current government policy that relates to the Consumer View chapter. Sources include: BEIS Energy White Paper 2020 - https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future and Ten point plan for a green industrial revolution 2020 - https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

2 Leading the Way and System Transformation just miss this policy date by 1 year, with two CCUS industrial clusters deployed in this scenario by 2026.

3 This is met in 2024 in Leading the Way.

4 Sale of plug-in hybrid cars and vans banned takes place in 2032 in Leading the Way.

FES 2021 / Consumer View / Introduction 59

Introduction

Policy timeline compared to this year's scenarios[1] Leading the Way

Key: ✗ Misses ✓ Meets ✓✓ Surpasses

Recent Government policy	Year	FES
Proposal to end gas grid connection for new homes	2025	✓
Two CCUS industrial clusters deployed[2]	2025	✗
Future Homes Standard – All new homes to be 'zero carbon ready'	2025	✓
600,000 heat pumps installed per year[4]	2028	✓✓
Two more CCUS industrial clusters	2030	✓
Ban on sale of new petrol and diesel cars and vans	2030	✓
First Hydrogen Town	2030	✓
Scotland: 1 million zero emission homes	2030	✓
Sale of Plug-in-Hybrid cars and vans banned[4]	2035	✓✓
78% emissions reduction compared to 1990 levels	2035	✓
One fully net zero industrial cluster	2040	✓

1 This is not an exhaustive list as we expect additional policy announcements this year in the run up to the UK's hosting of international climate summit COP26 in November 2021. However, it highlights some of the most relevant and current government policy that relates to the Consumer View chapter. Sources include: BEIS Energy White Paper 2020 - https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future and Ten point plan for a green industrial revolution 2020 - https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

2 Leading the Way and System Transformation just miss this policy date by 1 year, with two CCUS industrial clusters deployed in this scenario by 2026.

3 This is met in 2024 in Leading the Way.

4 Sale of plug-in hybrid cars and vans banned takes place in 2032 in Leading the Way.

FES 2021 / Consumer View / Introduction 60

Introduction

Policy timeline compared to this year's scenarios[1]

Steady Progression

Key: ✗ Misses ✓ Meets ✓✓ Surpasses

Recent Government policy	Year	FES
Proposal to end gas grid connection for new homes	2025	✗
Two CCUS industrial clusters deployed	2025	✗
Future Homes Standard – All new homes to be 'zero carbon ready'	2025	✗
600,000 heat pumps installed per year	2028	✗
Two more CCUS industrial clusters	2030	✗
Ban on sale of new petrol and diesel cars and vans	2030	✗
First Hydrogen Town	2030	✗
Scotland: 1 million zero emission homes	2030	✗
Sale of Plug-in-Hybrid cars and vans banned	2035	✗
78% emissions reduction compared to 1990 levels	2035	✗
One fully net zero industrial cluster	2040	✗

1 This is not an exhaustive list as we expect additional policy announcements this year in the run up to the UK's hosting of international climate summit COP26 in November 2021. However, it highlights some of the most relevant and current government policy that relates to the Consumer View chapter. Sources include: BEIS Energy White Paper 2020 - https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future and Ten point plan for a green industrial revolution 2020 - https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

2 Leading the Way and System Transformation just miss this policy date by 1 year, with two CCUS industrial clusters deployed in this scenario by 2026.

3 This is met in 2024 in Leading the Way.

4 Sale of plug-in hybrid cars and vans banned takes place in 2032 in Leading the Way.

FES 2021 / Consumer View / Introduction 61

Introduction

While FES takes a GB-wide view of the future of energy over the next 29 years, it is vital to remember that drivers to encourage the necessary consumer changes cannot be one-size-fits-all and everyone must be well informed and engaged.

We are starting to explore how to include a more regional view of the changing energy landscape out to 2050 in FES. To find out more about Regional Future Energy Scenarios, see our RIIO2 Business Plan.

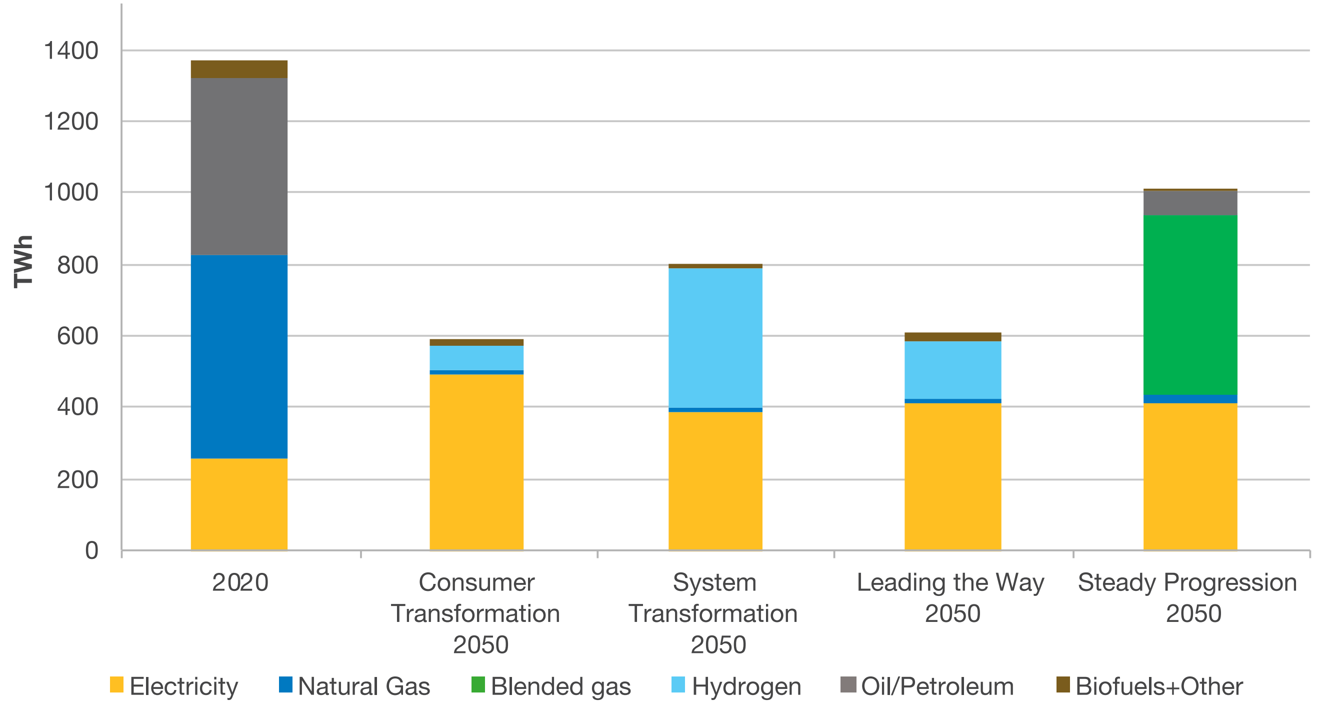
The opportunities that come from decarbonising the UK aren't easy to predict. Hence, we show a range (both in terms of the breadth and scale of societal change) in our scenarios.

Compared to FES 2020, this year, we've seen electricity demand increasing across all scenarios. This is because of:

1. Changes in fuel switching and thermal or appliance efficiency assumptions in the I&C sectors.
2. Changes to residential thermal efficiency assumptions accompanied by increases in the use of heat pumps of all types.
3. Changes to the use of thermal storage devices at times of peak demand in homes and businesses.
4. Reductions in Battery Electric Vehicle (BEV) efficiency assumptions.

For additional detail on the changes to this year's FES modelling, see our FES 2020/2021 comparison document.

Figure CV.1: Annual end consumer (including residential, road transport and I&C) energy demand in 2050[5] by fuel

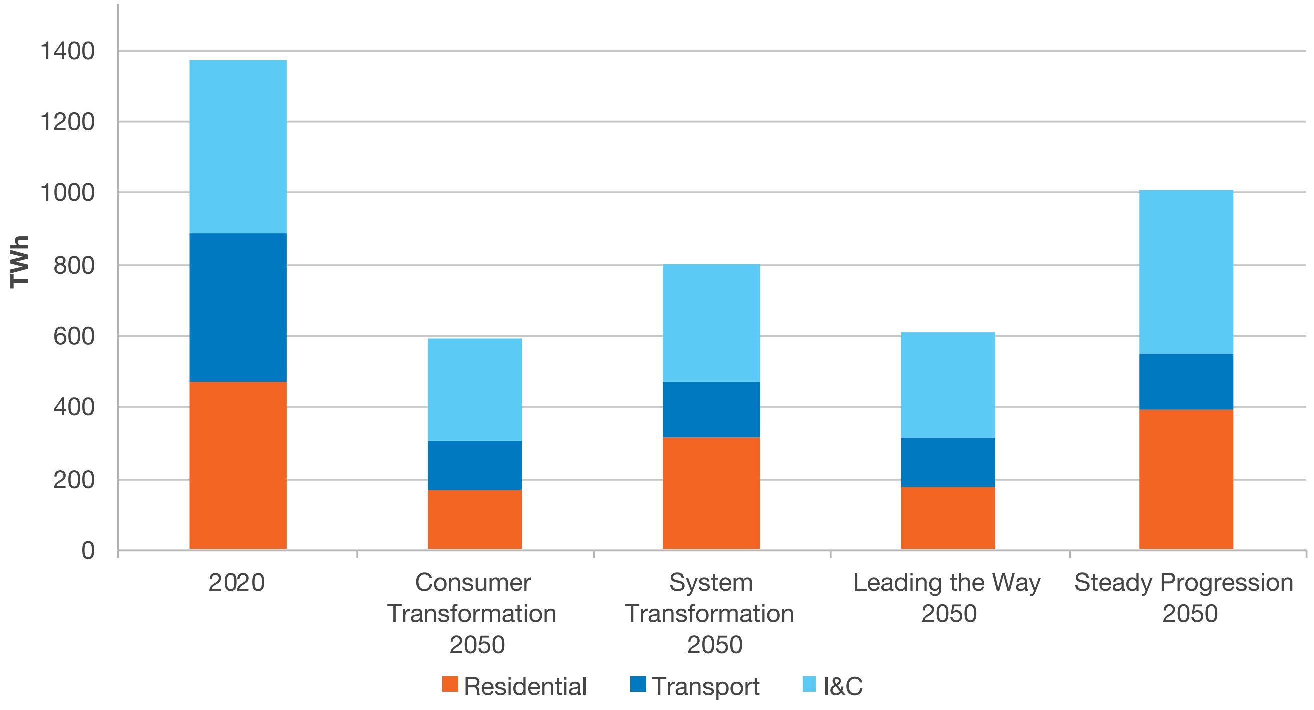


Figures CV.1 and CV.2 show that all three of our net zero scenarios have significantly lower energy demands in 2050 compared to today. This is even with increases in electricity and hydrogen demand, and is mainly a result of energy efficiency improvements in each of the residential, transport and I&C sectors.

5 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 2020 data is primarily made up of our modelled data for natural gas and electricity. However, some 2019 demand data from ECUK was used in order to provide a complete, whole energy system view of end consumer demand.

FES 2021 / Consumer View / Introduction 62

Figure CV.2: Annual end consumer (including residential, road transport and I&C) energy demand in 2050[5] by sector



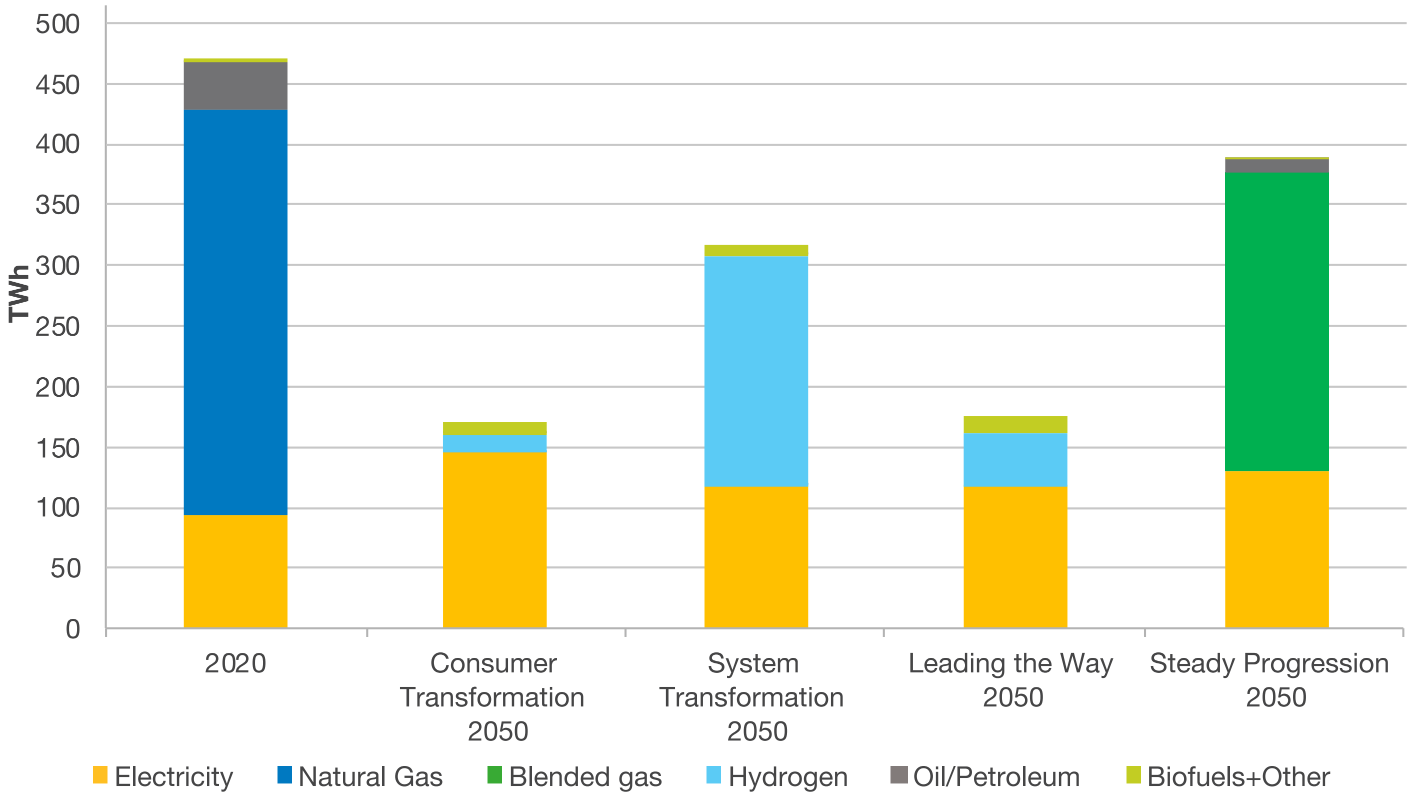
FES 2021 / Consumer View / Introduction 63

Residential

Key insights

- Consumer perception and engagement is vital to ensure low carbon heating will be installed in every home in the country to help achieve net zero emissions by 2050.
- Homes will benefit from a range of low carbon heating technology options. Our net zero scenarios show that heat pumps, district heating and hydrogen boilers are all needed. Their distribution throughout Great Britain (GB) is driven by factors such as infrastructure (hydrogen or electricity) availability and consumer choice.
- Homeowners' behaviour, like choosing to turn thermostats down, can lead to significant reductions in heat demand. For instance, a 1°C (on average) decrease in Leading the Way compared to today's levels can lead to up to a 13% reduction in heat demand.
- Government policy will be essential to encourage mass consumer uptake of energy efficiency measures. Our net zero scenarios show that insulation in lofts and walls will need to be retrofitted in homes in the 2020s continuing to the mid-2030s.
- The way homeowners use low carbon heating technologies could help us manage a future electricity system dominated by intermittent renewable supplies. For example, thermal storage devices can be installed in homes alongside heat pumps. They can release energy at peak times to reduce electricity demand from heating by up to 8% in System Transformation and 35% in Leading the Way.
- Home appliances such as washing machines, computers and TVs are highly efficient in all net zero scenarios, reducing demand (compared to today's levels) by up to 39% by 2050 in Leading the Way.

Figure CV.3: Annual residential energy demand (for heat and appliances) in 2050[1,2]



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 2020 data is primarily made up of our modelled data for natural gas and electricity. However, some 2019 demand data from ECUK was used to provide a complete, whole energy system view of end consumer demand.

2 This does not include the energy needed for EV charging which is covered in the Transport section.

FES 2021 / Consumer View / Residential 65

Key insights

Figure CV.4: Residential heating demand in 2020 and 2050

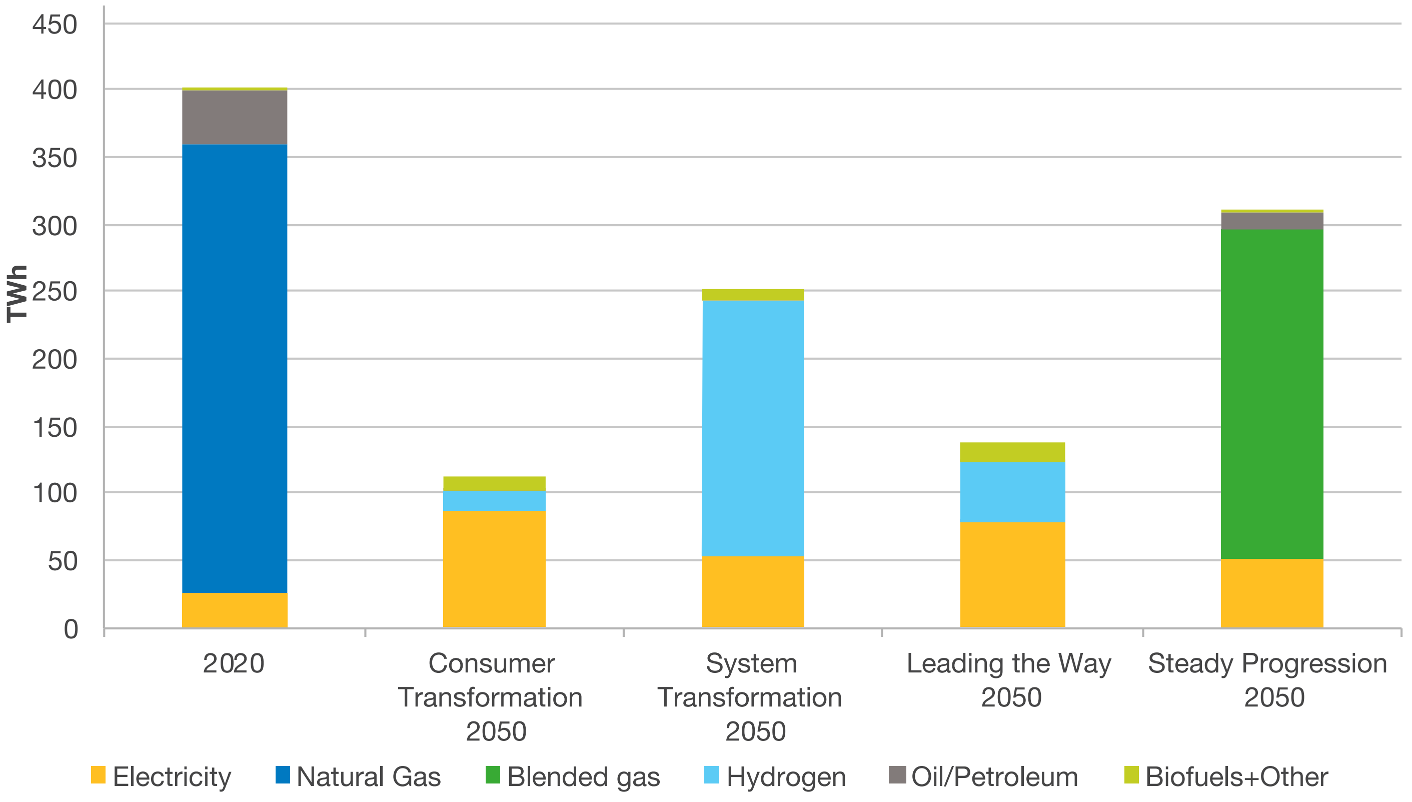
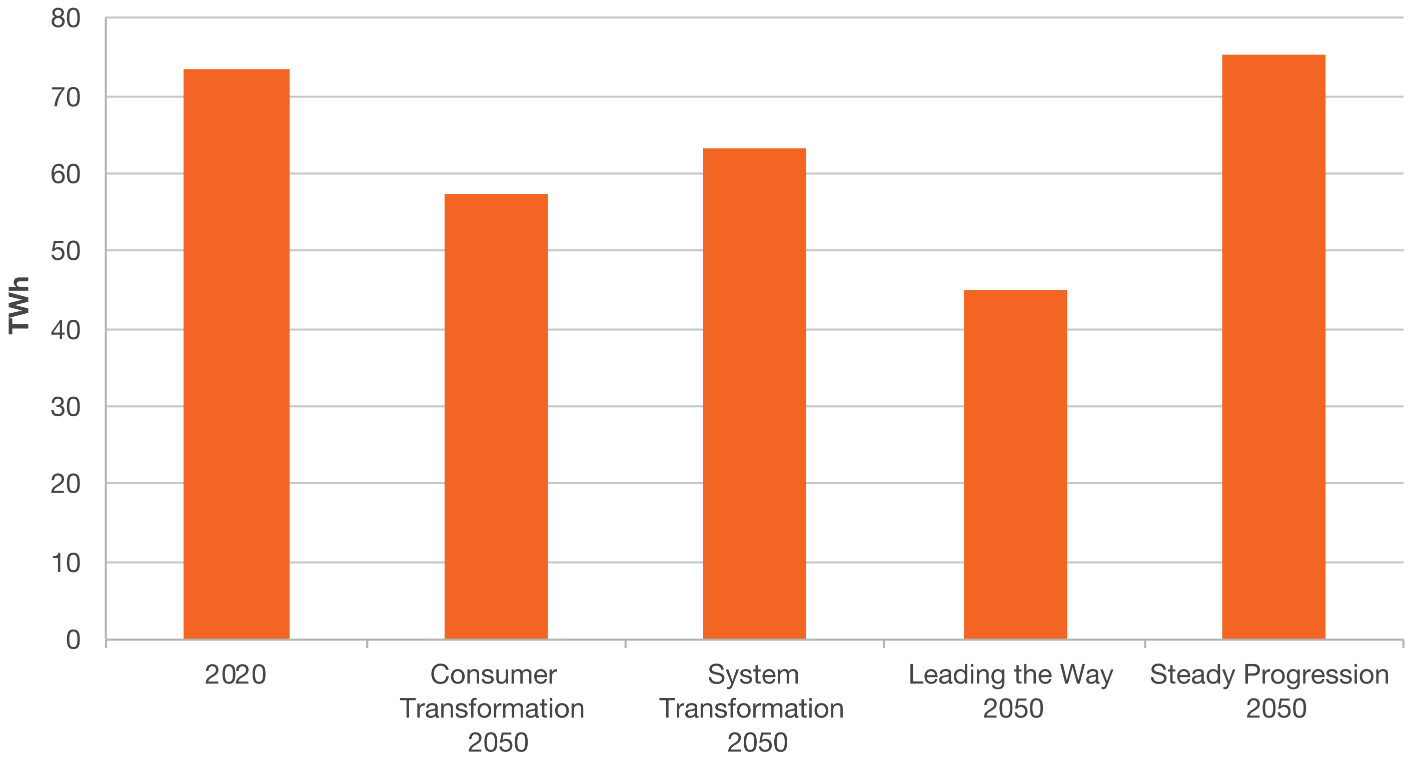


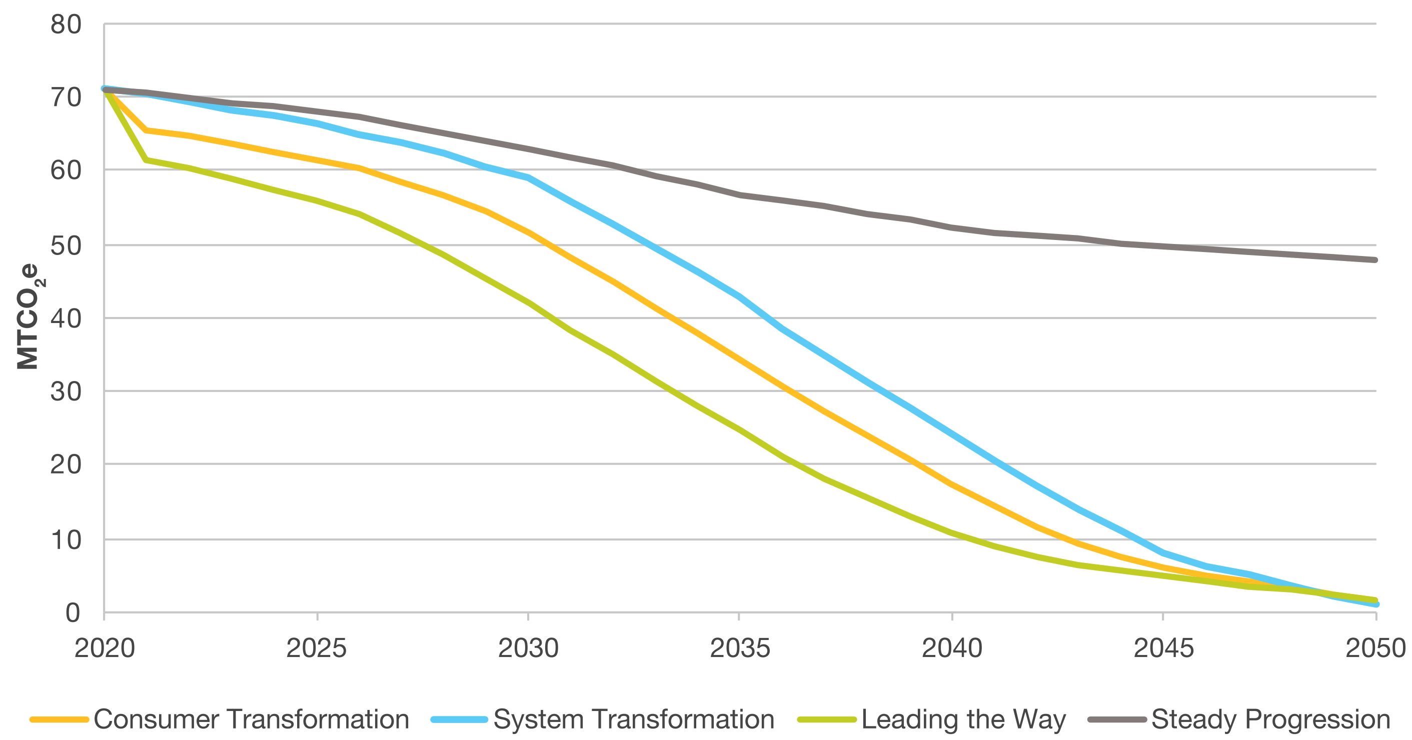
Figure CV.5: Residential appliance demand in 2020 and 2050



FES 2021 / Consumer View / Residential 66

Key insights

Figure CV.6: Emissions from the residential sector



FES 2021 / Consumer View / Residential 67

Where are we now?

Currently residential demand for energy in GB's 28.5 million homes accounts for around 480 TWh, which was 35% of GB total demand in 2020. Its heavy reliance on natural gas meant residential emissions in 2020 were 71 $MtCO_2e$; approximately 14% of the UK's total emissions.[3]

Government policy in this area includes the Future Homes Standard, which requires homes built in 2025 or after to have low carbon heating. Recently, the Government has pledged to install 600,000 heat pumps per year by 2028 in homes across England - compared to the approximately 30,000 heat pumps currently installed.[4] As noted in the Climate Assembly's 2020 findings, it's important that consumers have a choice over which low carbon heating technology to have installed and solutions need to be affordable for all income groups.[5]

While there have been some changes to appliance energy labels this year, UK government policy in this area has been fairly limited. Commitments in the Energy White Paper include plans to regulate smart appliances, focusing on interoperability, data privacy and cyber security.[6] It's also worth noting the importance of international policies to increase energy efficiency of domestic appliances, since we continue to rely on goods manufactured from around the globe.

Residential includes: domestic heating and appliances.

Heating includes: space heating and hot water.

Appliances includes: lighting, refrigeration, washing machines, consumer entertainment, computing, cooking appliances, vacuum cleaners and power supply units.

Energy labels

Appliance and product energy labels help consumers choose more energy efficient goods. They are now based on a simple A-G rating as opposed to the previous A+++ to D categories.

Heat pumps

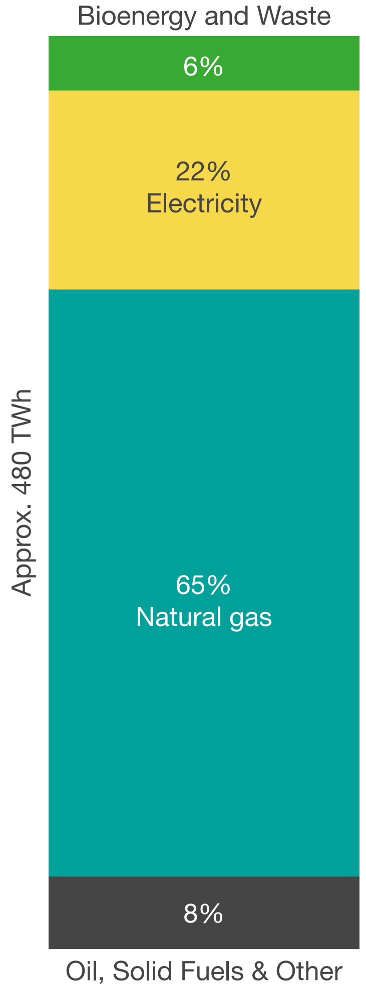
Heat pumps (either ground or air source) transfer energy from a lower temperature source to a higher temperature destination. They are an efficient and effective form of low carbon heating.

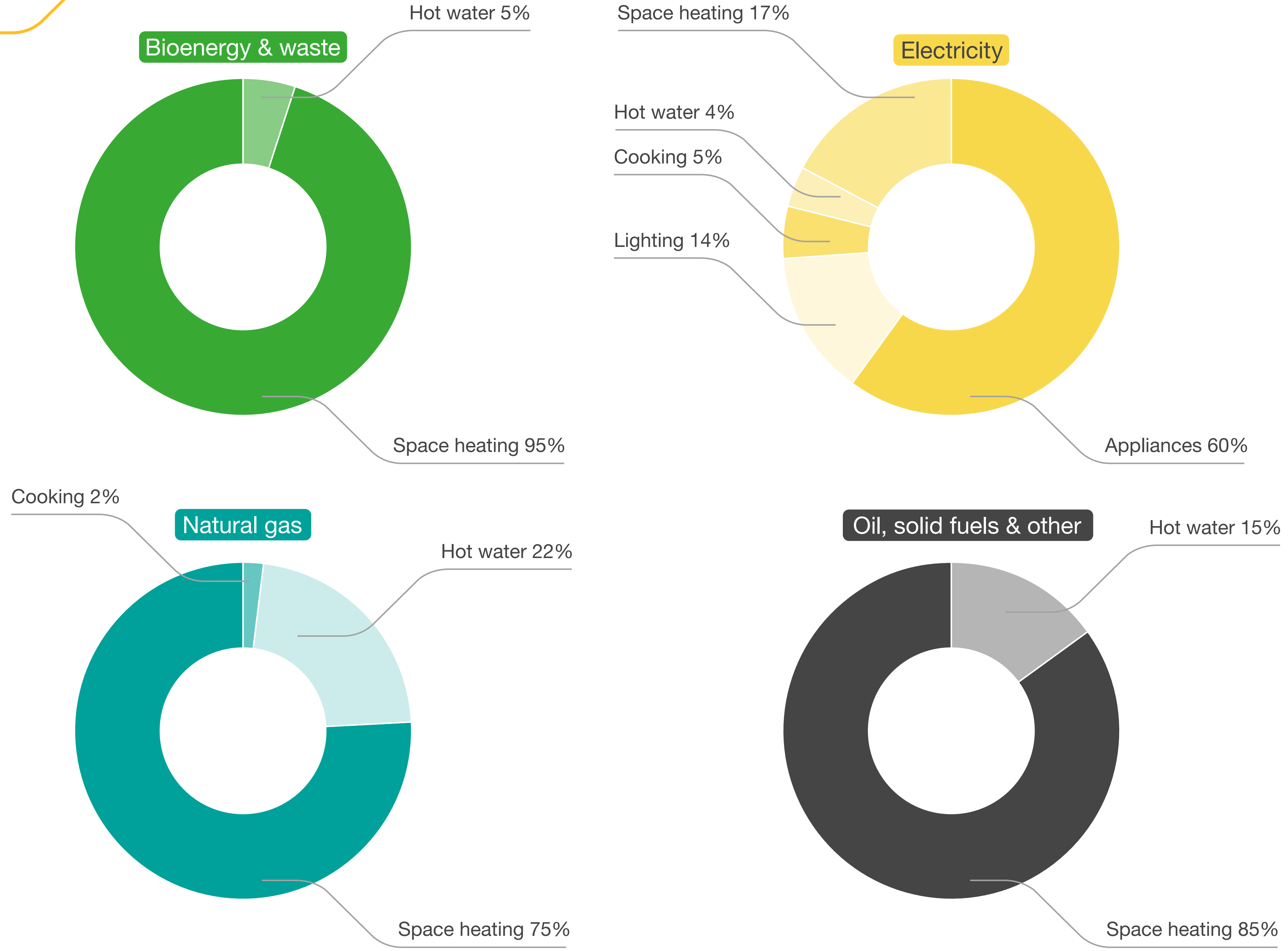
3 Whilst modelling in FES is based on GB energy demand and supply, in some areas (such as emissions and economic growth) it is necessary to talk in terms of the UK.
4 BEIS Energy White Paper 2020 - https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future
5 Climate Assembly 2020 Report - https://www.climateassembly.uk/report/read/final-report.pdf
6 BEIS Energy White Paper 2020 - https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

FES 2021 / Consumer View / Residential 68

Where are we now?

Figure CV.7: 2019 Domestic energy consumption by fuel[7]





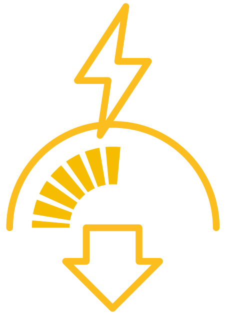
7 Data from: ECUK Energy Data Tables (Table U3) - gov.uk/government/statistics/energy-consumption-in-the-uk

FES 2021 / Consumer View / Residential 69

What we've found

Routes to decarbonisation

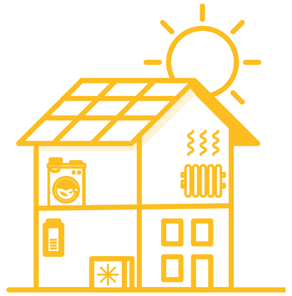
The residential sector will need the following to decarbonise and support the energy system:



Demand reductions

The lower the demand the less low carbon energy we need to produce. Measures include:

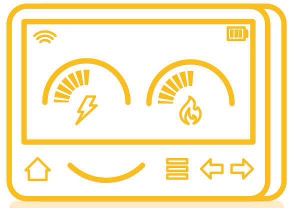
- Increasing thermal efficiency measures such as insulation and triple glazing
- Turning down indoor temperatures by an average of 1°C compared to today
- Investing in highly-efficient appliances



Electrification and low carbon technologies

Electrification allows us to capitalise on the decarbonisation of the electricity system and hydrogen produces no emissions at end consumer level. For example:

- Hydrogen boilers, heat pumps and district heating



Flexibility

Flexibility allows the energy system to be more efficient in managing demand and supply with low carbon electricity generation. Examples include:

- Smart appliances such as washing machines or dishwashers
- Thermal storage, usually to store hot water for household heating depending on the time of day
- Batteries to store excess electricity at times of high supply and dispense it when needed
- Hybrid heat pumps, with back up hydrogen or bioenergy on cold days when demand (and the wholesale price of electricity) is highest

All of this will require consumers to be well-informed and engaged; energy markets to be open, fair and interoperable; and effective government policy to drive widespread uptake and support the supply chains of low carbon technologies. New business concepts, such as energy as a service can also improve people's experiences of low carbon technologies in the home.

FES 2021 / Consumer View / Residential 70

Modelling information

This year, we have developed a new, detailed heating model on a region-by-region basis.

The **heat model** looks at the following:

- Energy efficiency and storage measures
- Impact of consumer behaviour (including willingness to pay and comfort levels)
- Individual building characteristics
- Policy incentives
- Regional suitability of low carbon heating technologies, driven by value for money
- Hourly dispatch of energy based on price sensitivities

Our **appliance model** examines:

- Efficiency improvements
- Sales of appliances (including smart appliances)

Despite leaving the European Union (EU), we expect the EU target of increasing energy efficiency by 32% by 2030 will continue to drive UK policy, and our models are based on this.

For further information, see the modelling methods document.

FES 2021 / Consumer View / Residential 71

Scenarios overview: residential

Consumer Transformation

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.
- 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.
- There is a 32% improvement in energy efficiency by 2030, with consumers changing their lightbulbs to LEDs, and investing in highly-efficient, smart appliances like washing machines and computers.
- The sale of natural gas boilers is banned from 2035.

What does 2050 look like?

- Total residential demand in 2050 is 172 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 25 million installations in homes by 2050.
- Around 10 million homes have thermal storage. Consumers respond to Time of Use Tariffs (TOUTs) 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.
- Households not previously connected to the gas grid either use heat pumps, biofuels or heat pump biofuel hybrids.
- District heat networks are used in some areas, with hot water piped to homes by centralised heat pumps.

FES 2021 / Consumer View / Residential 72

Scenarios overview: residential

System Transformation

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, resulting in a 32% improvement in energy efficiency by 2032.

What does 2050 look like?

- Total residential demand in 2050 is 318 TWh.
- A national hydrogen network means 69% of homes use hydrogen boilers for heating.
- Up to 11 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 2021 / Consumer View / Residential 73

Scenarios overview: residential

Leading the Way

The route to 2050

- By 2025, 2.6 million homes have heat pumps, thanks to strong government policy.
- This scenario has high levels of residential thermal efficiency installations. Retrofitting takes place from the mid-2020s, achieving a 12% reduction (from insulation measures) in average electricity demand per household by 2035, offsetting potential increases in 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 178 TWh.
- Over 80% 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.
- 21% of homes have hydrogen boilers, with a higher proportion in the north of England.
- 1.3 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 2021 / Consumer View / Residential 74

Scenarios overview: residential

The route to 2050

- There is some 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, so this scenario does not achieve the 32% increase in energy efficiency target.

What does 2050 look like?

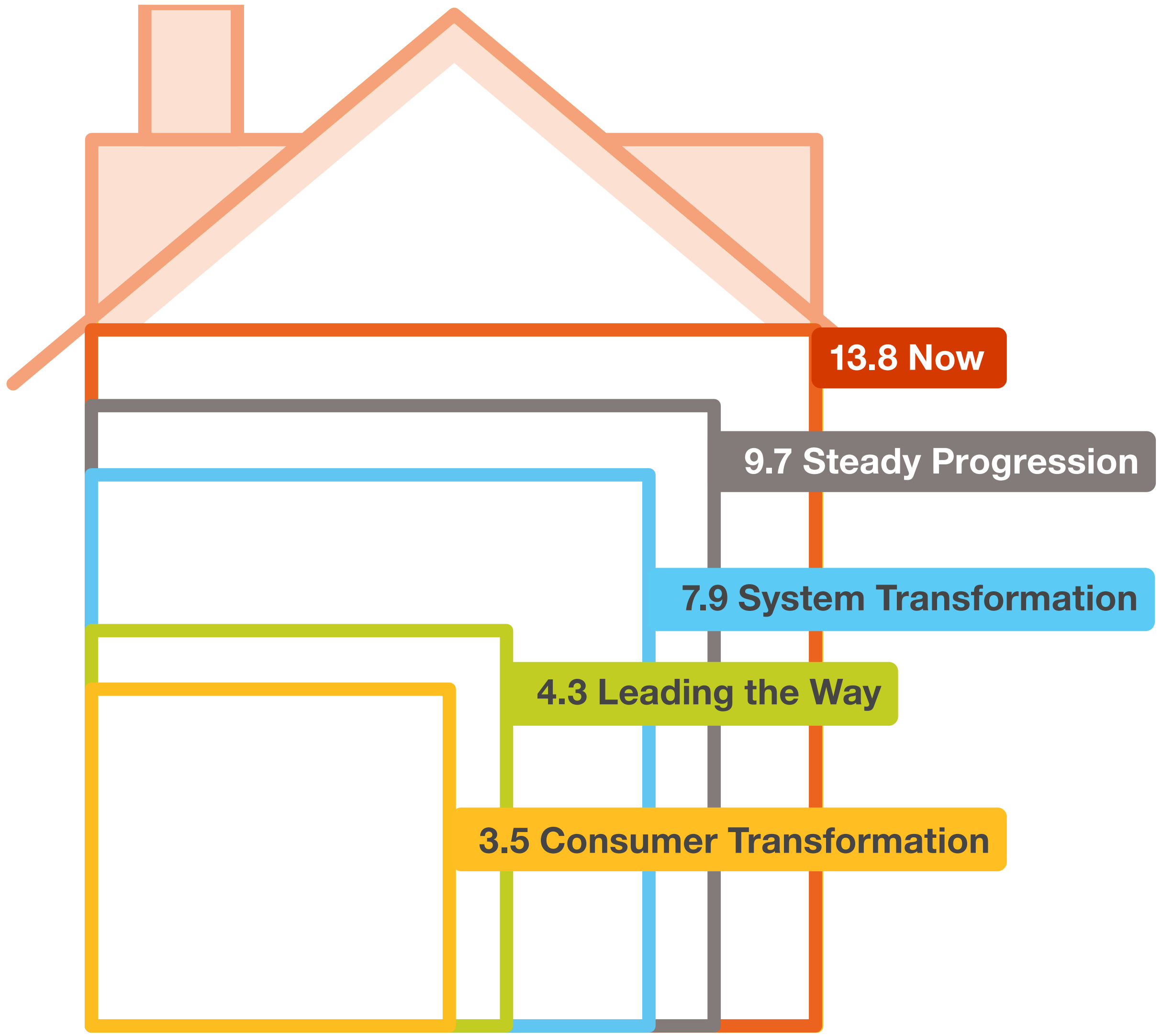
- Total residential demand in 2050 is 390 TWh.
- Most homes still use natural gas boilers.
- There are no hydrogen boiler systems as there is no hydrogen network.
- Some consumers install heat pumps with little to no insulation or thermal storage measures to help manage the increase in demand on the local and national electricity networks.
- While some appliances are highly efficient, most are not smart and cannot provide flexibility at times of peak supply or demand.

Steady Progression

FES 2021 / Consumer View / Residential 75

What we've found

Scenarios overview: residential



The average energy demand for household heating could be in 2050 (MWh/year/household) for each of our scenarios

FES 2021 / Consumer View / Residential 76

What we've found

Home heating

Figure CV.8: Total annual demand for heating homes

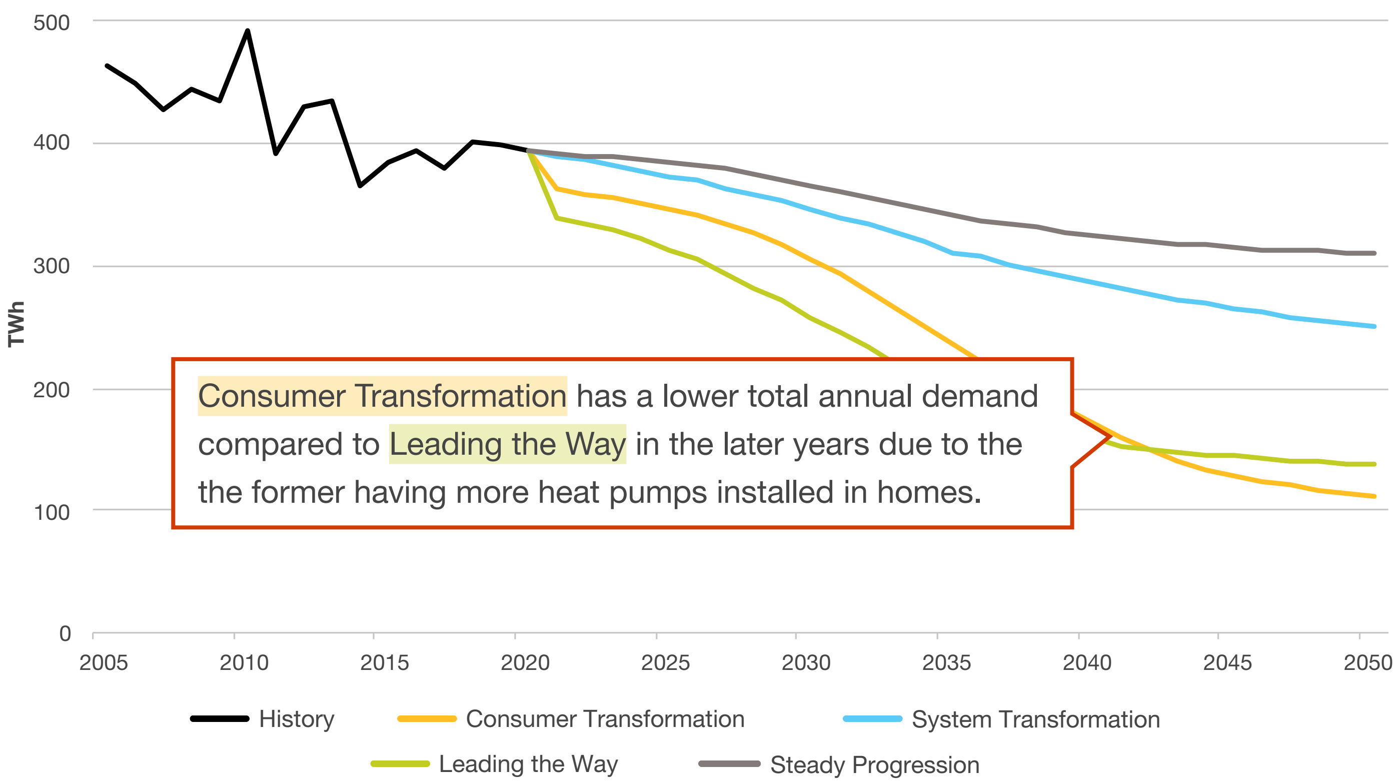
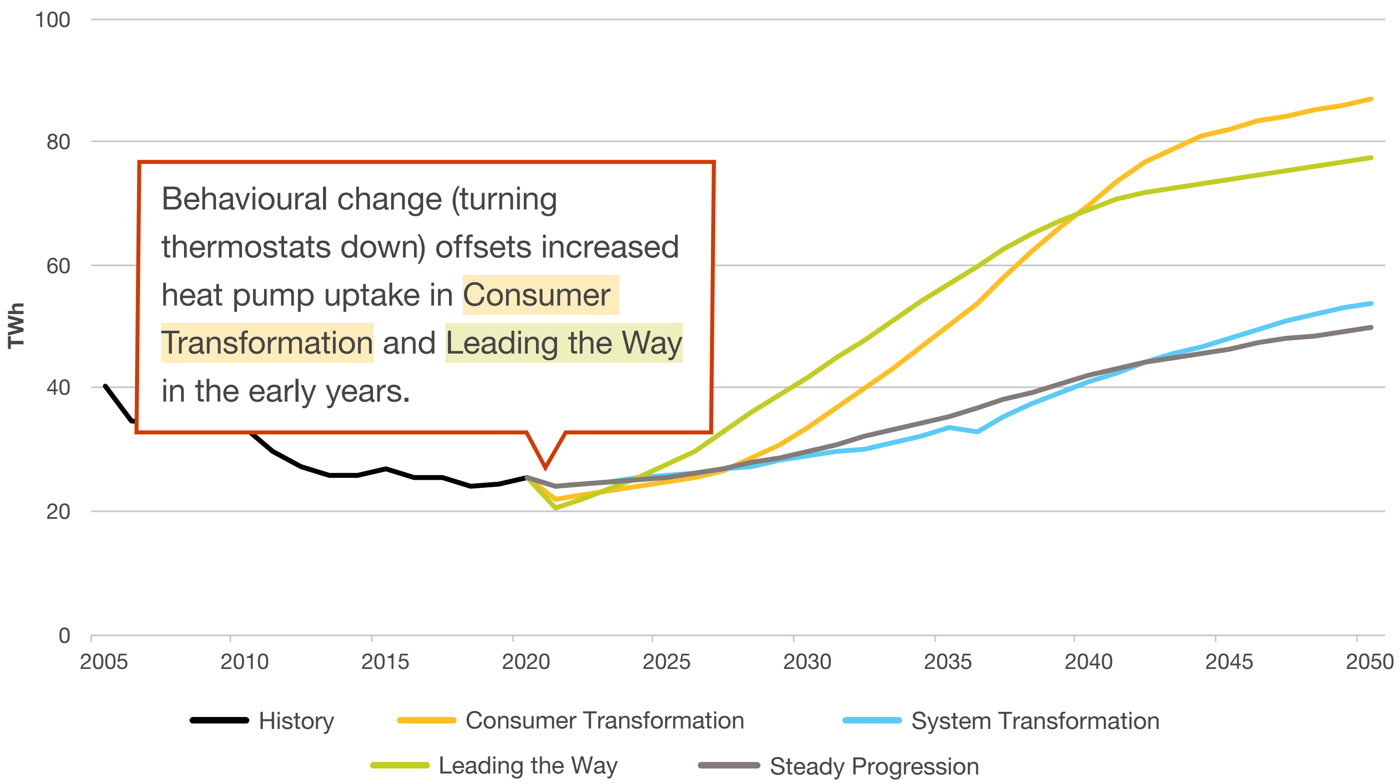


Figure CV.9: Annual electricity demand for heating homes



FES 2021 / Consumer View / Residential 77

What we've found

Figure CV.10: Annual hydrogen demand for heating homes

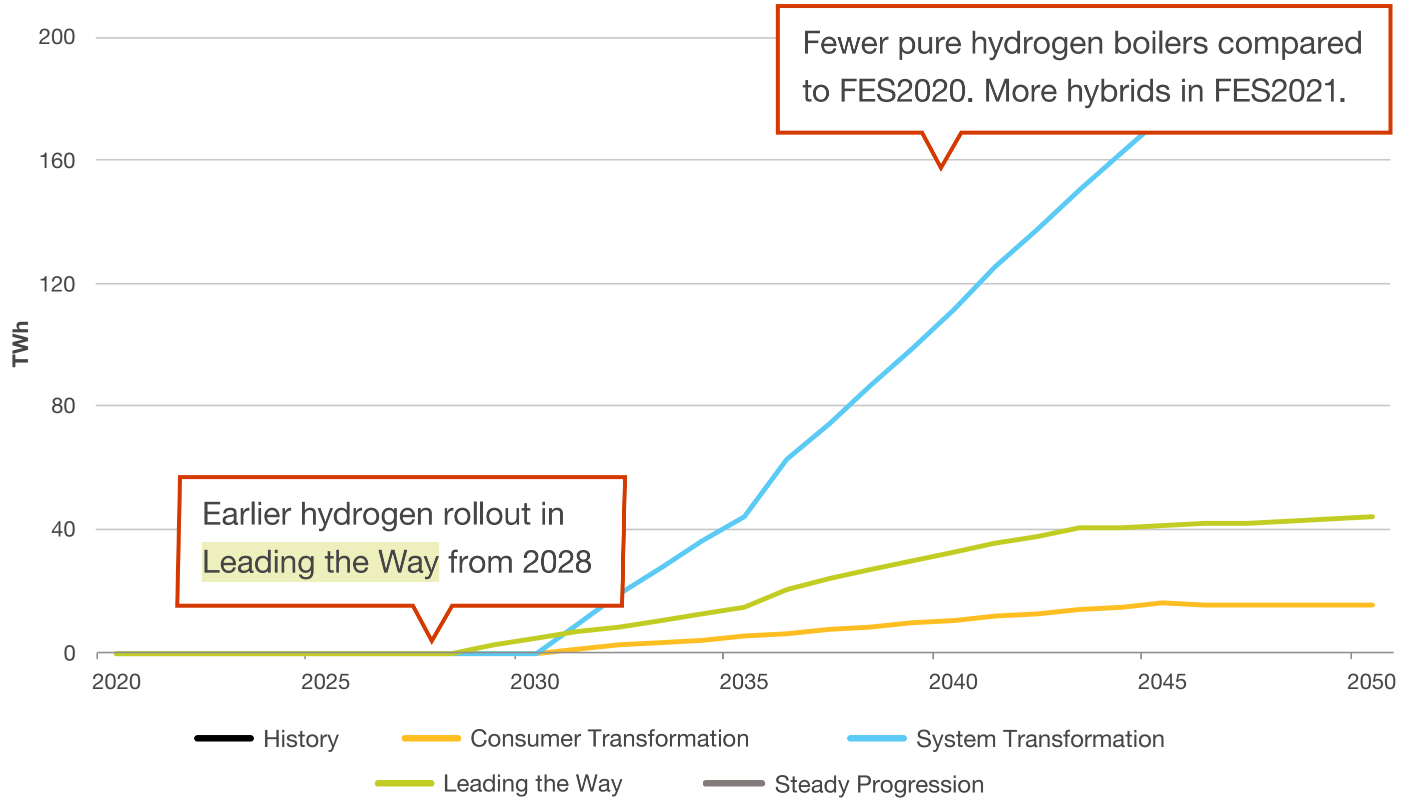
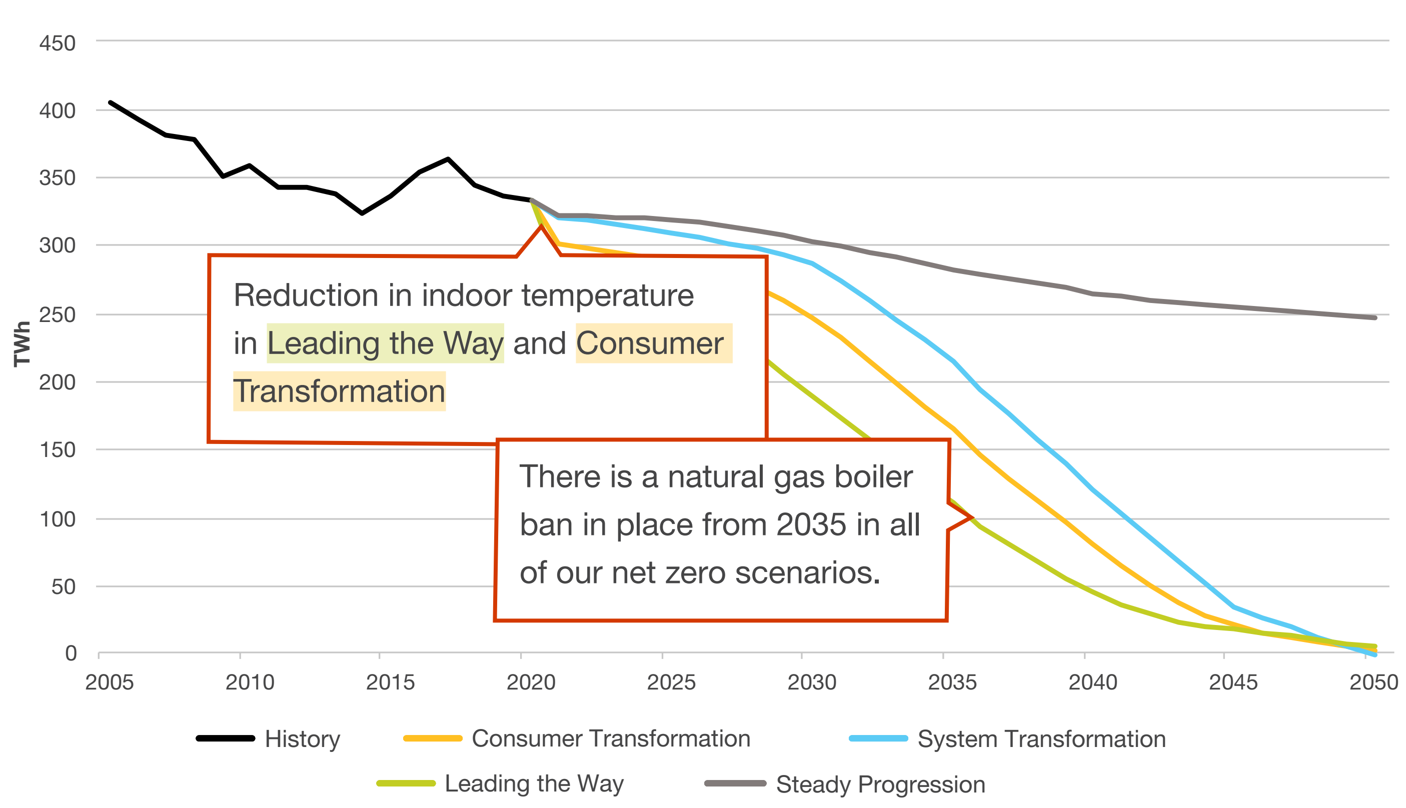


Figure CV.11: Annual natural gas demand for heating homes



What we've found

Thermal efficiency measures and consumer behaviour change

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. This is because it reduces the energy required for heating and supports the transition to new low-carbon heating solutions – both from a practical and economic perspective.

Our modelling shows an ambitious uptake in heat pumps from 2021 to 2025 in Leading the Way, with 2.6 million[8] installed in homes by 2025. Additionally, we assume that new-build properties in Leading the Way are very well insulated from 2025 onwards (in line with the Future Homes Standard) making them optimal for heat pumps and aiding heat demand savings. This is accompanied by widespread reduction in indoor temperatures, as consumers turn their thermostats down. On average this is by up to 1°C in Leading the Way and 0.5°C in Consumer Transformation compared to today's indoor temperature levels.[9] These reductions in indoor temperature align with the "level of societal change" axis on our FES framework and can suppress heat demand by 13% and 7% respectively. Figures CV.14 and CV.15 show more information on how our scenarios vary in the uptake of low-carbon heating technology and how consumer behaviour and building fabric changes can suppress peak heat demand.

The analysis shows that existing homes in Leading the Way and, to a lesser extent Consumer Transformation, could require lower levels of retrofitted thermal efficiency measures, such as extensive insulation in lofts and walls, to achieve similar energy savings. The main reason for this is that assumed reductions in indoor temperature reduce the demand for energy and, by extension, the need for so much insulation.

By comparison, System Transformation, with less assumed behavioural change, requires more ambitious thermal efficiency measures. Consumers may see more of an economic benefit insulating homes that have a hydrogen boiler (which is more prolific in this scenario) compared to a heat pump. This is because hydrogen boilers are likely to be around 3 times less efficient than a heat pump whereas the retail price of the hydrogen used as a fuel is expected to be only about two thirds cheaper than retail electricity prices on average.

In FES 2020, there was a higher reduction in demand, especially in Consumer Transformation, compared to FES 2021 due to lower energy efficiency assumptions. This change has reflected stakeholder feedback from our most recent cycle of engagement. For further detail, see our FES 2020/2021 comparison document.

The hydrogen retail price

The hydrogen retail price (what consumers see and pay for) is calculated from a range of factors, including production, storage, and transmission costs. The main production method in System Transformation is methane reforming.

8 This equates to around 9% of homes.
9 Note the average reductions in indoor temperatures refer to high temperature heat only, and excludes reductions in temperature as a result of air conditioning in future.

FES 2021 / Consumer View / Residential 79

What we've found

Figure CV.12: Annual savings in underlying heat demand from both improvements to building fabric and consumer behaviour changes

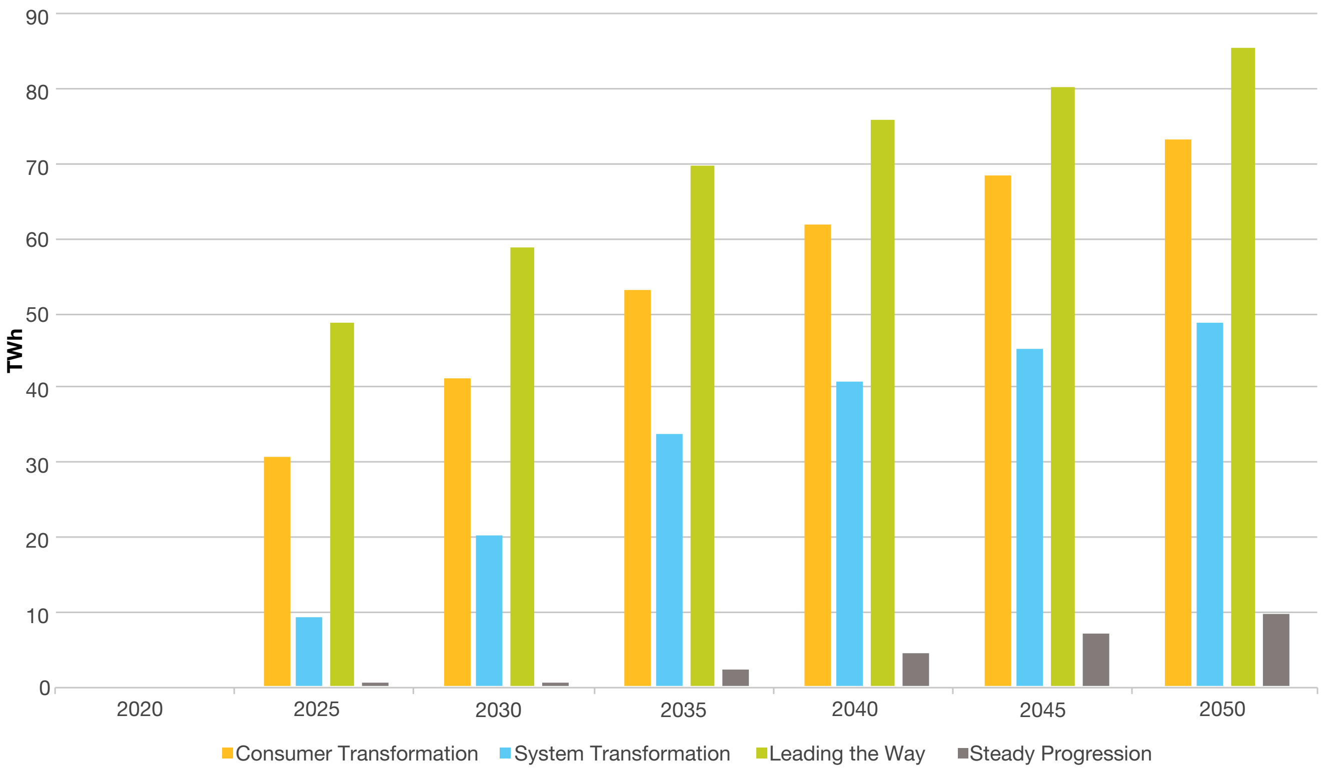
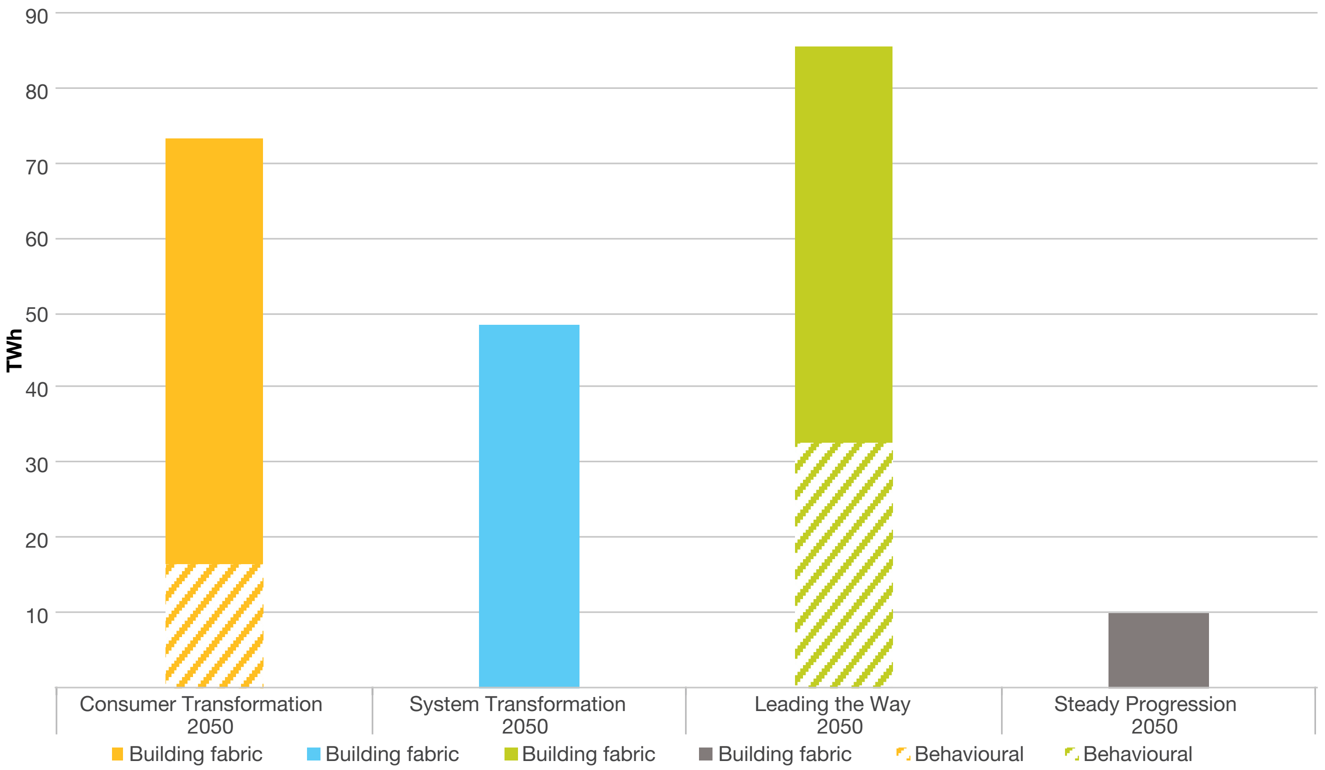


Figure CV.13: Breakdown of savings in underlying heat demand due to building fabric improvement and consumer behaviour change in 2050



FES 2021 / Consumer View / Residential 80

What we've found

Figure CV.14: Residential heat pump (including hybrids) uptake[10]

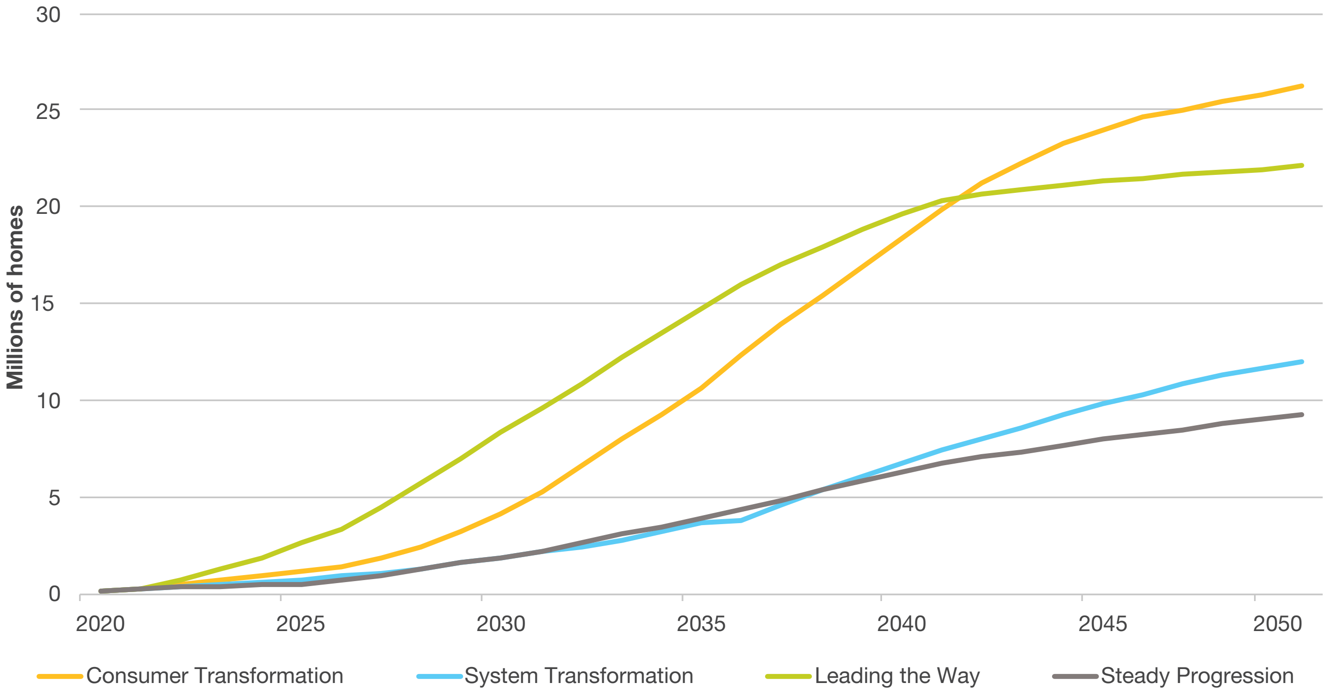
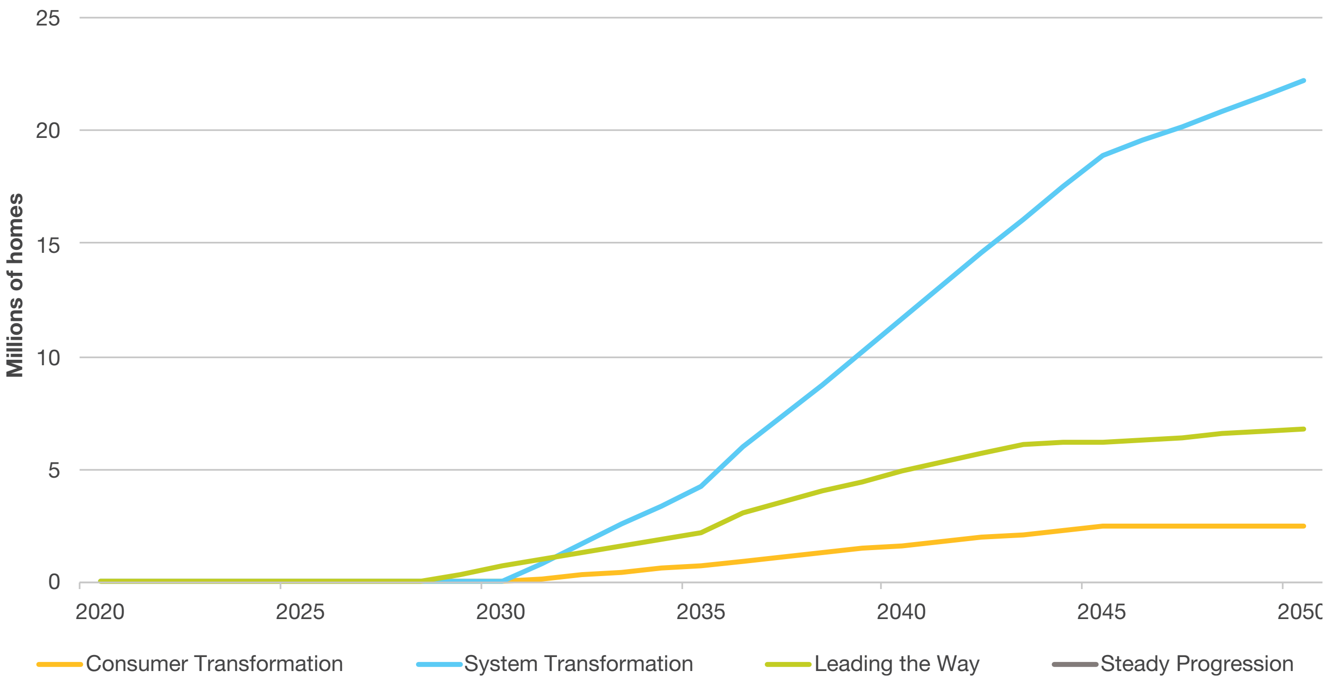


Figure CV.15: Residential hydrogen boilers (including hybrids) uptake[10]



10 Hybrid low carbon heating technologies are included in both of Figures CV.14 and CV.15 to show the total impact of electrical and hydrogen low carbon heating solutions on the whole energy system.

FES 2021 / Consumer View / Residential 81

Low carbon heating technology mixes

Figure CV.16: Overall home heating technology mix in 2050

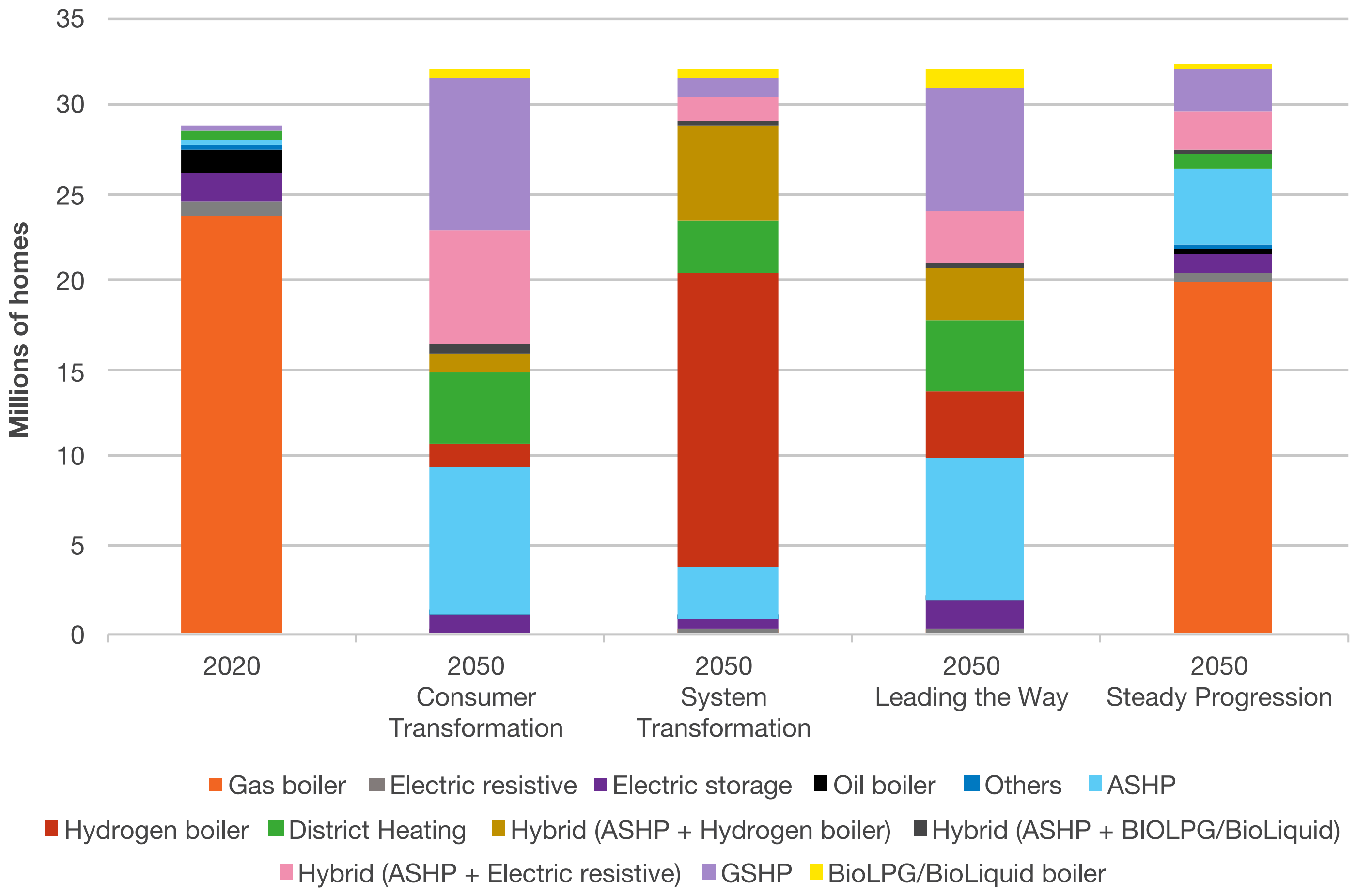
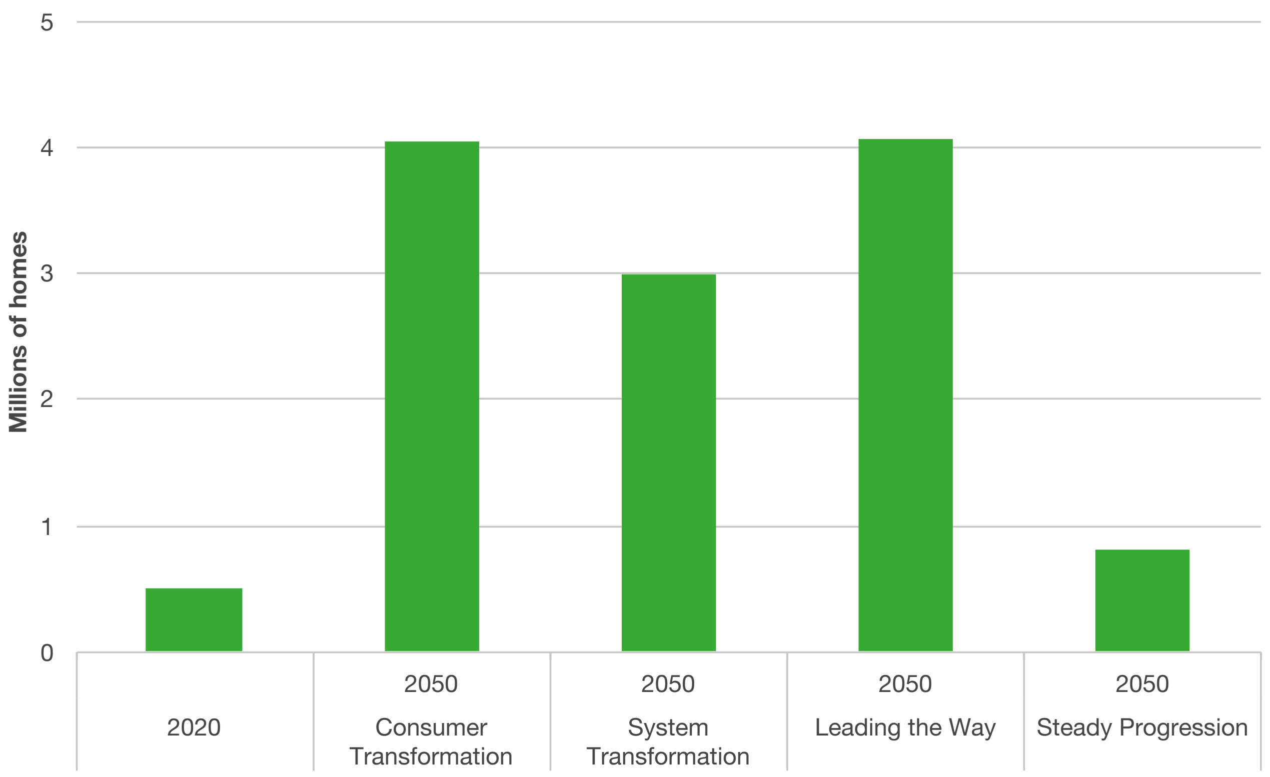


Figure CV.17: District heat networks in 2050



What we've found

Different regions, different heating types

Heat decarbonisation is one of the biggest challenges of net zero and will require tailored approaches across the different regions of GB. Regional factors such as building stock, housing density, proximity to hydrogen production and renewable electricity installations will affect how homes and buildings are heated. This year we've modelled low carbon heating types on a local authority basis for the first time.[11] Only two types are illustrated here, however the data for all heating types, across all local authorities in GB, are available in the data workbook, and further analysis will be presented in an upcoming FES thought piece.

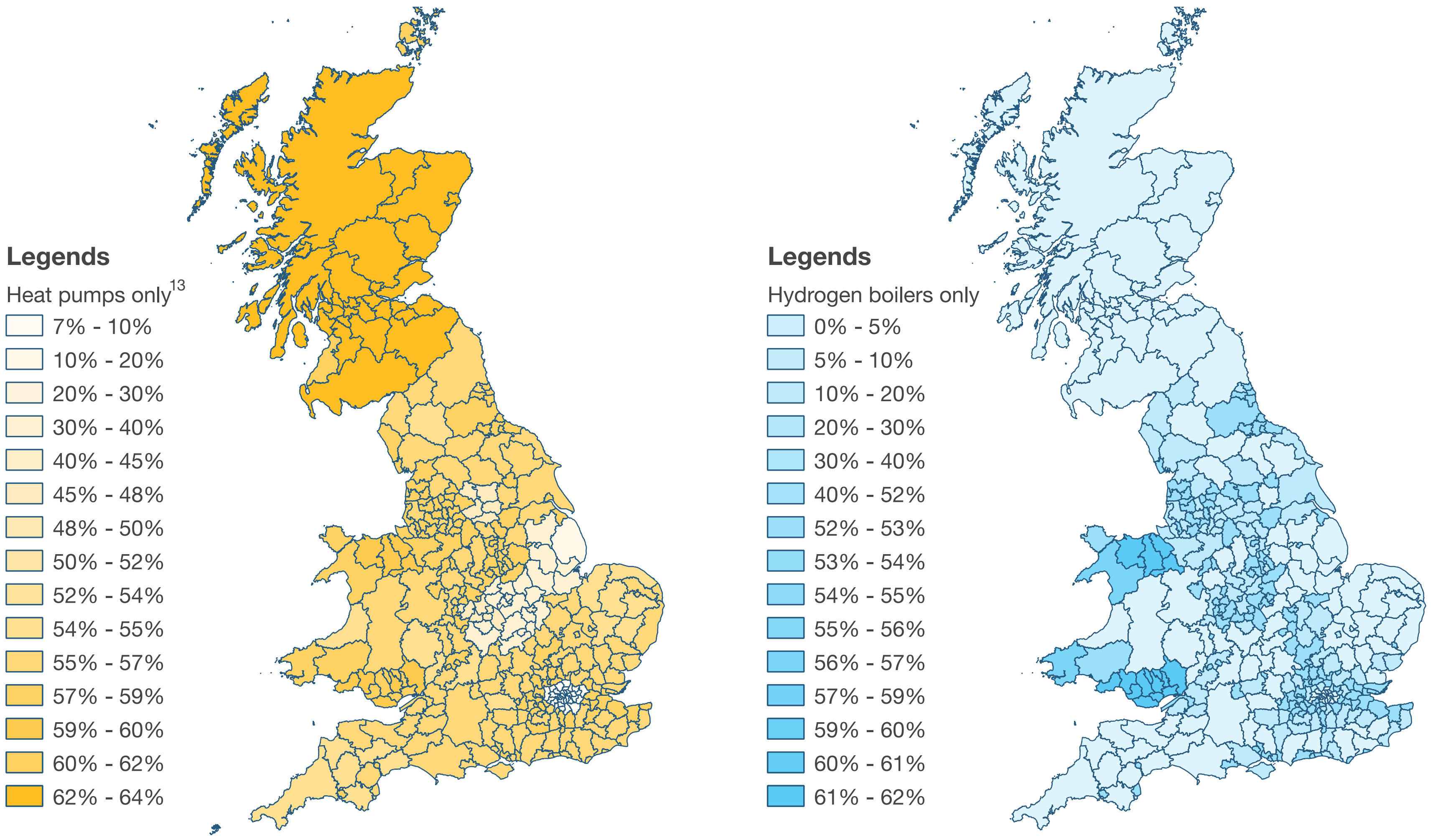
Heat pumps[12] are greatly influenced by the availability of alternative technologies. If there is no cost-effective alternative, for example in Scotland in Consumer Transformation, heat pumps fill the gap.

Hydrogen boiler[11] deployment depends on the availability of hydrogen. For example, the national hydrogen transmission system in System Transformation provides the opportunity for more homes to install hydrogen boilers. In this scenario, south Wales has high concentrations of hydrogen boilers, in part due to its high housing density and fewer alternatives compared to other areas.

Figure CV.18:

Proportion of homes in 2050 with heat pumps in Consumer Transformation

Proportion of homes in 2050 with hydrogen boilers in System Transformation



11 For more information on the spatial heat model, visit: https://smarter.energynetworks.org/projects/nia_nggt0154/
12 The maps here do not show hybrid solutions, so don't cover the full scale of heat pump and hydrogen boiler installations.
13 Minimum heat pump uptake by local authority is 7% (hence scale doesn't start from zero).

Household flexibility and storage

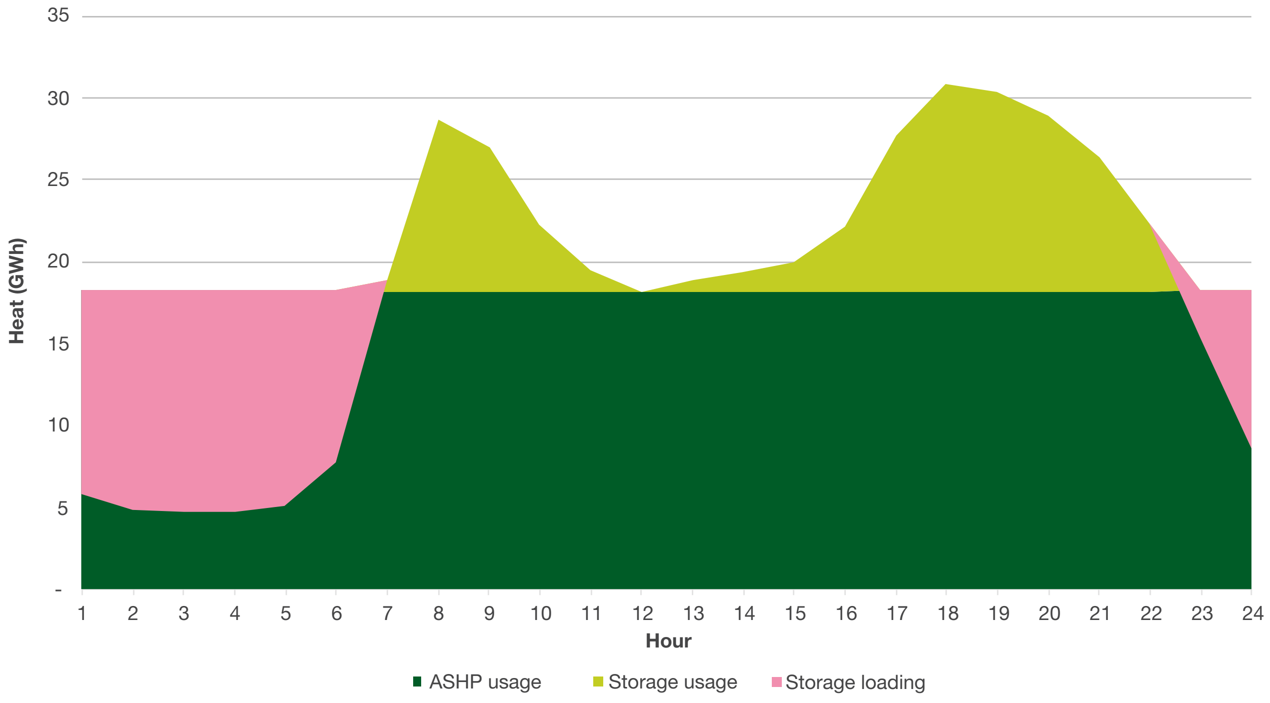
Two key factors drive the impact of consumers' energy use on carbon emissions: how much they use and when they use it.

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 incentivise consumers to increase or decrease their demand – turning on or off electrical appliances - depending on whether there is high or low electricity supply available. In FES, we assume that consumers change to a dynamic energy tariff after purchasing an EV. For more information see the transport section.

Thermal storage devices can help to manage household demand, typically alongside heat pumps. Effective price incentives will encourage consumers to store heat at times of low demand and high supply ready to use when demand on the local or national electricity networks are high. To do this, thermal stores could be manually operated, pre-programmed or managed as part of the 'energy as a service' proposition. We expect that technology types and commercial solutions for this flexibility service will become more suitable for different consumer requirements in line with similar services for low carbon heating technologies and private electric vehicle charging.

In Leading the Way, 60% of households with heat pumps (excluding hybrids) also have some form of thermal storage. 90% of these consumers are actively engaged to provide system flexibility at any point in time. See Figures CV.19 and CV.23 for further detail on how thermal storage could be used by consumers on a peak day with various low carbon heating technologies.

Figure CV.19: Thermal storage use on a peak day: hourly usage profiles for air source heat pumps in Leading the Way



The extent to which consumers embrace dynamic tariffs and thermal storage will have a significant impact on balancing the energy system and is closely aligned to the "level of societal change" across our scenarios.

Read more about flexibility from the system perspective here.

Thermal storage devices

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 2021 / Consumer View / Residential 84

What we've found

Figure CV.20: Thermal storage use on a peak day: hourly usage profiles for ground source heat pumps in Leading the Way

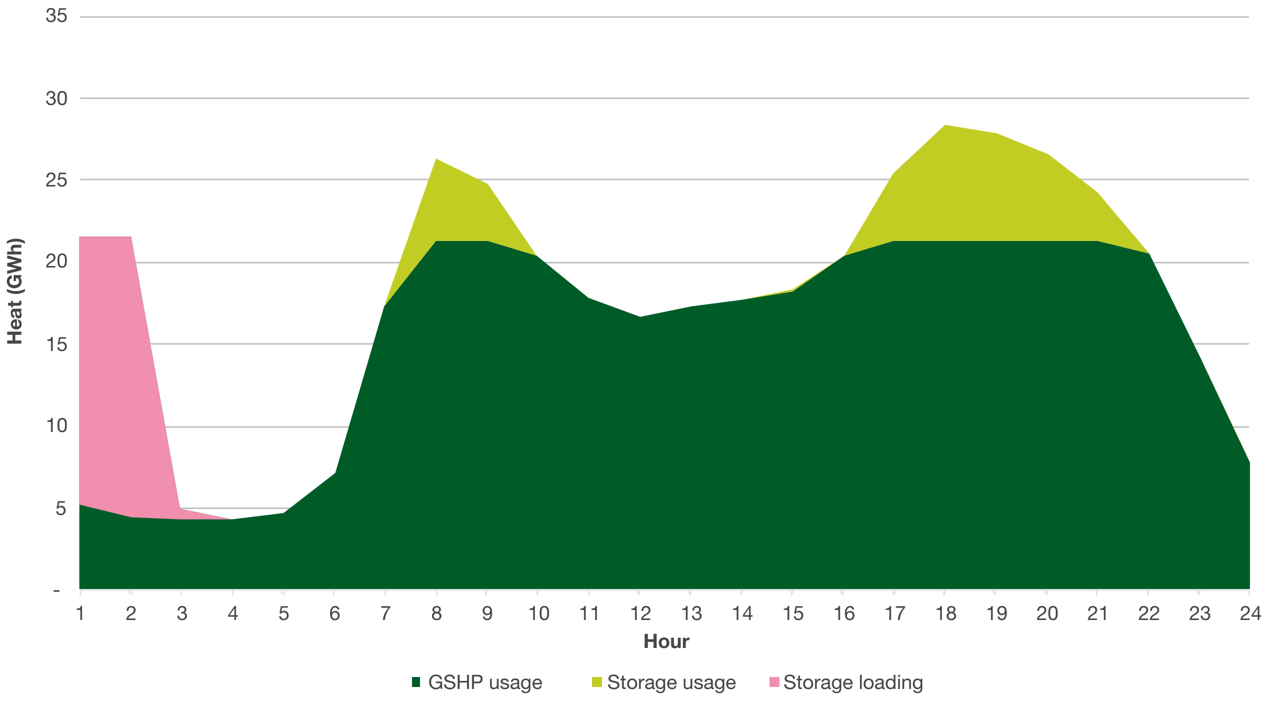
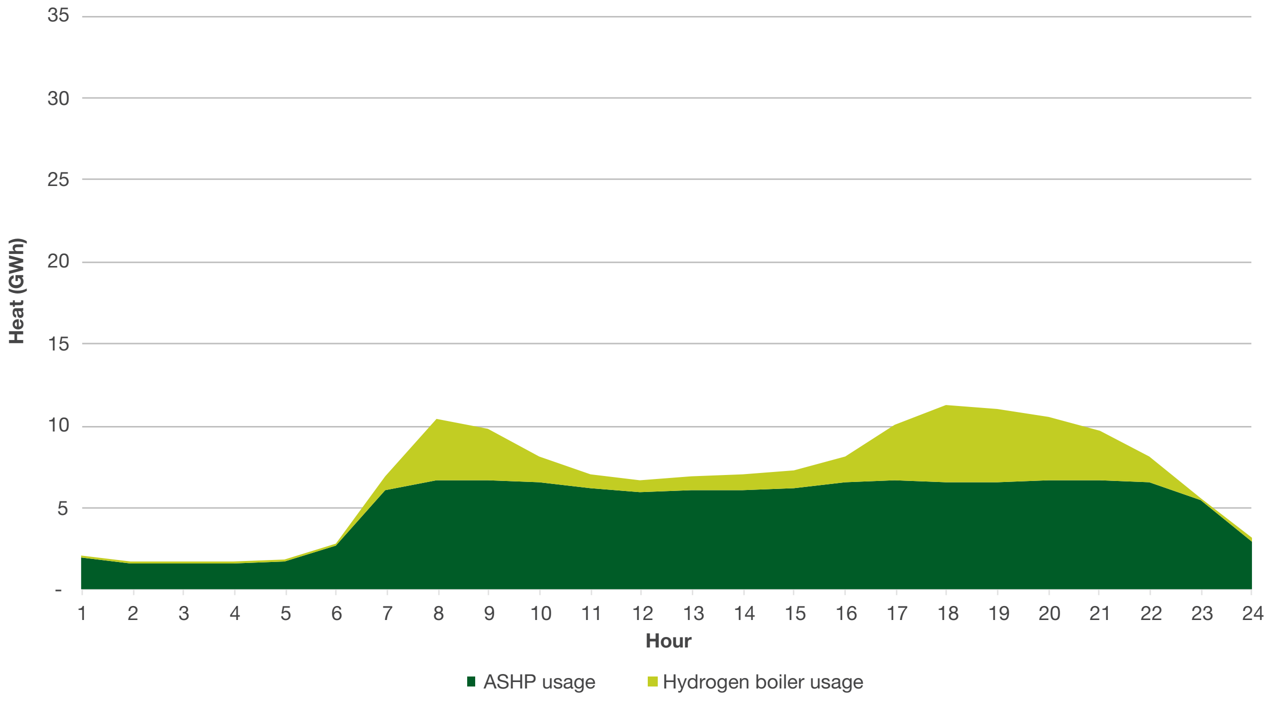


Figure CV.21: Thermal storage use on a peak day: hourly usage profiles for hybrid air source heat pumps and hydrogen boilers in Leading the Way



FES 2021 / Consumer View / Residential 85

What we've found

Figure CV.22: Thermal storage use on a peak day: hourly usage profiles for air source heat pumps and electric resistive heaters in Leading the Way

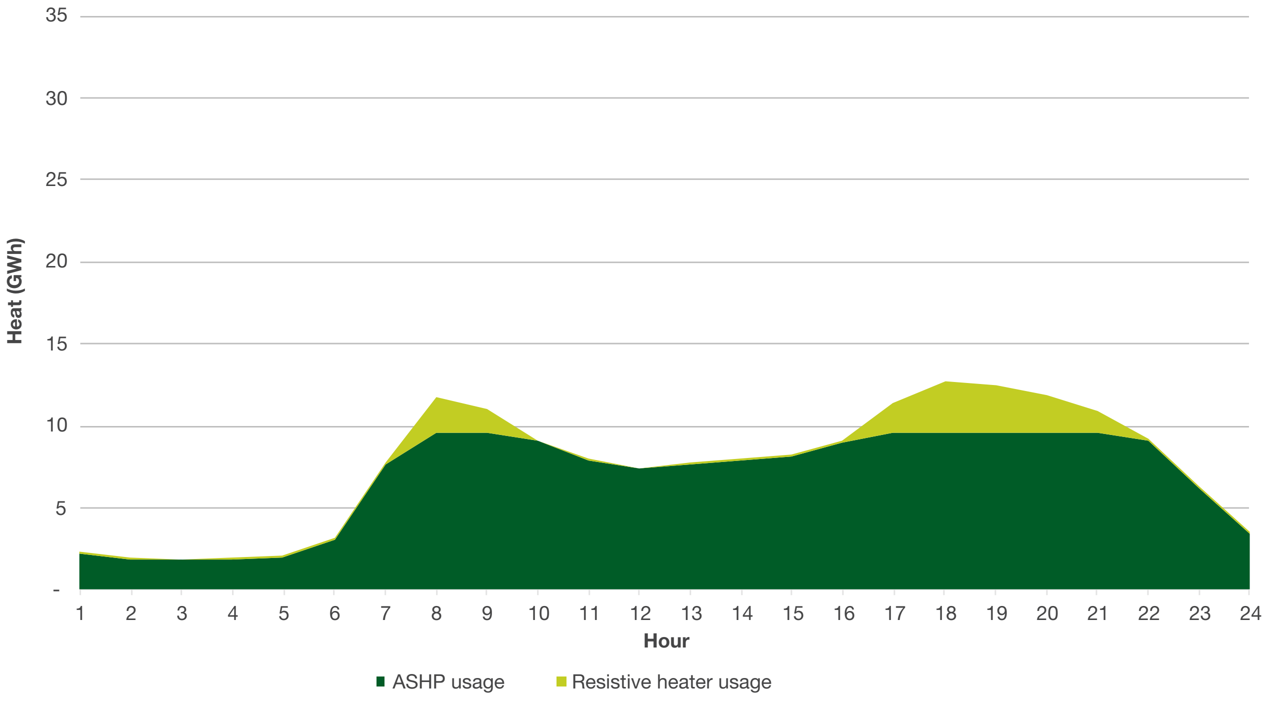
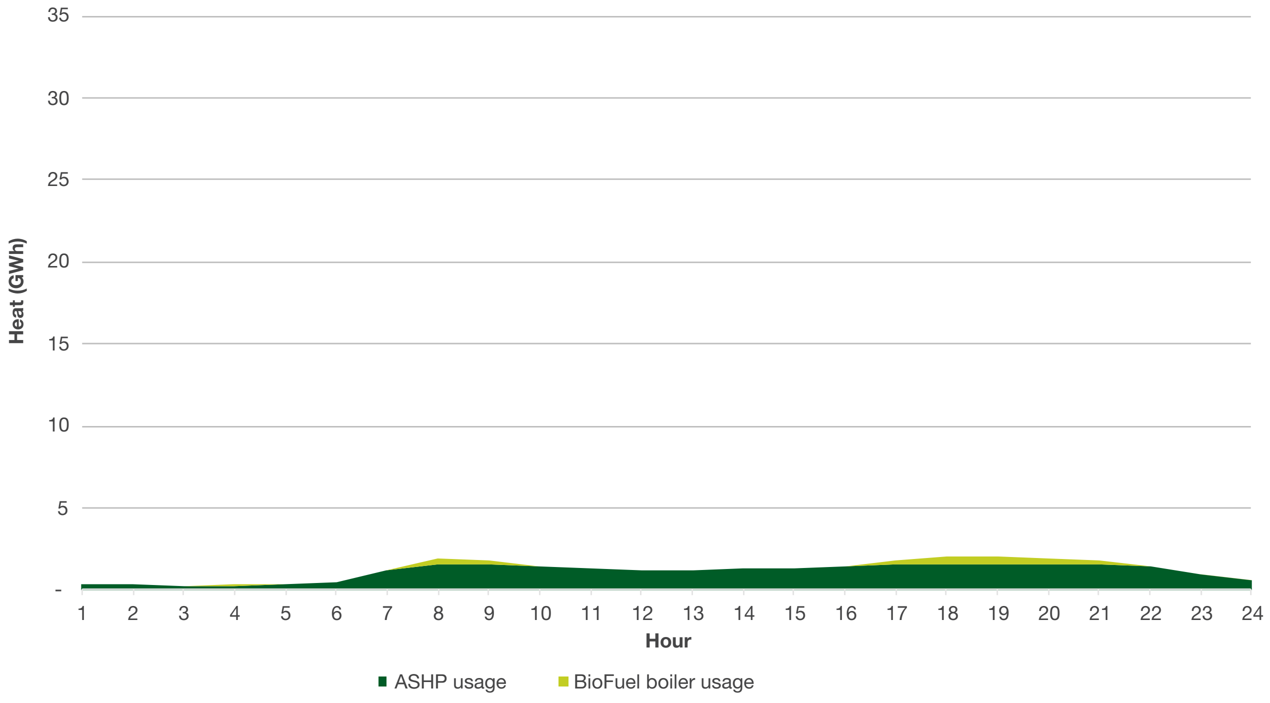


Figure CV.23: Thermal storage use on a peak day: hourly usage profiles for hybrid air source heat pumps and bioLPG boilers in Leading the Way



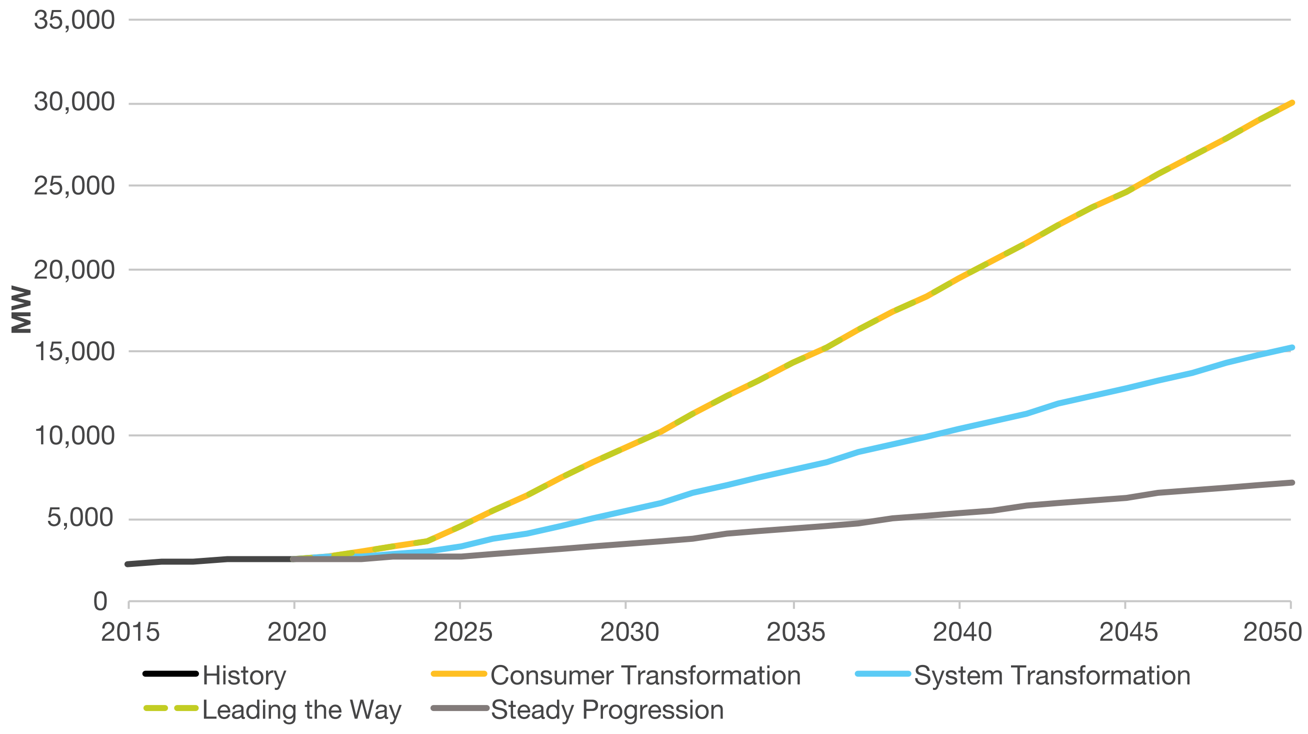
FES 2021 / Consumer View / Residential 86

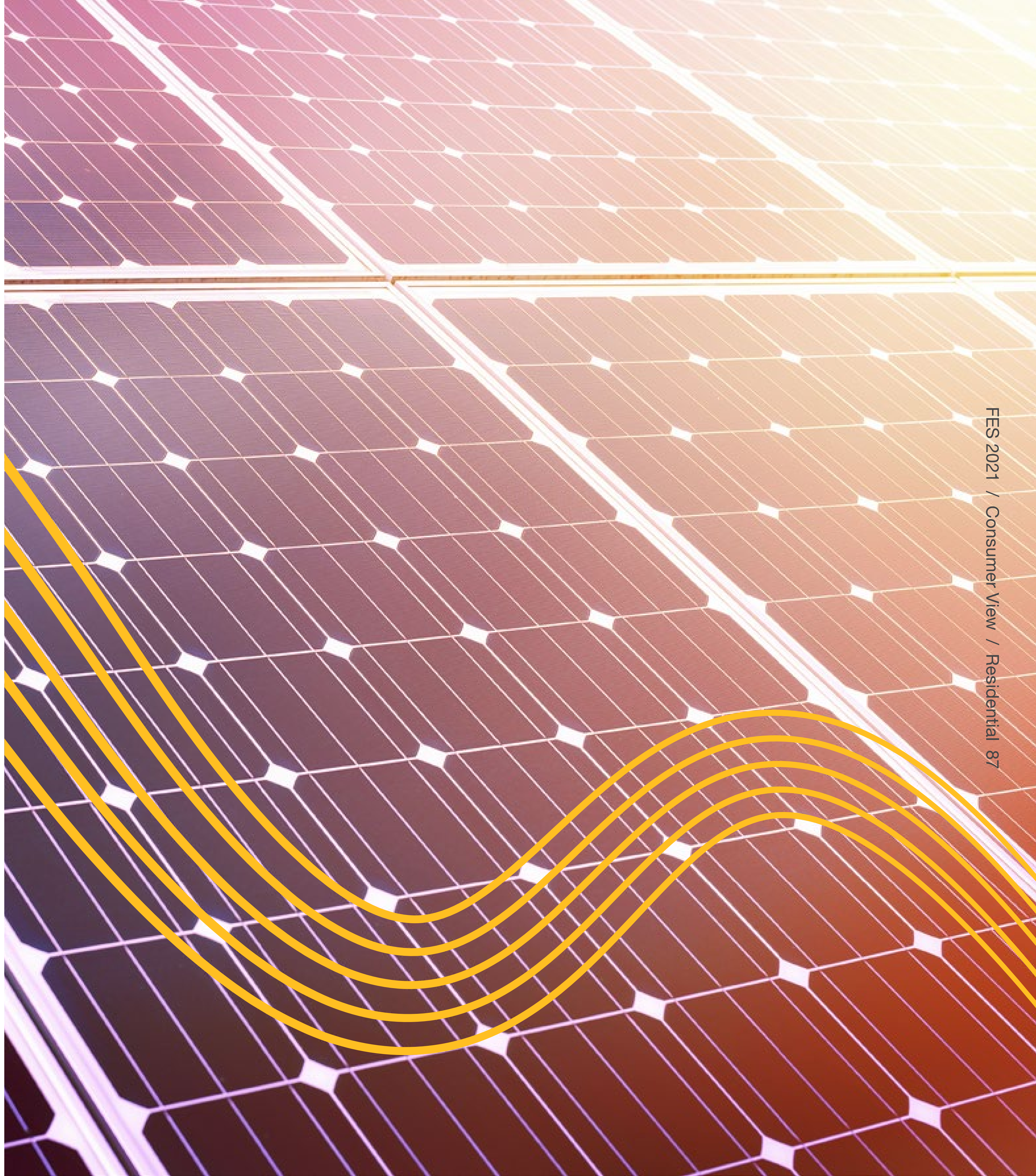
What we've found

Domestic electricity generation in the home

In all scenarios, small scale home generation increases, alongside thermal and battery storage. Consumer Transformation and Leading the Way have ten times more solar PV on rooftops by 2050 compared to today. This reflects a 912 MW (on average) increase per year over the next 29 years. Steady Progression has the lowest levels of on-site domestic generation, highlighting the low levels of consumer engagement in this scenario.

Figure CV.24: Domestic solar PV installed capacity



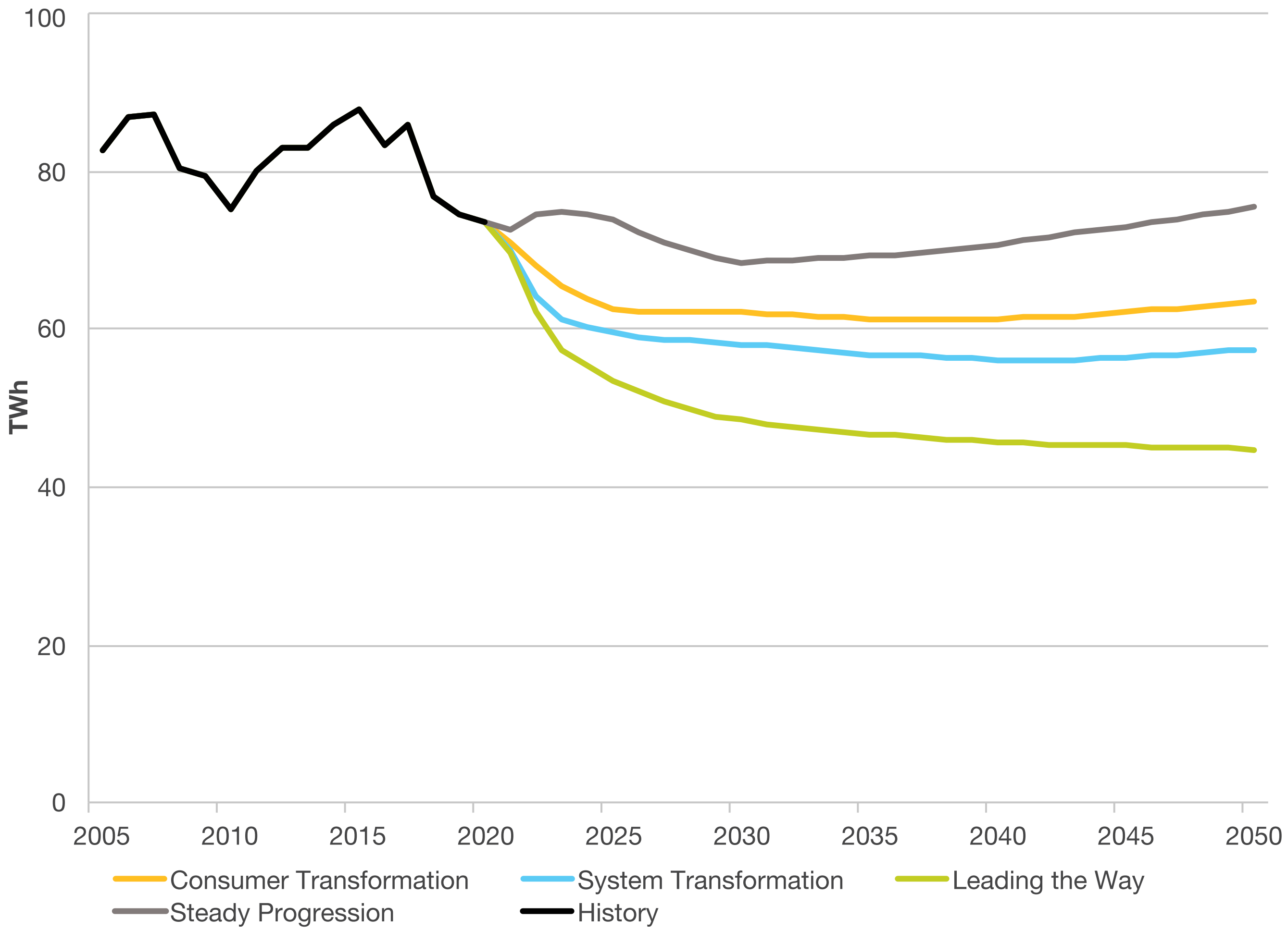


FES 2021 / Consumer View / Residential 87

What we've found

Appliances

Figure CV.25: Annual residential electricity demand for appliances



Demand from electrical appliances – ranging from white goods to computers and lighting – reduces in all net zero scenarios compared to today. This is thanks to increasing efficiency driven by international policies such as the 2018 European Union (EU) halogen ban or 2032 32% improvement to energy efficiency. In Leading the Way, consumers are highly engaged and informed, choosing to buy smart and very efficient appliances. Appliance demand is greatest in our 2050 non-compliant scenario, Steady Progression, where consumers are less engaged and have fewer efficient or smart appliances.

Consumers can flex their electricity demand by using smart appliances alongside smart meters to change consumption patterns. Read more about this in the **flexibility section**.

Smart appliances:

can reduce as well as shift demand.
For example, lights only turn on when needed and heating is more easily configurable.

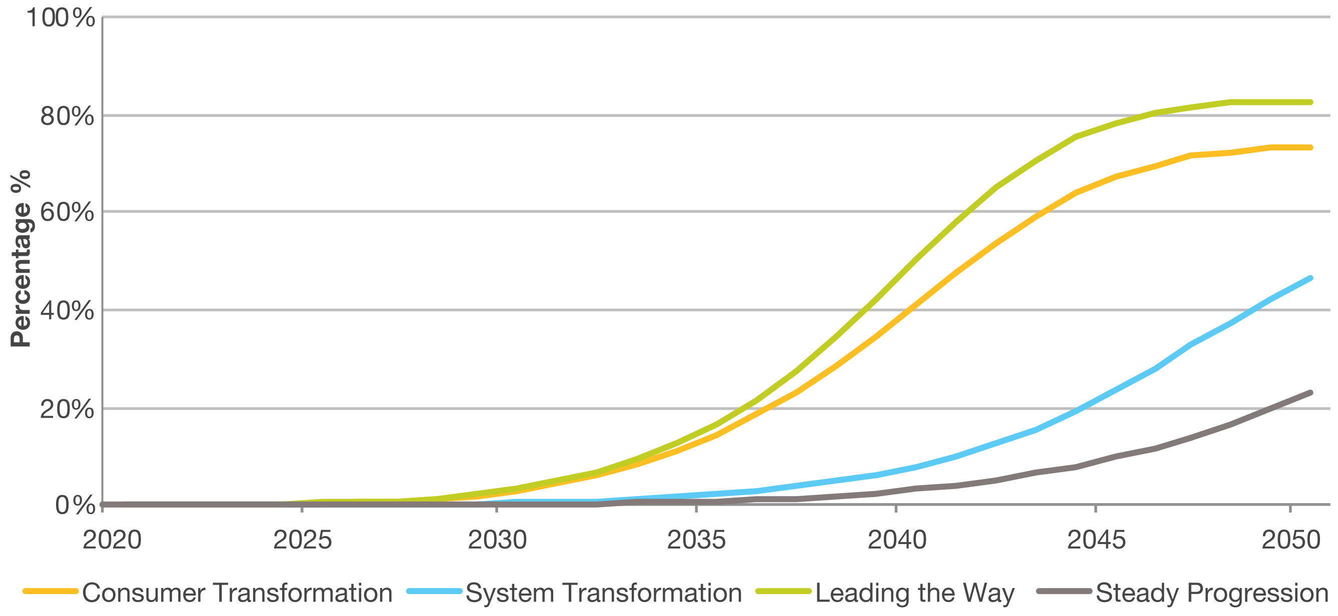
Halogen ban

Household lighting currently accounts for around 15% of electricity demand. Incandescent bulbs are around 10% efficient, with the rest lost to waste. Halogen bulbs are three times more efficient, but they still use large amounts of energy, and have fairly short lifespans of around two years. They were banned by EU legislation in 2018 although some consumers might have stockpiled before the ban. Light Emitted Diode (LED) lightbulbs convert over 90% of their energy into light and can last for over 20 years.

FES 2021 / Consumer View / Residential 88

What we've found

Figure CV.26: Smart appliance uptake in each scenario



FES 2021 / Consumer View / Residential 89

Transport

Key insights

- Even in the slowest decarbonising scenario, no new cars with internal combustion engines will be sold after 2040, including Plug-in Hybrid Electric Vehicles (PHEVs). This means all cars on the road will be ultra-low emission by 2050 at the latest, resulting in at least a 60% reduction in energy demand for road transport compared to today.
- System Transformation has 7.5 times more hydrogen cars, vans and lorries compared to our other net zero scenarios. Other modes of domestic and international transport, such as aviation and shipping, use hydrogen and bioresources to some extent in all net zero scenarios.
- As more consumers start to own Battery Electric Vehicles (BEVs), smart charging and Vehicle-to-Grid (V2G) uptake will increase helping to manage higher renewable supplies on the electricity system. This combined flexibility could lead to up to 32 GW of peak shaving in Consumer Transformation by 2050.
- It's essential consumers are encouraged to change their consumption patterns through appropriate Time of Use Tariffs (TOUTs), while protecting vulnerable consumers. We assume that the trigger point for residential consumers moving to dynamic tariffs is getting an EV. In Leading the Way over 80% of consumers engage in smart charging, and 45% in V2G services.

Peak Shaving

Reductions in electricity demand during times of peak electricity usage. Currently this is typically between 5pm-7pm.

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.

FES 2021 / Consumer View / Transport 91

Key insights

Figure CV.27: Total annual demand for road transport in 2050[1]

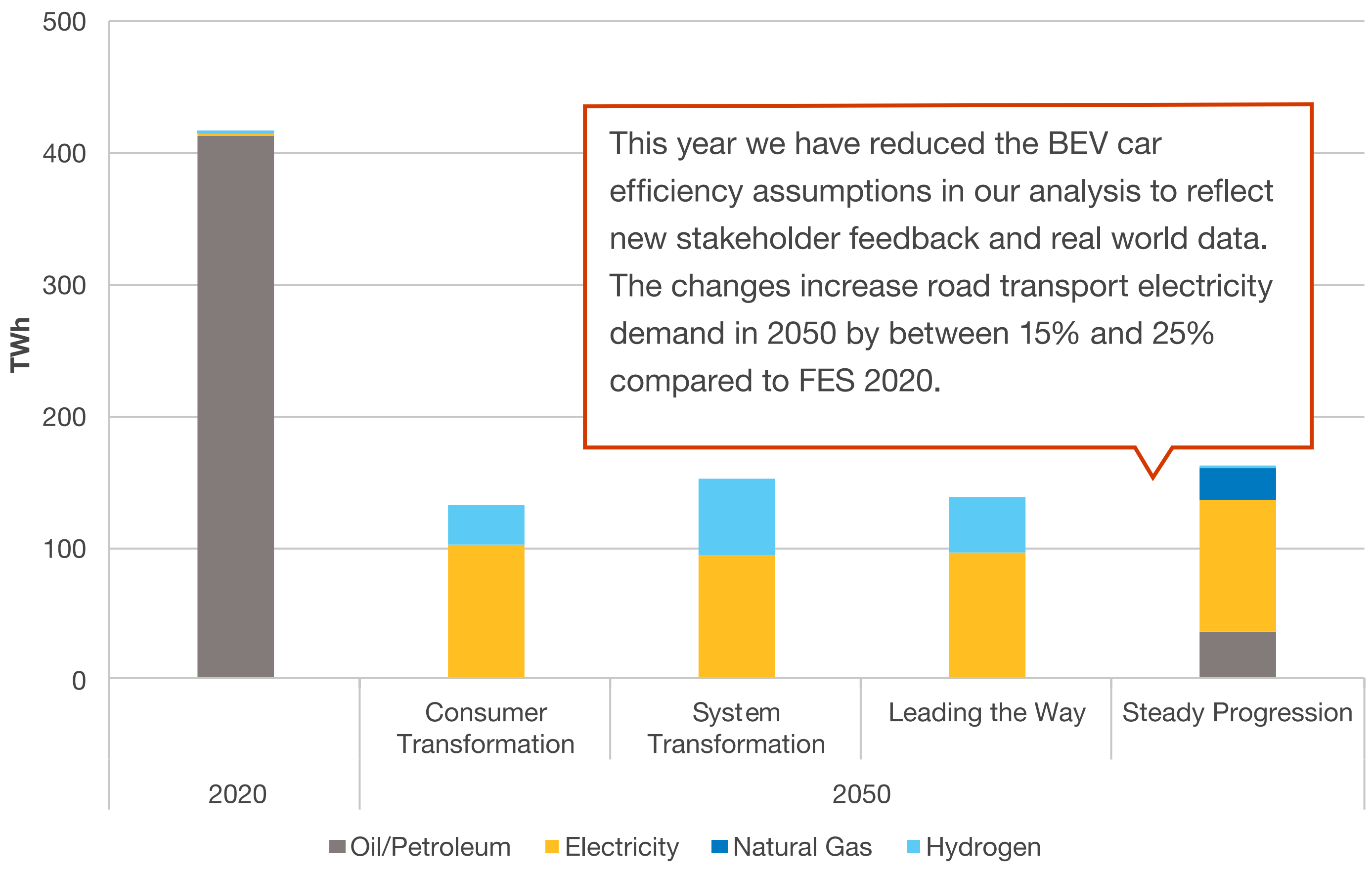
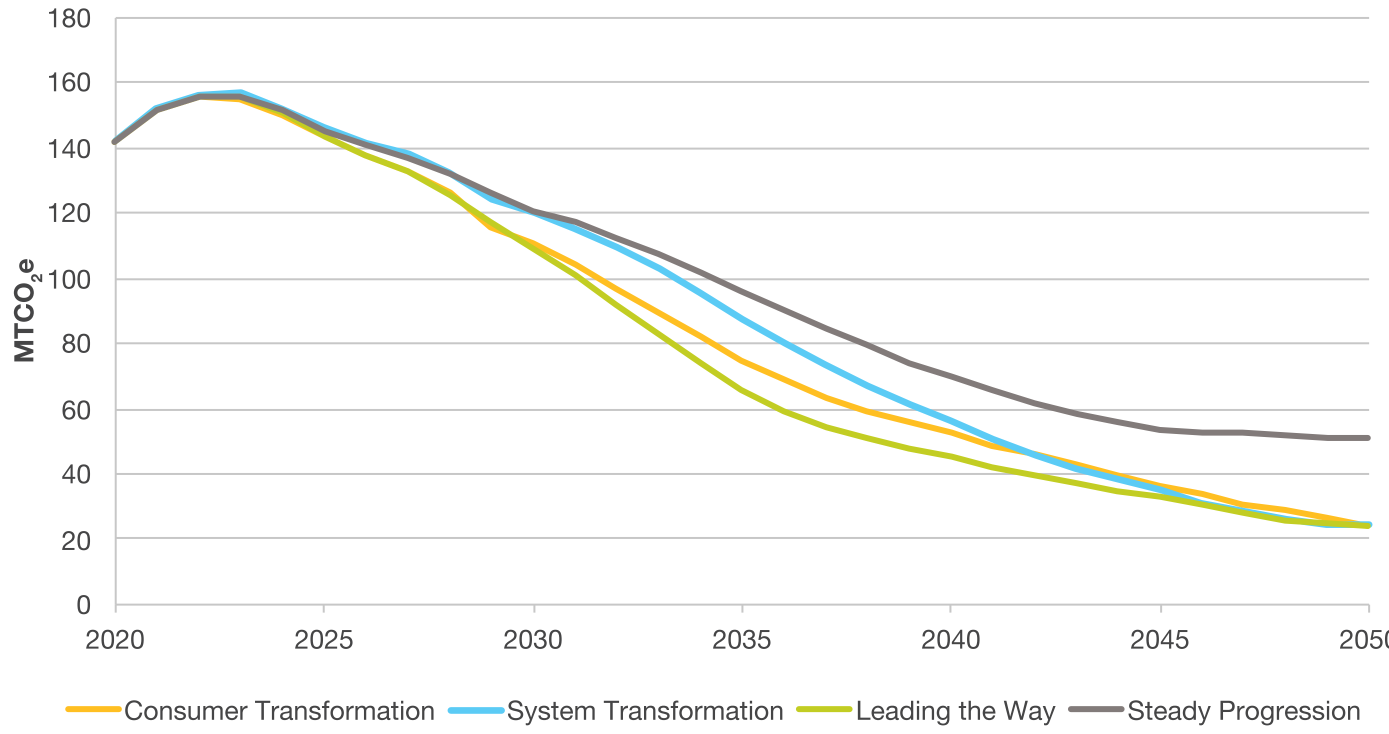


Figure CV.28: Emissions from road transport, rail, aviation and shipping



1 Energy demand figures 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 energy conversion, transport and storage losses, this will always be larger than the demand from end consumers.

FES 2021 / Consumer View / Transport 92

Where are we now?

The road transport sector used over 400 TWh of energy in 2020, equivalent to 113 $MtCO_2e$. This accounts for 30% of total energy demand in Great Britain (GB)[2] and 23% of the UK's greenhouse gas emissions.

Recent government policy has included bringing forward the ban on petrol and diesel car and van sales to 2030 (2035 ban of PHEVs) in the Ten Point Plan for a Green Industrial Revolution, as well as £1.3 billion to accelerate the roll-out of EV charge points.[3]

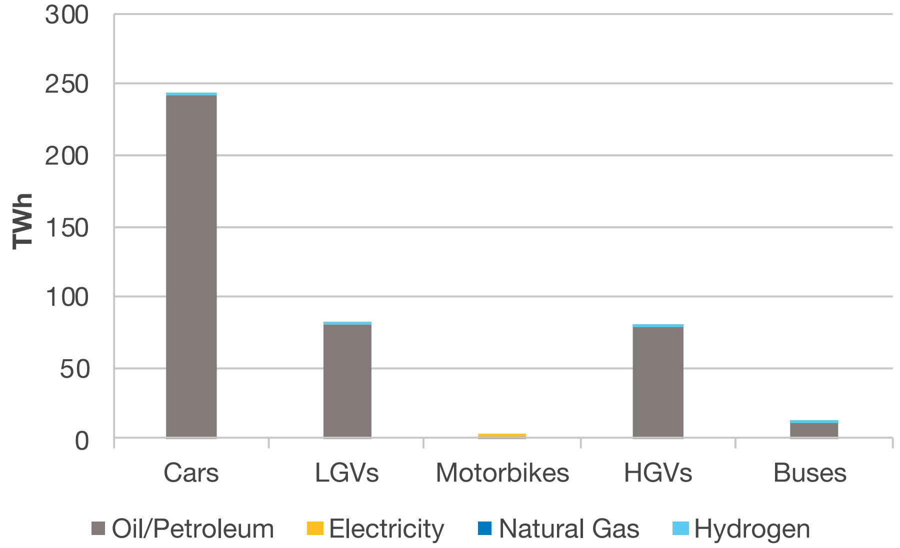
As noted by the Climate Assembly, future policy developments in this area will need to carefully consider accessibility and cost, addressing the potentially adverse impacts of future schemes on rural areas, people with disabilities and those on low incomes.[4]

The extent of the nationwide electricity charging network will also be a crucial element of this since not all consumers will have access to an EV home charge point. Therefore an extensive EV charging network - distributed fairly across urban and rural areas of GB - will ensure that those who can't charge at home have options to readily charge their vehicle whenever required. Widespread availability of EV chargepoints may also encourage consumers to purchase EVs rather than hybrids for longer journeys where they can easily recharge their car en route.

Transport
includes cars, vans, buses and HGVS, which mainly use fossil fuels for internal combustion engines (ICE).

We also consider the impact of rail, aviation, and shipping in achieving net zero emissions.

Figure CV.29: Total demand for road transport in 2020



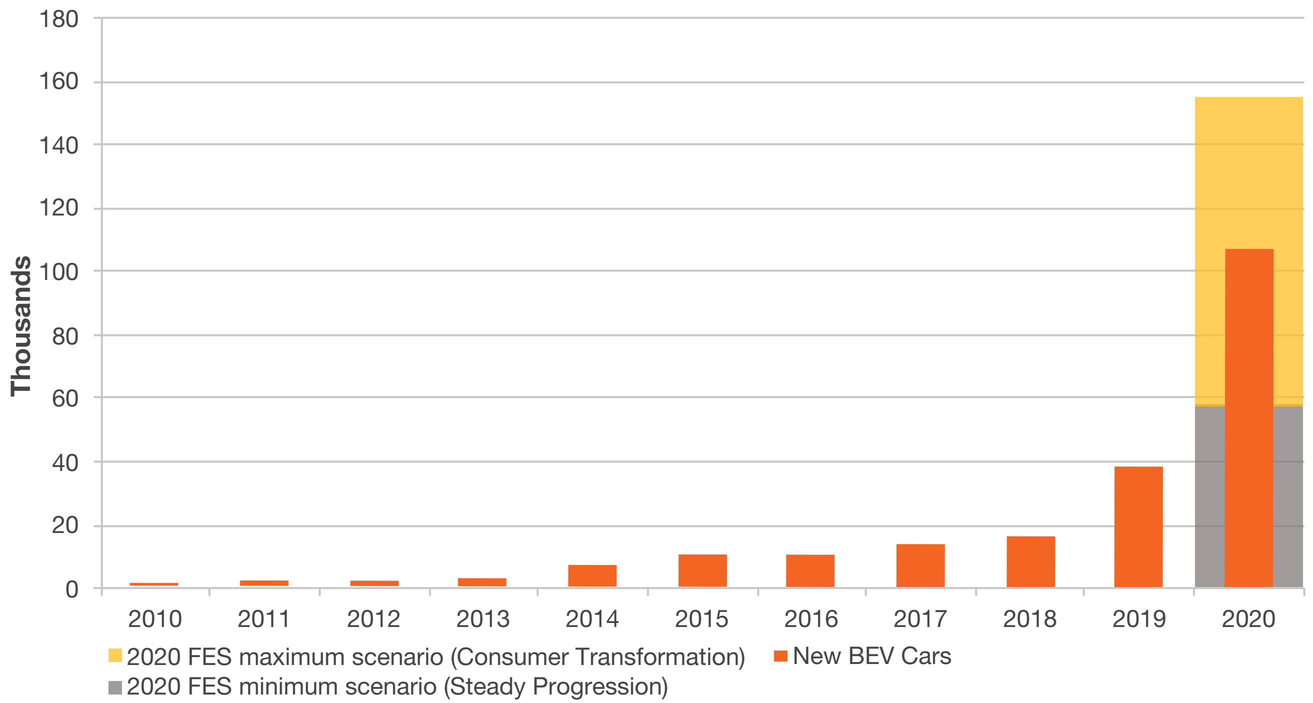
Other forms of transport, including rail, aviation and shipping also need to embrace decarbonisation.

Currently, 40% of the UK's rail network is electrified, with the rest reliant on diesel trains. Aviation and shipping rely solely on fossil fuels. In 2018, shipping accounted for 3% of UK greenhouse gas emissions, and aviation 7%.[5] Both are complex in terms of carbon accounting due to their international nature. See our net zero thought piece for more information. There is already a government policy target to remove diesel trains by 2040. The UK Government has also recently committed £20 million of funding to support the design and development of clean maritime technology and £15 million to fund the production of sustainable aviation fuels in the UK.[6]

2 Whilst modelling in FES is based on GB energy demand and supply, in some areas (such as emissions and economic growth) it is necessary to talk in terms of the UK.
3 Ten point plan for a green industrial revolution 2020 - https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution
4 Climate Assembly 2020 - climateassembly.uk/report/read/final-report.pdf
5 Committee on Climate Change (CCC) Sixth Carbon Budget - https://www.theccc.org.uk/publication/sixth-carbon-budget/
6 BEIS Energy White Paper - https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

Where are we now?

Figure CV.30: Sales of battery electric vehicle cars compared to our FES 2020 maximum and minimum scenario ranges[7]



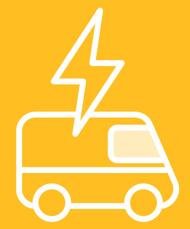
Despite the pandemic, last year saw an increase in the number of BEV sales compared to previous years and fell within the credible range of our scenarios. This pace will need to be accelerated further though to reach net zero emissions by 2050.

Vehicle manufacturing trends and markets

The strategic direction of automotive manufacturing is driven by government policy, legislation and consumer demand for cars. Uncertainty over fuel technologies has previously led many manufacturers to hedge their bets, simultaneously developing fuel cell electric vehicle (FCEV) and BEV prototypes in the absence of any definite market signal.

Today, BEVs dominate the strategies of most car manufacturers. There is a great deal of uncertainty around how or when the BEV second hand car market will grow in the UK. We expect this to be closely related to the average time people keep their cars for, before replacing it with a new or second hand vehicle. Today, typical car lease and financing deals are between 3 to 5 years.

In the commercial vehicle sector (light goods vehicles, buses and coaches), steadily growing demand for home delivery alongside increasing legislation and consumer awareness of environmental impacts has driven heavy investment in electrification. This sector has significant potential to reduce total vehicle emissions as commercial customers tend to order fleets of vehicles at a time.



7 Data from: DfT and DVLA VEH253: https://www.gov.uk/government/statistical-data-sets/veh02-licensed-cars

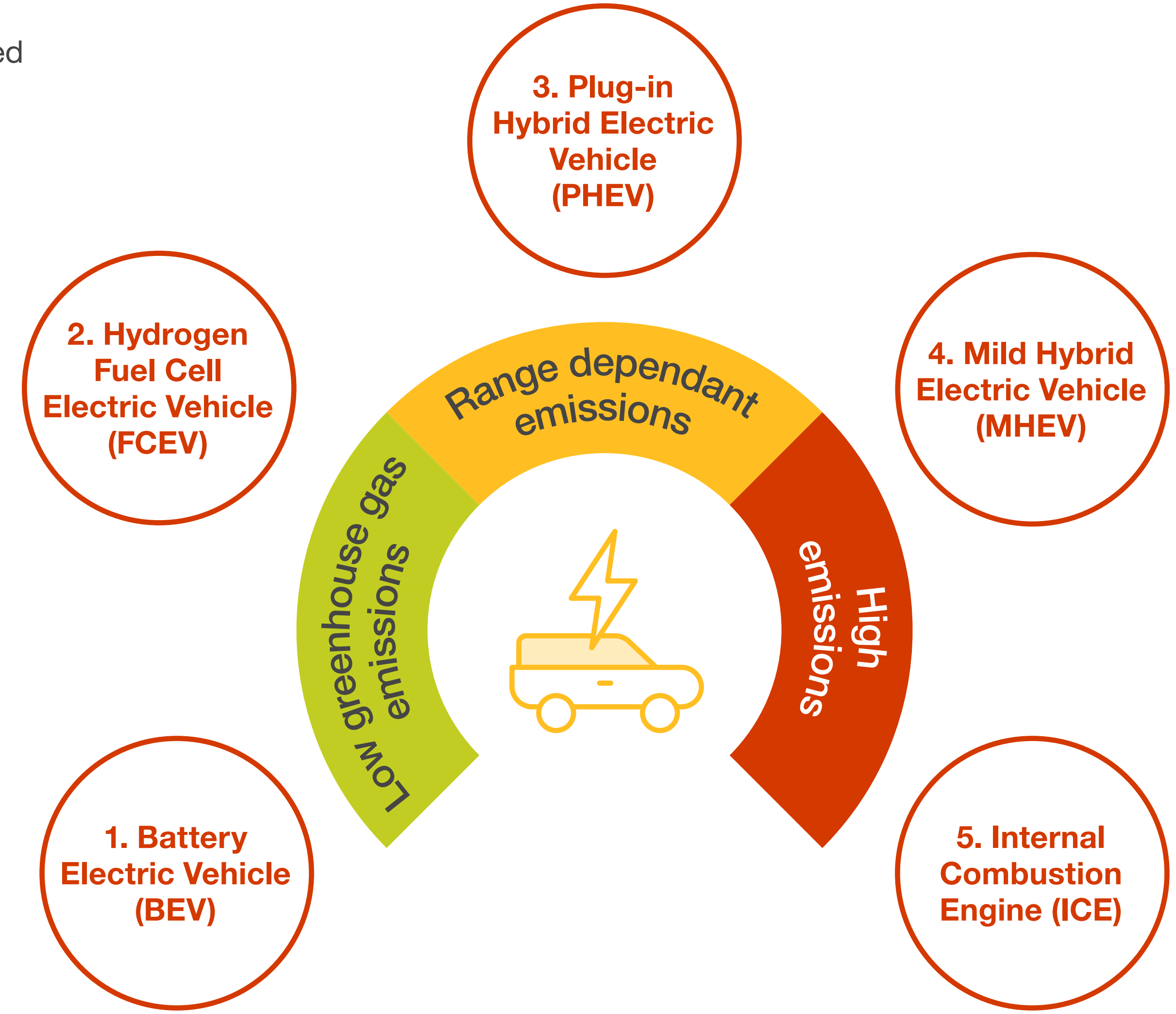
FES 2021 / Consumer View / Transport 94

Types of car available to consumers

3 Plug-in Hybrid Electric Vehicle (PHEV)
- ICE and battery both able to power the vehicle alone
- Can charge from mains, and have ranges of between 20 to 40 miles

2 Fuel Cell Electric Vehicle (FCEV)
- Hydrogen from a tank is combined with oxygen to make electricity
- Zero carbon/ghg emissions
- Approximate range of over 300 miles per tank
- Availability of these cars is not currently as widespread as BEVs

4 Mild Hybrid Electric Vehicle (MHEV)
- Cannot operate with zero emissions.
- Battery assists Internal Combustion Engine (ICE) engine to reduce fuel consumption and emissions



1 Battery Electric Vehicle (BEV)
- Powered solely by batteries and electric motors
- Zero emissions
- Up to 280 mile range
- 0.5-12 hour charge time

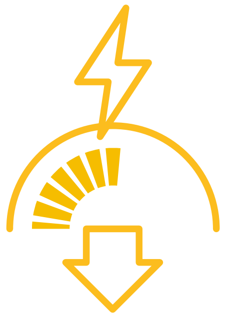
5 Internal Combustion Engine (ICE)
- Petrol or diesel
- High emissions
- Newer ICE vehicles have significantly lower emissions than older ones

FES 2021 / Consumer View / Transport 95

What we've found

Routes to decarbonisation

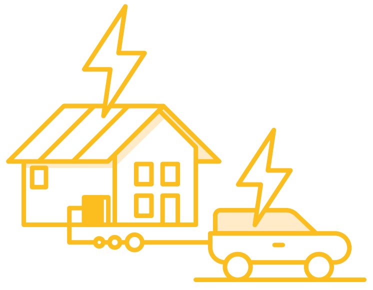
To decarbonise by 2050, all sectors of transport will need:



Demand reductions

The lower the demand, the less low carbon energy we need to produce. This includes:

- Investment in energy efficient vehicles and changing consumer behaviour. For example, sharing electric taxis, walking or reducing the number of cars per household and cycling more



Flexibility

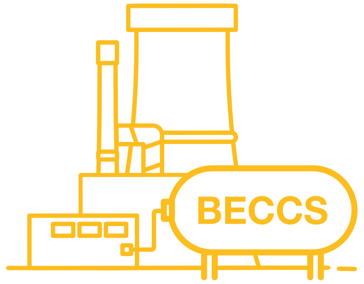
Flexibility allows the electricity system to be more efficient in managing demand and supply with low carbon generation. Examples include:

- Incentives for consumers with BEVs to charge their cars at off-peak times
- Use of V2G technology to charge at times of high renewable output and supply power back to the network when required

Low or zero carbon technology

This allows us to benefit from decarbonised electricity and new sources of fuel such as:

- Electricity for cars and vans
- Hydrogen for lorries
- Hydrogen for shipping and aviation (in the form of ammonia or synthetic fuels)



Offsetting emissions

This is essential in the hard-to-decarbonise areas such as aviation. Examples of greenhouse gas removal (GGR) solutions include:

- Using negative emissions technologies such as Direct Air Carbon Capture and Storage (DACCS) or Bioenergy with Carbon Capture and Storage (BECCS)
- Afforestation and reforestation

Consumers will need to be kept informed of these options and incentivised to change their behaviour, the vehicle they drive and when they charge it to meet net zero by 2050.

FES 2021 / Consumer View / Transport 96

Modelling information

Our modelling for road transport (cars, vans, buses, and heavy goods vehicles (HGVS)) is based on:

- Energy efficiency of vehicles
- Miles driven
- Use of public transport
- Sales of low carbon vehicles.

For rail:

- We refer to Government policy such as the pledge to remove all diesel-only trains by 2040

For aviation and shipping we refer to the Climate Change Committee's (CCC) scenarios in its Sixth Carbon Bugdet:

- For shipping, we broadly align to the CCC's Balanced Pathway scenario for Consumer Transformation and System Transformation, and its Widespread Innovation scenario for Leading the Way
- For aviation, we align all net zero scenarios to the CCC's Balanced Pathway
- We have included all fuels for domestic journeys, as well as any fuels stored and used to refuel international journeys

For further information, see the modelling methods document.

FES 2021 / Consumer View / Transport 97

Scenarios overview: road transport

Consumer Transformation

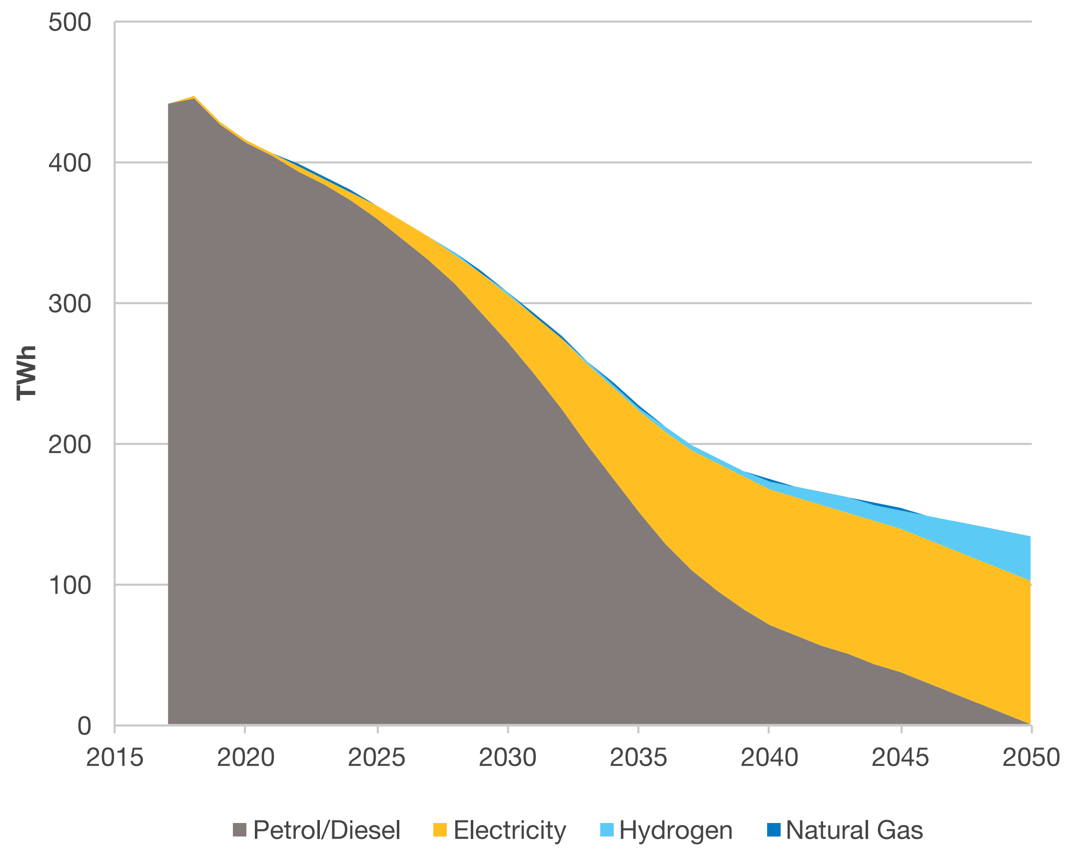
The route to 2050

- 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 electric vehicles (PHEV) from 2035.
- By the mid-2030s, uptake of hydrogen lorries begins to increase. This is accompanied by a similar increase in electric lorries.
- Smart charging of BEVs is widespread from the 2040s to help balance the local and national networks.

What does 2050 look like?

- Total demand for road transport in 2050 is 133 TWh. This is the scenario with the lowest demand, using minimal amounts of hydrogen. Most forms of road transport use electricity.
- Hydrogen use in this scenario is mainly for HGVs, which rely on regional refuelling infrastructure, since there is no national hydrogen network in this scenario.
- Most privately owned BEV cars are used to support the grid with 25% of households providing flexibility via vehicle-to-grid (V2G) services.

Figure CV.31: Annual energy demand for road transport in Consumer Transformation



FES 2021 / Consumer View / Transport 98

Scenarios overview: road transport

System Transformation

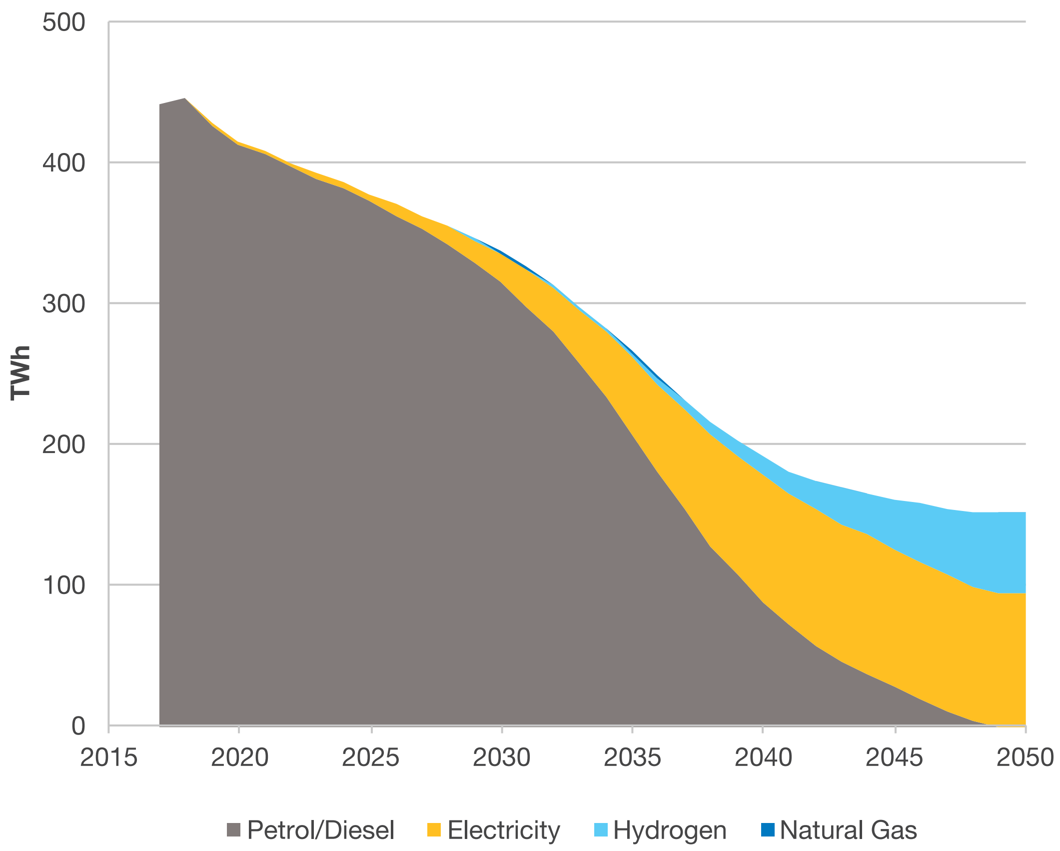
The route to 2050

- 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 the national refuelling network develops in to the 2040s.

What does 2050 look like?

- Total demand for road transport in 2050 is 153 TWh.
- This is our highest net zero scenario road transport demand, in part due to the higher uptake of hydrogen vehicles – reaching over three million HFCVs – 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.
- This scenario has high numbers of autonomous vehicles (AVs) (5.9 million), with many consumers investing in them for private use.

Figure CV.32: Annual energy demand for road transport in System Transformation



FES 2021 / Consumer View / Transport 99

Scenarios overview: road transport

Leading the Way

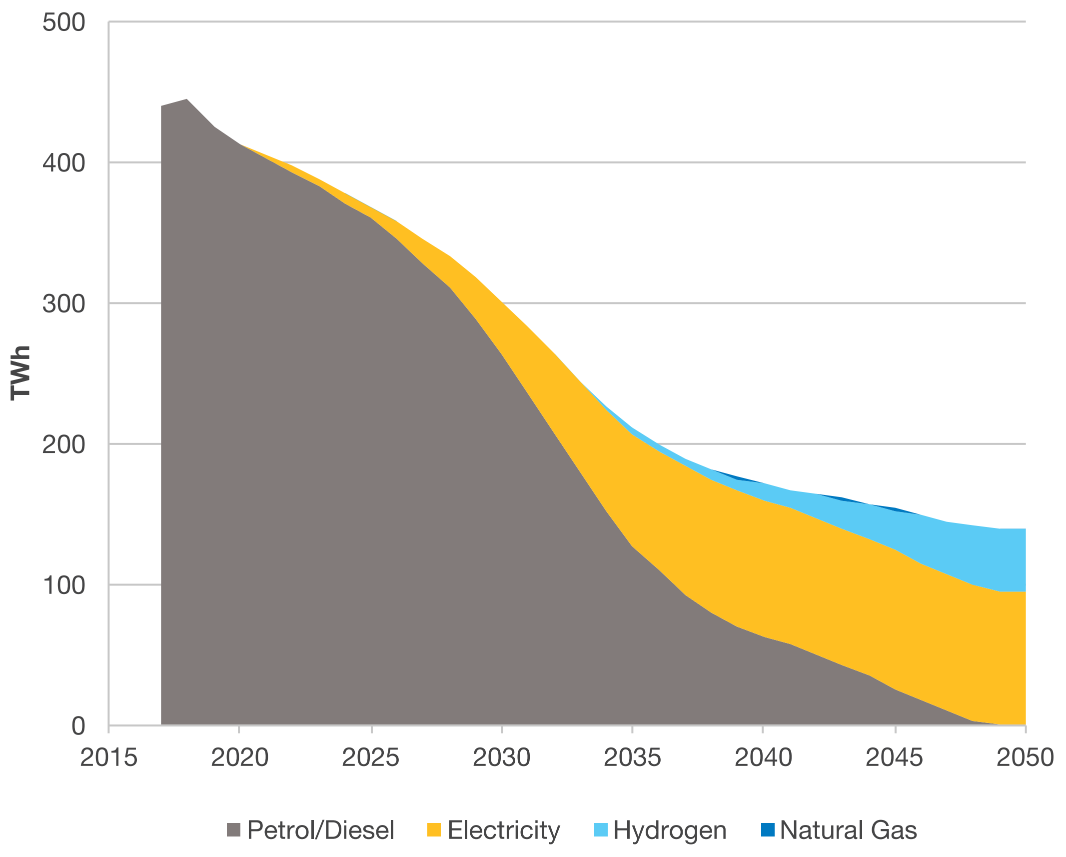
The route to 2050

- 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.
- Cars and vans are mainly electric, supported by the widespread national rollout of charging infrastructure, as well as smart charging devices at home.
- HGVs begin to use hydrogen from the mid-2030s, with some using electric batteries.

What does 2050 look like?

- Total demand for road transport in 2050 is 139 TWh.
- BEV cars and vans 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. This is reflected in the relatively low numbers of AVs in this scenario (1.8 million) compared to the miles driven (90,500 miles).
- BEV cars smart charge at home or at the office, frequently paired with on-site solar PV and batteries to encourage self-consumption.

Figure CV.33: Annual energy demand for road transport in Leading the Way



FES 2021 / Consumer View / Transport 100

Scenarios overview: road transport

Steady Progression

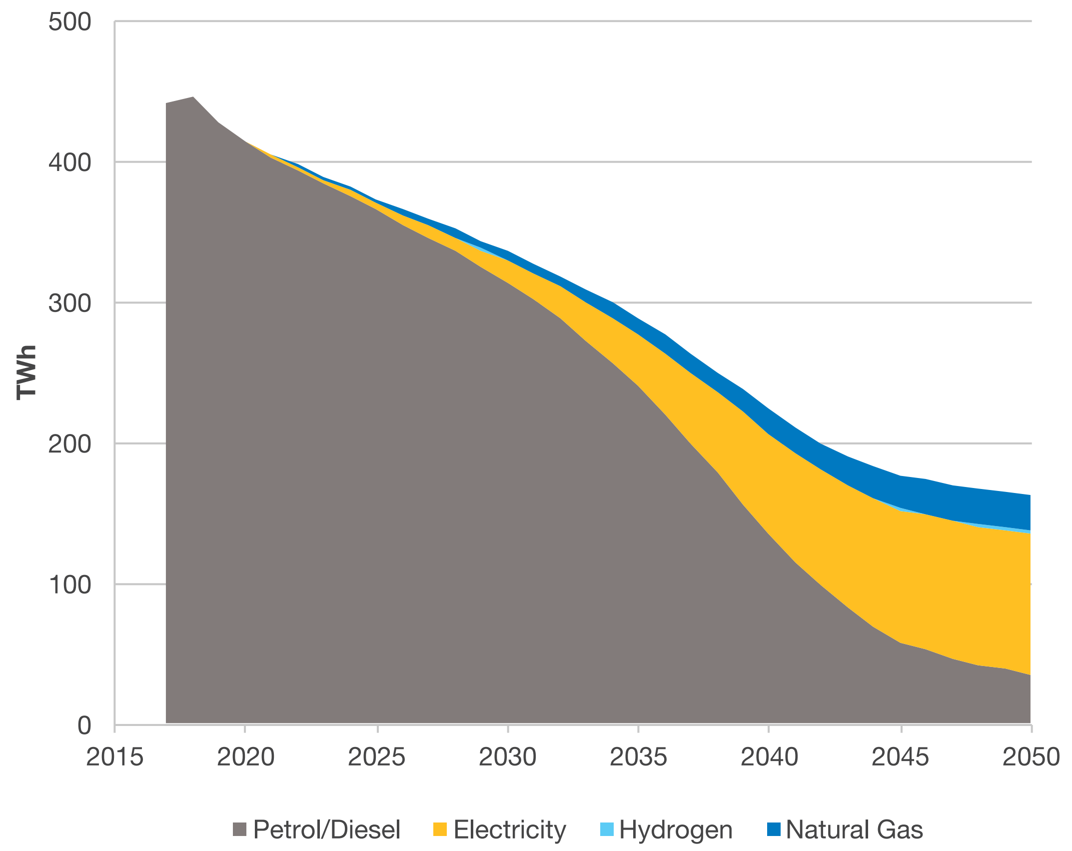
The route to 2050

- From the 2020s, natural gas becomes the dominant alternative fuel for buses and HGVs.
- 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 AVs on the road. They increase in availability and popularity throughout this decade.
- Some buses are electrified by the 2040s, supported by limited government policy.

What does 2050 look like?

- Total demand for road transport in 2050 is 163 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 CV.34: Annual energy demand for road transport in Steady Progression



FES 2021 / Consumer View / Transport 101

What we've found

Battery electric vehicle cars and vans

In 2020 the Government brought forward its 2035 petrol and diesel ban for cars and vans to 2030. As our modelling in last year's FES was already ambitious, we have only seen a small change in the speed of uptake for BEVs on the road in our scenarios. It's so far unclear what will happen to the second hand, and new, car market after these bans occur.

Figure CV.35: Number of BEV cars on the road

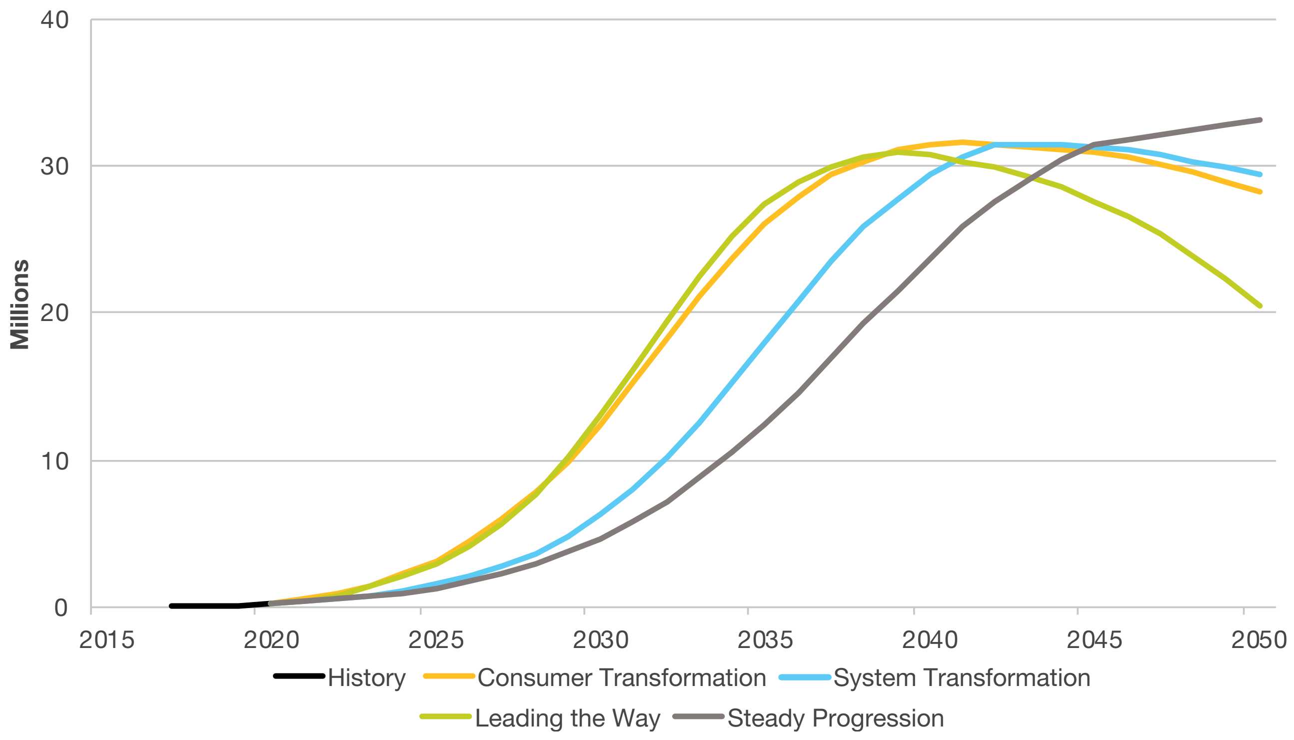
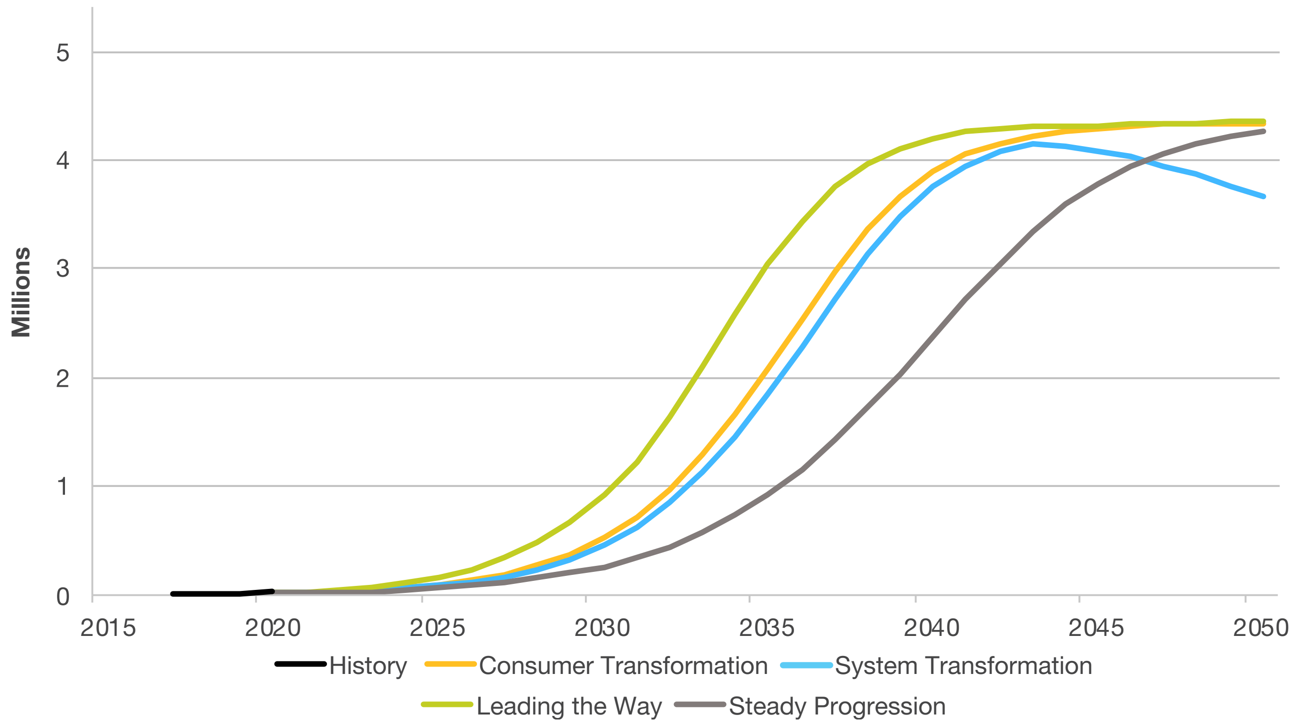


Figure CV.36: Number of BEV vans on the road



FES 2021 / Consumer View / Transport 102

Low carbon lorries

Lorries are integral to the transport of goods nationally and internationally. Currently, they run on petrol or diesel, emitting around 17% of emissions from the transport sector in 2019. There is a high degree of uncertainty surrounding the speed of decarbonisation for this sub-sector and our scenarios show various mixes of hydrogen and electricity.

We are expecting new legislation to ensure that lorries are fully decarbonised by 2050. This could be in the form of ICE bans or caps on carbon emissions. The National Infrastructure Commission has previously suggested that a 2040 diesel new sales ban for HGVs would be appropriate.[8]

Figure CV.37: Number of electric (BEV) HGVs on the road

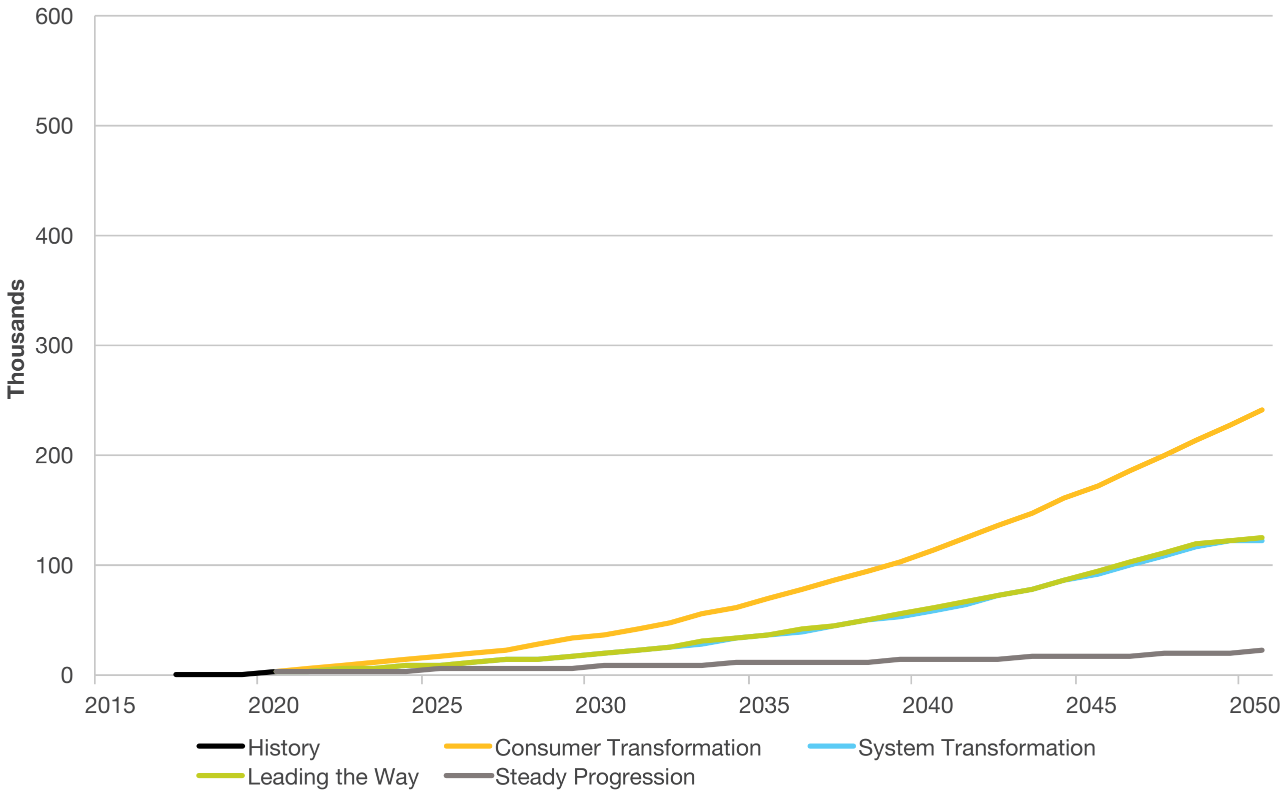
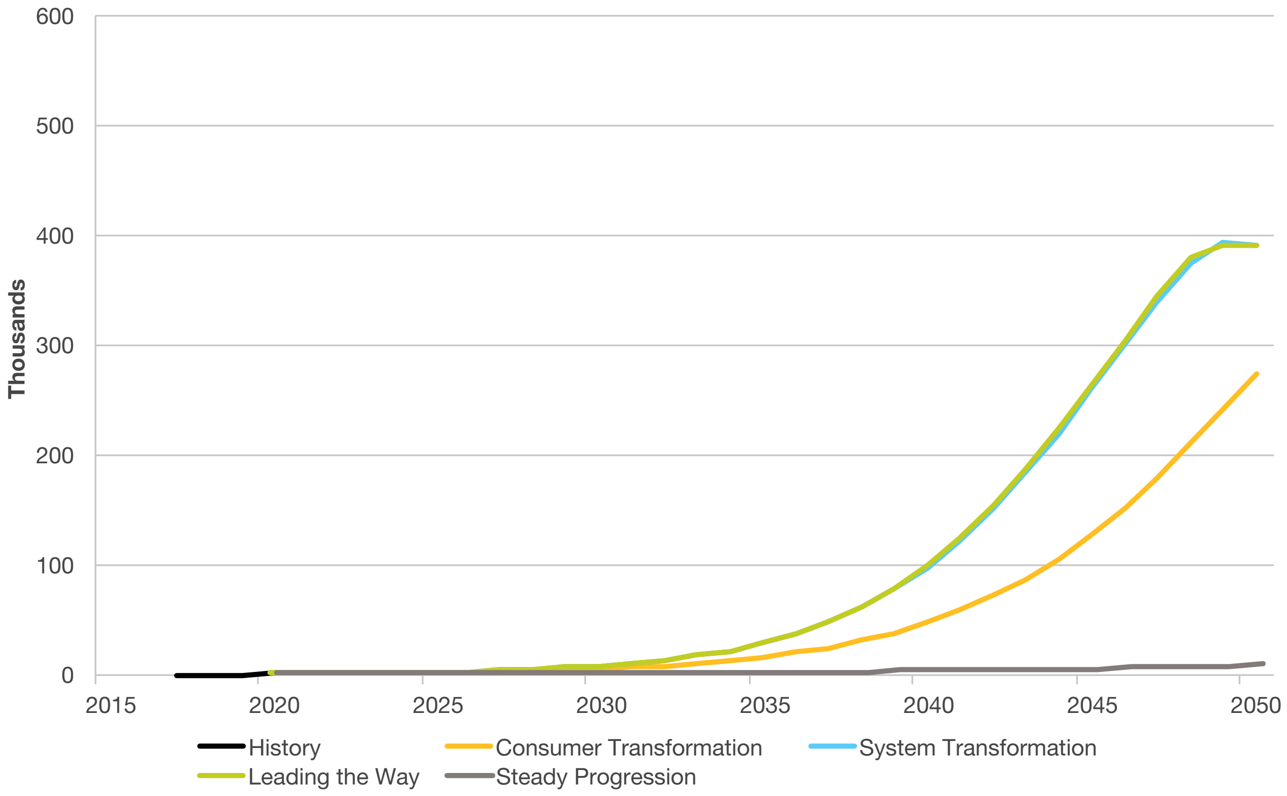


Figure CV.38: Number of hydrogen HGVs on the road



8 NIC 2019 Better Delivery: the Challenge for Freight - https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

What we've found

Figure CV.39: Number of natural gas HGVs on the road

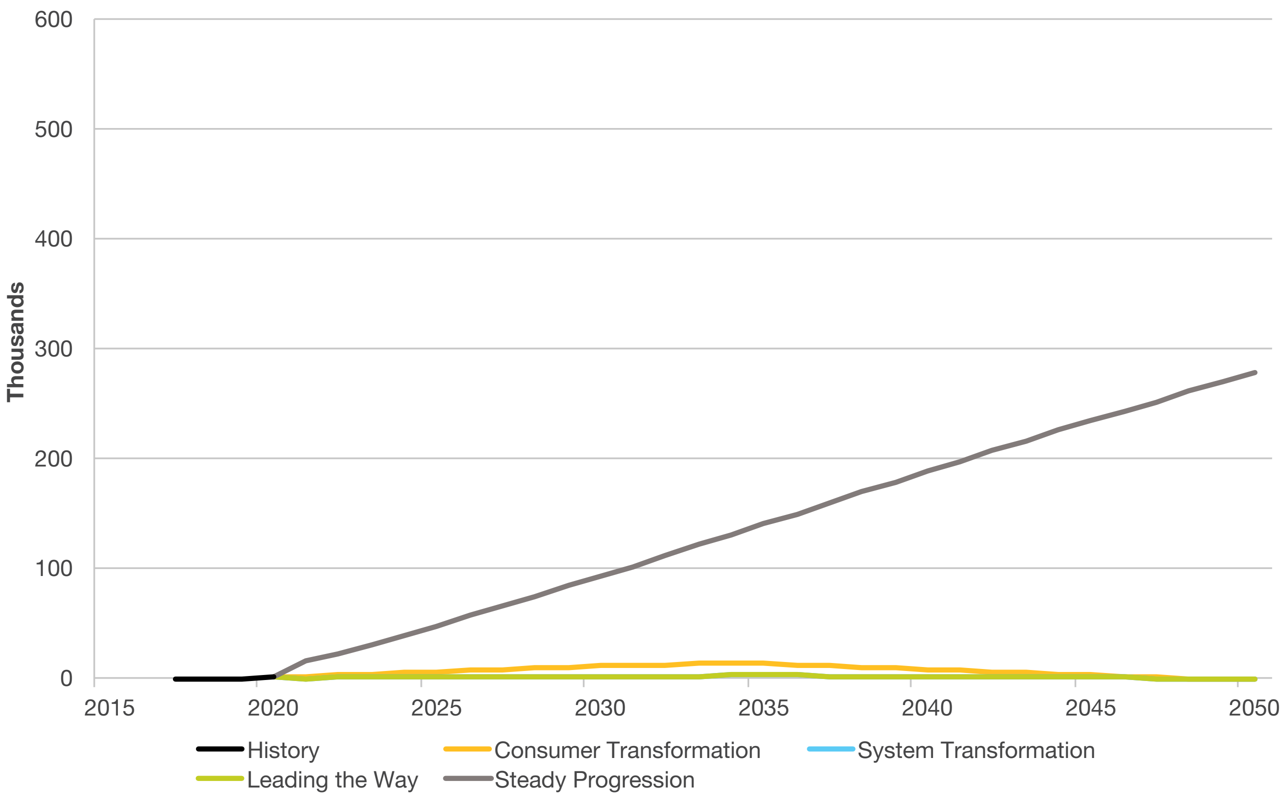
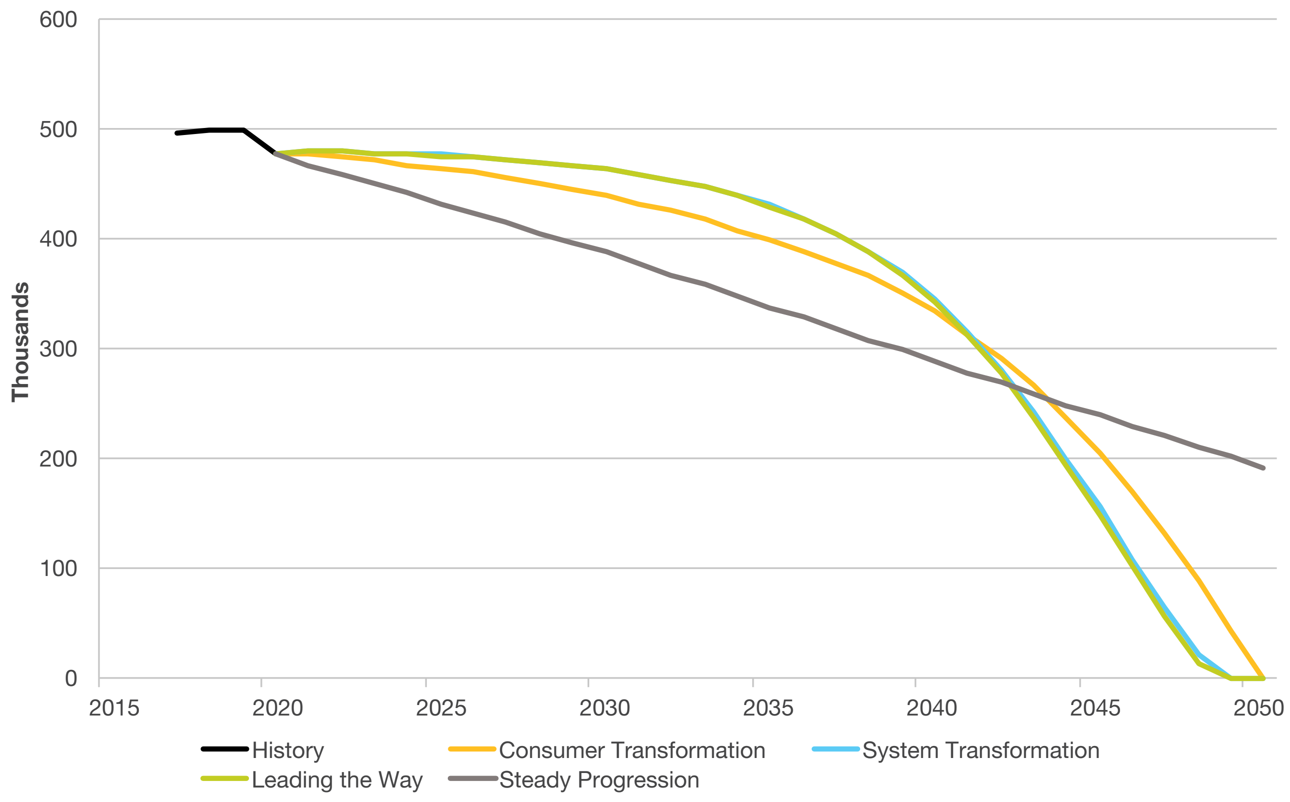


Figure CV.40: Number of petrol/diesel HGVs on the road



FES 2021 / Consumer View / Transport 104

What we've found

Smart charging and Vehicle-to-Grid

Smart charging, where EV owners release some control on the best time to charge to third parties or automation based on price signals, will be an effective tool to support the local and national electricity networks. This is shown in Leading the Way in particular, which has over 80% of consumers engaged in smart charging by 2050.

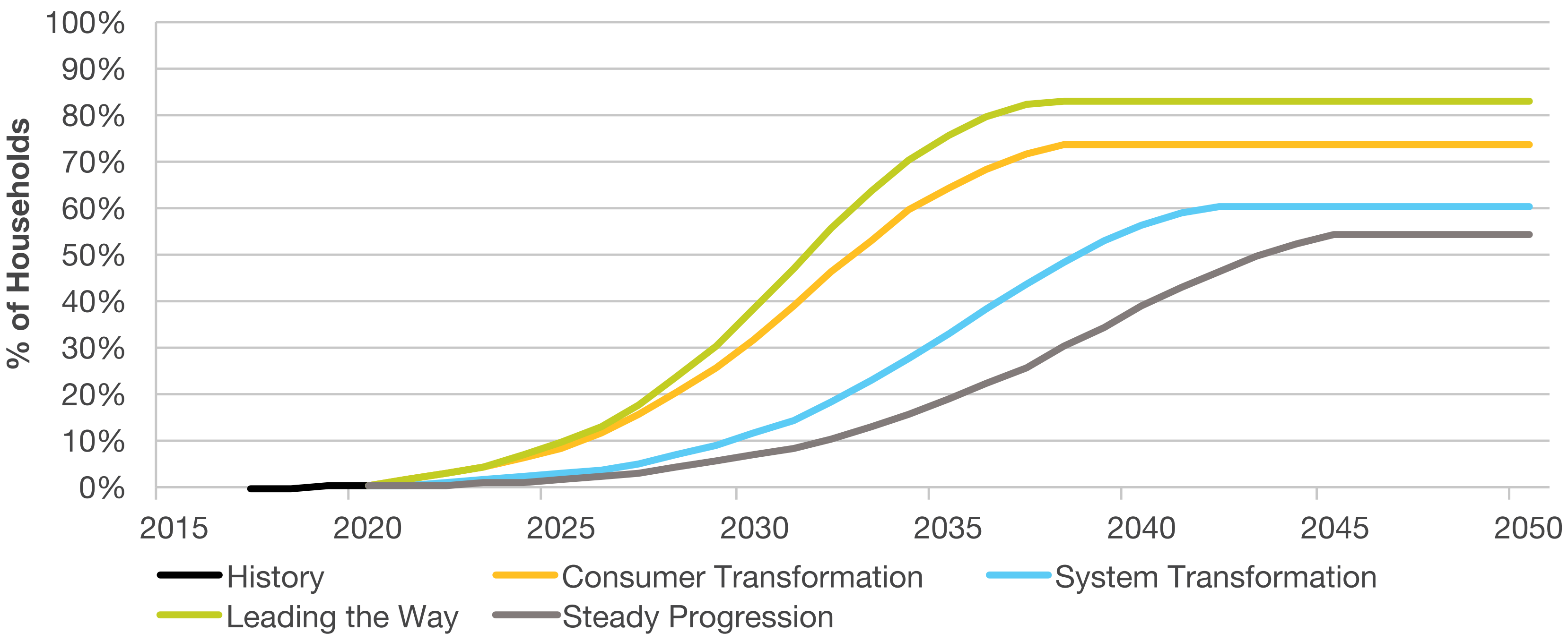
Vehicle-to-Grid (V2G) will enable BEVs to provide energy storage services to the electricity networks. Consumers will be able to plug their BEV in to charge and potentially sell any surplus electricity back to the local and national networks at times of peak demand. To enable this, consumers will need to purchase a bi-directional BEV charger to allow power flows from and to the electricity grid. These are currently more expensive than uni-directional chargers (where power only flows one way - from the electricity grid to the EV), but we expect costs to fall as EV uptake increases.

In FES, we assume that wider use of TOUTs is triggered by having an EV. TOUTs incentivise EV charging at times when flexibility is needed to balance the local and national electricity systems. We expect peak shaving to be as much as 32 GW in Consumer Transformation by 2050. See the flexibility chapter for more information. However, changes to the wholesale and retail electricity markets will be required to ensure these are cost effective for consumers. Tariffs will need to be carefully designed to protect vulnerable consumers. Energy regulator Ofgem and other relevant bodies are exploring how best to ensure that these consumers will not face disproportionately high energy bills for not having the required smart technology or failing to respond to price signals at appropriate times.[10]

Bi-directional BEV charger

Did you know that the bi-directional charging element can be manufactured so it's incorporated into your car's on board charging equipment. This can facilitate seamless V2G bi-directional charging.

Figure CV.41: Consumer engagement in smart charging

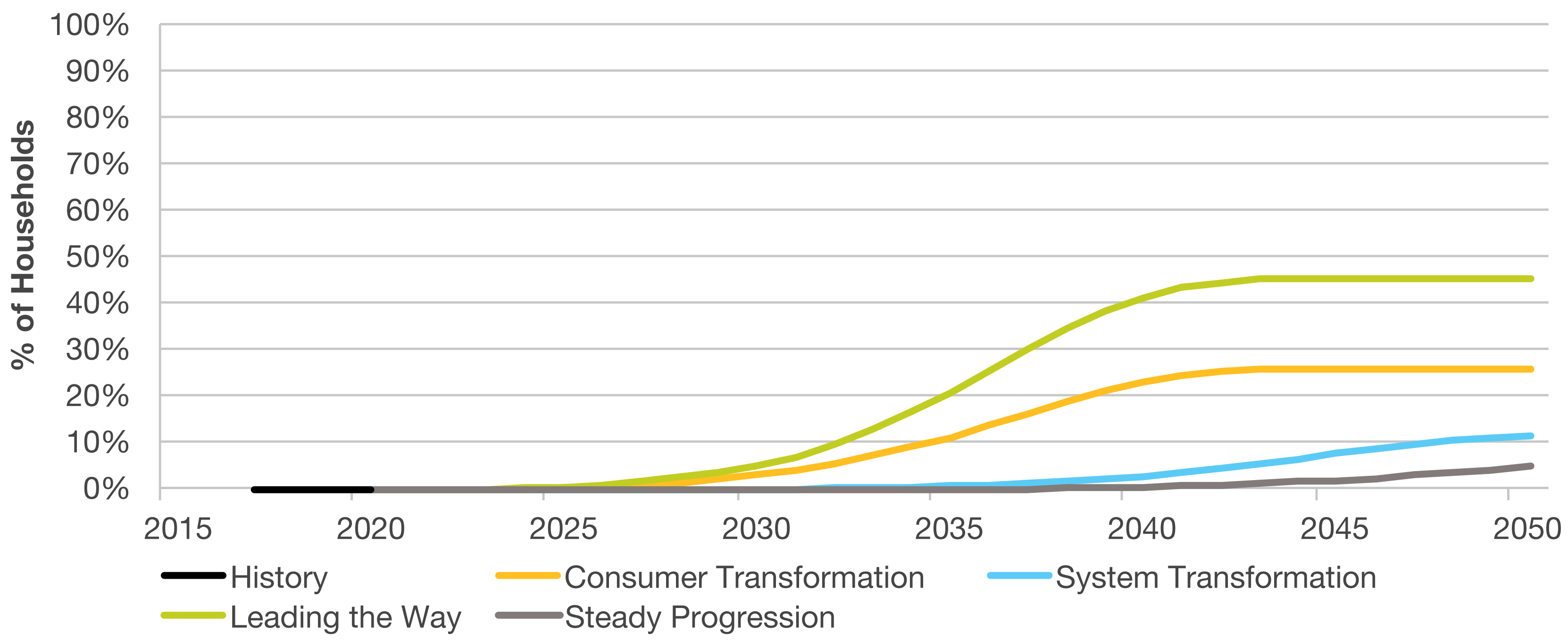


10 Ofgem vulnerability strategy 2019 - ofgem.gov.uk/system/files/docs/2020/01/consumer_vulnerability_strategy_2025.pdf

FES 2021 / Consumer View / Transport 105

What we've found

Figure CV.42: Consumer engagement in V2G



FES 2021 / Consumer View / Transport 106

What we've found

Scenarios overview: rail, aviation and shipping

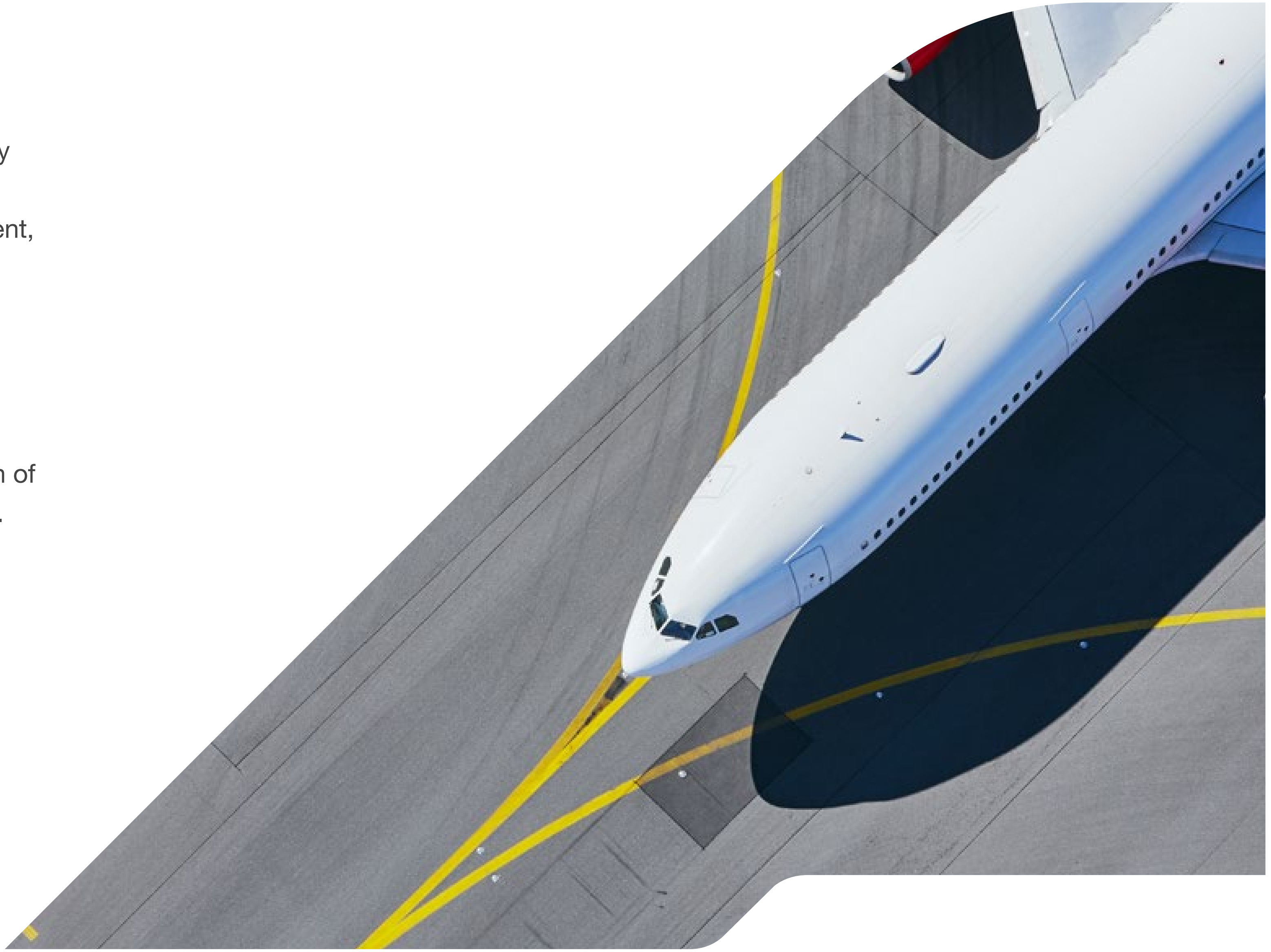
By 2050, trains mostly use electricity as the energy source (either directly or through battery technology) in Consumer Transformation and Leading the Way. In System Transformation, electricity as an energy source is also used for trains, with some hydrogen trains also present, due to the ready supply of hydrogen. Rail travel in Steady Progression is not successfully decarbonised, with diesel trains still frequently in use by 2050.

For shipping, all our net zero scenarios are broadly similar, with the roll-out of hydrogen converted to ammonia beginning in 2030 and used in place of heavy fuel oil.

Synthetic fuels replace traditional jet fuel in aviation. In all of our net zero scenarios, 10 TWh of synthetic fuel is used. A further 41 TWh of biofuel is used to create bio-jet fuel with BECCS.

Synthetic fuel

This represents an alternative to fossil fuel based jet fuel. Examples of synthetic fuels include electro fuels (made from carbon dioxide and water) generated by electrolysis and DACCS, or biofuels. While these fuels can be designed to reduce carbon - and other particulate - emissions, production costs remain high. It's also important to highlight the global nature of aviation and therefore the need for global action on reducing emissions via alternative fuels or technologies.



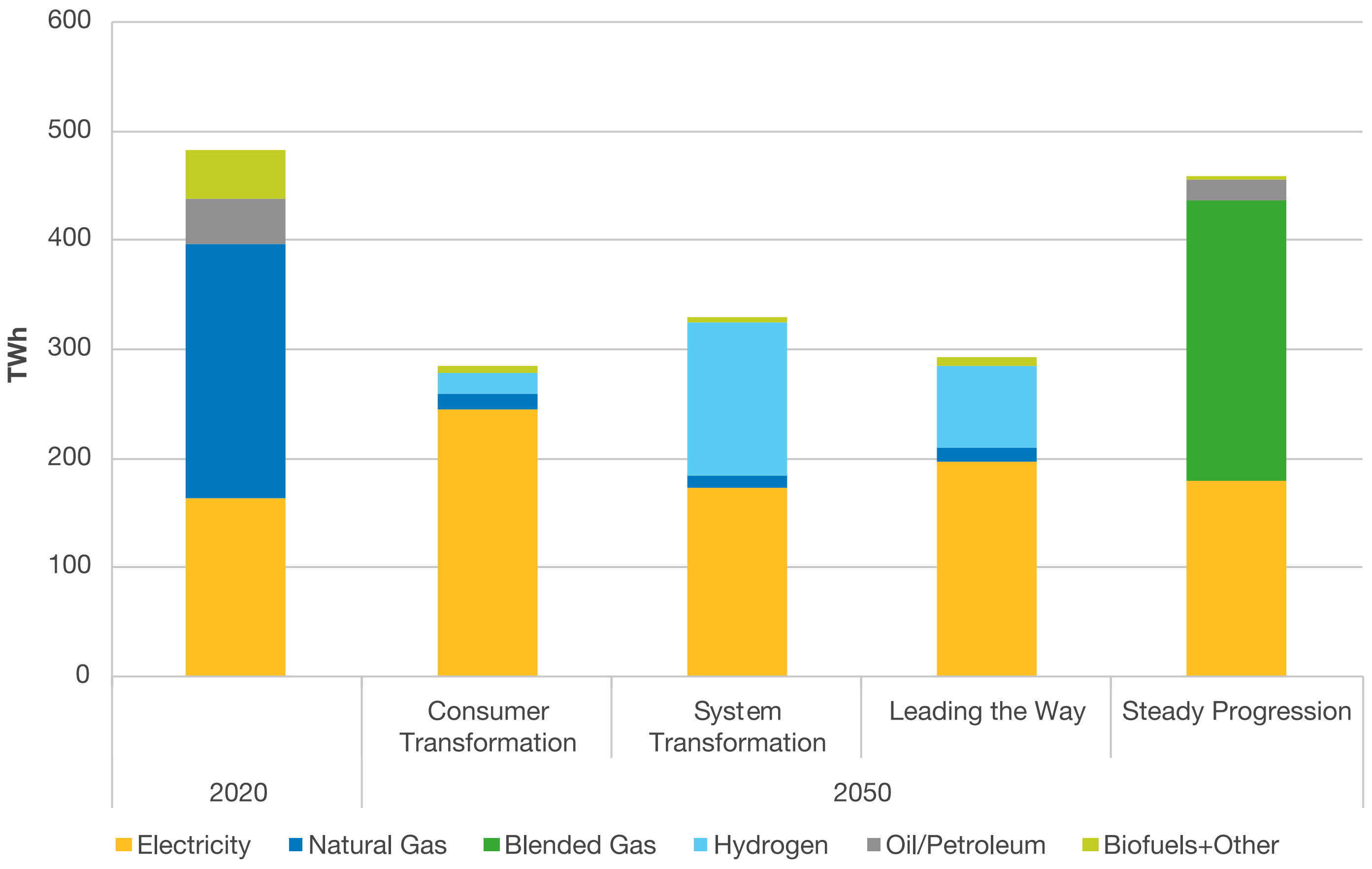
FES 2021 / Consumer View / Transport 107

Industrial and Commercial

Key insights

- The commercial sector is more straightforward to decarbonise than the industrial sector since most emissions come from heating and lighting, which can be reduced by investing in efficient lighting and low carbon heating. In contrast, some industrial sub-sectors are difficult and/or costly to decarbonise, because of their reliance on high-grade heat for industrial processes.
- In the commercial sector, electrification is frequently more cost-effective than hydrogen for decarbonising heating, even in System Transformation. Our updated modelling shows that electric heat pumps do not necessarily need the high levels of thermal efficiency as previously assumed to be cost-effective compared to hydrogen boilers.
- The industrial sector, which is one of the most polluting - emitting 13% of UK emissions in 2020 - will need to switch to low or zero carbon sources like electricity or hydrogen to achieve net zero. This will require a significant transformation of infrastructure.
- Small amounts of natural gas may be needed to some extent in all net zero scenarios for industrial sub-sectors that are particularly difficult or costly to decarbonise. Emissions from this will need to be abated using carbon capture, usage and storage (CCUS) or offset via negative emissions.

Figure CV.43: Annual Industrial and Commercial energy demand in 2050[1]

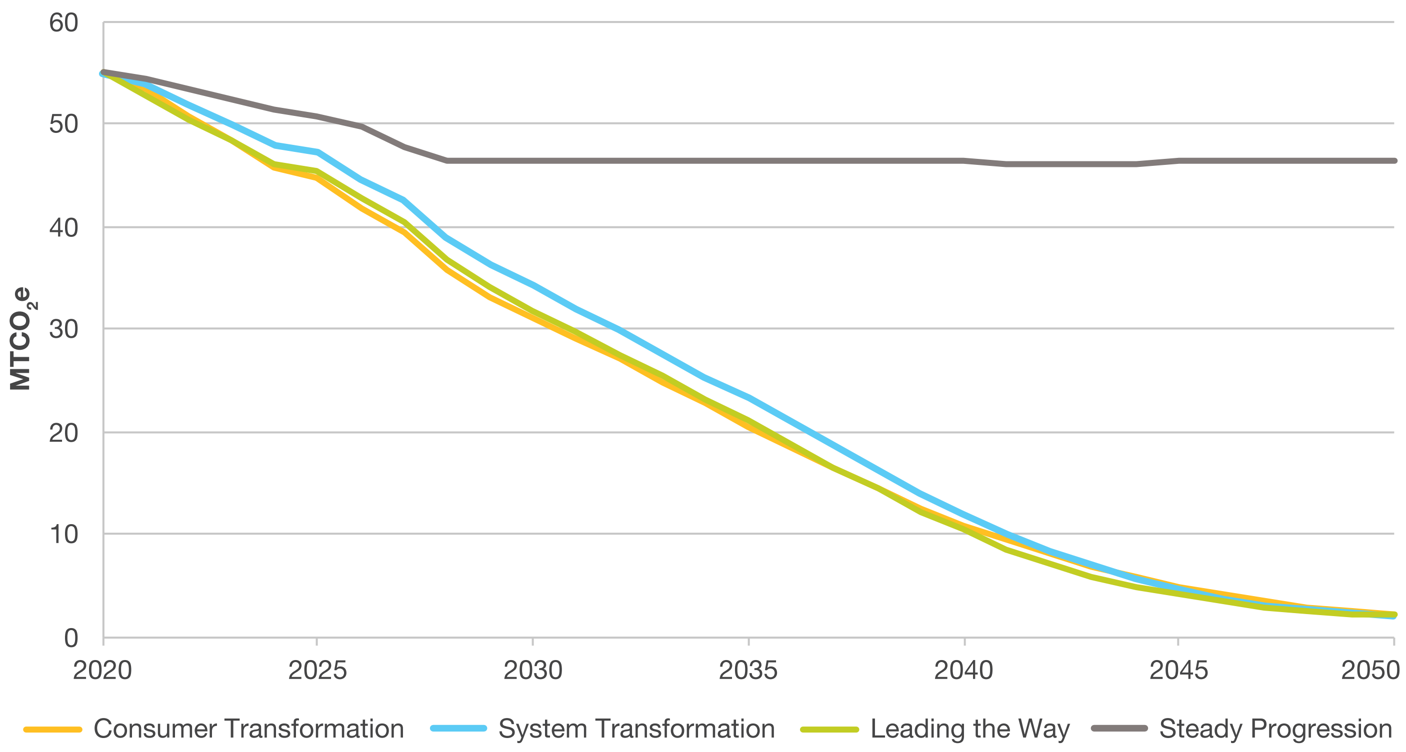


1 The 2020 data is primarily made up of our modelled data for natural gas and electricity. Some 2019 demand data from ECUK was used to provide a complete, whole energy system view of end consumer demand for these sectors. The chart reflects end user demand across I&C sectors.

FES 2021 / Consumer View / Industrial and Commercial 109

Key insights

Figure CV.44: Industrial and commercial emissions from heat



FES 2021 / Consumer View / Industrial and Commercial 110

Where are we now?

In 2020, the Industrial and Commercial (I&C) sectors accounted for around 500 TWh of energy demand, equivalent to 83 $MtCO_2e$. This made up approximately 35% of total energy demand in Great Britain[3] (GB) and 17% of the UK's greenhouse gas emissions.

I&C sectors typically use large amounts of energy. Examples include fossil fuels such as natural gas, oil or coal for heating large commercial premises, or for use in high temperature industrial processes like iron and steel production. Due to their heavy reliance on fossil fuels, these industries - which are vital to the UK's national and regional economies - represent some of the most challenging areas to fully decarbonise by 2050.

Previous government policy has mainly focused on energy efficiency improvements as part of the 2017 Clean Growth Strategy[4]. This has been supplemented by last year's Ten Point Plan commitments, which includes pledges to develop industrial clusters and CCUS 'SuperPlaces' in regional hubs around the country by 2030. More recently, the Government published its Industrial Decarbonisation Strategy[5], outlining a route to reduce emissions from industry by two-thirds by 2035 and at least 90% by 2050 compared to 2018 levels.[6]

Industrial and Commercial

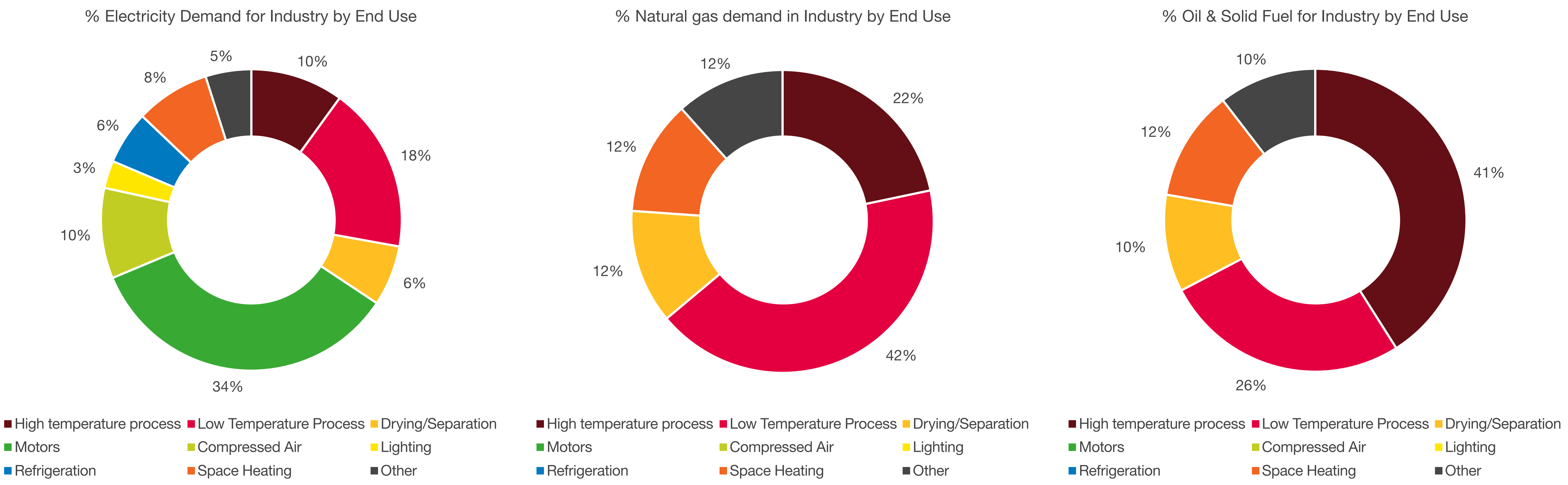
The definition of these sectors is specified by the Office for National Statistics (ONS). Examples of industrial sectors include iron, steel, cement and glass production, through to pharmaceuticals, engineering and vehicle manufacturing. Commercial sectors include agriculture, construction, offices, government bodies, retail and hospitality.

3 While modelling in FES is based on GB energy demand and supply, in some areas (such as emissions and economic growth) it is necessary to refer to the UK.
4 BEIS Clean Growth Strategy 2017 - https://www.gov.uk/government/publications/clean-growth-strategy
5 BEIS Energy White Paper 2020 - https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future
6 BEIS 2021 Industrial Decarbonisation Strategy - https://www.gov.uk/government/publications/industrial-decarbonisation-strategy

FES 2021 / Consumer View / Industrial and Commercial 111

Figure CV.45: Industrial and commercial demand in 2019 by end use[7]

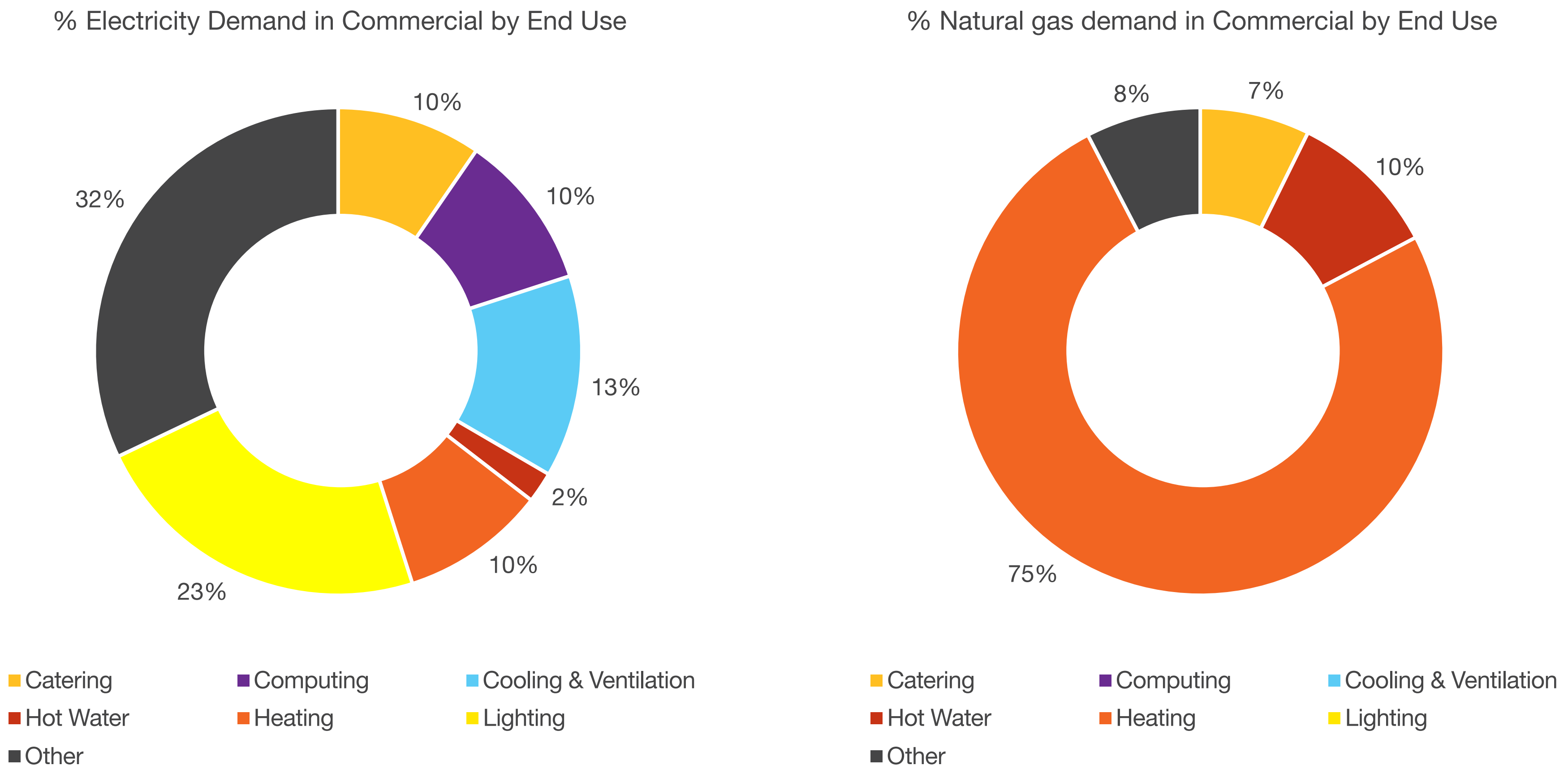
Industrial demand by end use



FES 2021 / Consumer View / Industrial and Commercial 112

Figure CV.45: Industrial and commercial demand in 2019 by end use[7]

Commercial demand by end use

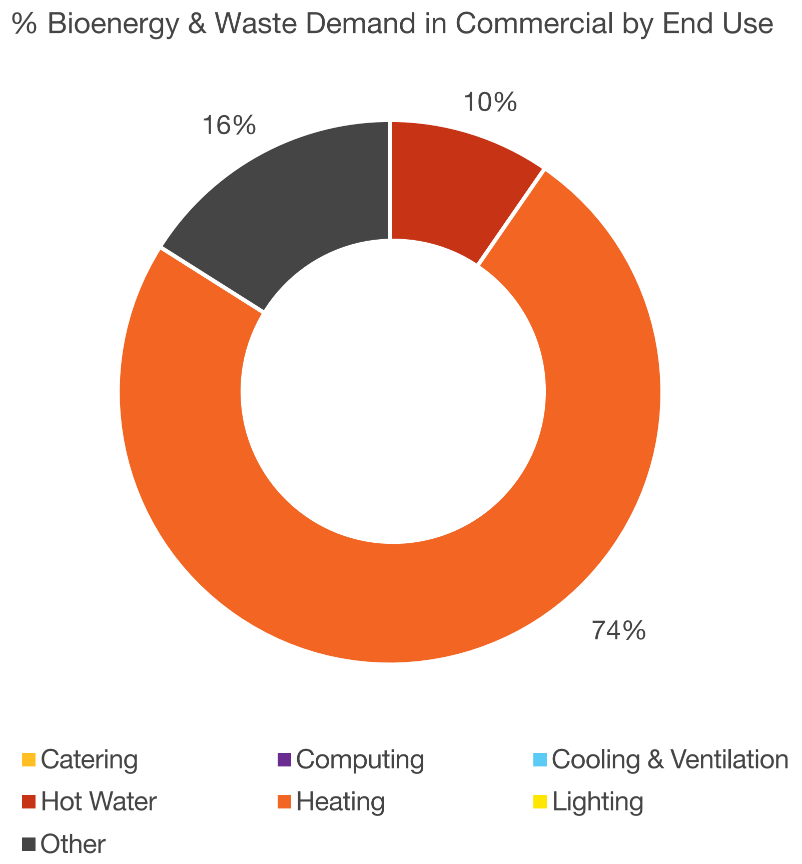


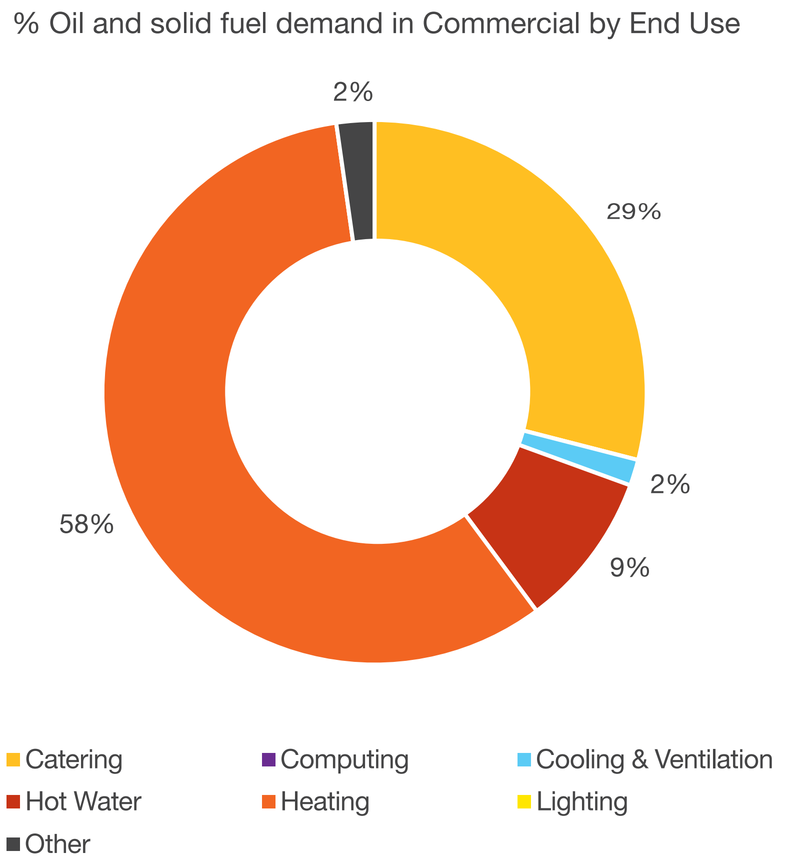
7 ECUK Energy Data Tables (Tables U3 and U4) - https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

FES 2021 / Consumer View / Industrial and Commercial 113

Figure CV.45: Industrial and commercial demand in 2019 by end use[7]

Commercial demand by end use





7 ECUK Energy Data Tables (Tables U3 and U4) - https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

FES 2021 / Consumer View / Industrial and Commercial 114

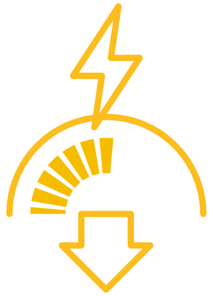
What we've found

Electric plasma heaters

These are electrical resistance heaters with plasma (an electrically charged gas), which produces an arc discharge. These heaters provide continuously controlled heating.

Routes to decarbonisation

The I&C sectors can reach low or zero carbon emissions through:



Demand reductions

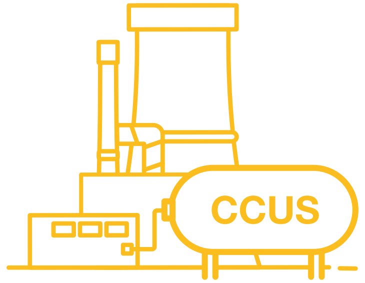
To decrease the environmental impact and cost of fuels:

- Increasing energy efficiency either from investing in up-to-date equipment, appliances or building improvements such as insulation and triple glazing or modifying industrial processes

Low or zero carbon fuels

To ensure any primary or secondary sources release low or no emissions that contribute to climate change:

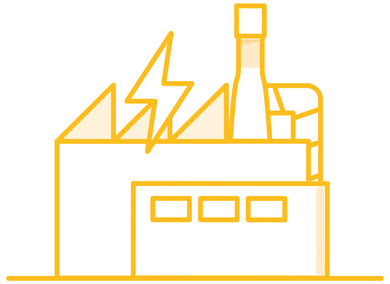
- Installing low carbon heating technologies such as heat pumps, hydrogen boilers, or electric plasma heaters
- Fuel switching from high emission fossil fuels to electricity or hydrogen



Emissions removal technologies

These are essential in hard-to-decarbonise areas like some industrial processes. Examples include:

- CCUS
- Some emissions remain unabated and will need to be offset via negative emissions elsewhere



Flexibility

Flexibility allows the electricity system to be more efficient in managing the load and supply with low carbon. For example:

- By responding to incentives such as Time of Use Tariffs (TOUTs) to minimise energy costs
- Encouraging businesses to participate in balancing services as a way to provide additional revenue streams

In most cases, several of these options will be needed. While some are available now, a combination of long-term government policy commitments, trade agreements and carbon pricing will be necessary to secure future growth alongside decarbonisation.

FES 2021 / Consumer View / Industrial and Commercial 115

What we've found

Modelling information

Our modelling is based on the following:

- Economic growth of 1.5% from 2023 onwards after an initial bounce back from COVID-19
- Energy efficiency measures
- Sales of low carbon technologies and appliances
- An industrial and commercial sector base similar to what we have today
- Offshoring is not used in our modelling – we assume there is an effective 'carbon neutralising' mechanism in place to ensure businesses don't move to other countries with no limits on emissions to manufacturer goods

For further information, see the **modelling methods document.**

FES 2021 / Consumer View / Industrial and Commercial 116

Scenarios overview: I&C

Consumer Transformation

The route to 2050

- During the 2020s, the I&C sector invests in energy efficiency measures such as insulation and LED lighting, as well as more efficient appliances. This reduces overall energy consumption and costs.
- Strong carbon pricing in the mid-2030s encourages I&C consumers to switch from fossil fuels to electricity, leading to a rise in electricity demand from 2035.
- A minority of industrial consumers who cannot switch to electricity look to hydrogen, and begin to relocate nearer to a reliable source in the 2030s.
- Fuel switching continues to 2050, with the local and national electricity network infrastructure developing to meet this increased demand.

What does 2050 look like?

- Total demand for I&C in 2050 is 284 TWh.
- Most industrial and commercial sub-sectors have switched to electricity to decarbonise.
- There is high participation in Demand Side Response (DSR) to shift industrial electricity use at times of peak supply or demand, in response to a price signal.
- Industrial sub-sectors unable to decarbonise by switching to electricity have re-located to industrial hubs, converting their processes to hydrogen.
- When hydrogen isn't feasible, a small number of industrial consumers use natural gas with CCUS.

FES 2021 / Consumer View / Industrial and Commercial 117

Scenarios overview: I&C

System Transformation

The route to 2050

- Uptake of energy efficiency measures increases thanks to government incentives in the 2020s, although consumer awareness and engagement is lowest compared to the other net zero scenarios.
- Industrial clusters develop in line with Energy White Paper recommendations from the 2030s.[6]
- Switching to low or zero carbon fuels is widespread by 2035, due to the high cost of emitting carbon and the introduction of innovative technologies to decarbonise industrial processes.
- Local and national electricity networks grow into the 2040s, in conjunction with the re-purposing of the gas grid to accommodate higher levels of hydrogen.

What does 2050 look like?

- Total demand for I&C in 2050 is 330 TWh.
- Industrial clusters encourage efficiencies in hydrogen and CCUS use, at sites where lots of heavy industry are located.
- Any industrial sub-sectors located outside of these hubs connect to the national hydrogen network.
- Whilst most industrial consumers have switched to hydrogen, the commercial sector sees electrification dominate as a more cost-effective route to decarbonise heating.
- The natural gas used for extremely difficult to decarbonise industrial processes comes from the extremities of the networks, near coastal industrial clusters. It is used with CCUS to remove emissions.

FES 2021 / Consumer View / Industrial and Commercial 118

Scenarios overview: I&C

Leading the Way

The route to 2050

- High electricity prices and strong carbon pricing incentivises far-reaching energy efficiency investments from the mid-2020s.
- Uptake of electric, hybrid and hydrogen low carbon heating technologies starts to increase from the mid-2020s too.
- Fuel switching occurs from 2025, with a slightly higher proportion of industrial consumers switching to electricity, rather than hydrogen.
- Electricity network investment continues to keep pace with fuel switching, alongside the widespread electrification of heat in the commercial sector throughout the 2030s and 2040s.

What does 2050 look like?

- Total demand for I&C in 2050 is 299 TWh.
- Thanks to frontloading of building insulation in the mid-2030s fuel consumption in the commercial sector is lowest in this scenario.
- Large numbers of I&C consumers have solar photovoltaics (PV) with storage installed, encouraging on-site generation and storage (for heat and electricity).
- TOUTs are taken by most consumers to turn up, down, on or off their demand in response to price signals. These happen automatically via smart-enabled devices.
- Where hydrogen is not suitable, small amounts of natural gas are used along with CCUS to capture emissions.

FES 2021 / Consumer View / Industrial and Commercial 119

What we've found

Scenarios overview: I&C

Steady Progression

The route to 2050

- Policy incentives are available to improve thermal or appliance efficiency in the 2020s.
- Electricity and gas prices are low and carbon pricing has little to no impact on encouraging fuel switching.
- In the 2030s and 2040s, some consumers buy more efficient replacement appliances.
- Local and national electricity networks grow into the 2040s, in conjunction with the re-purposing of the gas grid to accommodate higher levels of hydrogen.
- Some industrial processes switch to electricity from natural gas, oil, or coal thanks to developments in innovative technologies and economics.

What does 2050 look like?

- Total demand for I&C in 2050 is 459 TWh. There is a small reduction in demand due to some upfront investments in energy efficiency measures in the earlier decades.
- Emissions intensity per unit of output has still fallen compared to today's levels.
- Some oil is used by I&C consumers, mainly for industrial processes.
- Hydrogen is blended into the natural gas network by up to 20% by volume.
- Small numbers of commercial premises use low carbon heating technologies such as heat pumps.

FES 2021 / Consumer View / Industrial and Commercial 120

What we've found

Figure CV.46: Annual electricity demand for the industrial and commercial sectors (excluding hydrogen production)

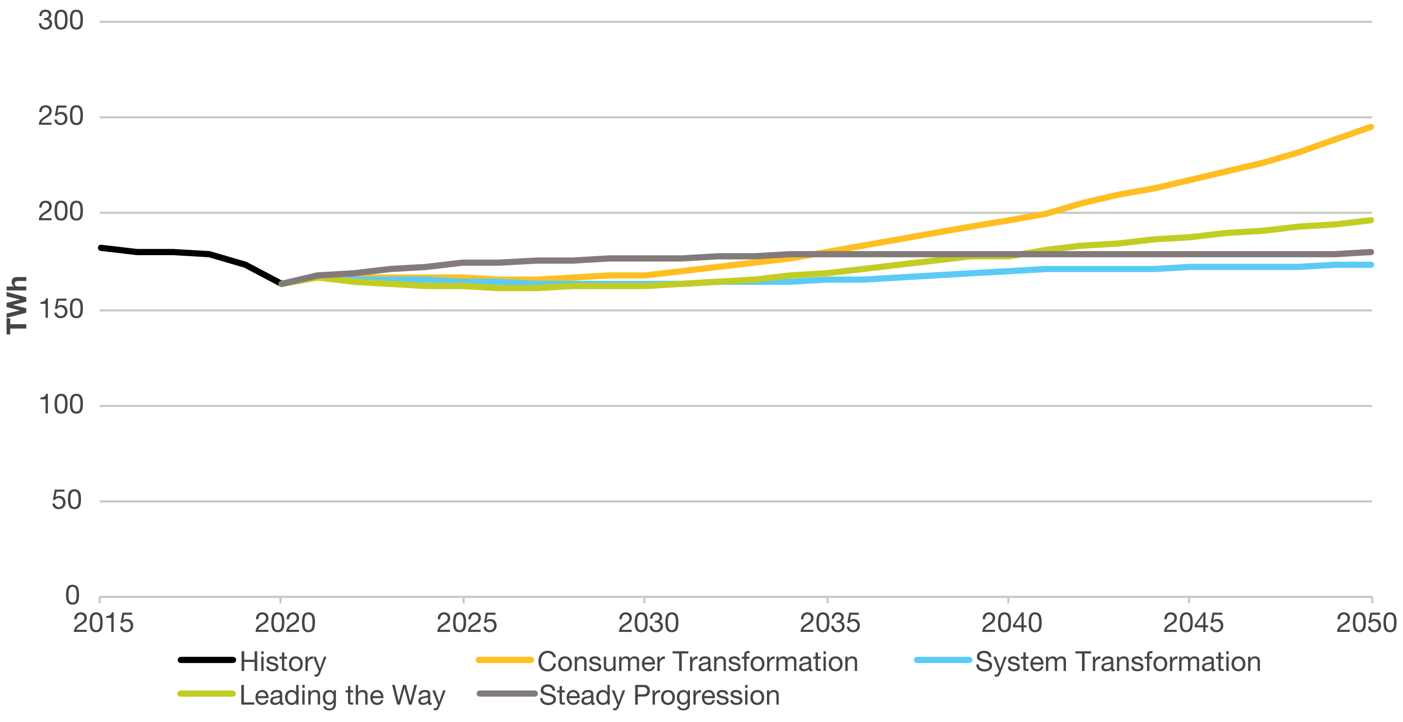
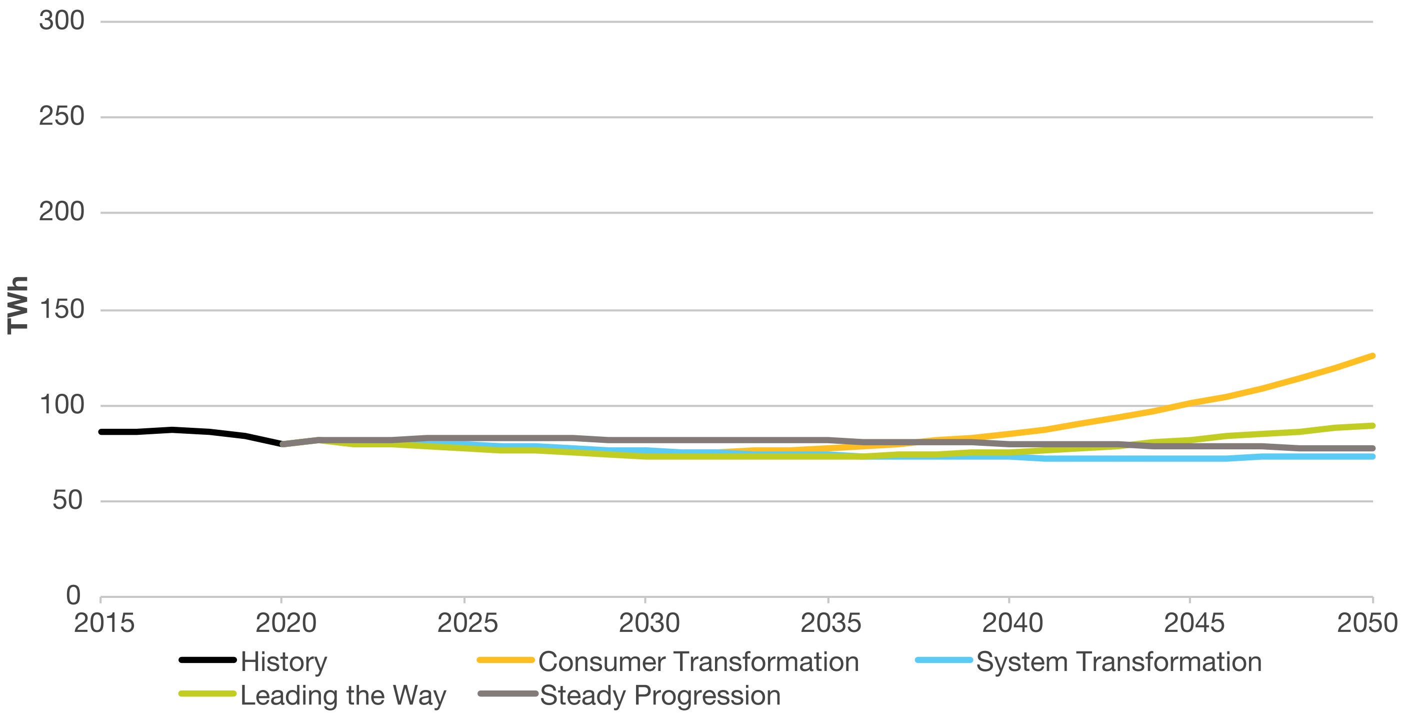


Figure CV.47: Annual electricity demand for the industrial sector (excluding hydrogen production)



FES 2021 / Consumer View / Industrial and Commercial 121

What we've found

Figure CV.48: Annual electricity demand for the commercial sector (excluding hydrogen production)

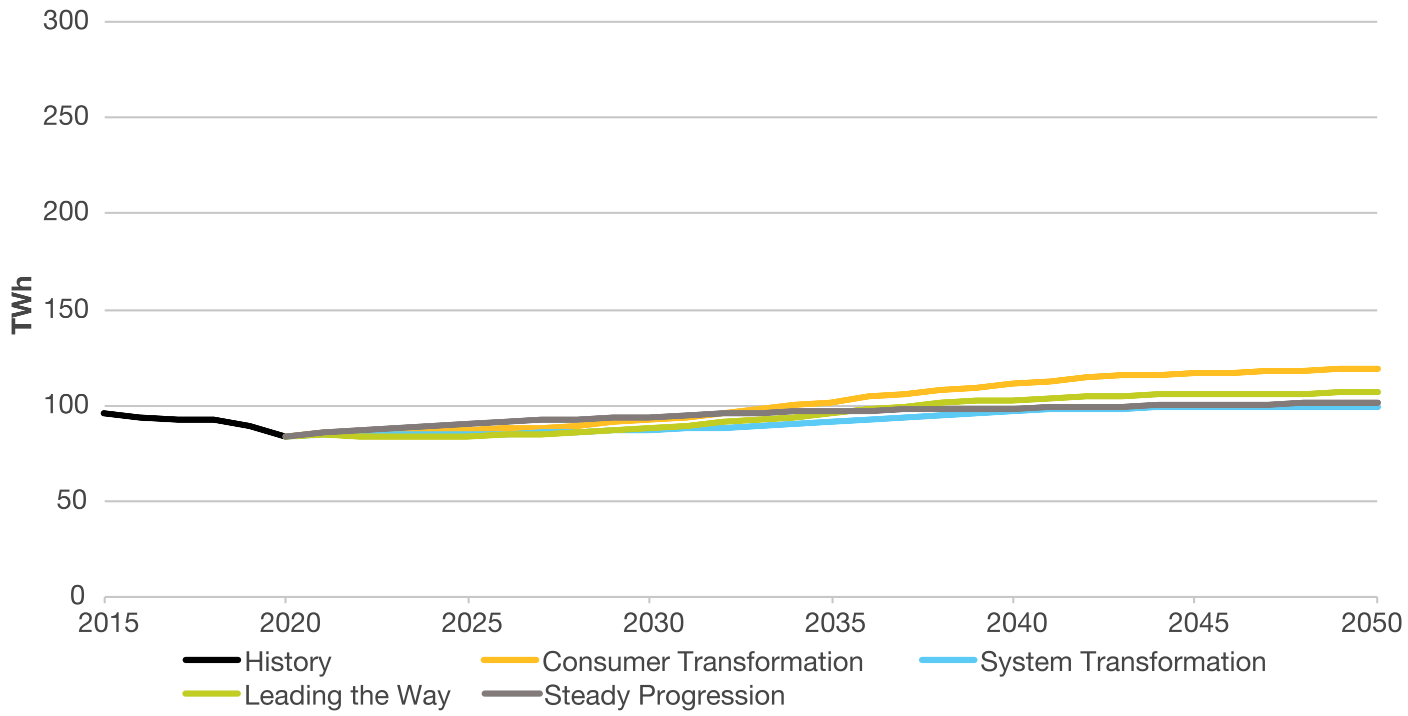
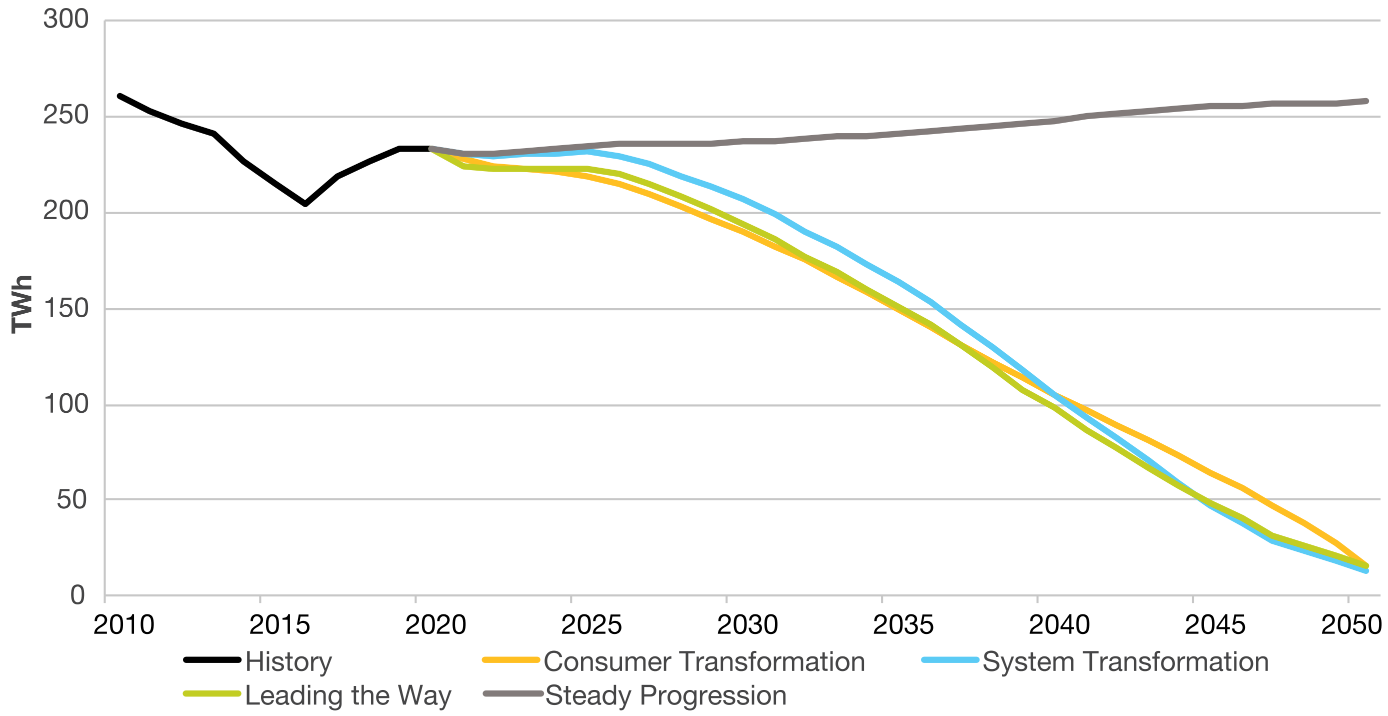


Figure CV.49: Annual natural gas demand for the industrial and commercial sectors (excluding hydrogen production)



FES 2021 / Consumer View / Industrial and Commercial 122

What we've found

Figure CV.50: Annual natural gas demand for the industrial sector

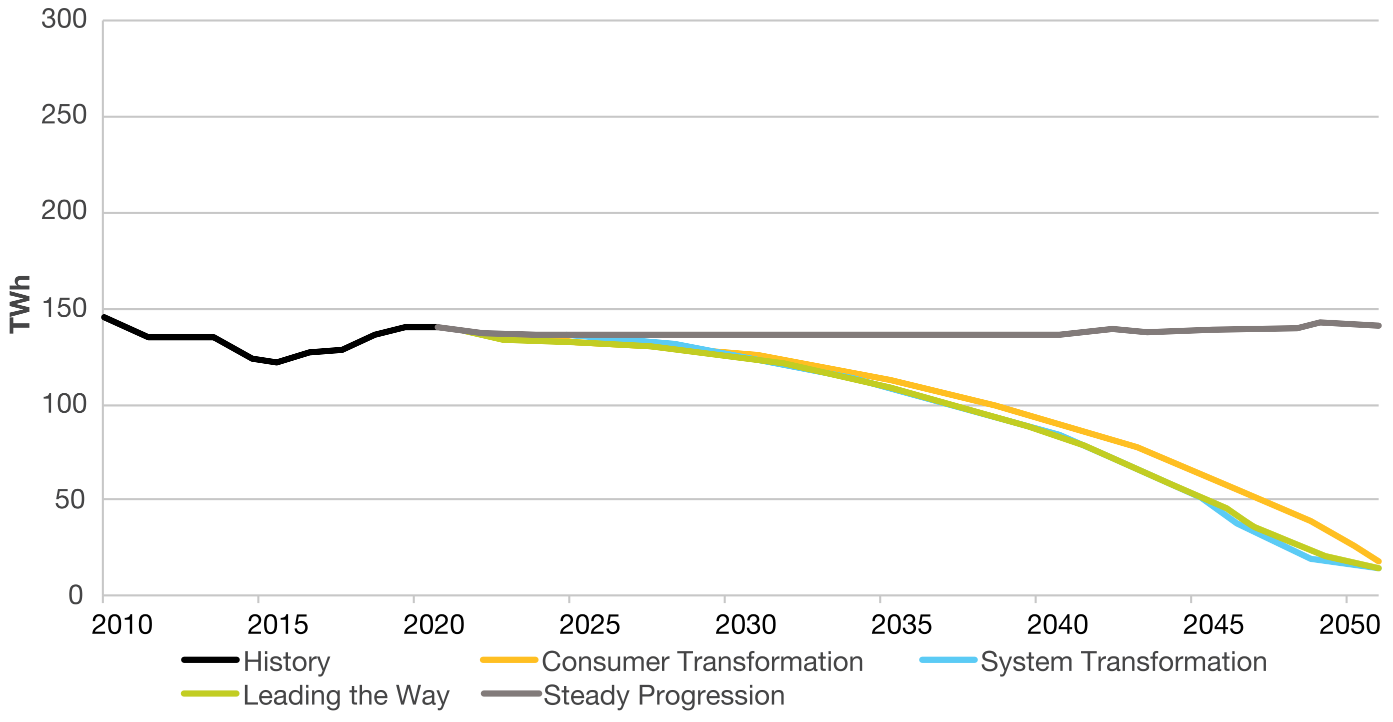
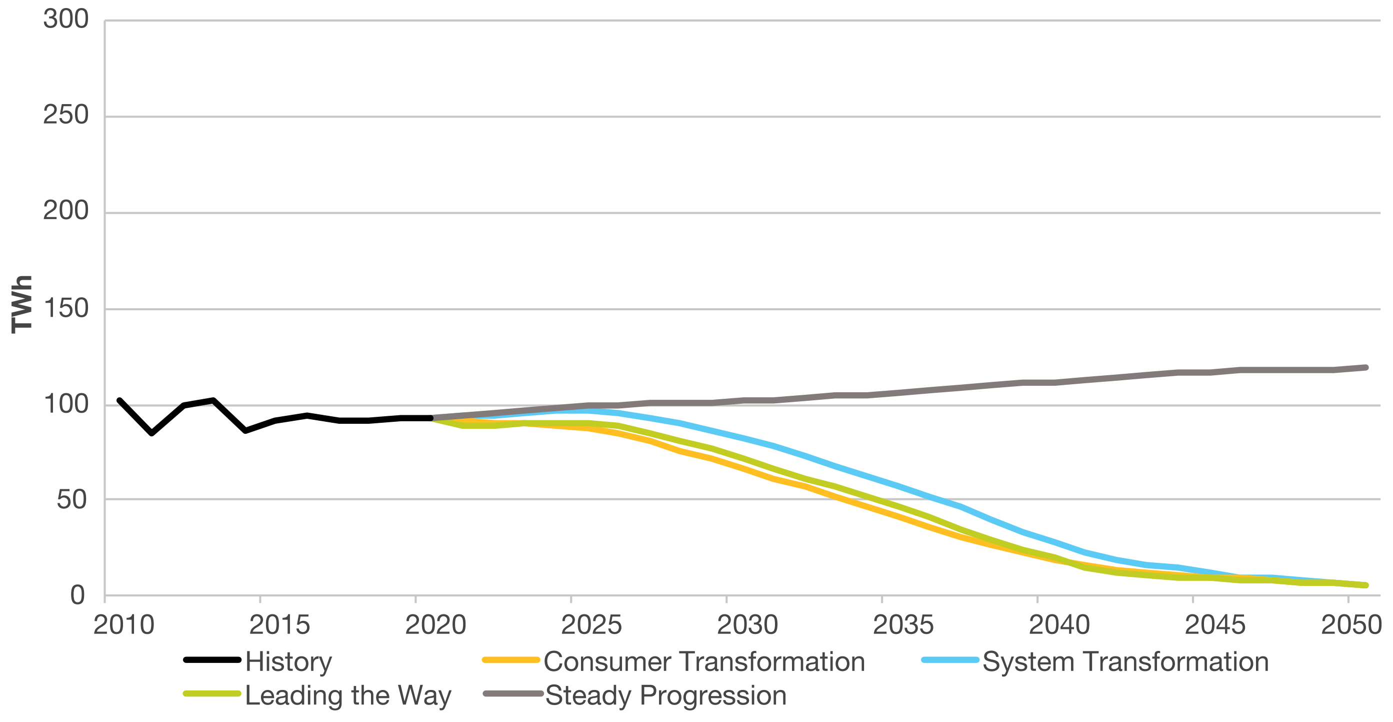


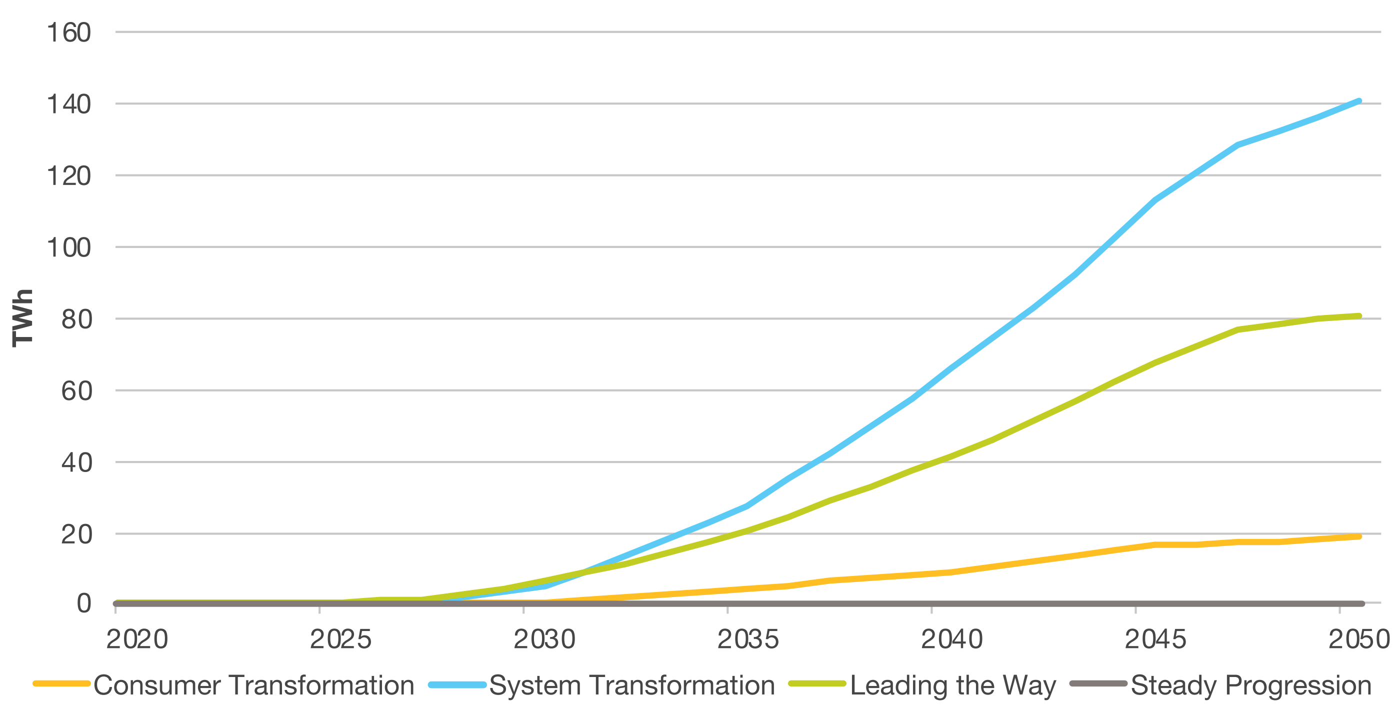
Figure CV.51: Annual natural gas demand for the commercial sector



FES 2021 / Consumer View / Industrial and Commercial 123

What we’ve found

Figure CV.52: Annual hydrogen demand for the industrial and commercial sectors



FES 2021 / Consumer View / Industrial and Commercial 124

What we've found

Figure CV.53: Annual hydrogen demand for the industrial sector

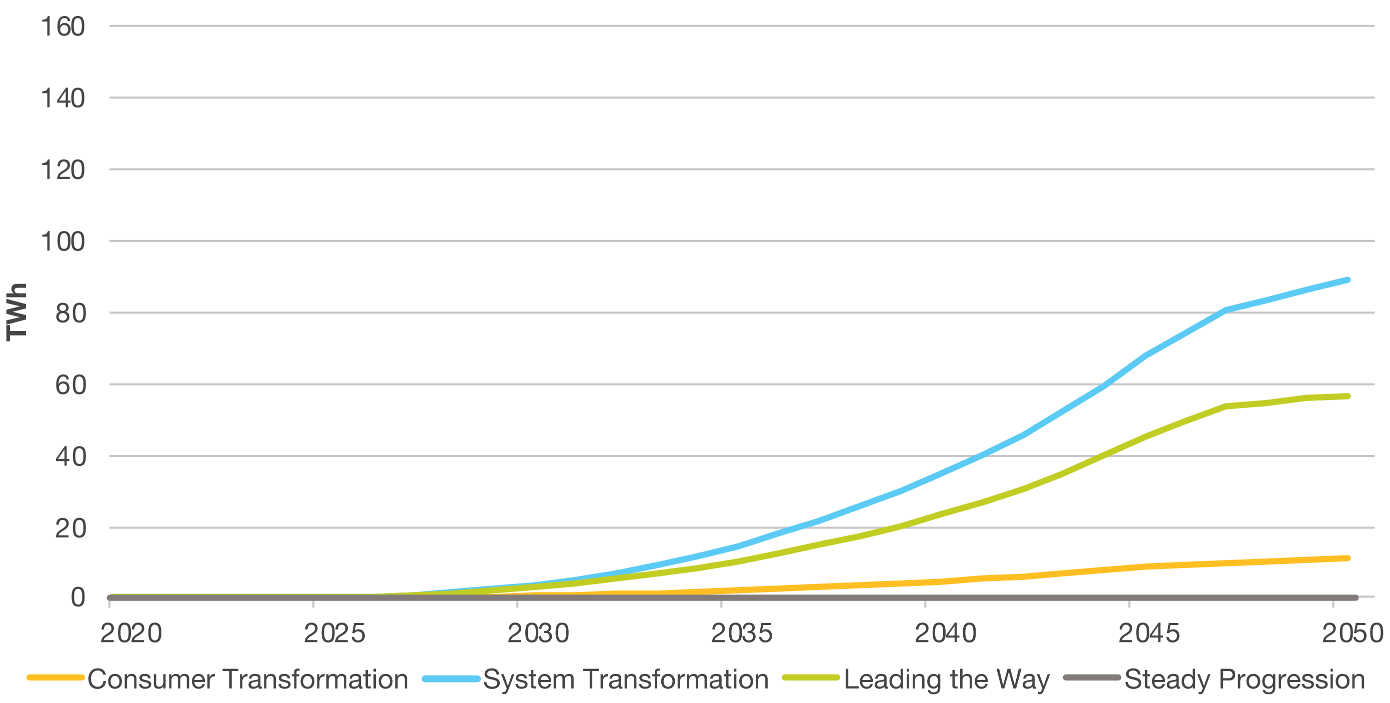
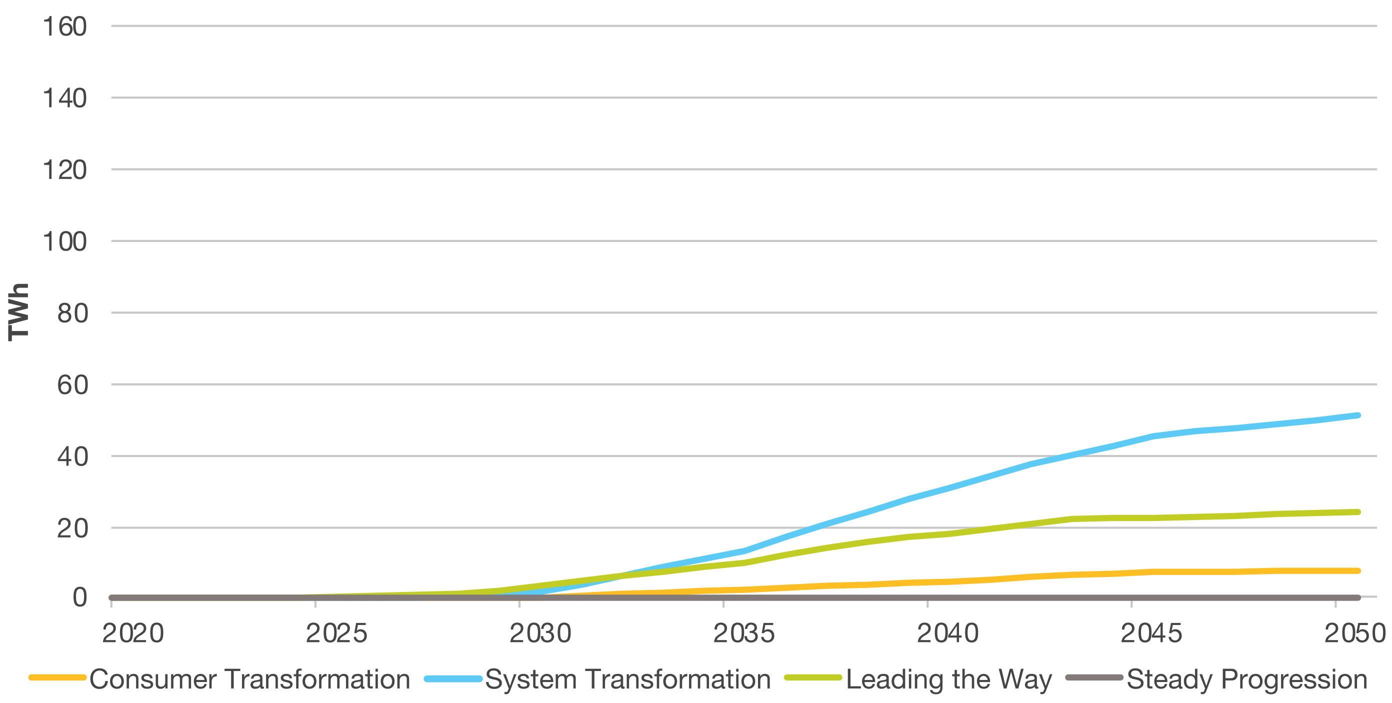


Figure CV.54: Annual hydrogen demand for the commercial sector



FES 2021 / Consumer View / Industrial and Commercial 125

What we've found

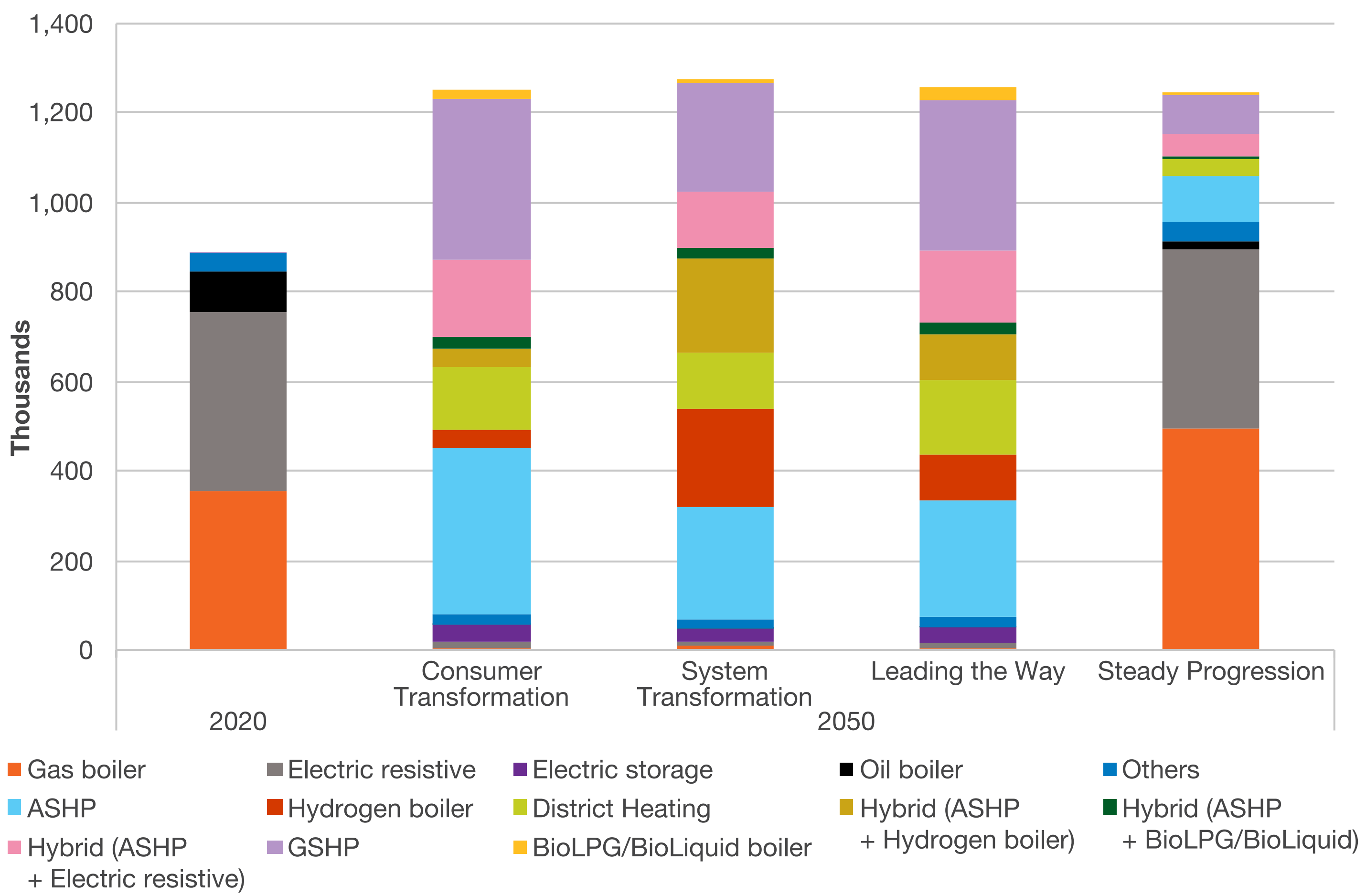
Heating in the commercial sector

The main source of carbon emissions and energy demand in the commercial sector comes from natural gas used for heating. Because of this, the sector is more straightforward to decarbonise compared to the industrial sector, with most low carbon technology options currently available. However, strong government policy commitments are needed to encourage extensive uptake.

Our net zero scenarios show a mixture of low carbon technologies, using low or zero carbon fuels. The heating option chosen for commercial sub-sectors like catering and hotels will be dependent on factors including: cost, availability of infrastructure and building type. It will be important to ensure consumers can choose the technology that best suits them.

We have started to look at the regional uptake of heating technologies for commercial buildings in more detail, through our new spatial heating model. Find out more in our spatial heat thought piece.

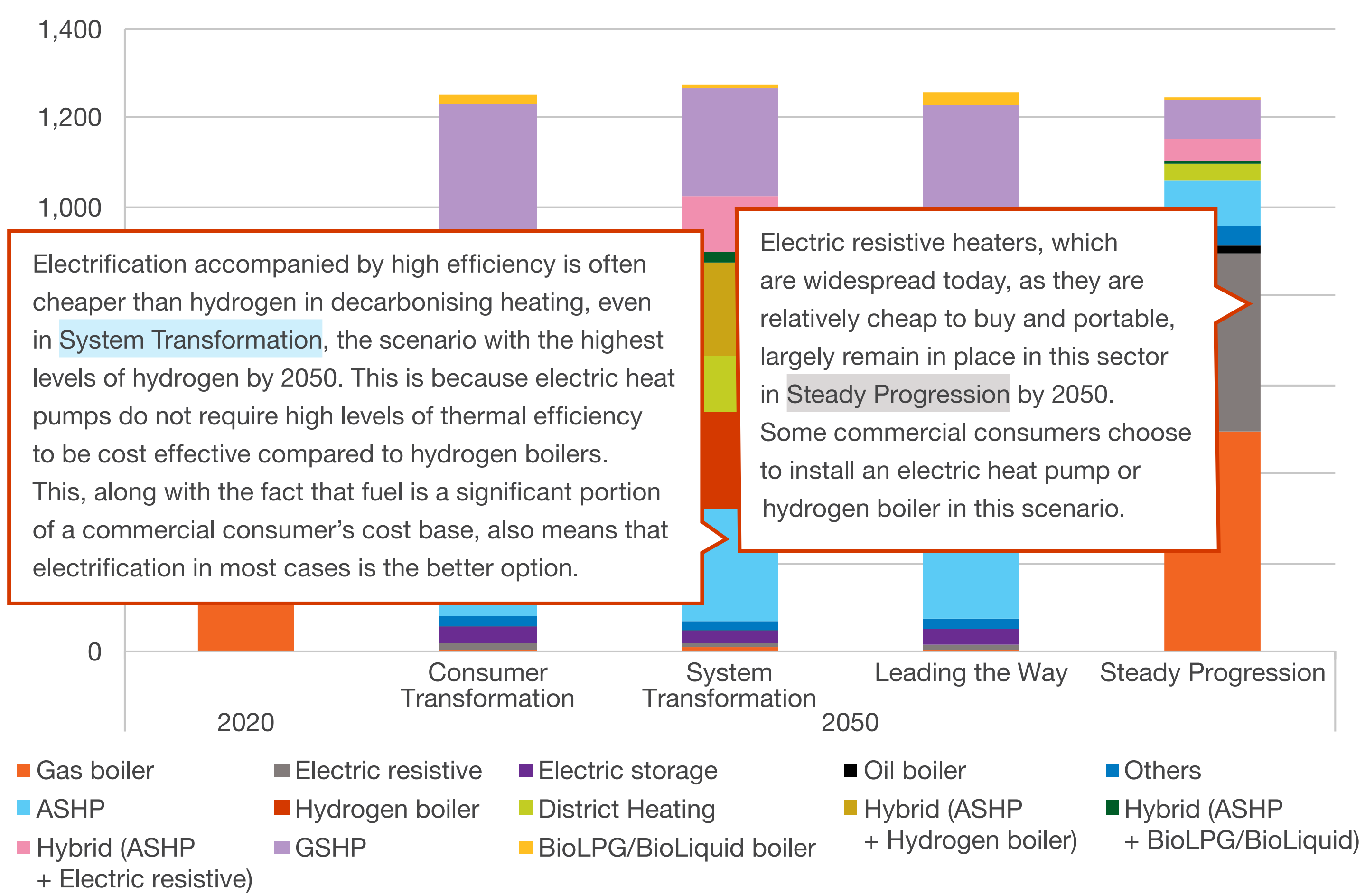
Figure CV.55: Low carbon heating technologies for the commercial sector in 2050



FES 2021 / Consumer View / Industrial and Commercial 126

What we've found

Figure CV.55: Low carbon heating technologies for the commercial sector in 2050



FES 2021 / Consumer View / Industrial and Commercial 127

What we've found

Options for difficult to decarbonise industrial processes

Industrial sub-sectors often use high-grade heat, high carbon feedstocks or large amounts of energy for industrial processes. Examples include blast furnaces to produce pig iron, cement kilns and steam reforming for ammonia production.

Some industrial processes will be able to switch to low or zero carbon fuels to decarbonise by 2050. This will require industrial consumers to invest in alternative technologies and possibly relocate to industrial hubs to use hydrogen.

One option is to relocate to a low or zero carbon industrial cluster (where heavy industry and high emissions are located today) and to use economies of scale to produce and consume hydrogen. The prevalence of industrial clusters is particularly strong in Consumer Transformation, where these are needed for processes that cannot switch to electricity. In this scenario, the hydrogen network is only evident in and around clusters.

In Leading the Way, the first low carbon industrial cluster is operational towards the end of the 2020s. See the hydrogen supply chapter for a timeline of industrial cluster development. It is highly likely that CCUS and industrial clusters will develop in the same areas, especially since some industrial processes may choose to use small amounts of non-networked natural gas in 2050 and abate using CCUS.

Switch

Some industries have already taken steps to decarbonise, such as some Scottish distilleries which have switched from heavy fuel oil to biomass. This was largely driven by government funding to support investment in biomass boilers.

At the start of this year, 17 distilleries from around the UK received part of the Government's £10 million funding package to help to decarbonise.

Alternative technologies

The technologies used in our modelling include: 100% hydrogen fired kilns and hydrogen glass furnaces, more commonly seen in System Transformation, and microwave and electric plasma heaters in Consumer Transformation.

What is an industrial cluster?

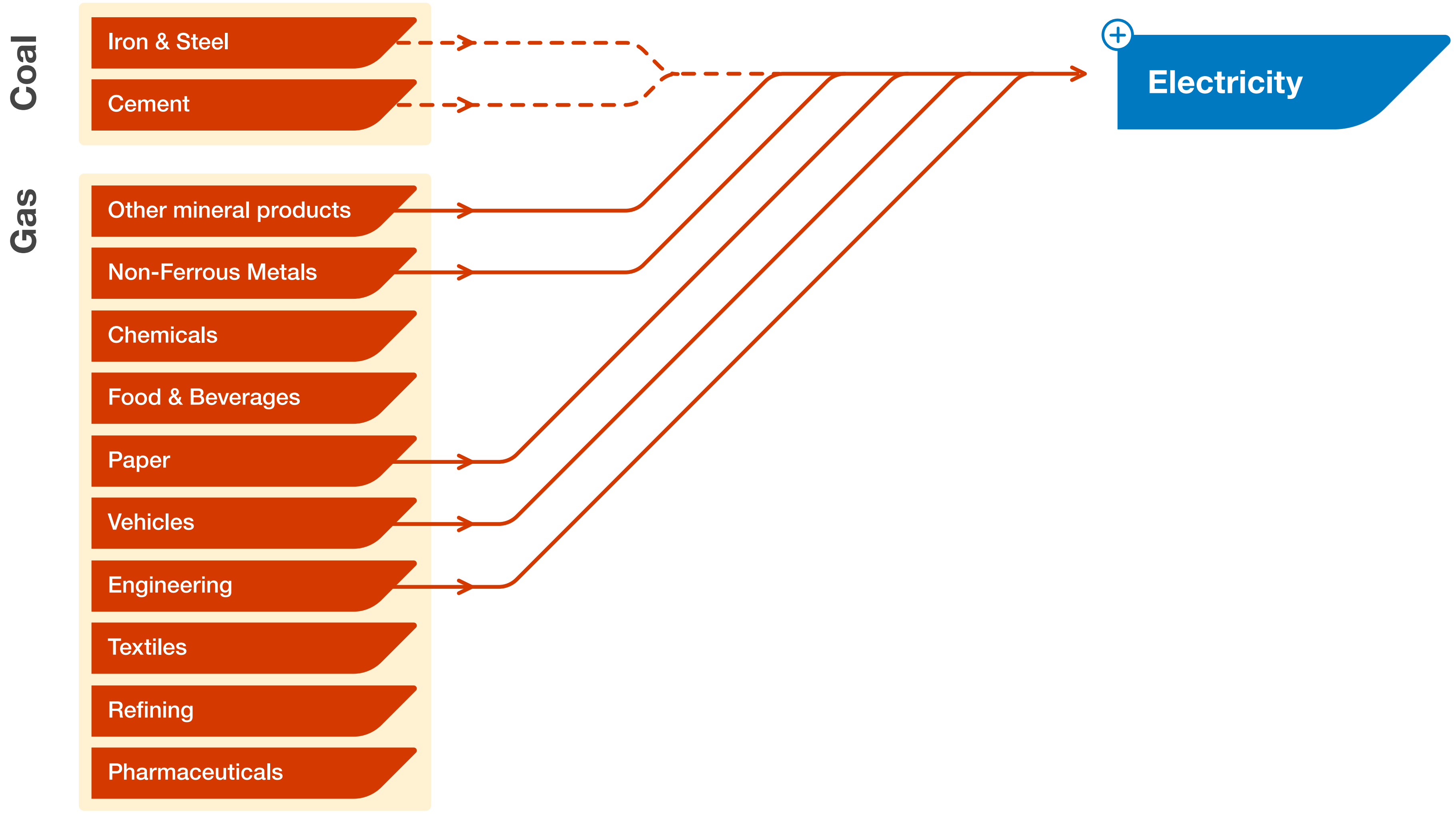
An industrial cluster is a collection of energy and carbon intensive industrial plant manufacturing items such as chemicals, glass, steel, ceramic and cement.

The Government is proposing to bring together these industries into clusters, allowing expensive decarbonisation technologies to be deployed in one location and for economies of scale to be exploited. In practice, this means looking at an industrial area like Humberside, which alone is responsible for over 12 MtCO_2 each year. Industries which require carbon capture and storage to decarbonise will be located here so that the carbon can be used or stored straight away, without having to be transported. Clusters can also be located close to BECCS plants, where electricity is generated from biomass and the carbon emissions are captured and stored immediately. In System Transformation, these hubs will be where hydrogen is made from natural gas and the carbon is taken directly to storage locations.

9 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

Industrial fuel switching options for decarbonisation[9]



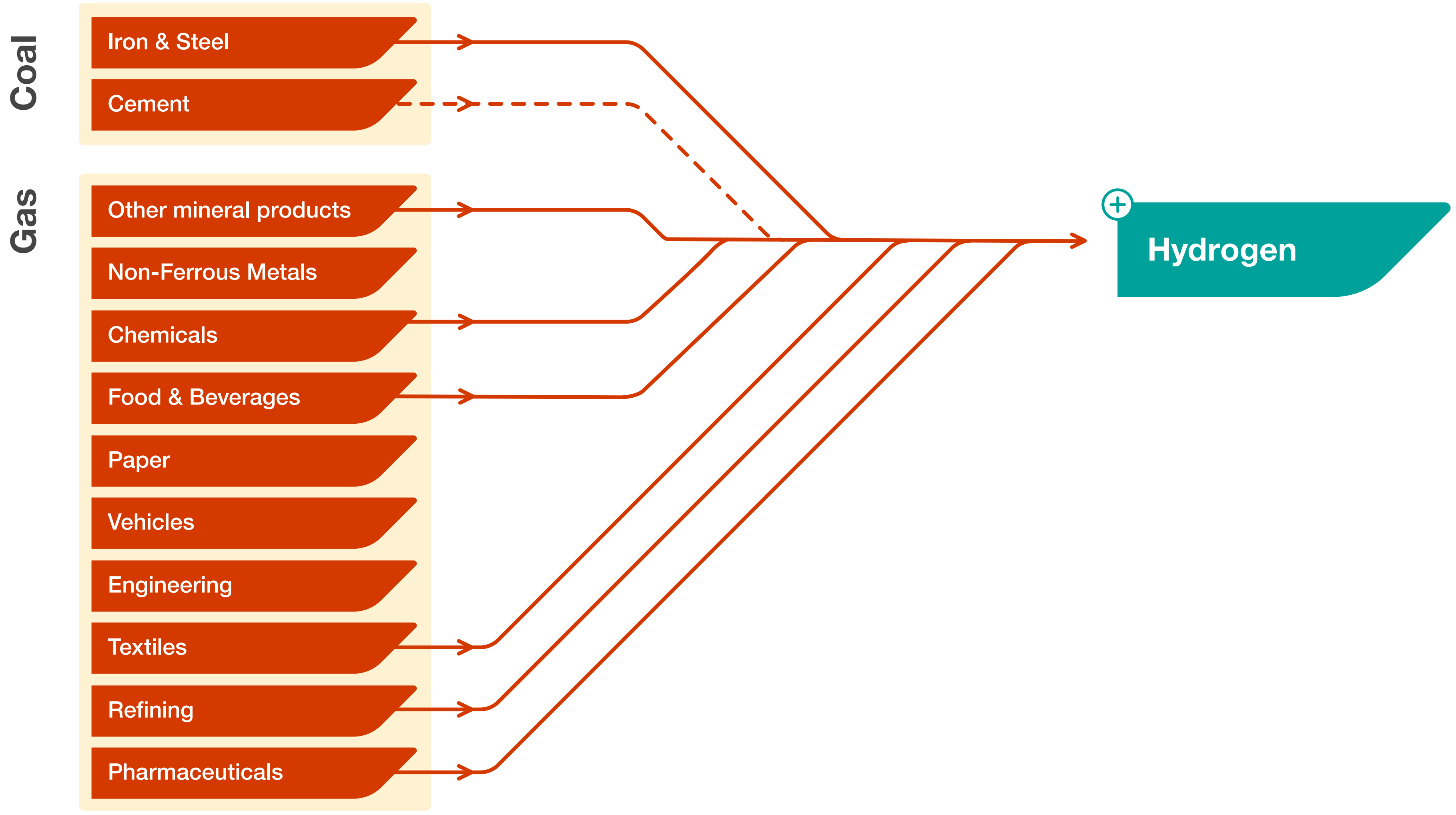
The dotted lines come from the hardest to decarbonise sectors, where a mixture of alternative fuels will be required.

9 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.

FES 2021 / Consumer View / Industrial and Commercial 129

What we've found

Industrial fuel switching options for decarbonisation[9]



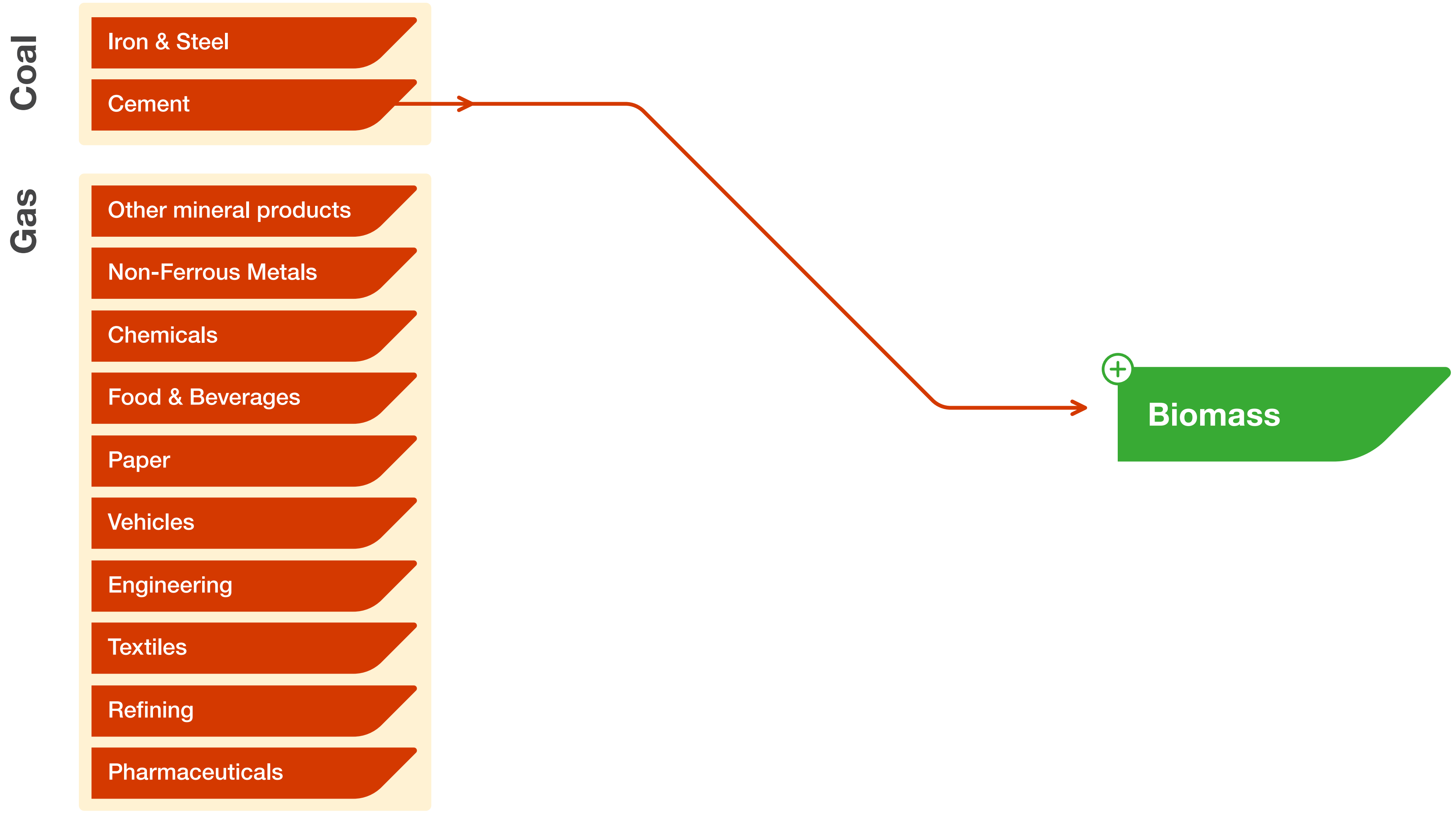
The dotted lines come from the hardest to decarbonise sectors, where a mixture of alternative fuels will be required.

9 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.

FES 2021 / Consumer View / Industrial and Commercial 130

What we've found

Industrial fuel switching options for decarbonisation[9]

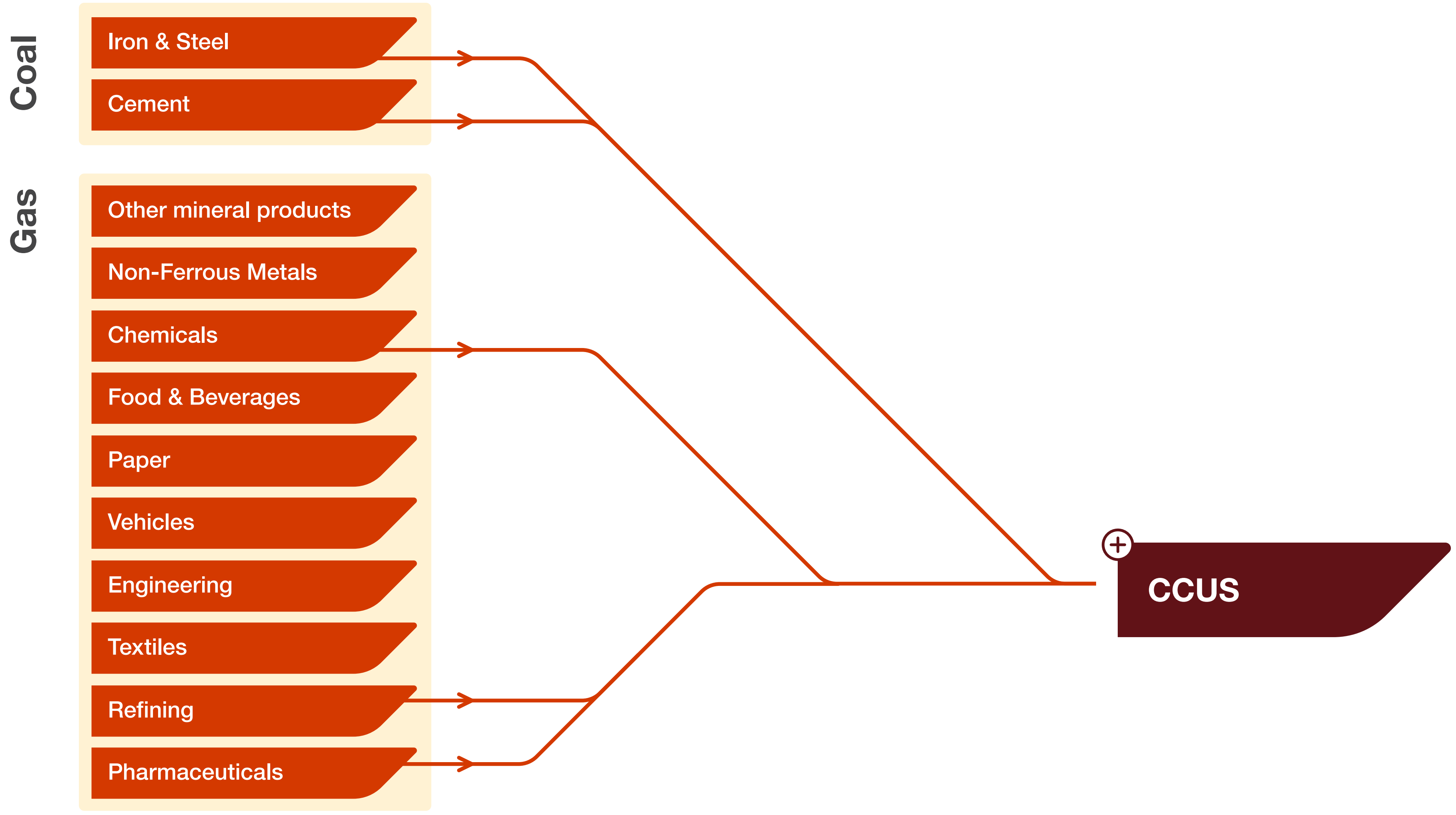


9 The fuel switching options shown in this infographic are based on current technologies and may change in line with future innovation developments for the industrial sector.

FES 2021 / Consumer View / Industrial and Commercial 131

What we've found

Industrial fuel switching options for decarbonisation[9]



9 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.

FES 2021 / Consumer View / Industrial and Commercial 132

What we've found

National and international emissions

Electricity and fossil fuel prices are a significant cost for many I&C consumers. The addition of a carbon price encourages switching to electricity or increased investment in energy efficiency measures to reduce fuel consumption in the medium term. This only becomes viable when the price of emitting carbon becomes sufficiently expensive. Fossil fuel users unable to switch to electricity convert to hydrogen as the network develops in the later decades in System Transformation especially. A carbon border adjustment tariff would ensure that industrial companies are not incentivised to move energy intensive production overseas, where the cost of emitting greenhouse gases could be less.

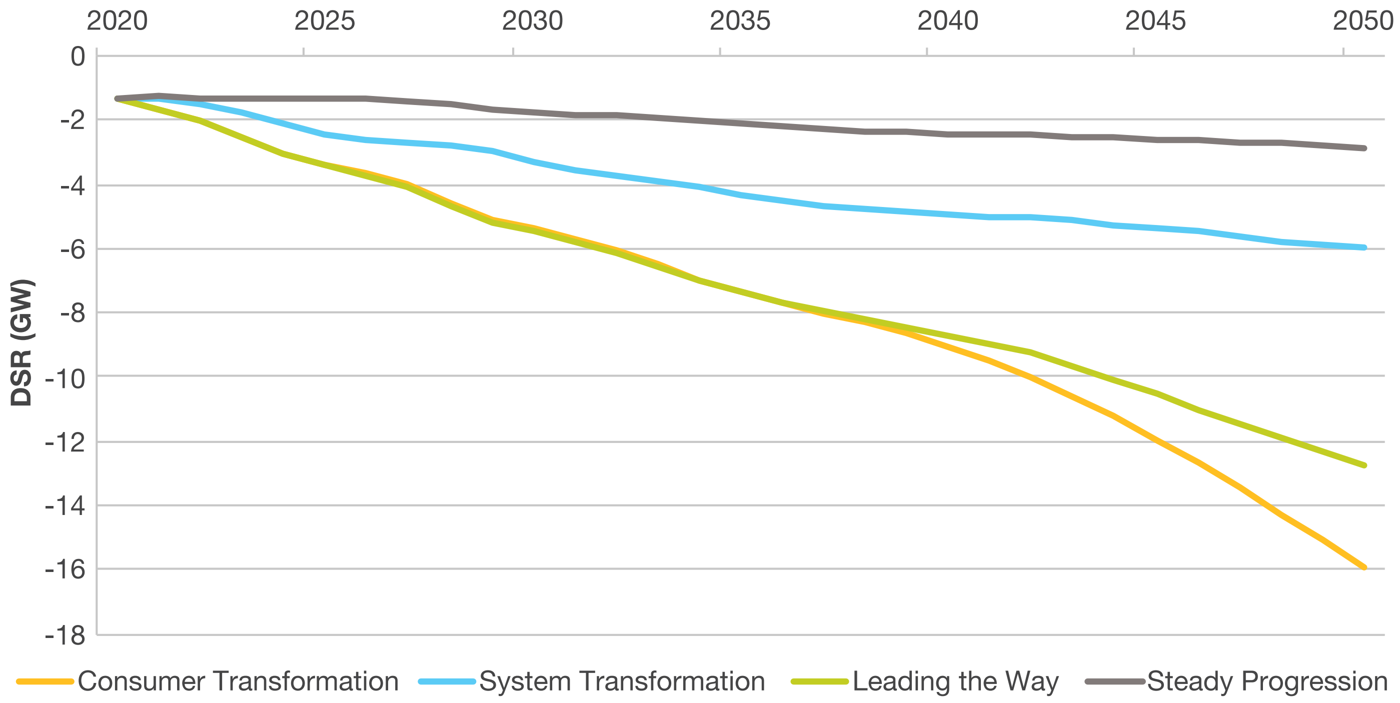
The UK Emissions Trading Scheme (ETS)[10] set out in the Energy White Paper, and operational as of January 2021, intends to cap greenhouse gas emissions, gradually lowering this cap over time. Businesses will be able to buy and sell emissions allowances. It is unclear how valuable the UK ETS will be in driving extensive decarbonisation in the I&C sectors.

I&C demand side response

I&C consumers can play an increasingly active role in the energy system, providing sources of flexibility. For I&C consumers, this can be in the form of turning demand up, down, on or off in response to a price signal. This is particularly important in Consumer Transformation which has the highest levels of electrification and electricity demands. In this scenario, demand side response (DSR) could be up to 16 GW by 2050. Other forms of flexibility, such as generation and storage, can also be deployed to meet these demands. For more information, see the flexibility chapter.

I&C consumers who choose to participate in DSR will undoubtedly need to modify existing processes to cope with shifting demand based on TOUTs. The revenue these consumers receive from the electricity market therefore must be enough to offset any inefficiency costs in actual business processes - for example, if a process was shut down for a few hours to help manage peak demand. Inevitably I&C DSR at this level will require significant changes to existing market frameworks to offer attractive revenue streams to incentivise uptake.

Figure CV.56: Industrial and Commercial demand side response (DSR)



System View

Introduction

The energy system is changing rapidly. The UK's net zero decarbonisation targets are accelerating the growth of new low carbon energy sources. Energy demands are changing as consumers choose new technologies for heat and transport. And smart technology and digitalisation is driving a change in how consumers interact with energy.

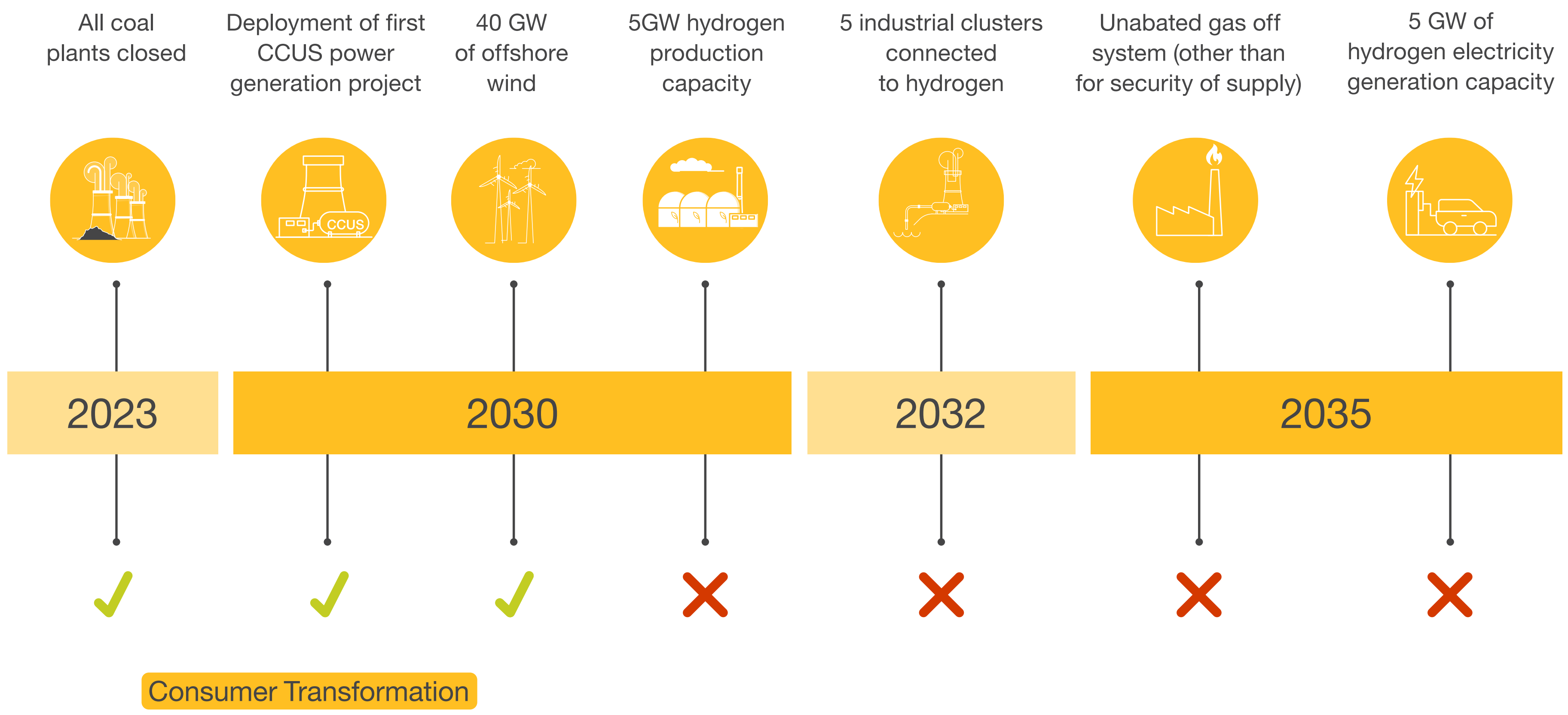
The system view chapter considers the interactions between energy supply and demand and the implications of energy choices presented in the consumer view chapter. We explore the links between primary energy inputs, and transformations between different energy carriers that will be needed as we move into a low carbon future.

Included within this section is a view of the different sources of energy supply:

- Bioenergy
- Natural gas
- Hydrogen
- Electricity

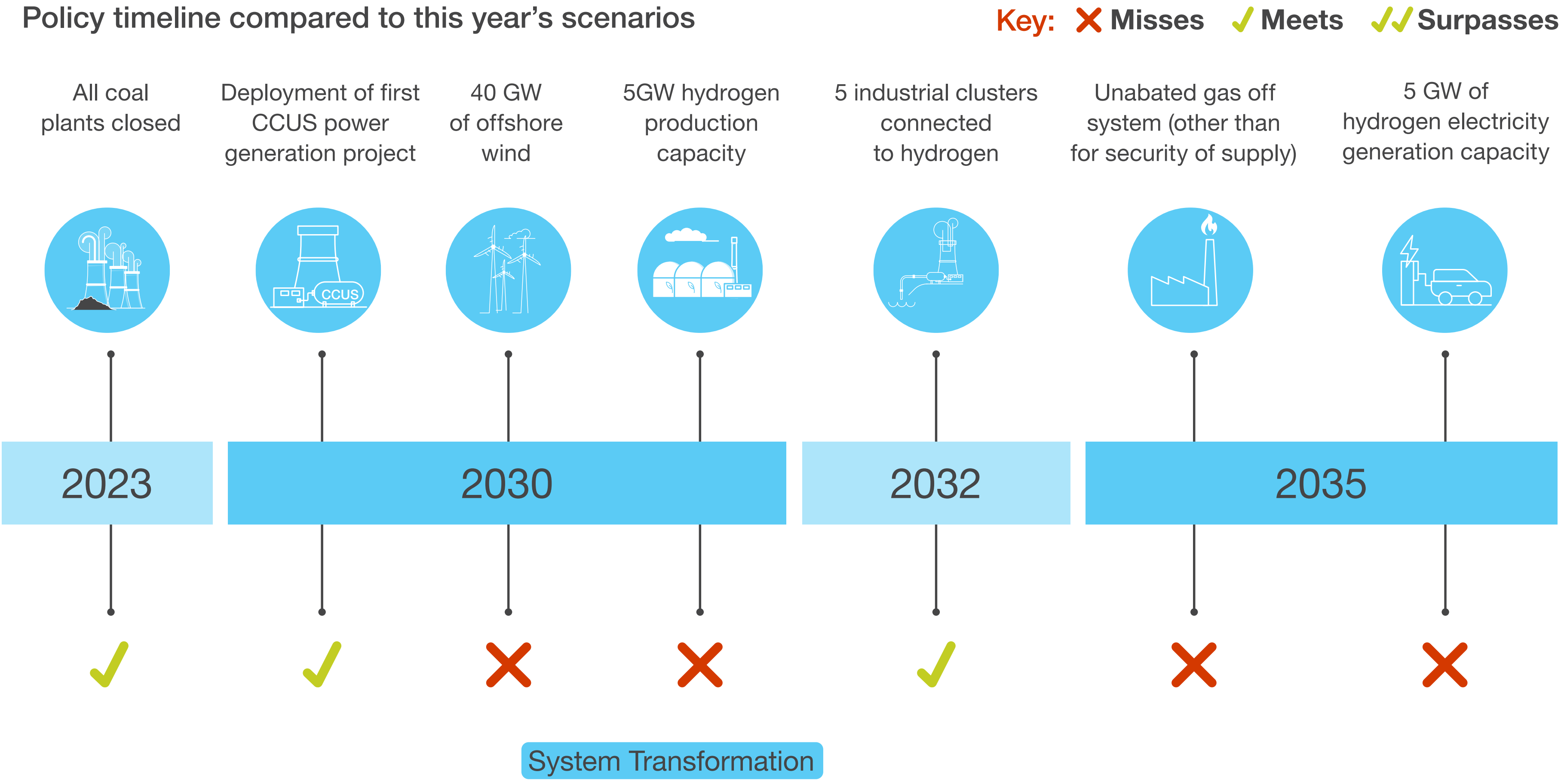
Policy timeline compared to this year's scenarios

Key: ✗ Misses ✓ Meets ✓✓ Surpasses



FES 2021 / System View / Introduction 135

Policy timeline compared to this year's scenarios



FES 2021 / System View / Introduction 136

Introduction

Policy timeline compared to this year's scenarios

Key: ✗ Misses ✓ Meets ✓✓ Surpasses

Milestone	Year	Leading the Way
All coal plants closed	2023	✓
Deployment of first CCUS power generation project	2030	✓
40 GW of offshore wind	2030	✓✓
5GW hydrogen production capacity	2030	✓
5 industrial clusters connected to hydrogen	2032	✓
Unabated gas off system (other than for security of supply)	2035	✓
5 GW of hydrogen electricity generation capacity	2035	✓

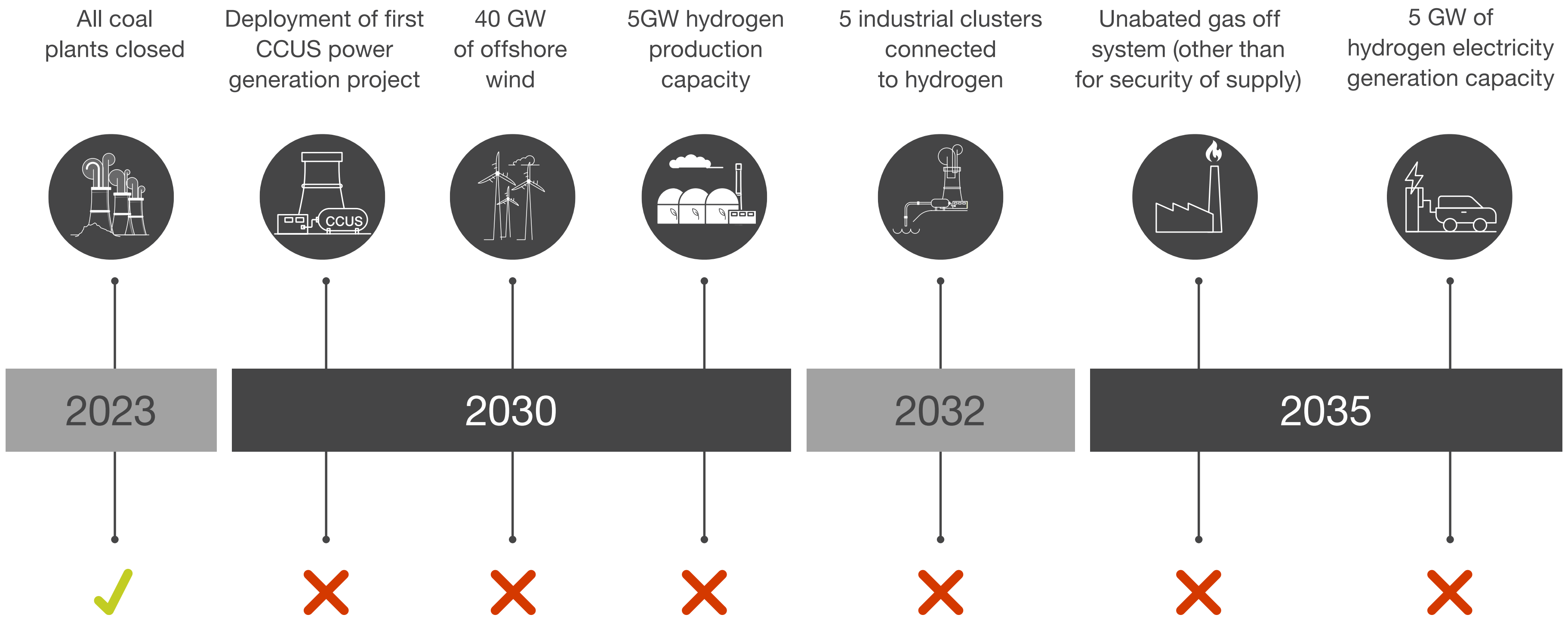
Leading the Way

FES 2021 / System View / Introduction 137

Introduction

Policy timeline compared to this year's scenarios

Key: ✗ Misses ✓ Meets ✓✓ Surpasses



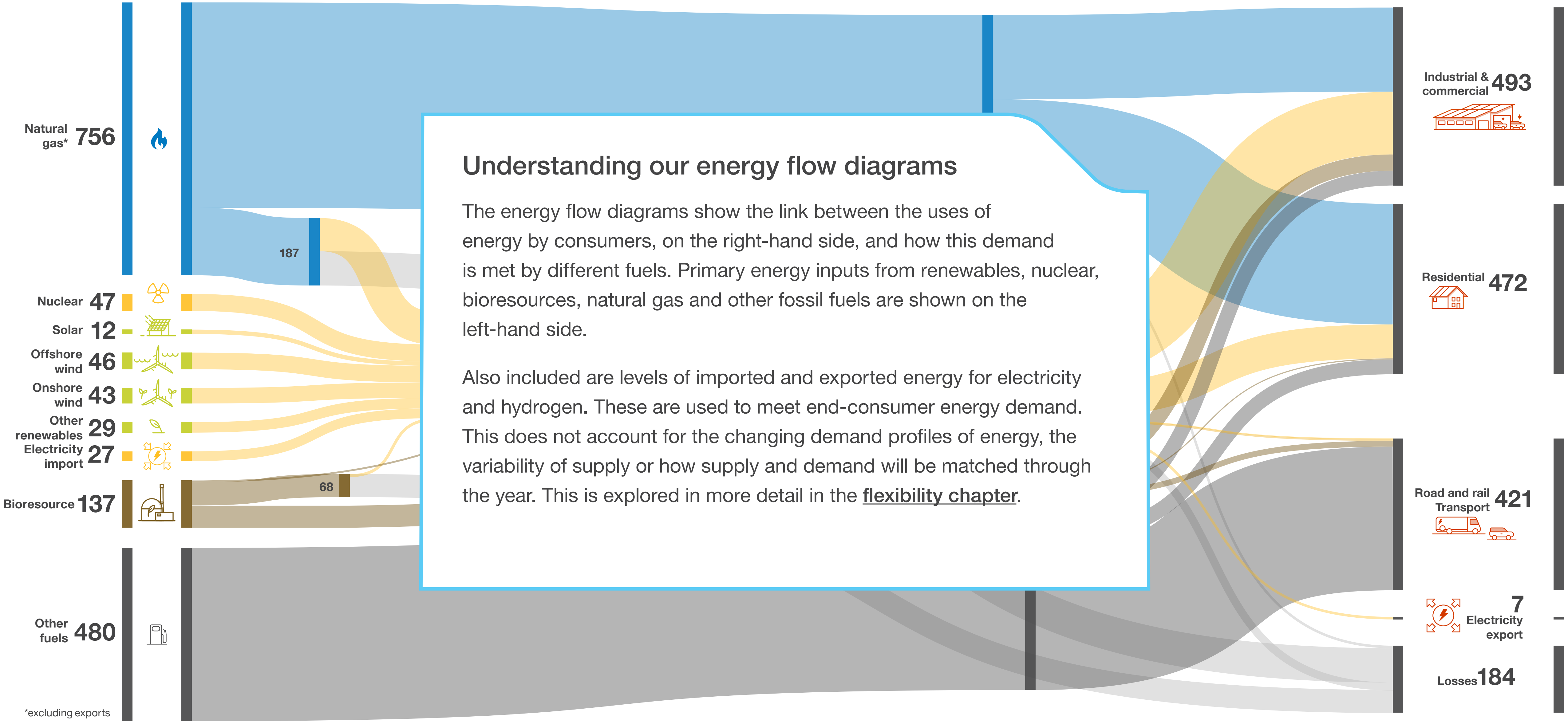
Steady Progression

FES 2021 / System View / Introduction 138

Introduction

2020: energy demand and supply (TWh)

- Relative to net zero scenarios energy demand is much higher today than in 2050
- Fossil fuels provide the majority of energy supply
- Energy demand for transport is much higher today than in 2050 due to the relative inefficiency of ICE vehicles compared to electric vehicles



Understanding our energy flow diagrams

The energy flow diagrams show the link between the uses of energy by consumers, on the right-hand side, and how this demand is met by different fuels. Primary energy inputs from renewables, nuclear, bioresources, natural gas and other fossil fuels are shown on the left-hand side.

Also included are levels of imported and exported energy for electricity and hydrogen. These are used to meet end-consumer energy demand. This does not account for the changing demand profiles of energy, the variability of supply or how supply and demand will be matched through the year. This is explored in more detail in the flexibility chapter.

Energy transformation and losses

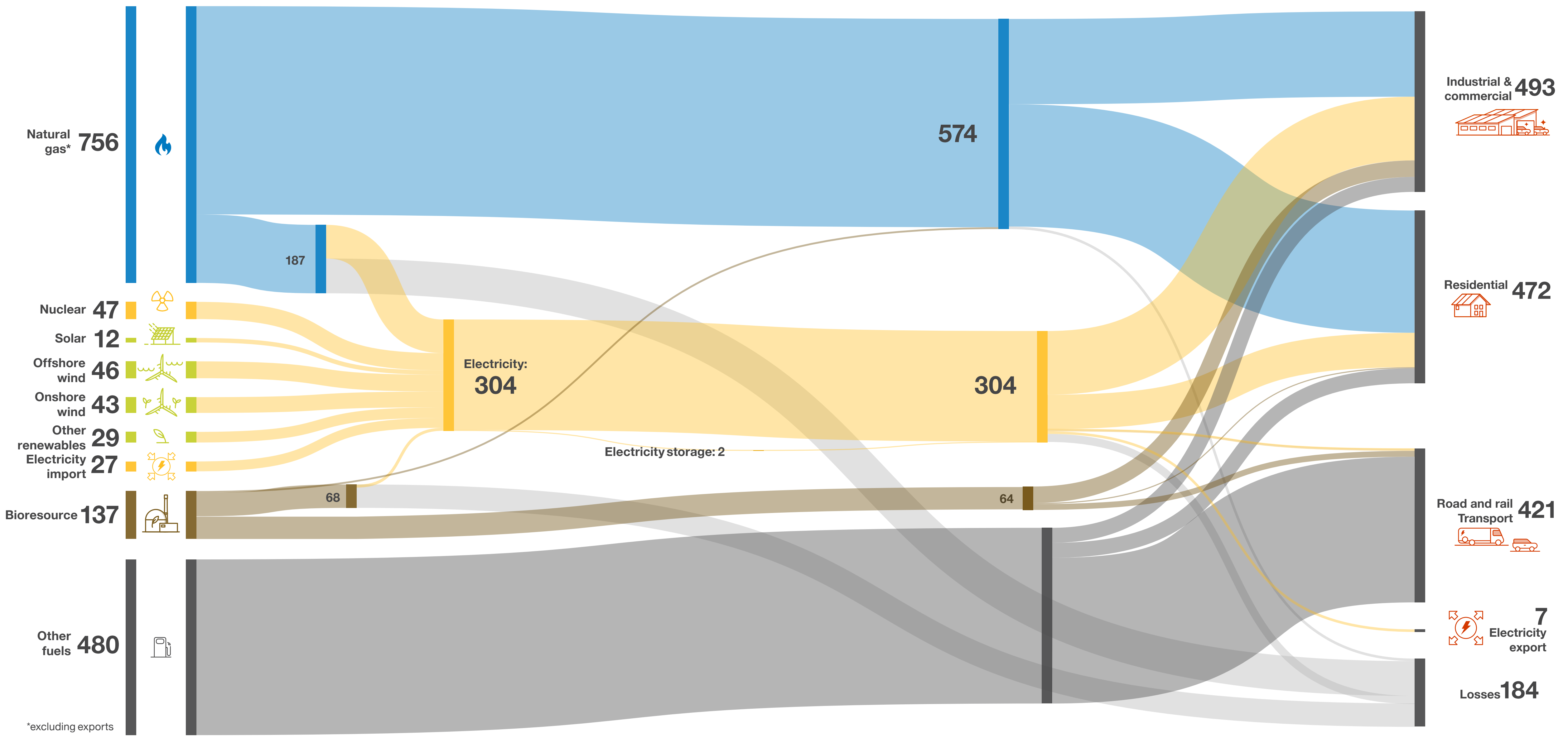
Understanding our energy flow diagrams

FES 2021 / System View / Introduction 139

2020: energy demand and supply (TWh)

- Relative to net zero scenarios energy demand is much higher today than in 2050
- Fossil fuels provide the majority of energy supply
- Energy demand for transport is much higher today than in 2050 due to the relative inefficiency of ICE vehicles compared to electric vehicles

Primary energy inputs



End consumer demands

Energy transformation and losses

Understanding our energy flow diagrams

FES 2021 / System View / Introduction 140

Introduction

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 again 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; a lot of the heat is wasted, however. 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 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.

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.

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.

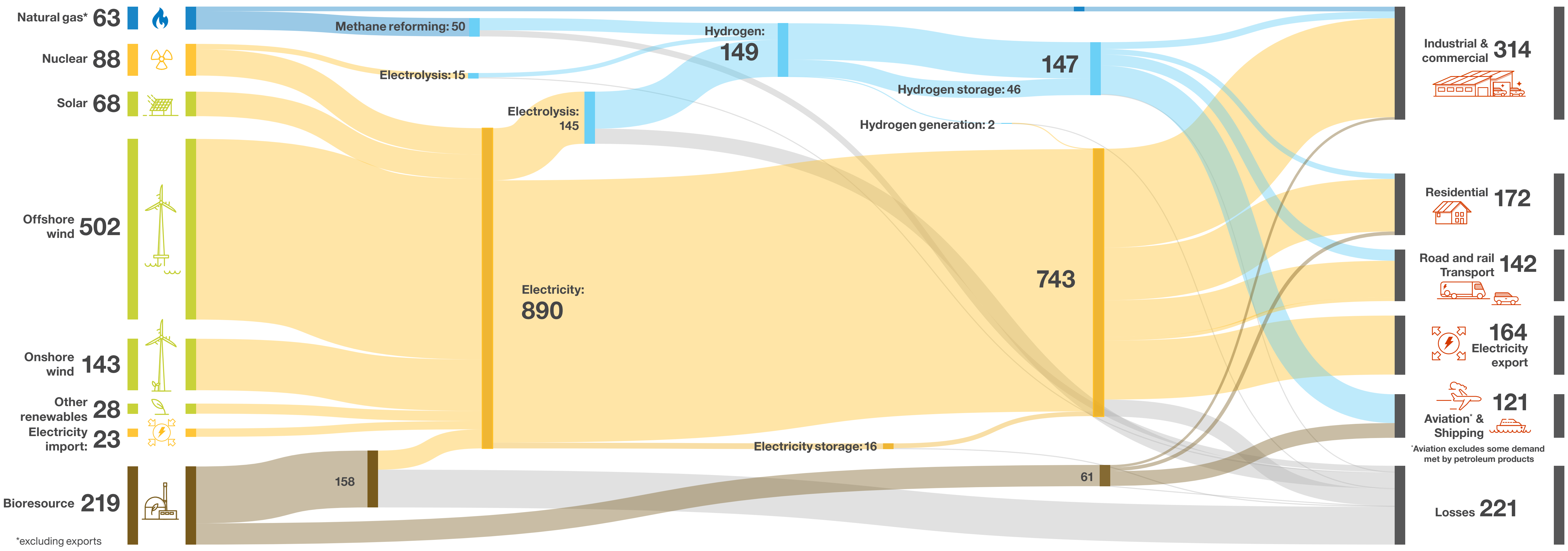
While Consumer Transformation and System Transformation have relatively similar heat demands, on the energy flow diagram these look markedly different in size. This is because System Transformation relies heavily on hydrogen boilers to produce heat – around 90% efficient – while Consumer Transformation 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 2021 / System View / Introduction 141

Introduction

Consumer Transformation: energy demand and supply (TWh)

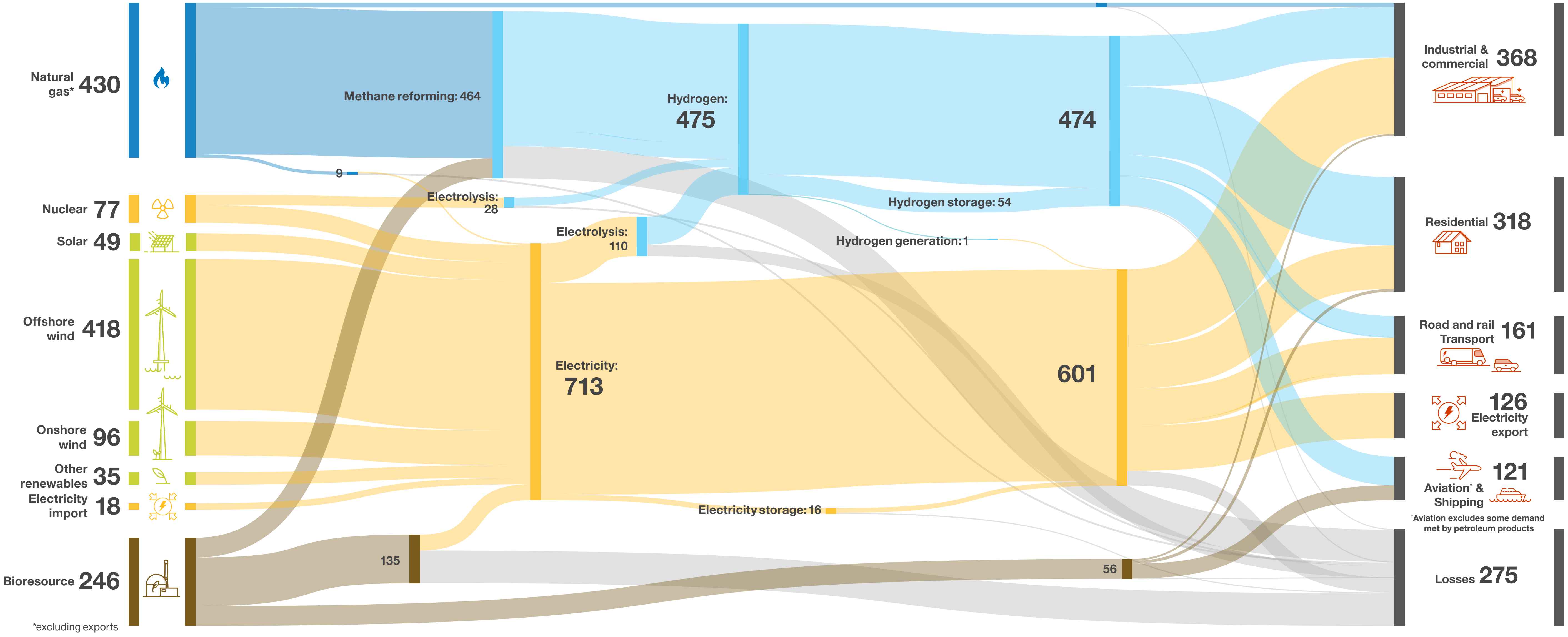
- Home heating, transport and industry largely electrified
- Hydrogen produced in the UK, primarily through electrolysis
- Electricity generation capacity and output is highest in this scenario to meet high annual electricity demands
- High levels of energy efficiency measures, lowest end user demand



Introduction

System Transformation: energy demand and supply (TWh)

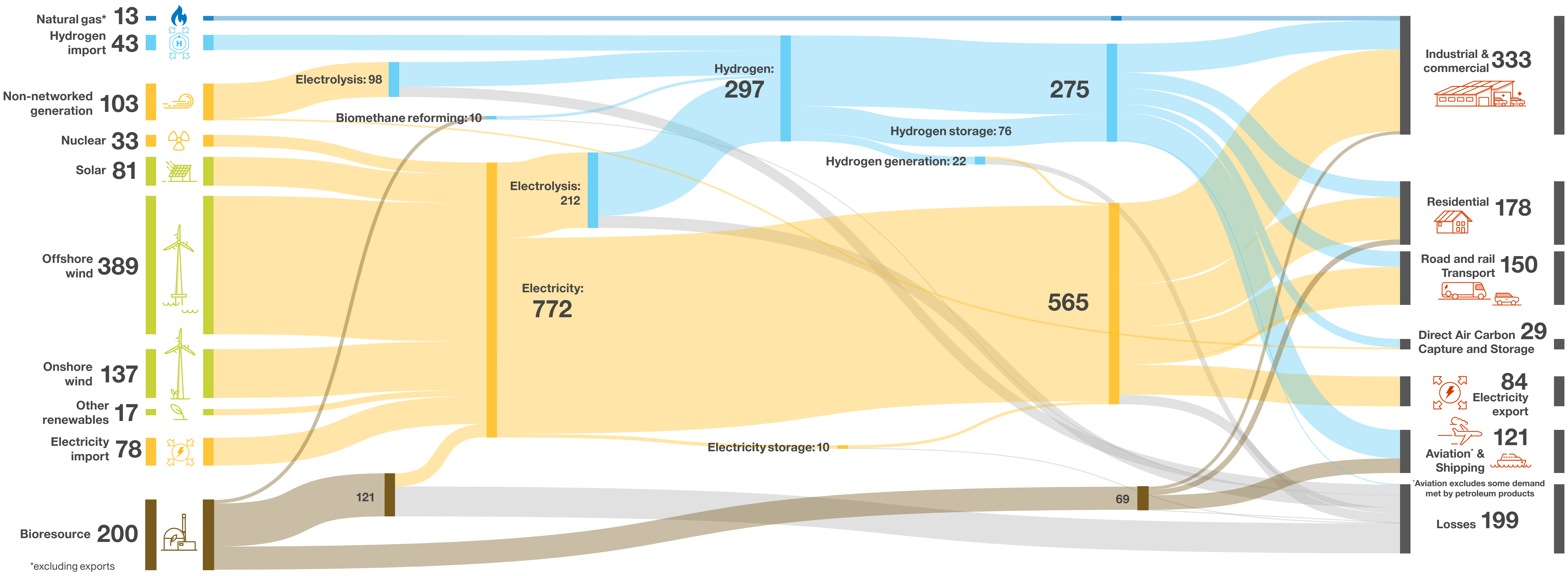
- Highest proportion of hydrogen with widespread use for home heating, industry and HGVs
- Hydrogen produced in the UK, mainly through methane reforming, with large requirement for natural gas with CCUS
- Some negative emissions from hydrogen production from bioresources with CCUS
- Highest level of bioresource use, particularly for BECCS in the power sector



Introduction

Leading the Way: energy demand and supply (TWh)

- Combination of hydrogen and electricity used in industry and to heat homes using hybrid heat pumps or hydrogen boilers
- No natural gas used to produce hydrogen
- Some use of direct air carbon capture and storage (DACCS) for negative emissions
- The only scenario to include non-networked electricity generation and hydrogen imports

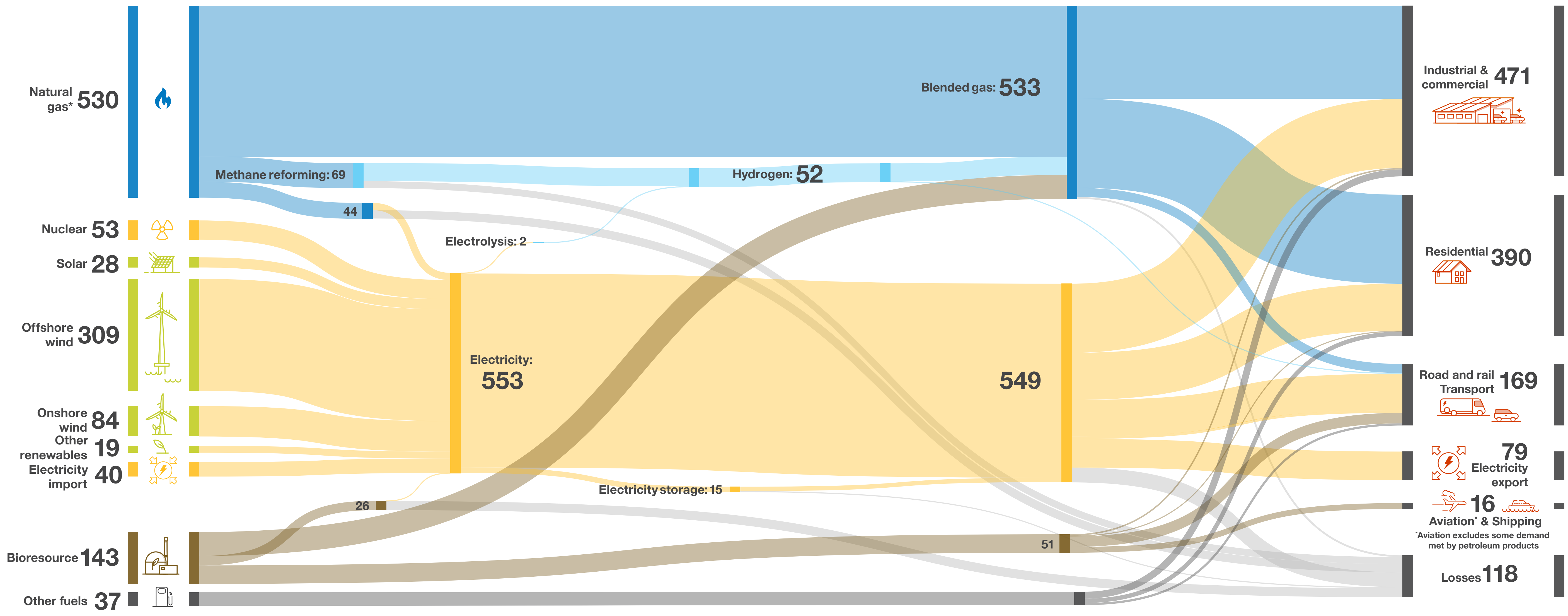


FES 2021 / System View / Introduction 144

Introduction

Steady Progression: energy demand and supply (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

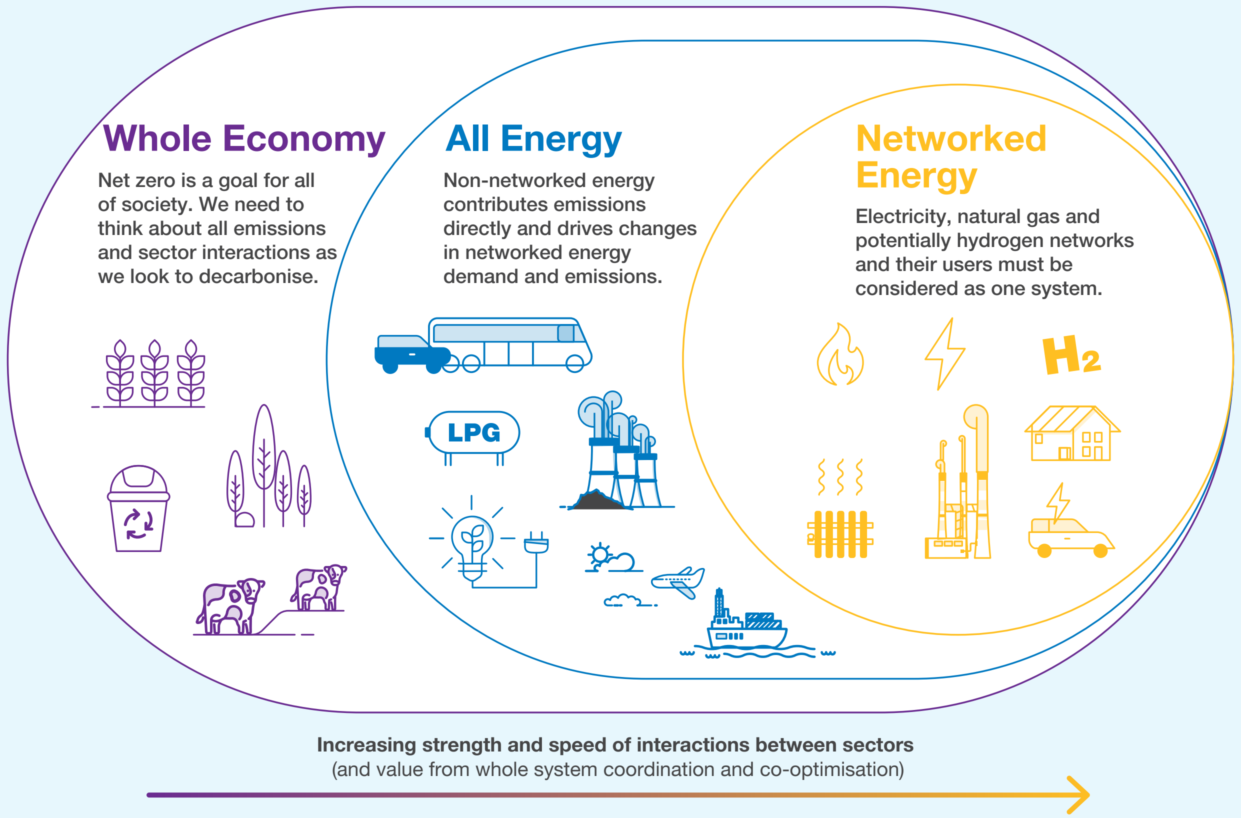
What we've found

Whole system thinking helps decarbonisation

The net zero target requires a more comprehensive way of thinking about the way we use energy. It makes us focus on energy use across society and consider the emissions from its use in all sectors.

- **Networked energy –** this is energy transported from where it is produced to where it is consumed using 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 impact on 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



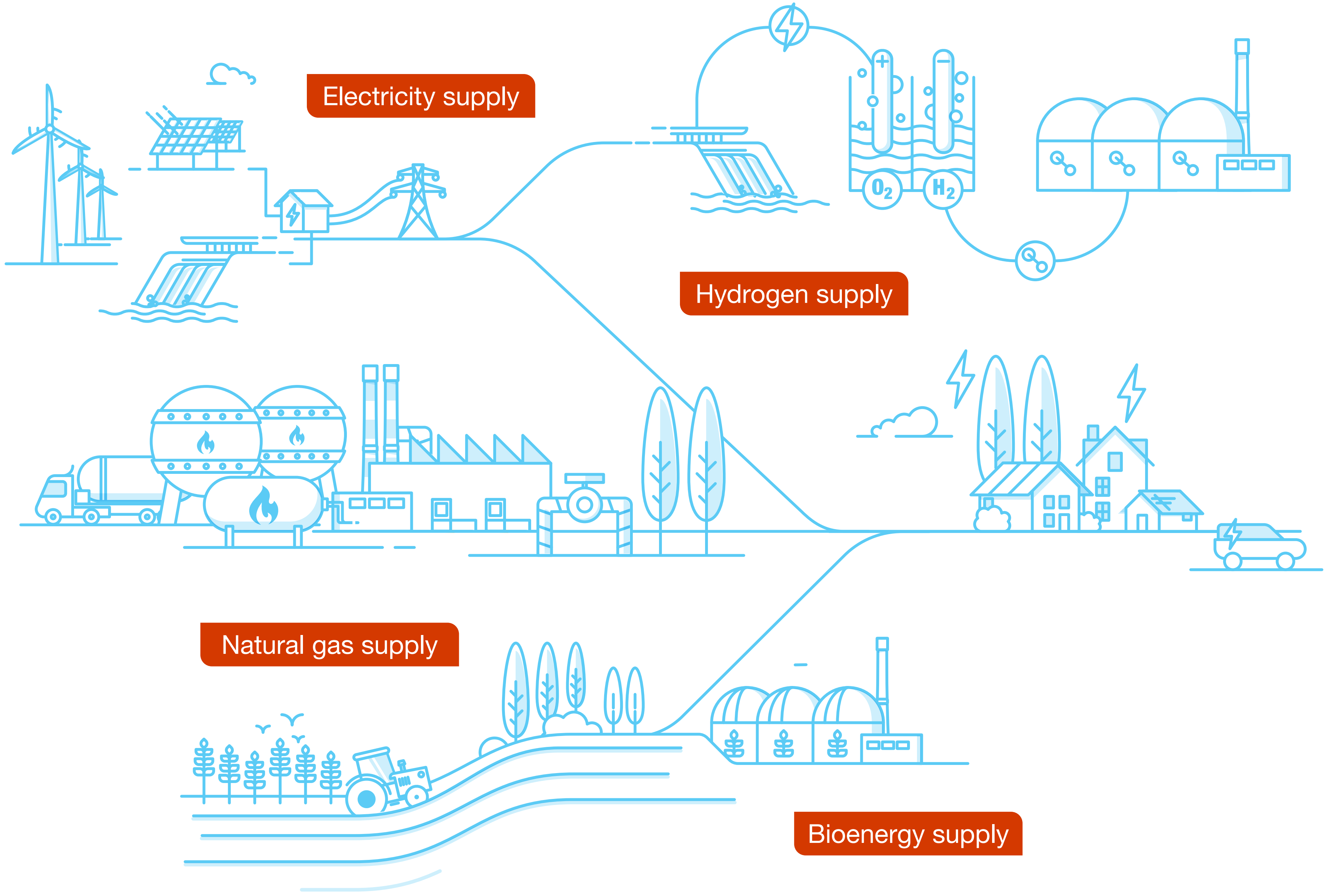
FES 2021 also considers energy use for aviation and shipping, as well as from non-energy sectors such as agriculture and Land Use, Land Use-Change and Forestry (LULUCF). For these sectors where we don't have deep expertise, or where we do not yet have strong stakeholder evidence, we use inputs from published analysis from the Climate Change Committee (CCC) and engagement with their experts.

FES 2021 / System View / Introduction 146

What we've found

Whole system thinking helps decarbonisation

The energy flow diagrams illustrate how interconnected different energy uses are in a net zero world, 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.



FES 2021 / System View / Introduction 147

What we've found

Electricity – more electricity from wind and solar is vital to our net zero target; however it won't always be available when we need it. 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. One example is using electric vehicles 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 can be found in the flexibility section.

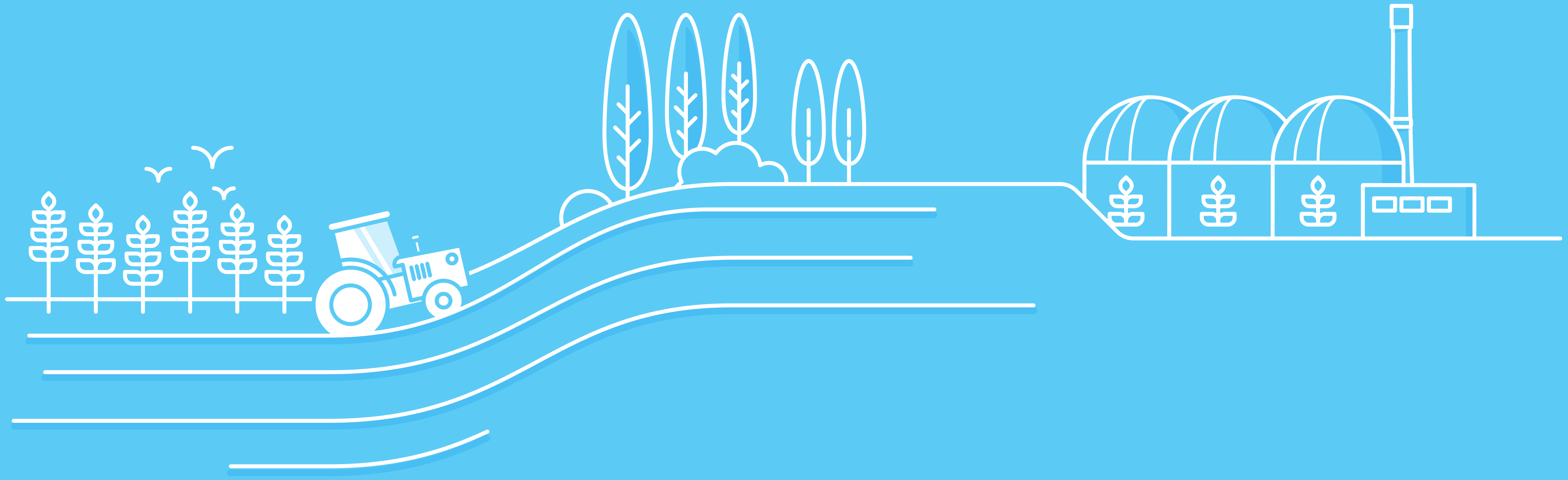
Natural Gas – although a fossil fuel, natural gas continues to play an important role in the transition to a net zero energy system. Its use in power stations provides a flexible electricity source for times when renewable generation is not possible. The network of supply pipes it uses could also be part of a net zero system, used to transport hydrogen around the country. Whole energy system thinking for natural gas means making sure that its benefits are not forgotten through the energy transition, while also reducing and eventually eliminating its carbon emissions.

Hydrogen – hydrogen is a versatile source of energy, which can help across the whole energy system. It can store renewable energy and then be used for transport, heating and electricity. For this reason, it features in all our net zero scenarios. Whole system thinking means ensuring locations for electrolysers are sited close to renewable generation to minimise network constraints and are convenient for the use of the hydrogen produced.

Bioenergy – bioenergy is renewable and flexible. It can provide fuels for aviation, for heating, for 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 bioresources we have to maximise negative emissions and to focus on those areas hardest to decarbonise.

FES 2021 / System View / Introduction 148

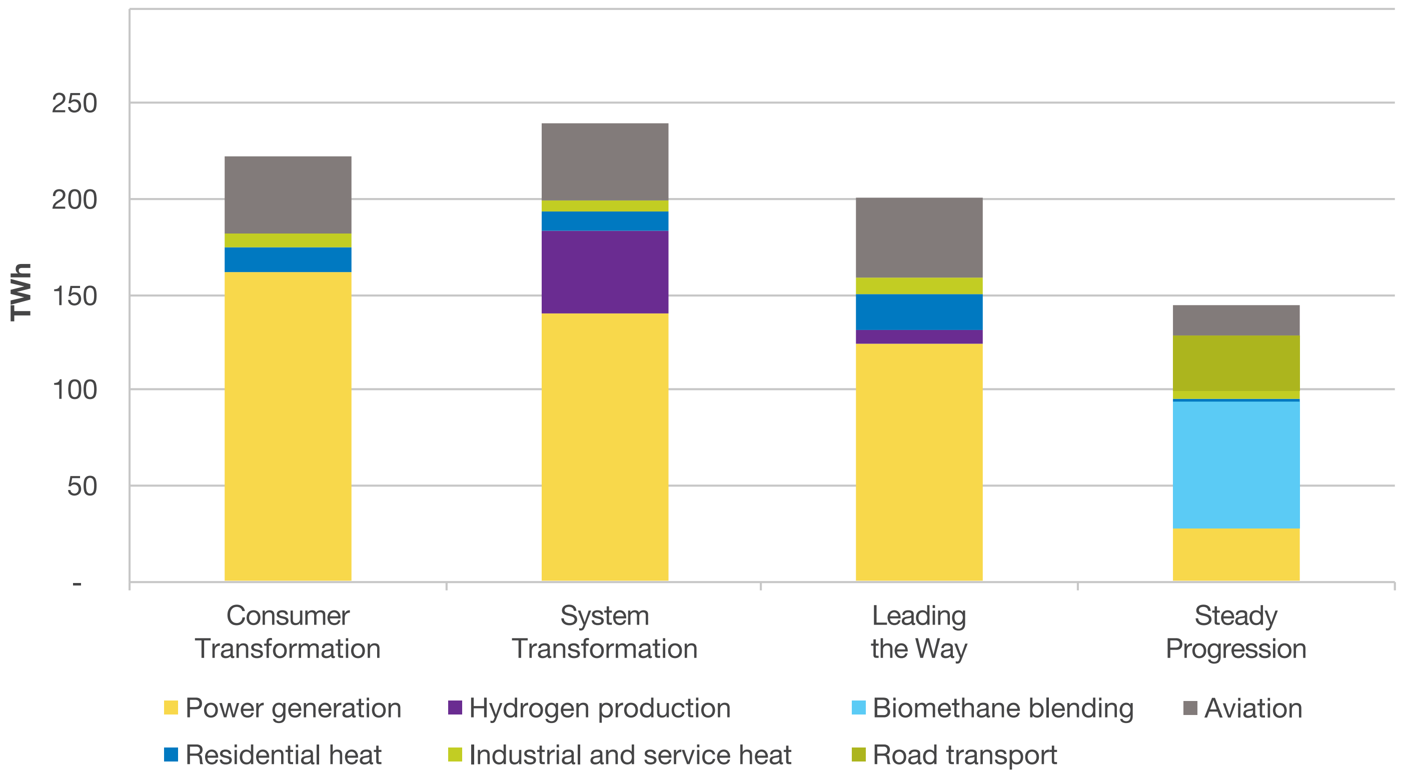
Bioenergy Supply



Key insights

- At least 75% of bioresources are used with carbon capture technology (CCUS) in our net zero scenarios. Bioenergy has a critical role to play in decarbonisation because when combined with CCUS, it results in negative emissions. Without these, meeting net zero will be very challenging.
- The UK will need either more domestic supplies or imports of sustainably certified biomass to generate the negative emissions we need to achieve net zero. Imported biomass is the largest single source of bioresources in System Transformation and Consumer Transformation (at least a third of total bioresource demand).
- For net zero scenarios, power generation with carbon capture accounts for over half of the bioresource demand. In Consumer Transformation in 2050, over 70% of total bioresources are used to generate electricity and the associated negative emissions.
- The maximum amount of bioresources used in 2050 is 246 TWh, in the System Transformation scenario. Here, over 85% of the bioresources are used for either power generation, hydrogen production or aviation fuels, all combined with CCUS.
- In Leading the Way, 45% of bioresource demand is met by energy crops, which are grown in the UK. This avoids the need for importing wood pellets.

Figure SV.1: Total bioenergy annual demand in 2050 (TWh)



FES 2021 / System View / Bioenergy supply 150

Key insights

Bioenergy

Bioenergy comes from renewable, organic feedstocks like wood, used cooking oil, and agricultural waste and energy crops (like elephant grass). These absorb carbon as they grow, which is then released when they are burned to produce heat or power.

So, bioenergy is considered to have no net carbon emissions in our scenarios, which is in line with international carbon accounting standards. Combining CCUS with bioenergy (BECCS) results in negative emissions, (for more information go to the Net Zero chapter) which help achieve net zero by offsetting emissions from those sectors unable to completely decarbonise, like aviation. We have assumed that the bioenergy used in our net zero scenarios comes from sustainable sources and that the supply chain is transparent and its emissions are accounted for, regardless of whether the bioresources are from the UK or outside.

FES 2021 / System View / Bioenergy supply 151

Where are we now?

Bioenergy is already an important part of the UK's energy system as it can be used in a variety of ways.

For example, the Renewable Transport Fuel Obligation (RTFO) requires a proportion of transport fuel to come from bioenergy and over 2,000 million litres of biofuels were used in 2020[1]. In the UK in 2019, more electricity was generated from biomass (28%) than from offshore wind.

Many of the biomass power stations were originally built as coal-fired plant in the 1960s, which have been converted to burn wood pellets. The UK's largest biomass power station produces 15 TWh of electricity each year, enough to supply approximately 4 million homes.

The bioenergy value chain

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

1 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/959182/renewable-fuel-statistics-2020-third-provisional.pdf

FES 2021 / System View / Bioenergy supply 152

Where are we now?

The bioenergy value chain

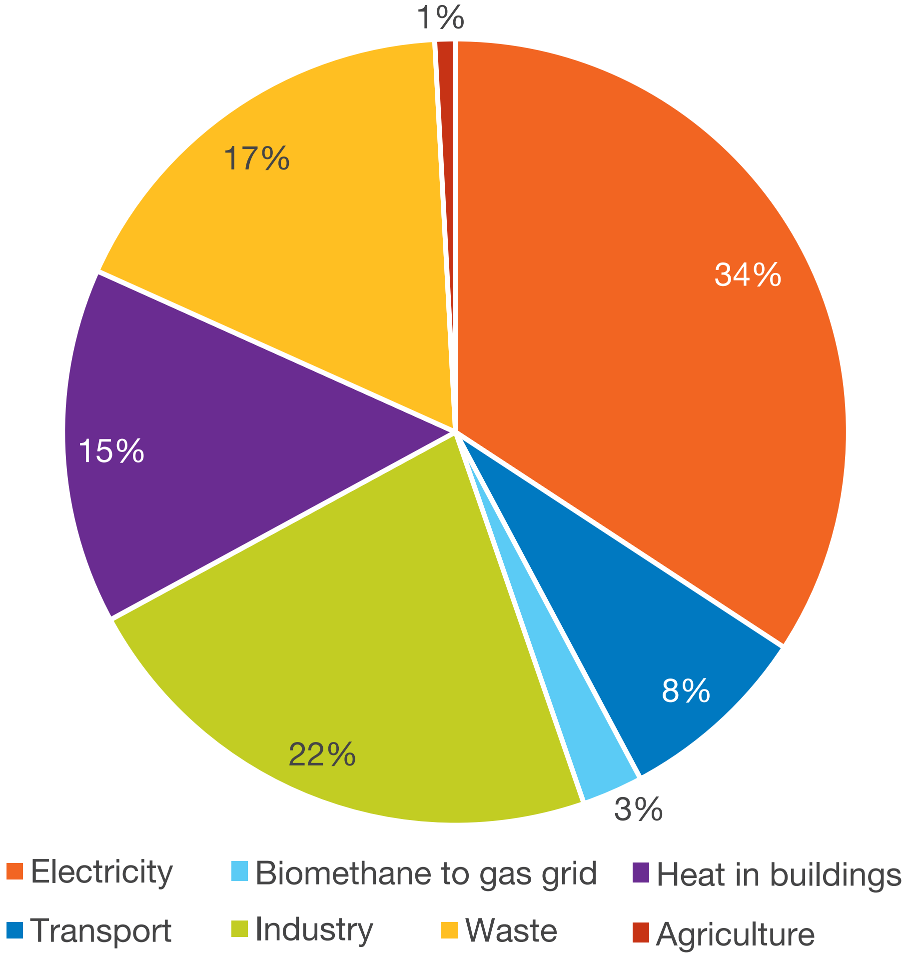
Feedstock	Processing		Outputs		End Use	
Biomass Energy crops agricultural and forest residues (GB and imported)	**COMBUSTION - Generation** (with/out CCUS)		**ELECTRICITY** negative carbon emissions if CCUS		**APPLIANCE USE LIGHTING, ELECTRIC TRANSPORT ETC.**	***Both combustion processes and outputs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

1 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/959182/renewable-fuel-statistics-2020-third-provisional.pdf

FES 2021 / System View / Bioenergy supply 153

Where are we now?

Figure SV.2: Bioenergy use in 2020



The sources of bioenergy are also varied. Processes such as anaerobic digestion convert a variety of waste products, including food, sewage and animal biomass into gas which can be used in power stations or injected into the national gas grid. 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 a consistent quality and in large volumes, so a great deal is imported as the UK forest 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[2].

The level of imports and the sustainability of biomass mean that opinions about its use are split. As countries around the world start to decarbonise more, demand and competition for supplies globally is expected to increase. The recent Climate Assembly raised concerns about how and where bioenergy was produced and whether there were adequate regulations and standards in place. 40% of assembly members agreed that bioenergy should be used, whilst 60% were unsure or disagreed.

The sustainability of biomass production and transport globally has to be considered. Research has shown that currently over 90% of the GHG emissions from imported wood pellets come from their production and transportation. UK produced wood pellets' emissions are approximately 15% of the North American alternative[3].

2 https://www.ons.gov.uk/economy/environmentalaccounts/articles/aburningissuebiomassisthebiggestsourceofrenewableenergyconsumedintheuk/2019-08-30
3 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48193/3153-final-report-carbon-factor.pdf

FES 2021 / System View / Bioenergy supply 154

FES 2021 / System View / Bioenergy supply 155

Where are we now?

Sustainability of supply chains

On paper the use of biomass for heat, transport or electricity is carbon neutral; at scale, however, many issues need to be addressed to make sure it is both carbon neutral and sustainable. Its classification as carbon neutral is not universally accepted; some commentators argue that using trees for power generation creates a ‘carbon debt’ as their ability to absorb carbon cannot be immediately replaced, taking several years until a young tree absorbs as much carbon as a larger, older tree.

Another aspect is the impact of the rising demand for biomass from countries like the UK without their own large forestry industry. Sustainability standards for forestry management can be very hard to implement and enforce internationally. There is a danger that climate critical forests in all parts of the world will be felled to meet this demand. Additionally, trees could be grown on farmland instead of food, which in turn could make food more expensive. These issues have led the Netherlands to ban the import of biomass for the production of heat and power[4].

There are ways to manage the supply chain to avoid these problems. Firstly, by prioritising the use of waste biomass, such as by-products from industry or from farms and homes. Secondly, by sourcing as much biomass as possible from within the UK, where its production can be more closely monitored. For wood pellets specifically, sustainable forest management is required to ensure enough trees are planted to replenish those being felled and that they are allowed to grow before being harvested. Global monitoring of forestry will require stringent sustainability standards and strict enforcement; biomass buyers will need to make sure they are buying from responsible and sustainable sources. Germany is considering a ‘tree premium’[5], a payment for each hectare of forest absorbing carbon. On a global scale this could help developing countries avoid felling untouched forests.

4 https://www.euractiv.com/section/energy/news/the-dutch-have-decided-burning-biomass-is-not-sustainable/
5 https://www.euractiv.com/section/biomass/news/berlin-and-brussels-mull-forest-protection-as-climate-change-takes-its-toll/

What we've found

Bioresources have an important role to play in all our scenarios. To reach net zero, we have prioritised its use in our modelling to be nearly always paired with carbon capture and storage (either with power generation or gasification for hydrogen) to result in the negative emissions required to reach overall net zero.

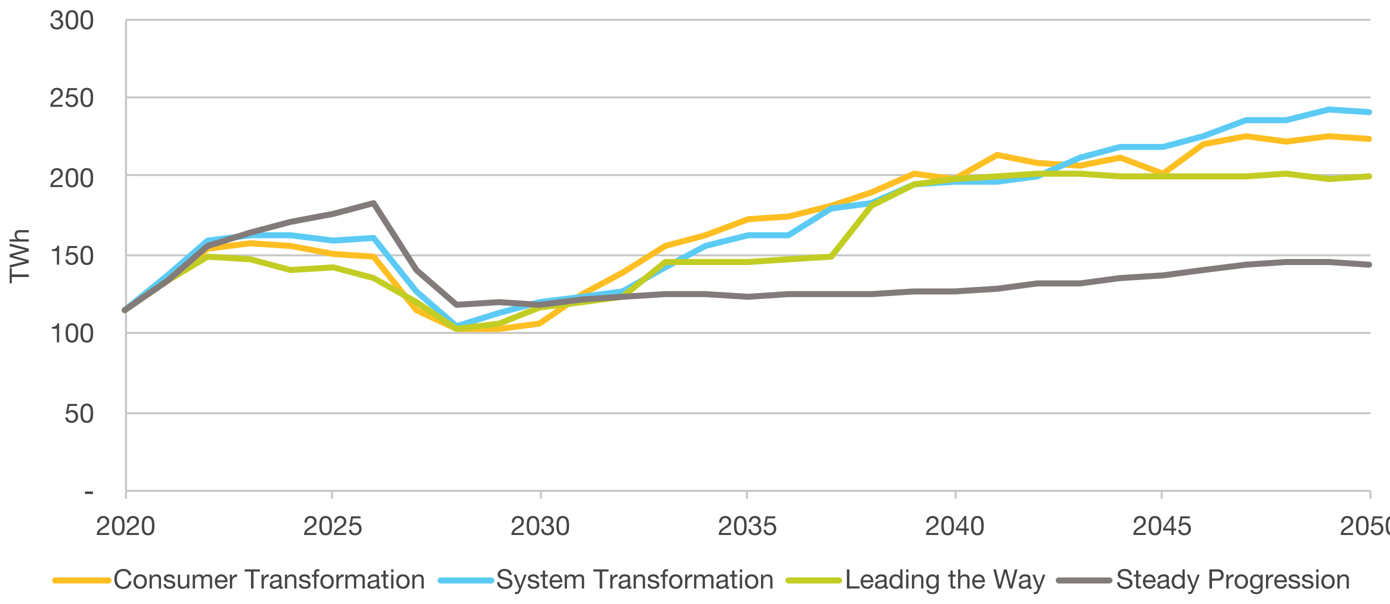
The volumes of bioresources are based on our own research as well as the Climate Change Committee's (CCC) estimates. We see their potential for negative emissions as a driver for increased availability over the coming decades. The level of imports of biomass has been varied in the different scenarios, from nothing in Leading the Way, to 40% of total bioresource demand in System Transformation.

System Transformation has the highest volume of bioenergy demand, of which almost 60% is for electricity generation. Additionally, 22% of the bioenergy is used to produce hydrogen to meet the high levels of hydrogen demand in this scenario.

Energy crops, grown in the UK, contribute to the supply of bioresources in all scenarios. In Leading the Way however, they are the largest single source for bioresources. This assumes changes to land use in the UK, partly because of dietary choices. It also eliminates the need for importing wood pellets from overseas.

In Steady Progression, the volume of bioenergy declines as the Renewables Obligation is gradually removed and only slowly increases after this point. Bioenergy is used to reduce the carbon intensity of transport fuels, electricity and gas.

Figure SV.3: Total bioenergy demand in each scenario out to 2050[6]



6 The dip in demand at the end of the 2020s is due to the removal of Renewable Obligation subsidy support in power sector

FES 2021 / System View / Bioenergy supply 156

What we've found

Importantly, we assume that any wood comes from sustainably managed forests, in addition to reforestation and the creation of new forests elsewhere.

Across all scenarios, the level of forestry waste and other waste wood is roughly the same. The levels of available agricultural waste and energy crops vary, dependent on consumer engagement in issues such as reducing dairy and animal products to help the environment.

Bioenergy is used to produce **sustainable aviation fuel** in every scenario. Taking either biomass or waste fats and oils, an alternative aviation fuel can be produced to meet some demand from aeroplanes. In all scenarios, we assume that this process is combined with CCUS, generating enough negative emissions to offset the continued use of fossil fuels for flying with other fuels. Biofuels also meet demand in off gas-grid locations, from domestic properties as well as industrial and commercial needs. This could be solid biomass, liquid biofuels or bioLPG.

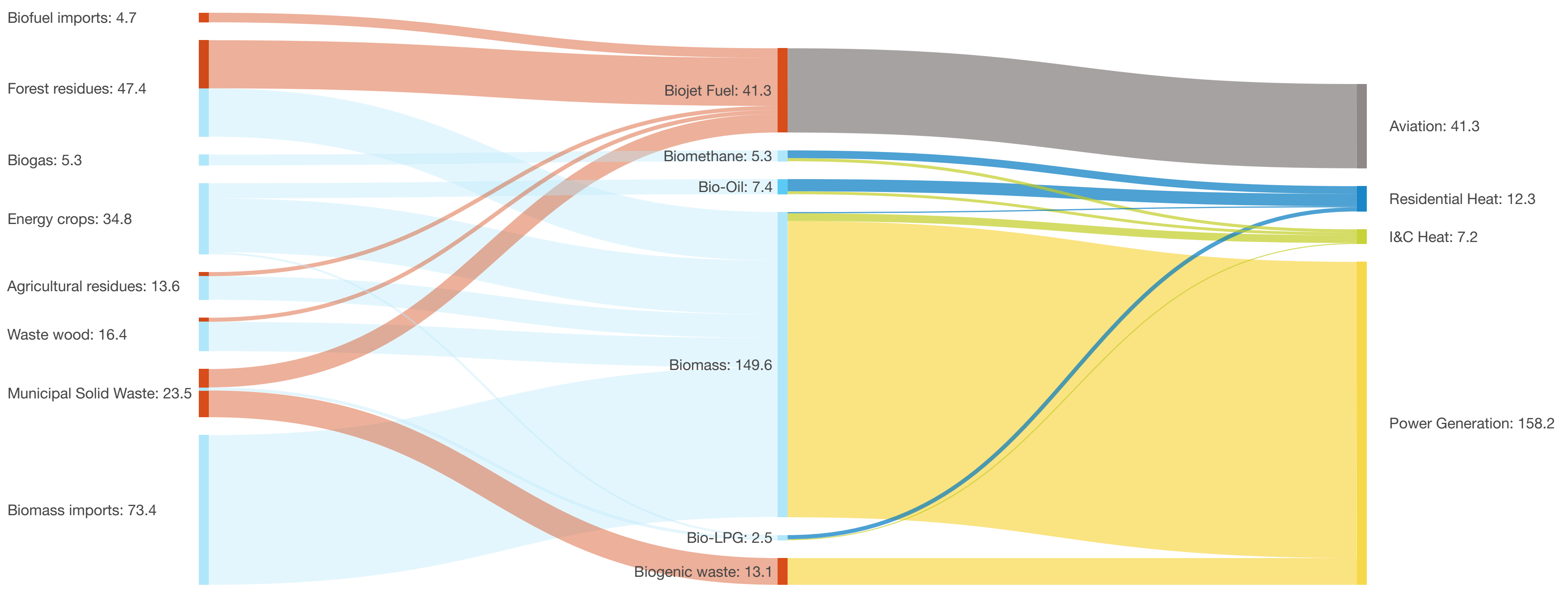
FES 2021 / System View / Bioenergy supply 157

Scenario results

The energy flow diagrams here illustrate how the different bioresources are used in each scenario in 2050[7]. 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

Bioenergy is primarily used with CCUS for power generation and bio-jet fuel (90%). The remainder is for I&C and residential needs. Consumer Transformation has the second highest level of biomass imports.



Total annual bioenergy demand in 2050: 219 TWh.

7 The diagrams represent supply and demand; any energy losses are included within the total end demand.

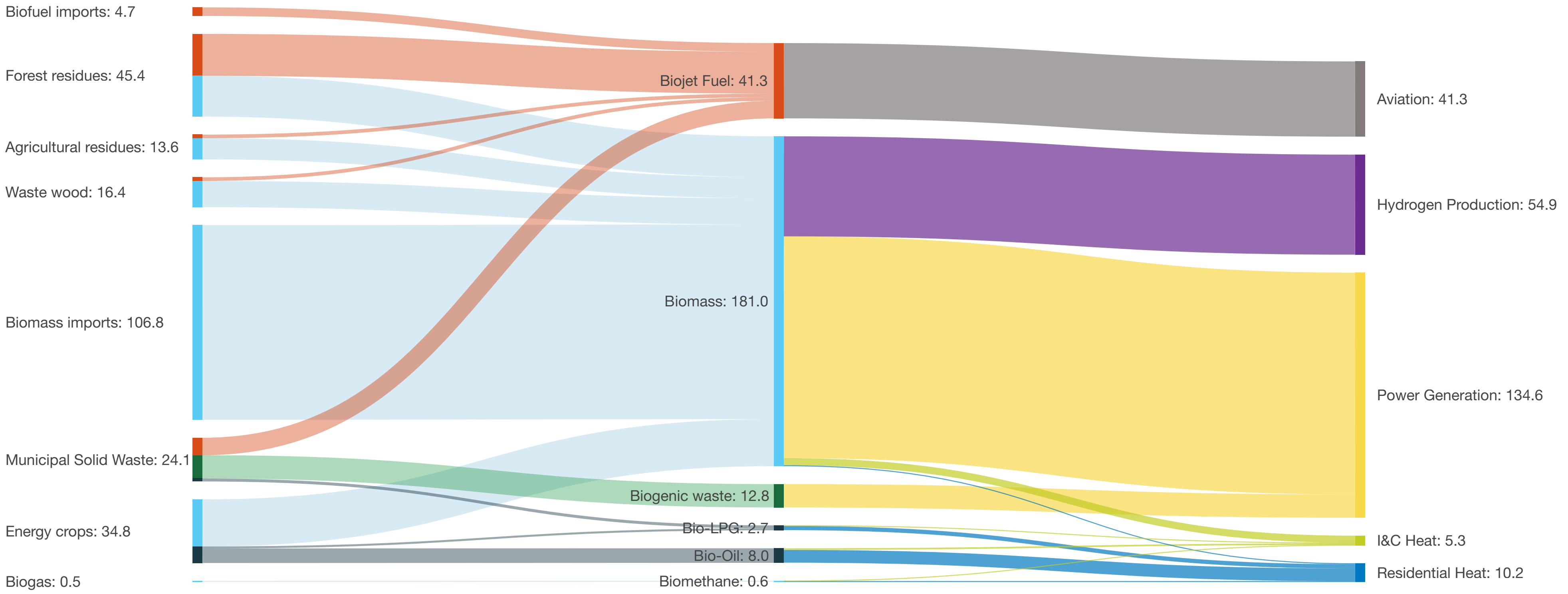
FES 2021 / System View / Bioenergy supply 158

Scenario results

The energy flow diagrams here illustrate how the different bioresources are used in each scenario in 2050[7]. 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.

System Transformation

This scenario has the highest level of bioresource demand and the highest levels of imports. Bioenergy fulfills 44% of total annual energy demand in 2050.



Total annual bioenergy demand in 2050: 246 TWh.

7 The diagrams represent supply and demand; any energy losses are included within the total end demand.

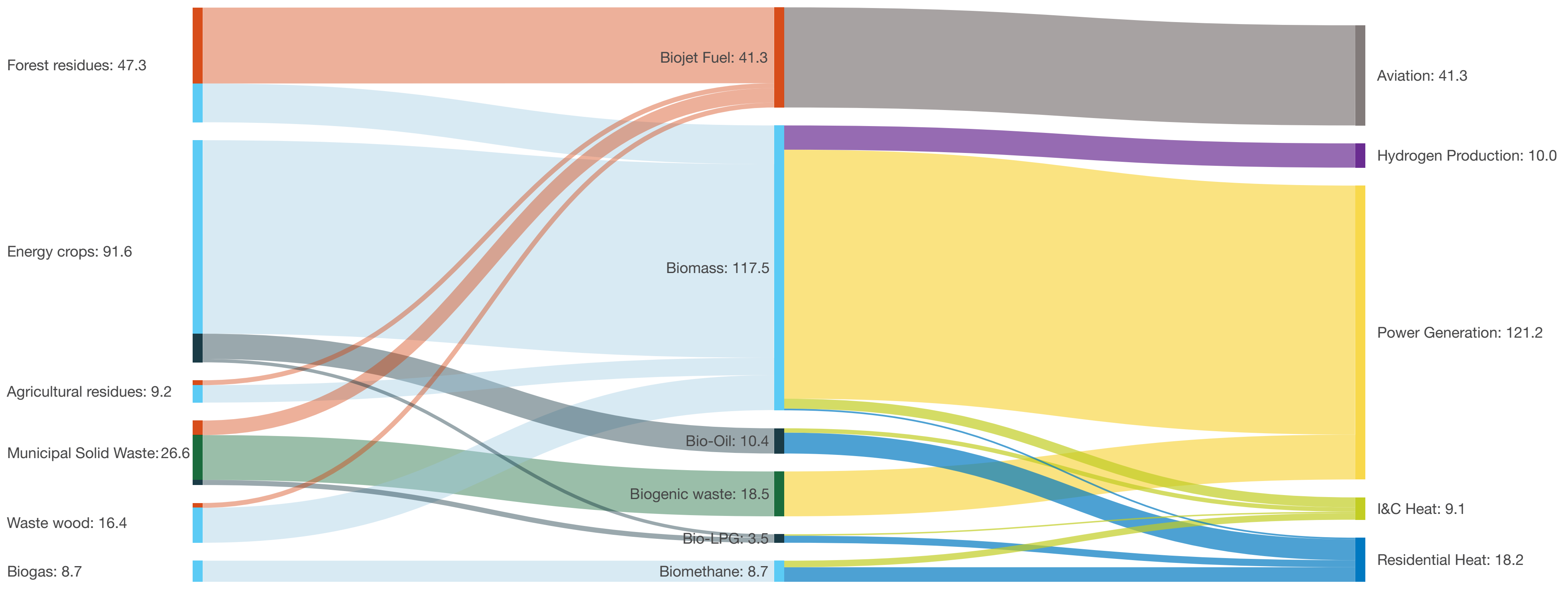
FES 2021 / System View / Bioenergy supply 159

Scenario results

The energy flow diagrams here illustrate how the different bioresources are used in each scenario in 2050[7]. 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.

Leading the Way

This has the smallest increase in bioenergy demand in a net zero scenario, as greater consumer engagement helps to suppress imports. Almost two thirds of the demand are from power generation, which includes BECCS as well as energy from waste.



Total annual bioenergy demand in 2050: 200 TWh.

7 The diagrams represent supply and demand; any energy losses are included within the total end demand.

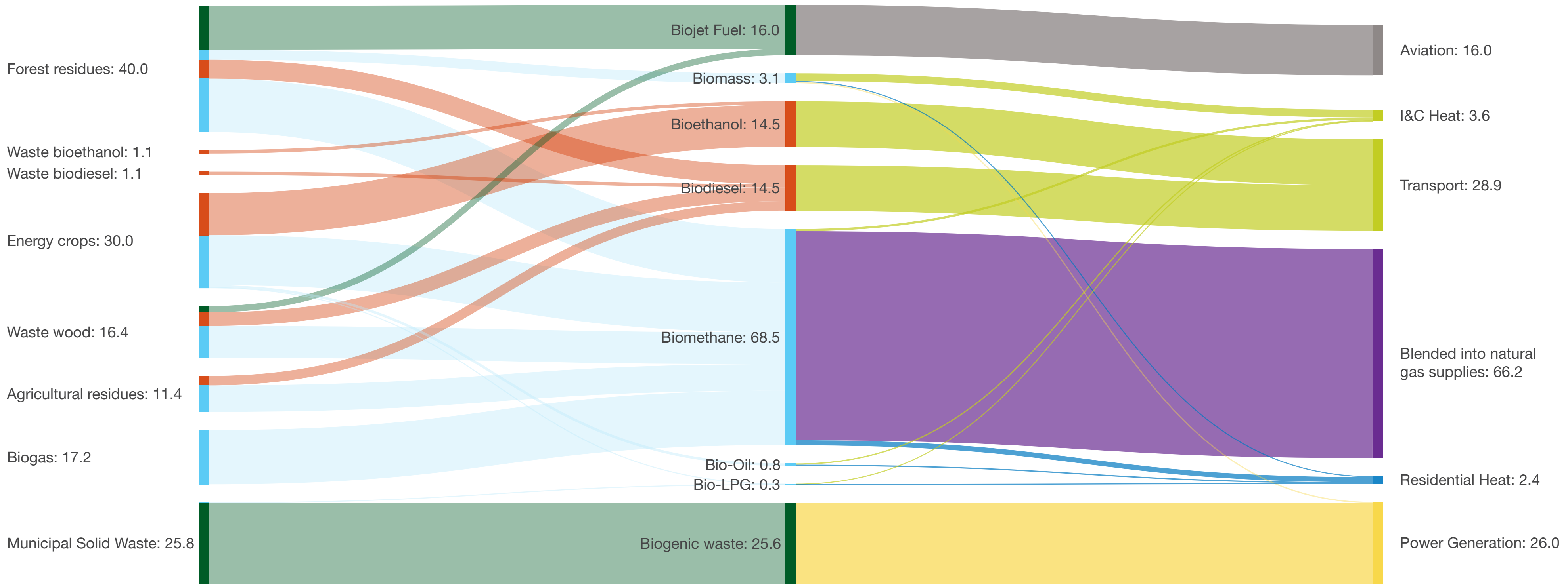
FES 2021 / System View / Bioenergy supply 160

Scenario results

The energy flow diagrams here illustrate how the different bioresources are used in each scenario in 2050[7]. 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.

Steady Progression

Total bioenergy demand in 2050 is the lowest of all scenarios. Almost 50% of the bioresources are being used for green gas (biomethane), which is blended with natural gas supplies to reduce its overall carbon impact.

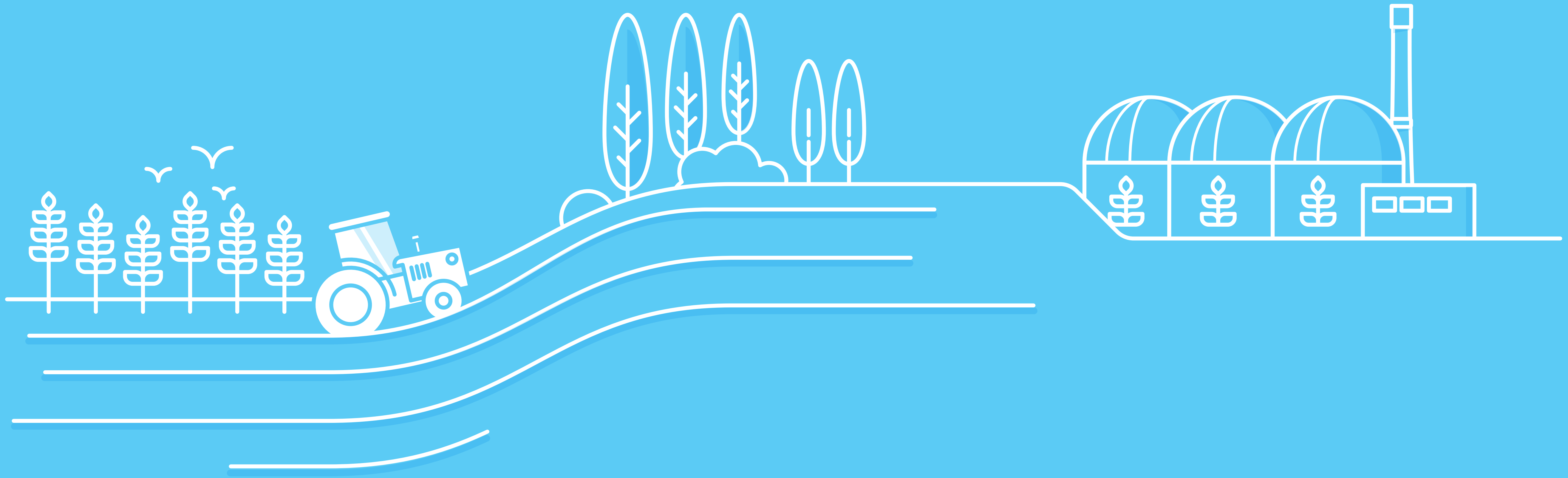


Total annual bioenergy demand in 2050: 142 TWh.

7 The diagrams represent supply and demand; any energy losses are included within the total end demand.

FES 2021 / System View / Bioenergy supply 161

Natural Gas Supply



Key insights

Natural gas is an important part of today's energy mix. It provides heat and the means to cook in most homes and businesses. It is also used to generate electricity and crucially, gas-fired power stations can easily be turned up and down in response to renewable generation levels. Gas can meet the significant seasonal differences in demand through a variety of sources as well as storage. However, natural gas cannot be used in a net zero world without capturing its emissions.

In order to reach net zero, we will need to decide how we replace natural gas in our energy mix in the next decade and start making the necessary changes to our energy system, businesses and homes.

- System Transformation has 60% of today's demand levels (almost 50 bcm annual demand), while Leading the Way has just 2 bcm annual demand in 2050. This range illustrates the difference between a blue hydrogen net zero scenario and a more electrified, green hydrogen net zero scenario.
- Imports, from LNG, Norway or gas interconnectors, will provide 98% of natural gas supply in System Transformation in 2050 as the UK's Continental Shelf (UKCS) gas supplies decline. However, there is uncertainty about future LNG supplies as global energy demand shifts to gas over coal, which could impact availability.
- The gas network is still being used in 2050 in System Transformation and Steady Progression, albeit with modifications in the former to transport hydrogen. Reduced demand and lower levels of hydrogen mean by 2050 the network is not required to be as extensive in Leading the Way and much reduced in Consumer Transformation.
- In our most ambitious net zero scenario, Leading the Way, we assume the unabated combustion of natural gas for power generation will stop by 2035.

Liquefied Natural Gas

Liquefied natural gas, formed by chilling natural gas to -161˚C to condense as a liquid. Its volume reduces 600 times from the gaseous form, which makes it easier to transport around the world by ship.

Unabated Combustion

Unabated combustion means burning natural gas without any way to capture its emissions.

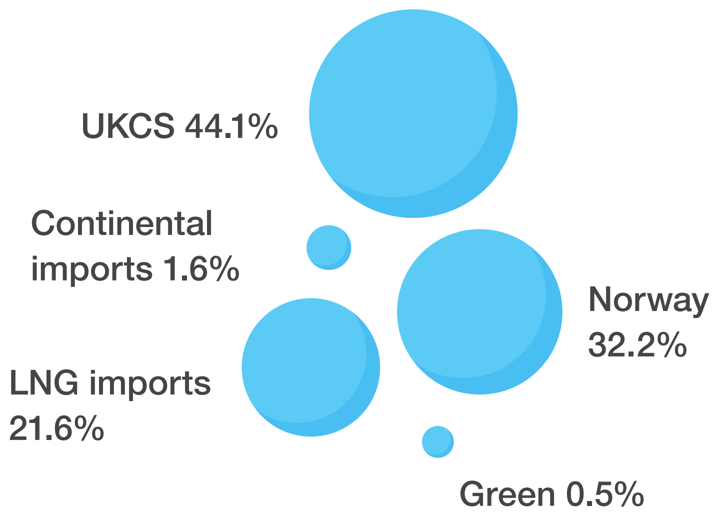
FES 2021 / System View / Natural Gas supply 163

Where are we now?

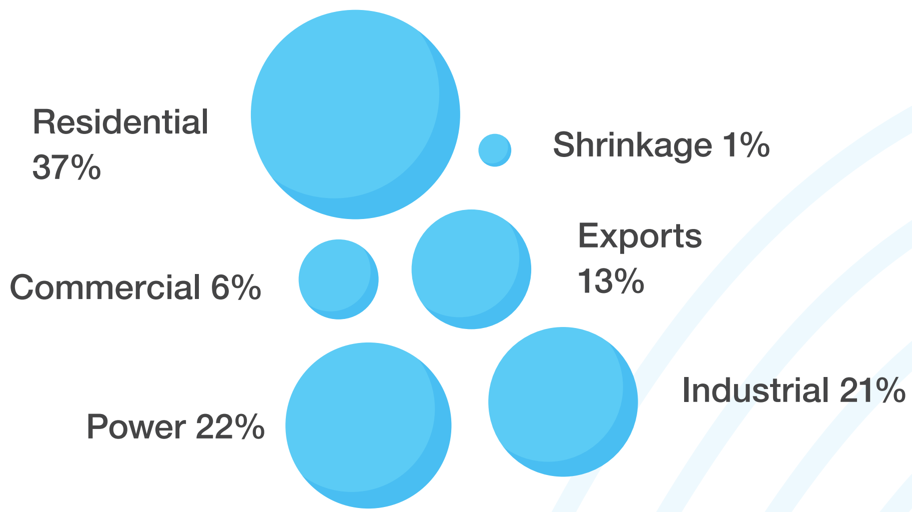
Great Britain used 82 bcm of natural gas in 2020, equivalent to around 907 TWh from a variety of sources. This diversity is important in security of supply as it reduces reliance on a single source. Over the winter of 2020/21, high demand in Asia increased the price of LNG, resulting in fewer imports to the UK but we met our needs with imports from Europe. Our current gas supply system can cope with the changing nature of flows and sources without affecting supplies to end consumers.

Some countries have committed to stopping oil and gas exploration in the North Sea by 2050 (e.g. Denmark). However, the UK Government has not yet indicated if it will follow suit. As natural gas can be a feedstock for hydrogen, it is unlikely this decision will be made until there is more clarity on the UK's hydrogen strategy.

Natural gas supply sources (2020)



Natural gas demand (2020)



BCM

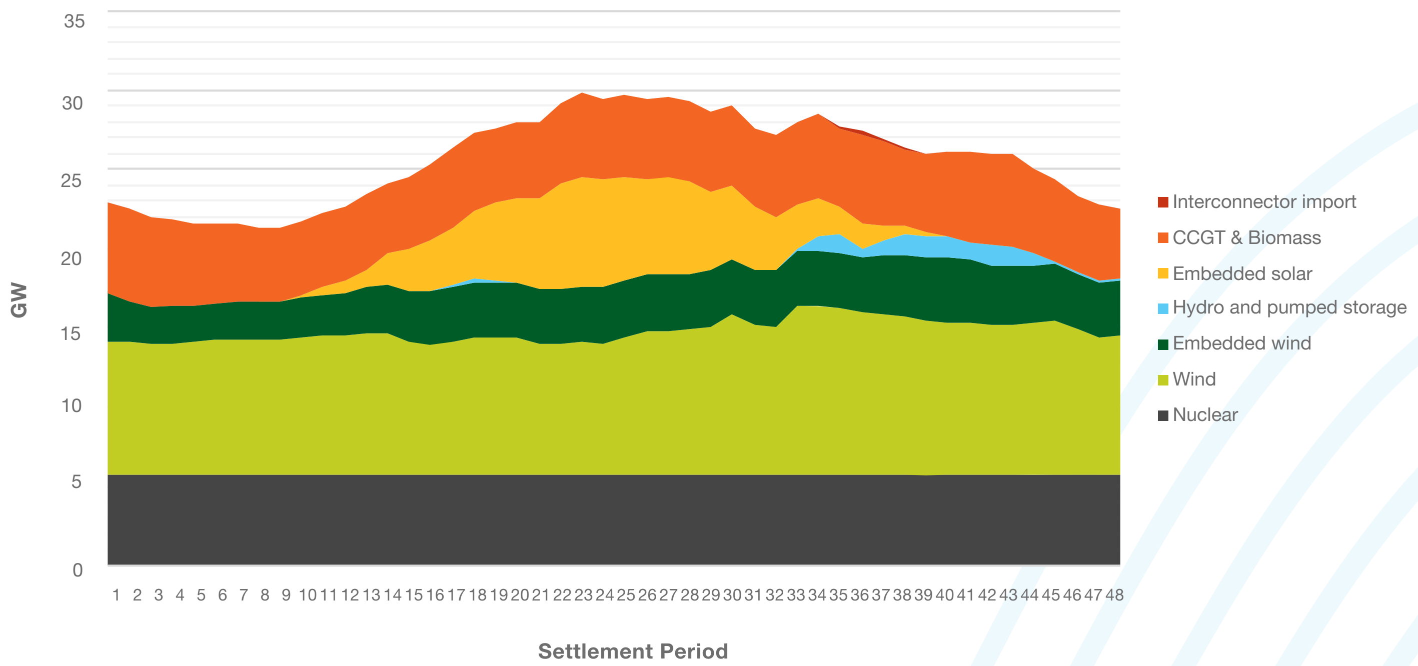
For gas, in Great Britain, a good guide for converting from energy in watt hours to gas volume in cubic metres (or from TWh to bcm) is to divide by 11.

FES 2021 / System View / Natural Gas supply 164

Natural gas provides flexibility to the system

During the first COVID-19 lockdown in 2020, we had a glimpse of how a decarbonised electricity system might look. With sunny weather and low levels of electricity demand, UK electricity generation had its lowest ever carbon intensity (this record has since been beaten). However, we also saw low inertia on the system (which can impact stability) and low levels of flexibility (meaning supply couldn't adjust to meet demand). Despite having sufficient renewable electricity, National Grid ESO needed to use natural gas and biomass generation to make sure electricity continued to flow to consumers. Power stations burning natural gas can respond quickly to increases or decreases in demand and provide the inertia required to maintain the correct system frequency.

National Grid ESO is on track for its ambition of net zero carbon operation in 2025 and investigating other sources of inertia to avoid using natural gas in future. In the meantime, it will play an important role in the transition to maintain a safe and secure electricity system. More details about how National Grid ESO managed the challenges of lockdown in May 2020 and also how we plan to support further decarbonisation can be found in our Operability Strategy report.



Generation mix on Saturday May 23, showing how natural gas and biomass power plant helped meet demand and keep the system stable.

What we've found

The UKCS supplies natural gas in all our scenarios until 2040. In Steady Progression and System Transformation, large volumes of natural gas for methane reformation come from outside the UK as well as from the UKCS. In both scenarios, supplies are predominantly from LNG, with gas from Norway and interconnectors to the continent supplementing demand.

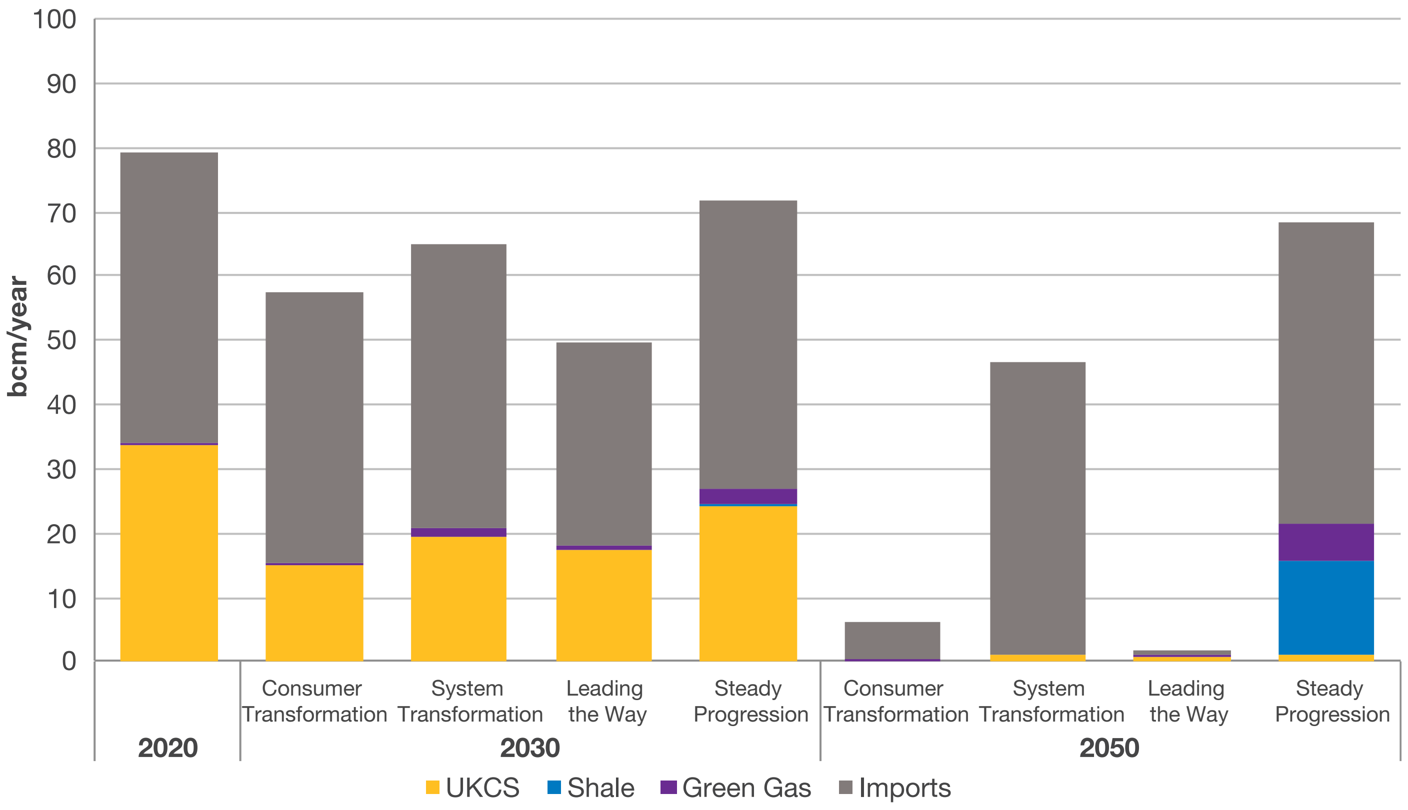
Demand for natural gas reduces dramatically after 2030 in both Consumer Transformation and Leading the Way, as homes are retrofitted with heat pumps.

By 2036, 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 2042 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, very little natural gas is used in 2050, but it is still required for some industrial processes. In Consumer Transformation, small amounts are used for methane reformation to produce hydrogen. More details about how demand changes in the different scenarios can be found in the Consumer View chapter.

Figure SV.4: Natural gas supply from different sources, in 2030 and 2050



FES 2021 / System View / Natural Gas supply 166

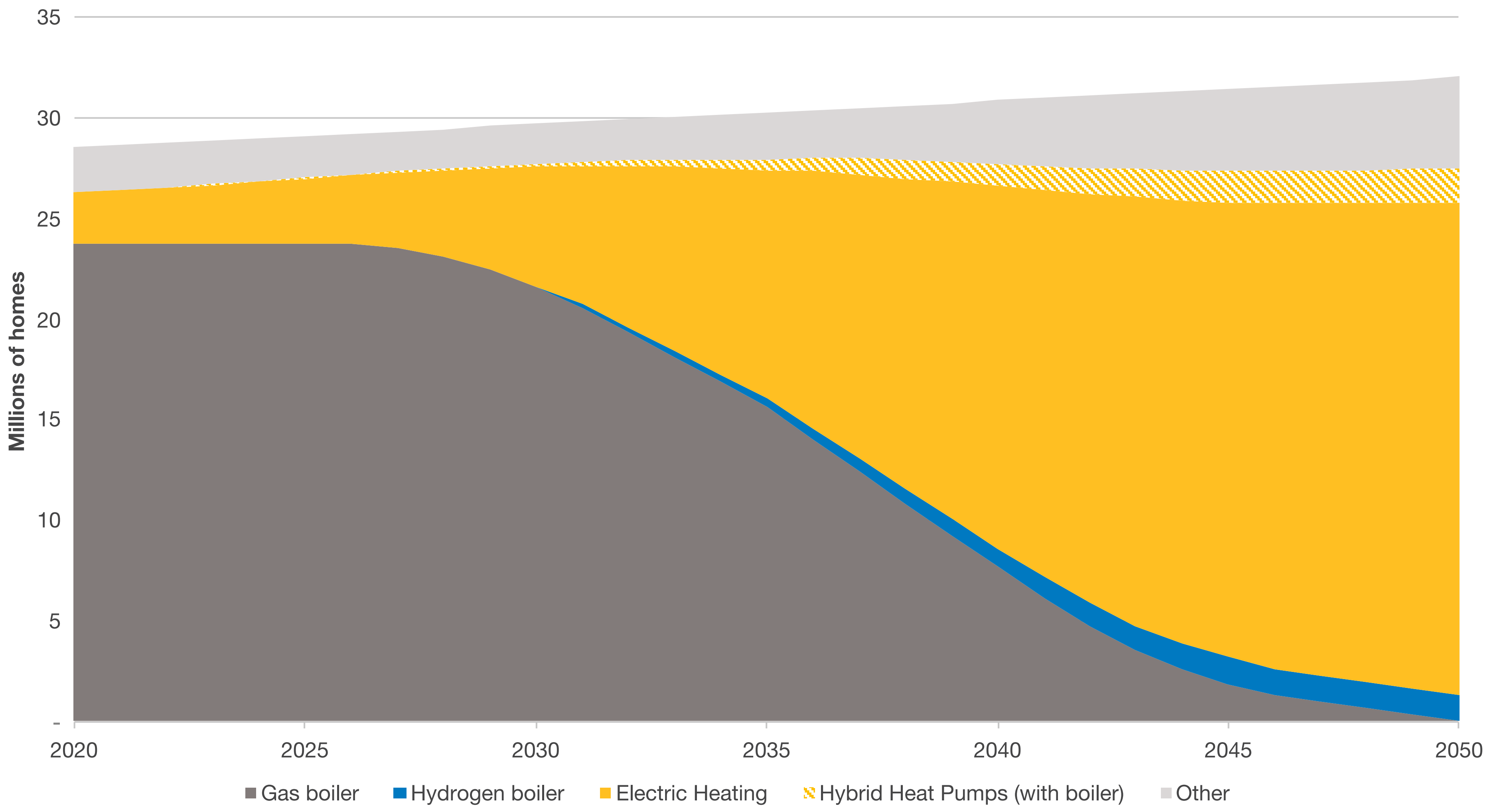
How we heat our homes in a net zero world

In a net zero world, homes are no longer heated by natural gas. However, it may still provide the energy as a feedstock for blue hydrogen.

Figure SV.5: Reduction in natural gas as a fuel used directly for domestic heating[1]

Consumer Transformation

Natural gas boilers decline as electric heating becomes more common. Electricity is produced from renewable sources, while a mix of blue and green hydrogen is used.



1 Steady progression is not included as natural gas remains the main source of heating for homes and buildings.

FES 2021 / System View / Natural Gas supply 167

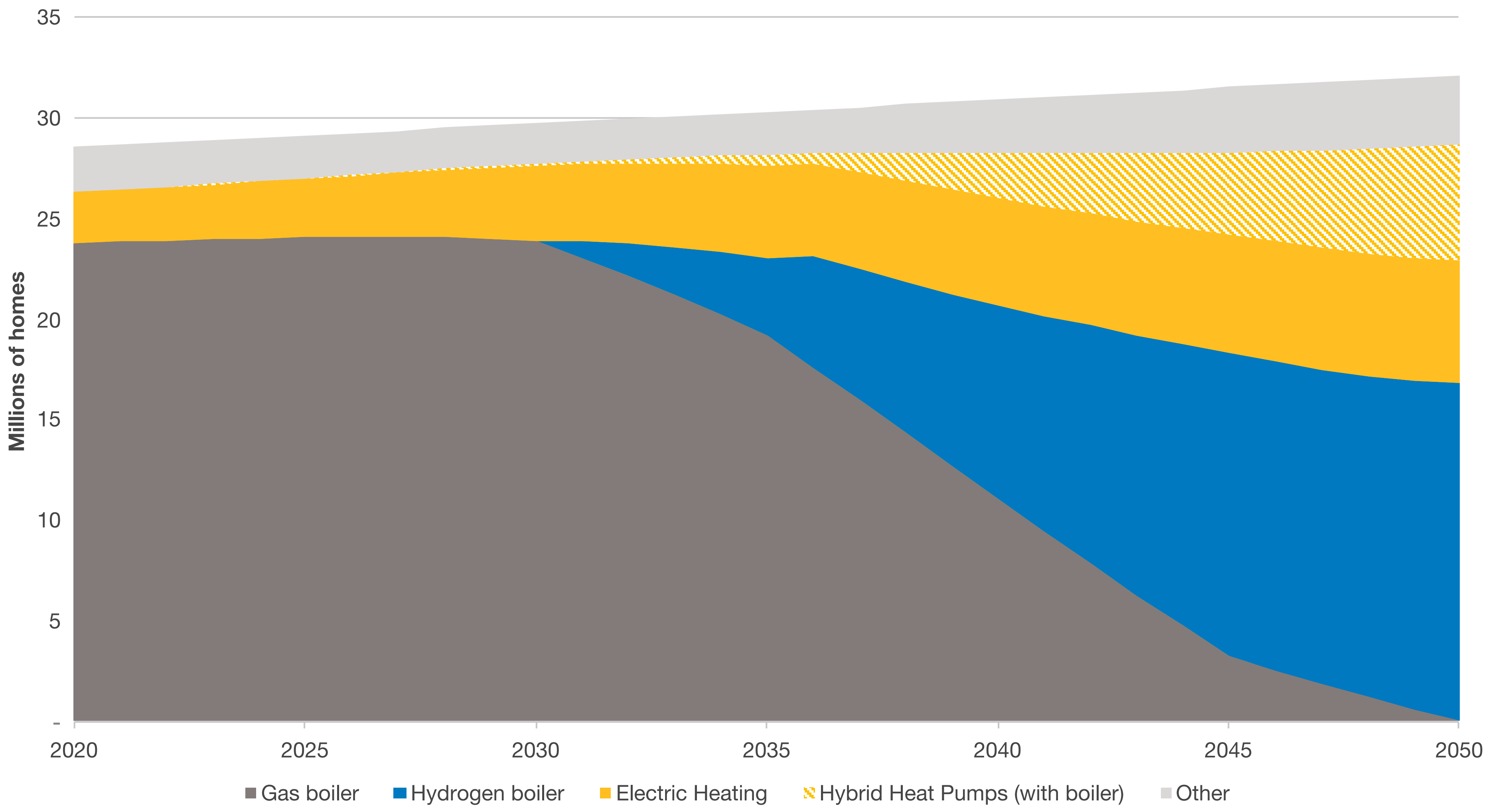
How we heat our homes in a net zero world

In a net zero world, homes are no longer heated by natural gas. However, it may still provide the energy as a feedstock for blue hydrogen.

Figure SV.5: Reduction in natural gas as a fuel used directly for domestic heating[1]

System Transformation

The hydrogen boilers here are burning mainly blue hydrogen, made from natural gas.



1 Steady progression is not included as natural gas remains the main source of heating for homes and buildings.

FES 2021 / System View / Natural Gas supply 168

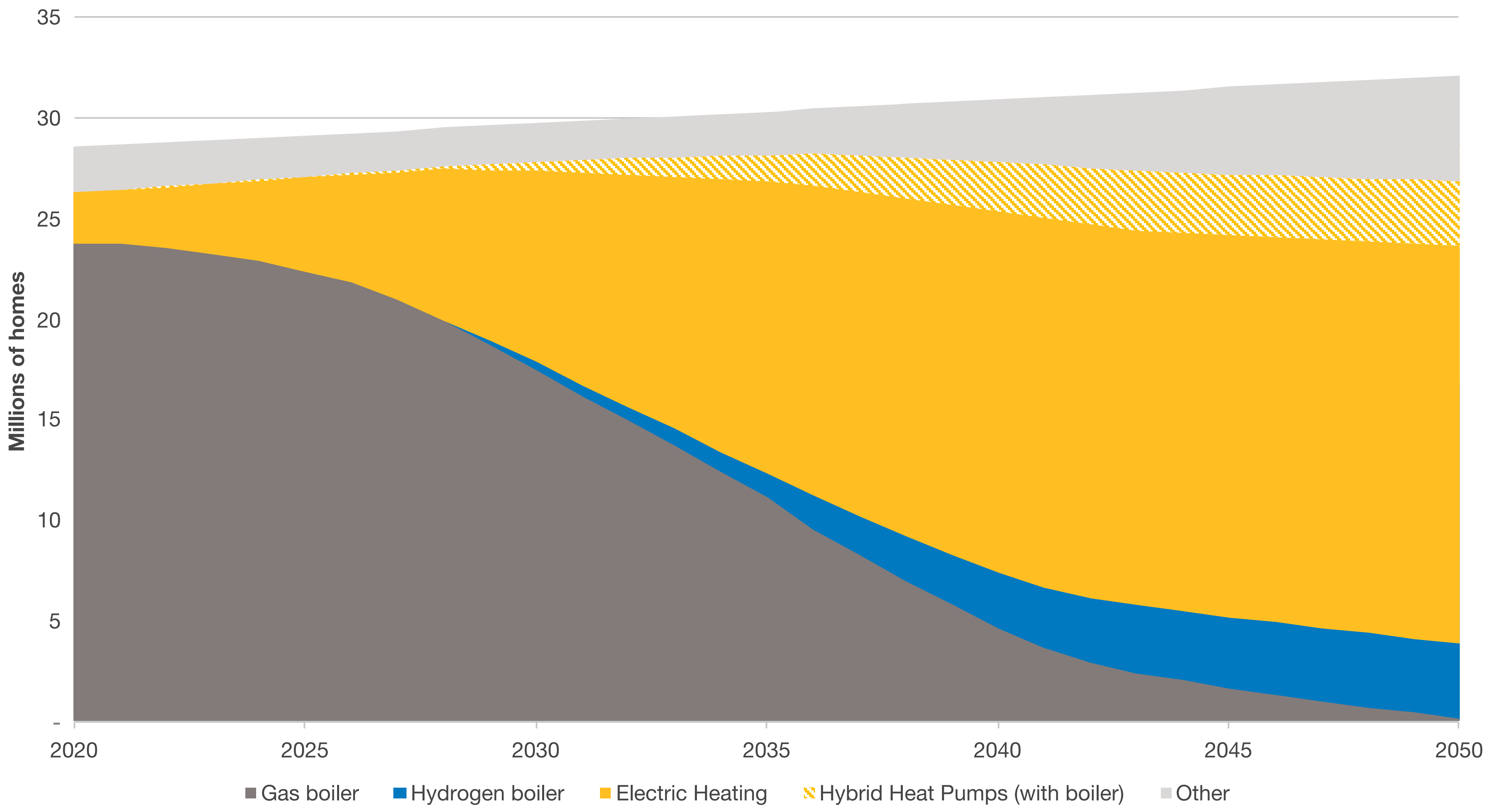
How we heat our homes in a net zero world

In a net zero world, homes are no longer heated by natural gas. However, it may still provide the energy as a feedstock for blue hydrogen.

Figure SV.5: Reduction in natural gas as a fuel used directly for domestic heating[1]

Leading the Way

Only green hydrogen is used in Leading the Way, there is no use of natural gas for hydrogen or for domestic heating in 2050.



1 Steady progression is not included as natural gas remains the main source of heating for homes and buildings.

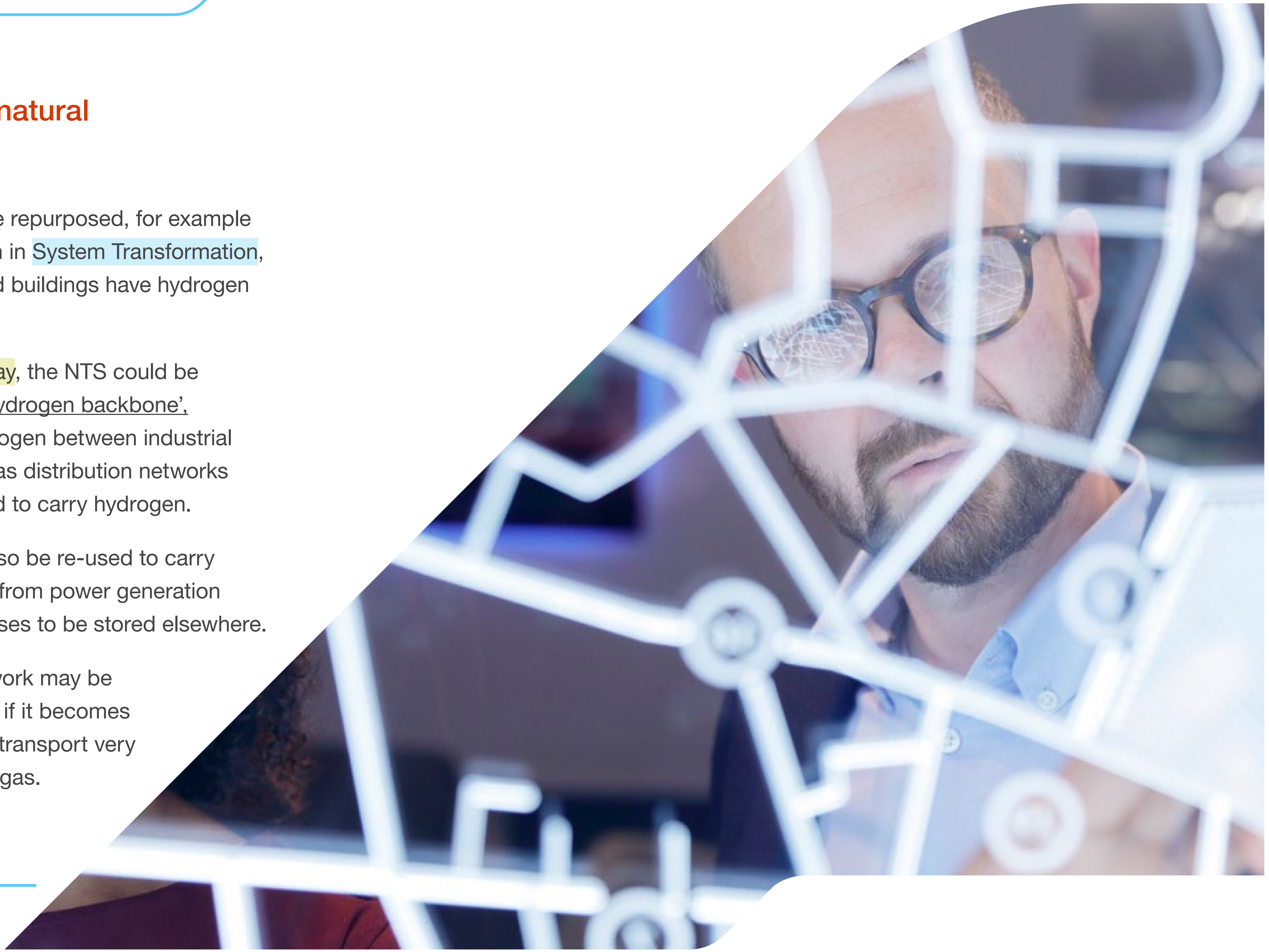
FES 2021 / System View / Natural Gas supply 169

The natural gas network in a net zero world

In the transition to net zero, the role of the existing natural gas network is currently unclear.

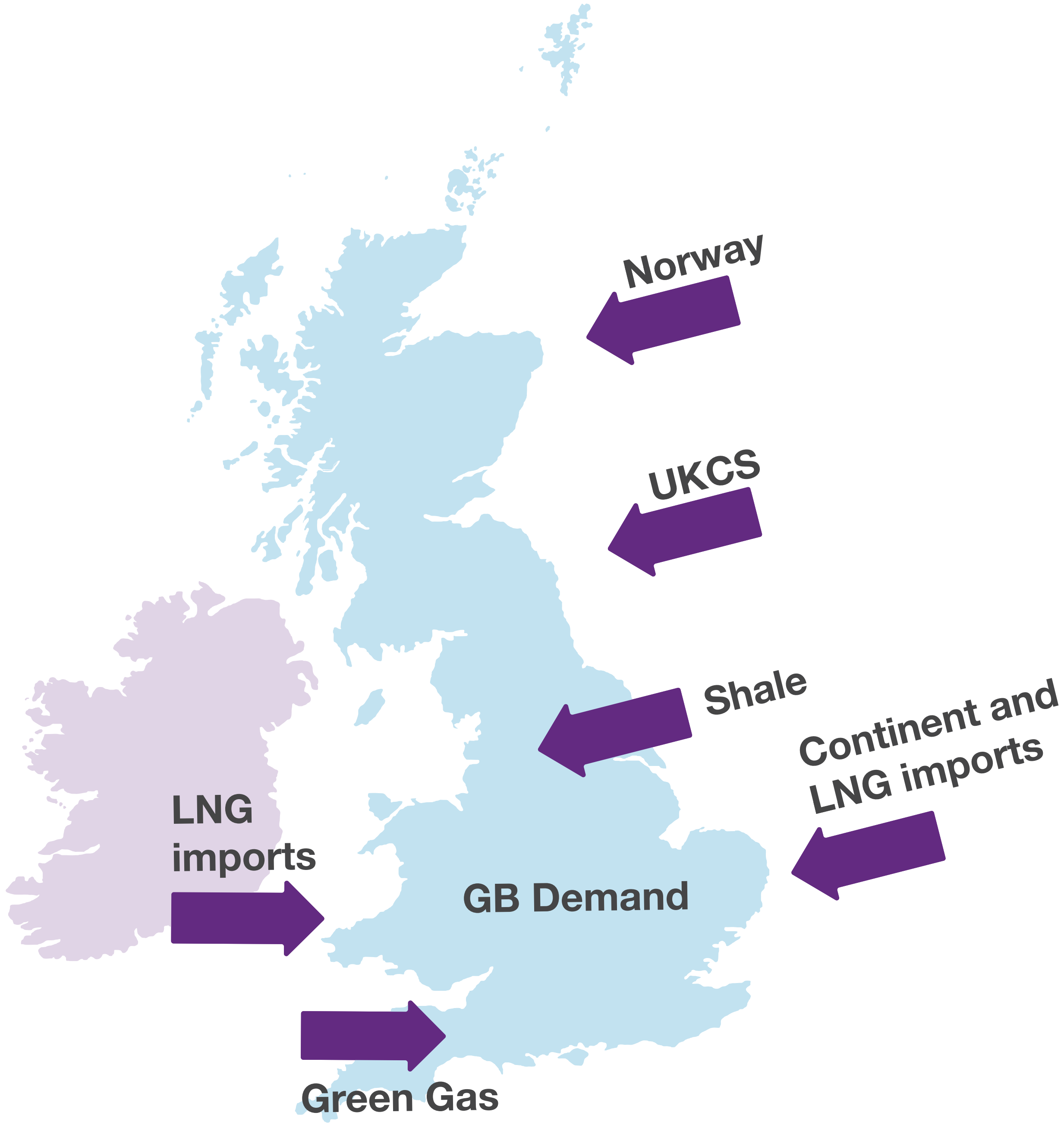
The gas national transmission system (NTS) is over 5000 km long and transports gas at a high pressure around the country. It supplies gas to approximately 85% of the homes in Great Britain through its connections to the gas distribution networks and local distribution zones. How homes and buildings are heated in future will determine the role of this extensive network. That decision is dependent on factors including security of supply, the cost of retrofitting homes and consumers' willingness to change. Our scenarios cover a number of possibilities for the future of the NTS and other gas networks.

- The pipes may be repurposed, for example to carry hydrogen in System Transformation, where homes and buildings have hydrogen boilers for heat.
- In Leading the Way, the NTS could be converted to a 'hydrogen backbone', transporting hydrogen between industrial clusters. Some gas distribution networks may be converted to carry hydrogen.
- The pipes may also be re-used to carry carbon captured from power generation and other processes to be stored elsewhere.
- Some of the network may be decommissioned if it becomes uneconomical to transport very small volumes of gas.



FES 2021 / System View / Natural Gas supply 170

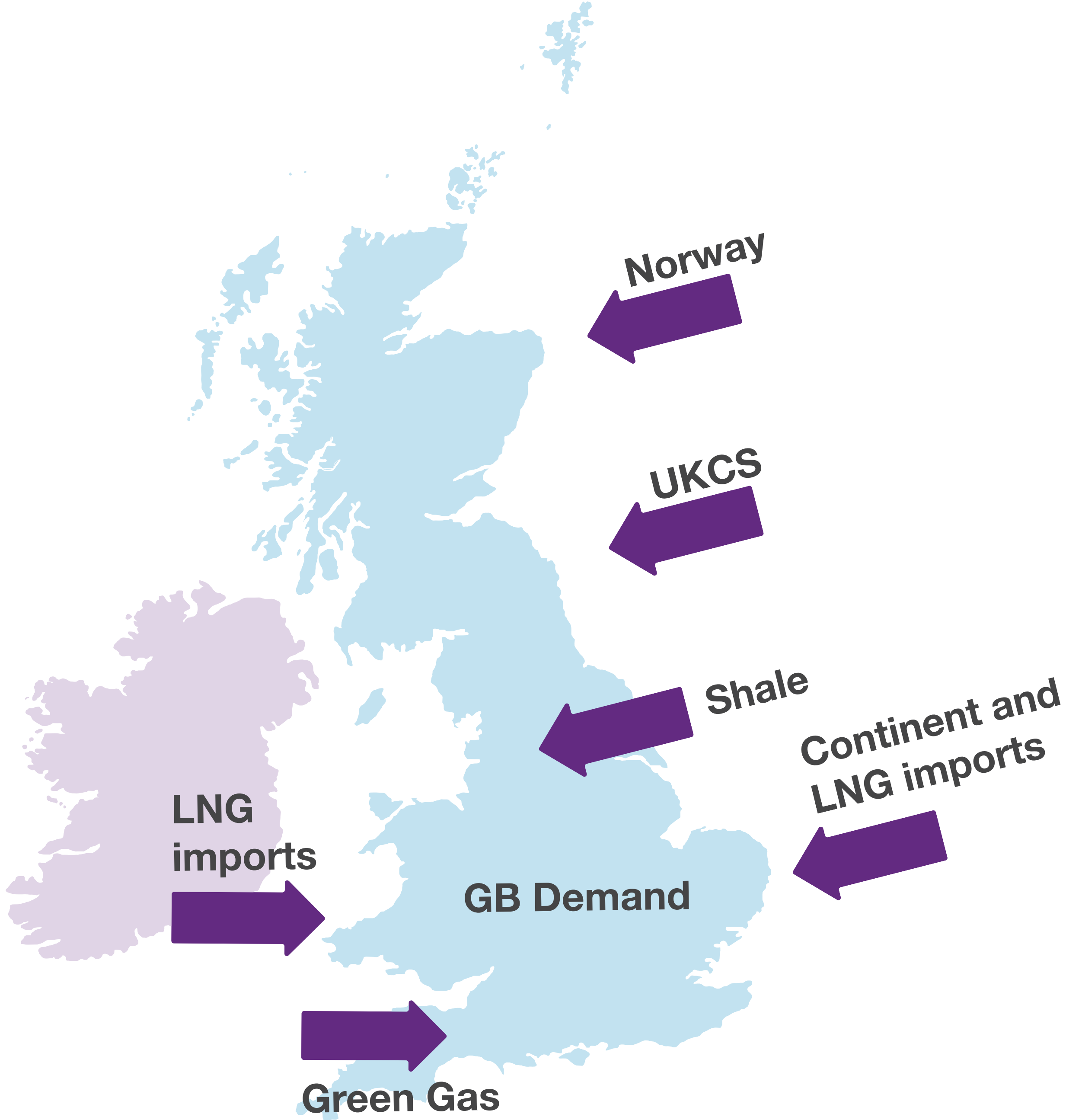
What we've found



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

FES 2021 / System View / Natural Gas supply 171

What we've found



Norway

Norway's large and flexible reserves mean it could keep supplying gas to the UK for longer than our own UKCS. However, we also think that in Consumer Transformation, the UK will stop importing gas from Norway before 2050.

UKCS

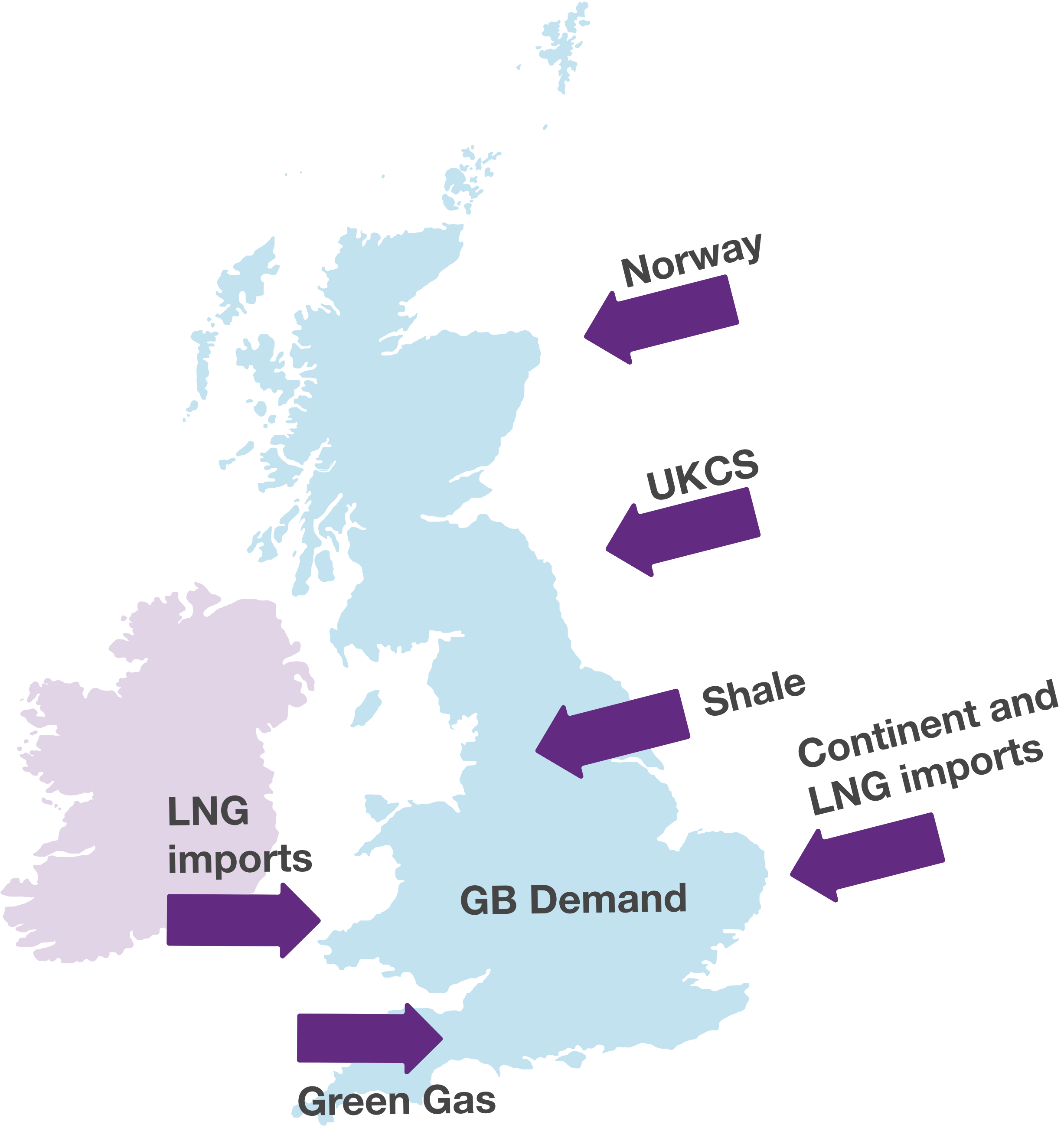
Overall production will fall in all scenarios between now and 2050 as the fields deplete. In Consumer Transformation, we expect production to stop in the mid-2040s, due to falling demand and the cost of continued extraction. In future, any natural gas needed for either a feedstock for hydrogen, in a power station or industrial process with carbon capture fitted, will have to be imported.

Shale

This is only used in the Steady Progression scenario. However, if the current moratorium on shale exploration in the UK remains for the next few years, we do not anticipate the UK using shale gas at all.

FES 2021 / System View / Natural Gas supply 172

What we've found



Imports

A second wave of liquefaction projects in the mid-2020s results in more LNG available globally. However, demand for LNG may also rise globally as countries shift away from coal to decarbonise. Only System Transformation and Consumer Transformation include imports of LNG for reformation into hydrogen. Imports from the continent via the existing gas interconnectors continue to play a key role in the supply of natural gas in all scenarios.

Green gas

Green gas is made from bioresources and is considered to be carbon neutral. It has a role to play in all the scenarios. The term green gas is used in our scenarios to refer to both biomethane and bioSNG, see glossary for more information. In Steady Progression it is injected into the gas network to reduce the overall carbon intensity of the gas used in homes and businesses. In the net zero scenarios, green gas is still produced but in smaller volumes as bioresources are prioritised for other uses.

FES 2021 / System View / Natural Gas supply 173

What we've found - scenario details

Figure SV.6: Annual gas supply in Consumer Transformation

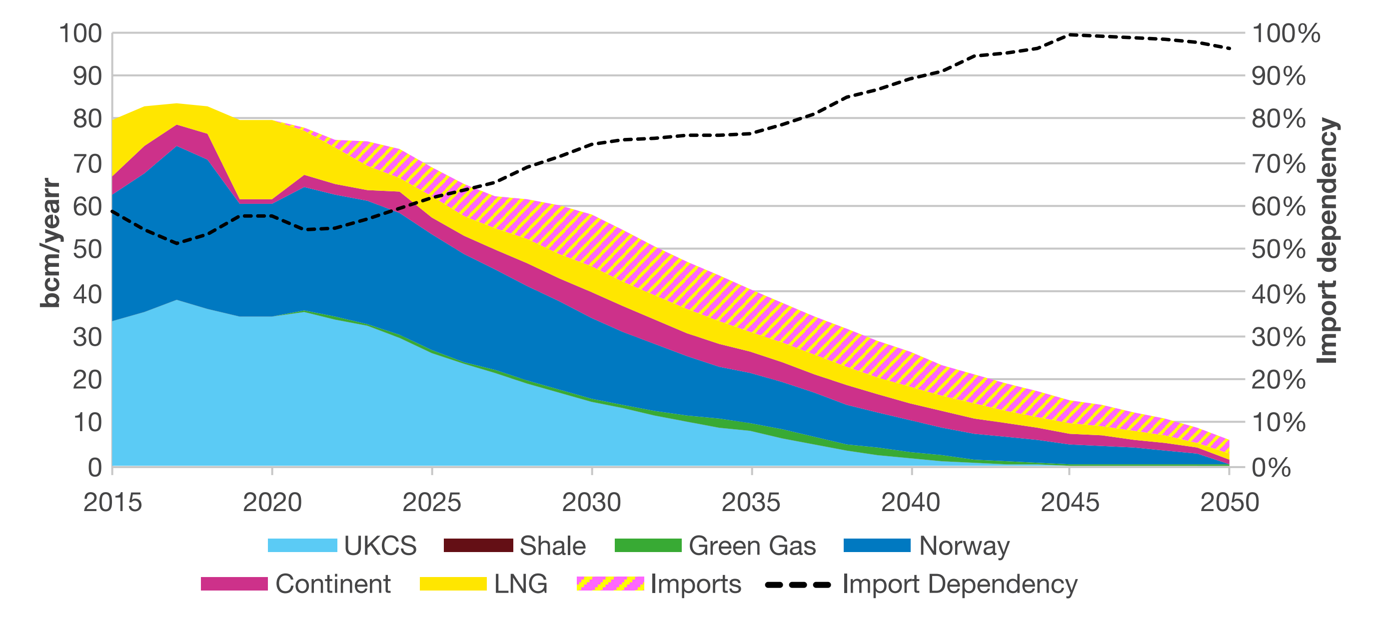
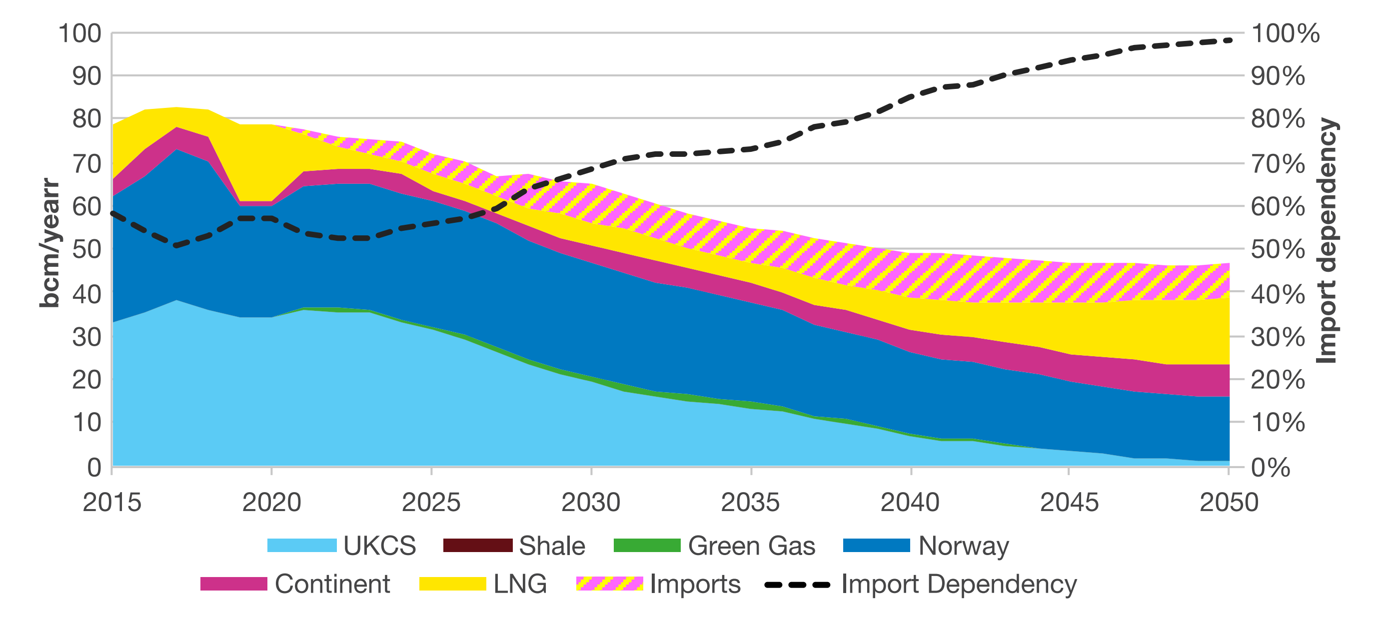


Figure SV.7: Annual gas supply in System Transformation



- Natural gas consumption declines fairly rapidly between now and 2050, losing a quarter of today's demand by 2030. This is down to natural gas being replaced in most cases by electricity for heating homes and buildings.
- UKCS ceases to provide gas to the UK by 2045 as demand is much lower and the profile for the remaining uses requires a more flexible supply source.
- There is still some 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.

- Natural gas demand reduces to about 60% of 2020 levels, due to switching to using more electricity for heating and more energy efficiency in homes and buildings.
- By 2040, demand levels stabilise around the volume required for the methane reformation to produce the levels of hydrogen required for heating and other applications.
- UKCS, after an increase in output in the mid-2020s, steadily declines to almost zero by 2050. In 2050, we are almost 100% dependent on imports, with the majority of the UK's gas arriving from either Norway, the continent or in the form of LNG, bought on the global market.

FES 2021 / System View / Natural Gas supply 174

What we've found - scenario details

Figure SV.8: Annual gas supply in Leading the Way

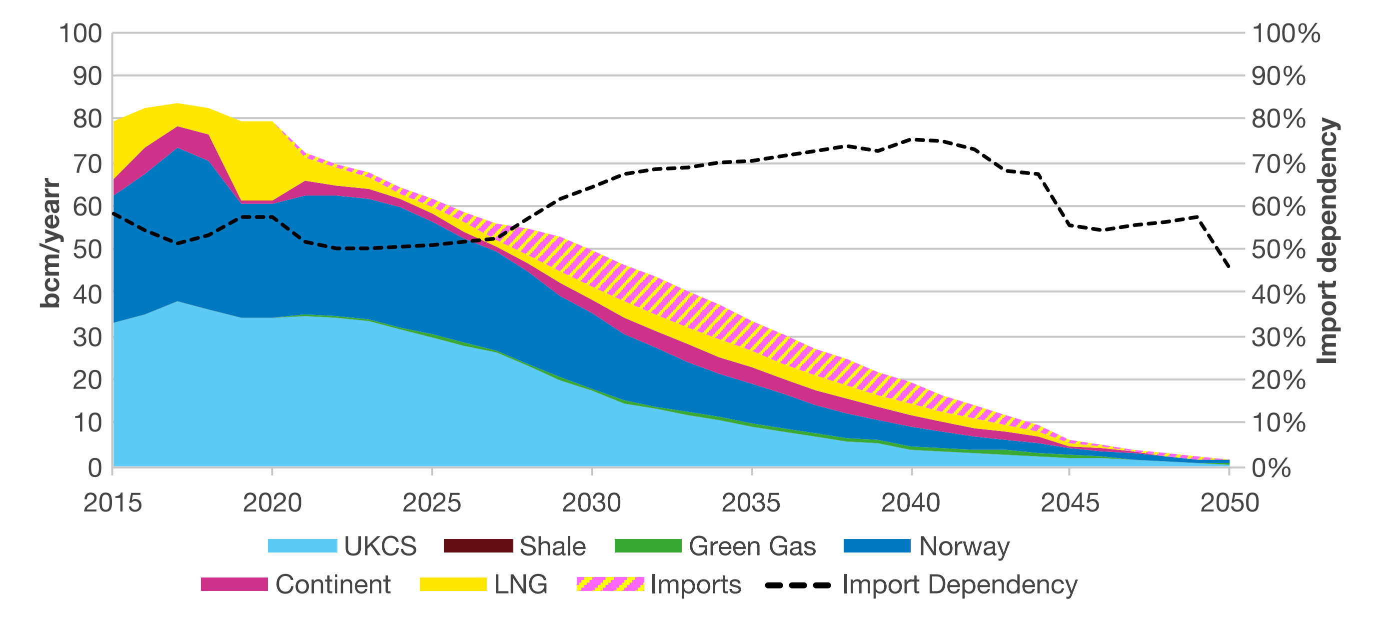
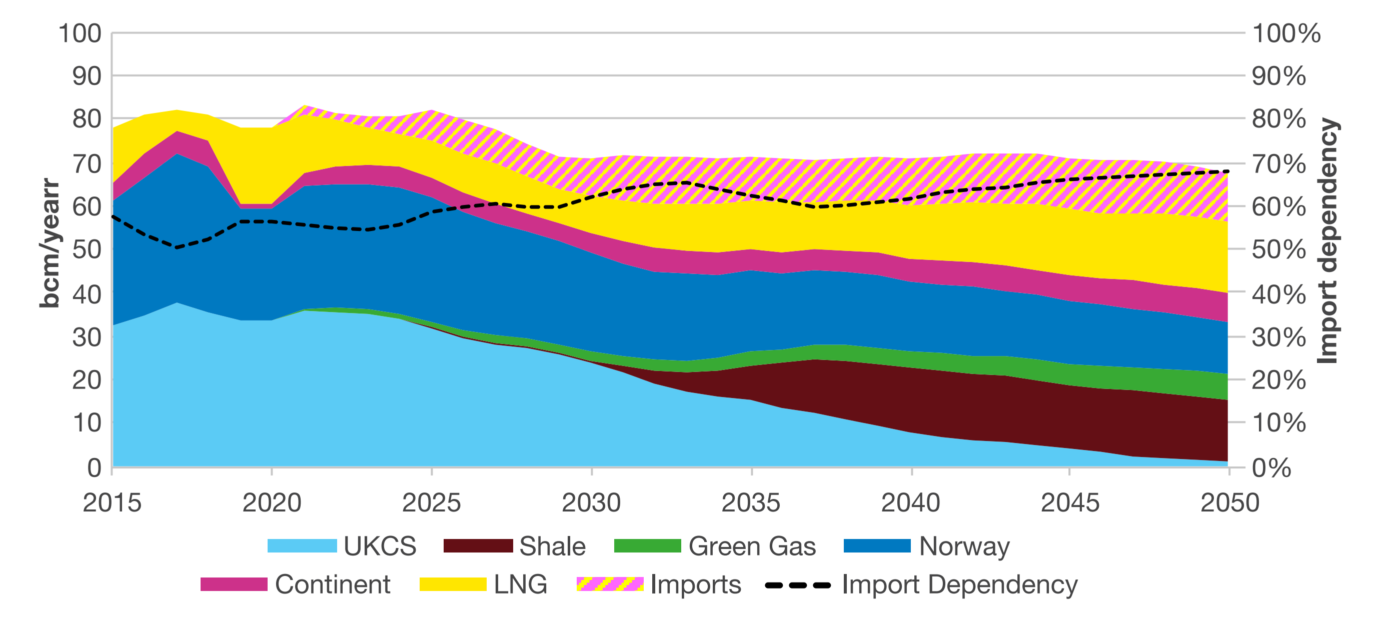


Figure SV.9: Annual gas supply in Steady Progression

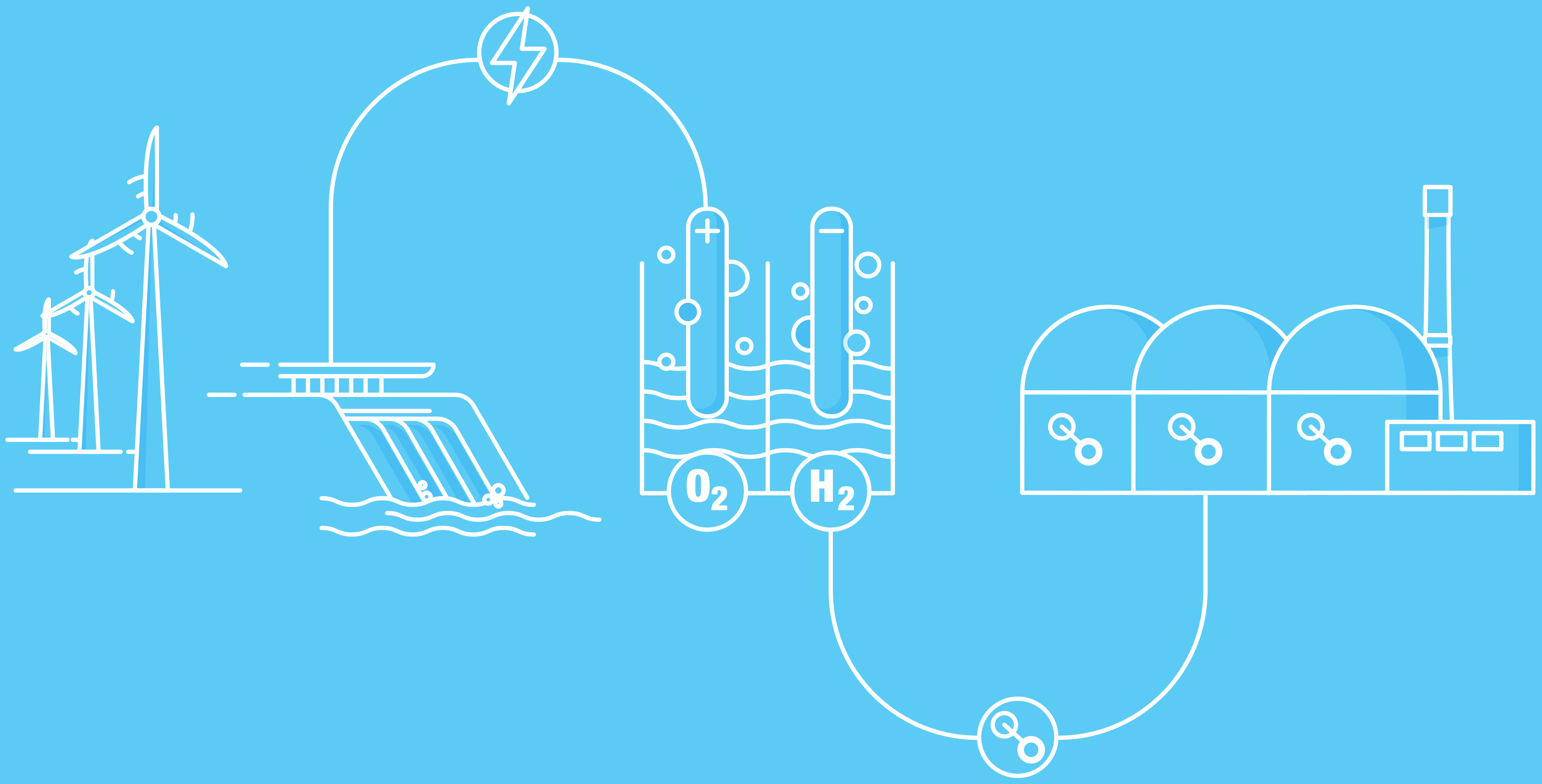


- Leading the Way has the quickest reduction in natural gas demand, with over a third of demand removed by 2030. Most of the demand between 2020 and 2050 is met by gas from the UKCS and Norway.
- Here is the smallest volume of natural gas being used in 2050, as most natural gas applications have switched to electricity or green hydrogen. The remaining demand is for some industrial applications and its combustion is combined with CCUS.
- The UKCS is still providing a small amount of the residual annual demand in 2050, meaning that the UK is not 100% reliant on imports at this point.

- Natural gas demand reduces in this scenario but only by about 10%. It is still widely used in the UK to heat homes and buildings and for industrial applications.
- Shale is introduced in the early 2030s and becomes one of the largest sources by 2050. Shale gas is needed to meet demand as the UKCS output declines. In addition to reducing the level of import dependency, indigenous shale also has a lower overall carbon footprint than imported LNG.
- 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 2021 / System View / Natural Gas supply 175

Hydrogen Supply

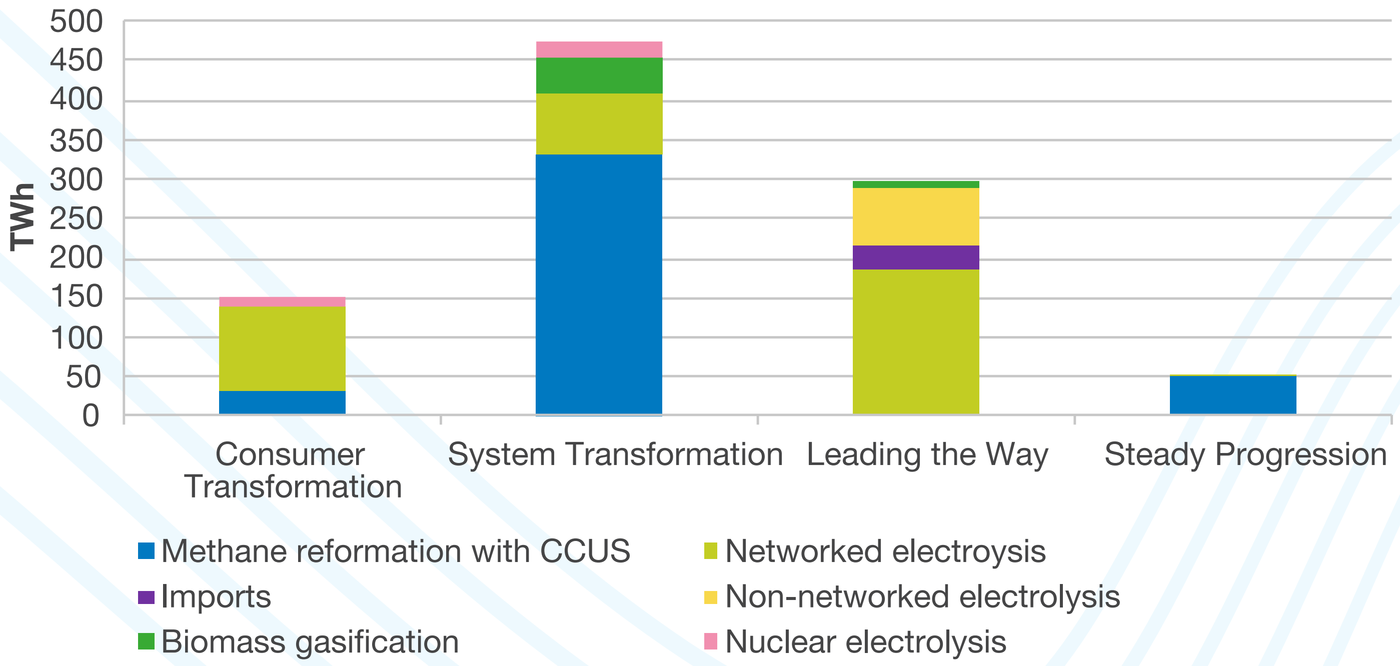


Key insights

The supply and use of hydrogen is central to all of our net zero scenarios and has a key role to play in helping the UK achieve net zero by 2050. It can be stored over long periods and can provide the low carbon, high-intensity heat needed for some applications. But before it can reach its full potential, there are challenges around its production and transportation.

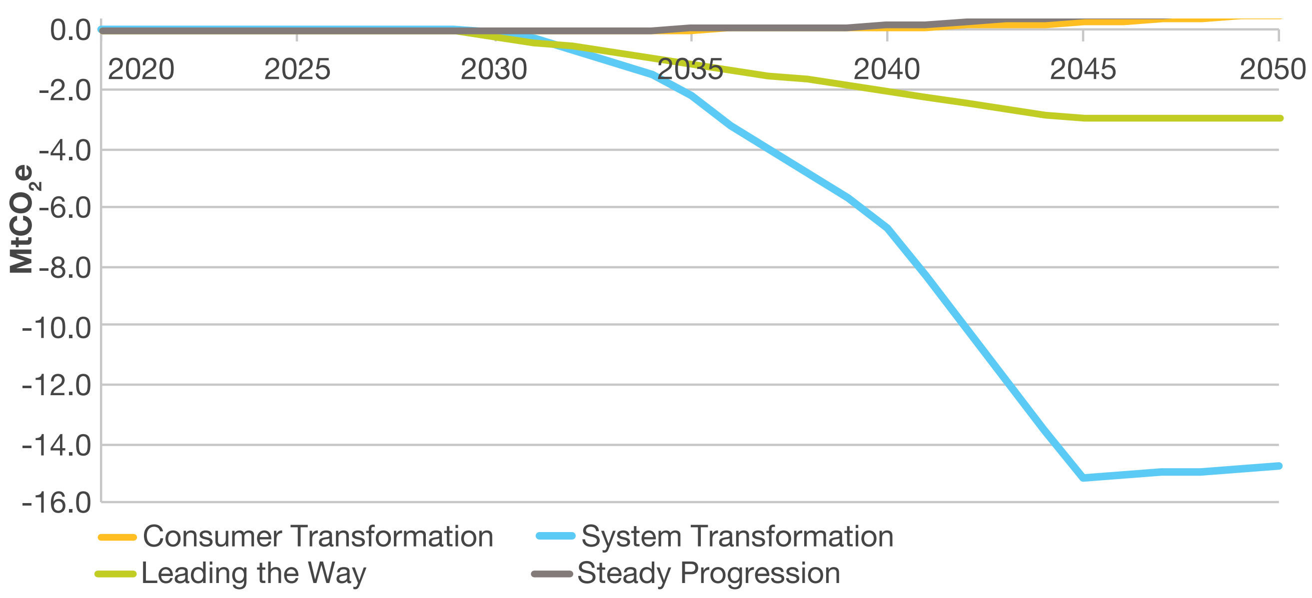
- Hydrogen generation is needed in all of our net zero scenarios to provide electricity security of supply.
- Storage capacity is as important as production facilities to get the greatest whole energy system benefit from hydrogen.
- The production of hydrogen via electrolysis helps to maximise the use of renewable electricity generation. Electrolysis can use surplus electricity to produce hydrogen or operate at times of network congestion. The resulting hydrogen can be transported for immediate use or stored for later.
- Government intervention is required to help deliver production facilities and encourage demand for hydrogen. This is assumed to happen in System Transformation and Leading the Way. Specifically, in Leading the Way we have assumed that government support ensures the Energy White Paper target of 5GW of production capacity by 2030 is met.
- By 2045 in System Transformation the nationwide gas grid is almost all converted to transport hydrogen. However, in the other net zero scenarios changes to the gas grid vary significantly by geographic location.
- Biomass gasification to produce hydrogen, combined with carbon capture utilisation and storage (CCUS) for the CO_2 emitted, makes up almost 10% of hydrogen supply in System Transformation. Even at this level, the carbon stored is enough to offset the carbon emissions from methane reformation, meaning the production of hydrogen in System Transformation is carbon negative.

Figure SV.10: Hydrogen supply in 2050



Key insights

Figure SV.11: Emissions from hydrogen production



FES 2021 / System View / Hydrogen Supply 178

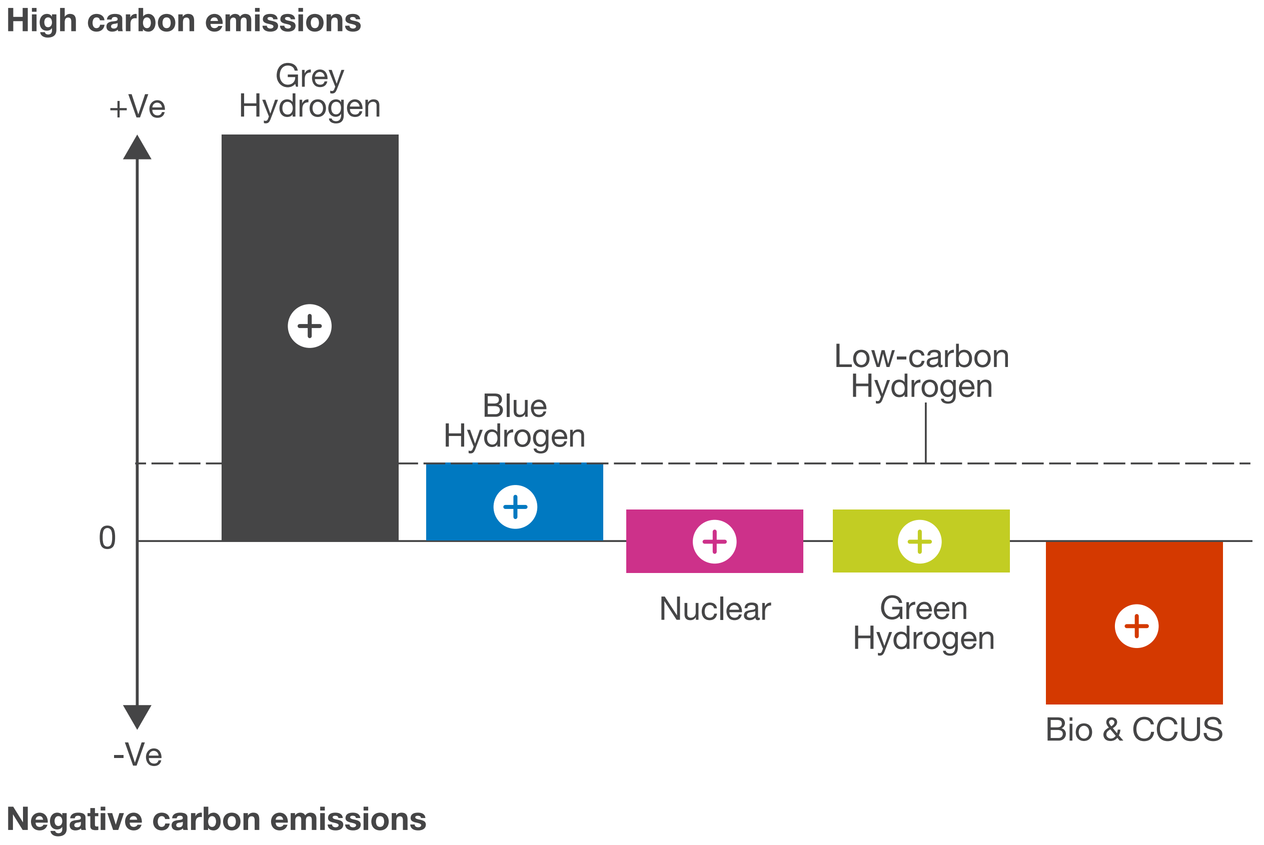
Where are we now?

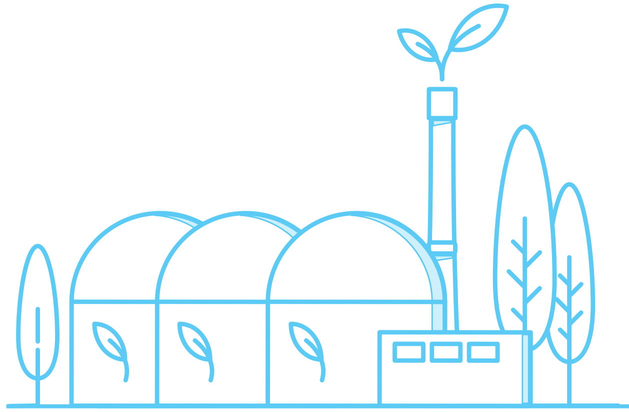
Hydrogen is already commonly used worldwide for refining oil and in the production of ammonia for fertilisers. Each year, around 50 Mt hydrogen (or 2,000 TWh of energy equivalent) is produced globally, of which around 0.7 Mt (~27 TWh/annum) is both produced and consumed in the UK.

There are various methods of producing hydrogen, but almost all UK hydrogen production uses methane reformation without CCUS, which has a carbon footprint of 10-12 kgCO_2e per kg of hydrogen. The UK's annual carbon footprint for hydrogen consumption is 7.7 MtCO_2e.

In the Government's 2020 Energy White Paper, there are plans for further trials of hydrogen in the 2020s. It has set a target of 5 GW of clean (i.e. low or zero carbon) hydrogen production capacity by 2030, initially for use either in industrial processes or transportation. More details on the Government's plans for hydrogen will be outlined in its hydrogen strategy, due later in 2021.

Different types of hydrogen production





FES 2021 / System View / Hydrogen Supply 179

Where are we now?

Grey Hydrogen

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

Green Hydrogen

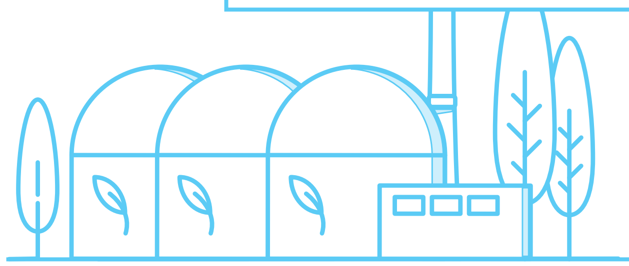
Renewable electricity is combined with electrolysis to produce hydrogen without carbon emissions. With the growth in offshore wind, there are projects planned to produce hydrogen offshore, using the existing offshore gas network to transport the hydrogen onshore.

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.

Nuclear

Nuclear power provides the energy for producing hydrogen. There are a number of ways of pairing nuclear technologies with hydrogen production, including solid oxide electrolysis (using heat as well as electricity from a nuclear power plant) or thermochemical production (using high temperature gas reactors and heat from the nuclear plant). However, for this year's FES we have focused on the one with most certainty at the moment, low temperature electrolysis, which can be combined with large or small nuclear reactors.

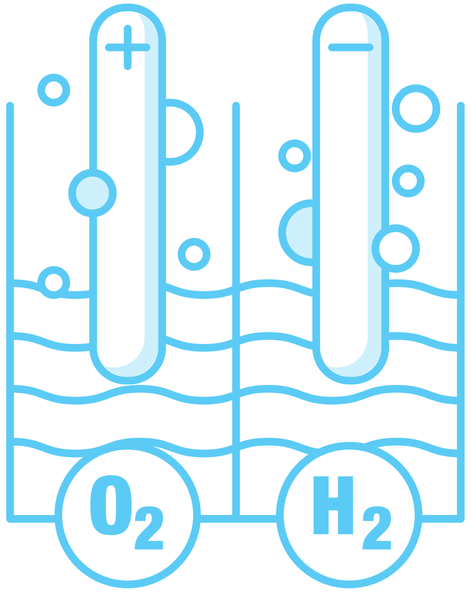


FES 2021 / System View / Hydrogen Supply 180

Where are we now?

Hydrogen produces no carbon emissions at the point of combustion, which initially makes it seem a perfect fuel for a net zero world. However, it is most commonly found as water or bonded with carbon, so to be used on its own as a fuel, it has to be separated using another form of energy.

There are other advantages and disadvantages to using hydrogen, which means government intervention will be needed to encourage action and investment, if it is to become a replacement for natural gas.



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 2021 / System View / Hydrogen Supply 181

What we’ve found

Uses of hydrogen

As explored in the Consumer View chapter, hydrogen could solve many of the hardest parts of the transition to net zero.

This includes:

- HGVs, shipping and aviation
- Some industrial processes that rely on high grade heat

In our modelling, we’ve also used hydrogen to help manage electricity system balancing challenges. At times of surplus renewable generation, we assume the electricity can be used to produce hydrogen, which is stored for use later in industrial applications, transport or even power generation (covered in more detail in the Flexibility chapter).

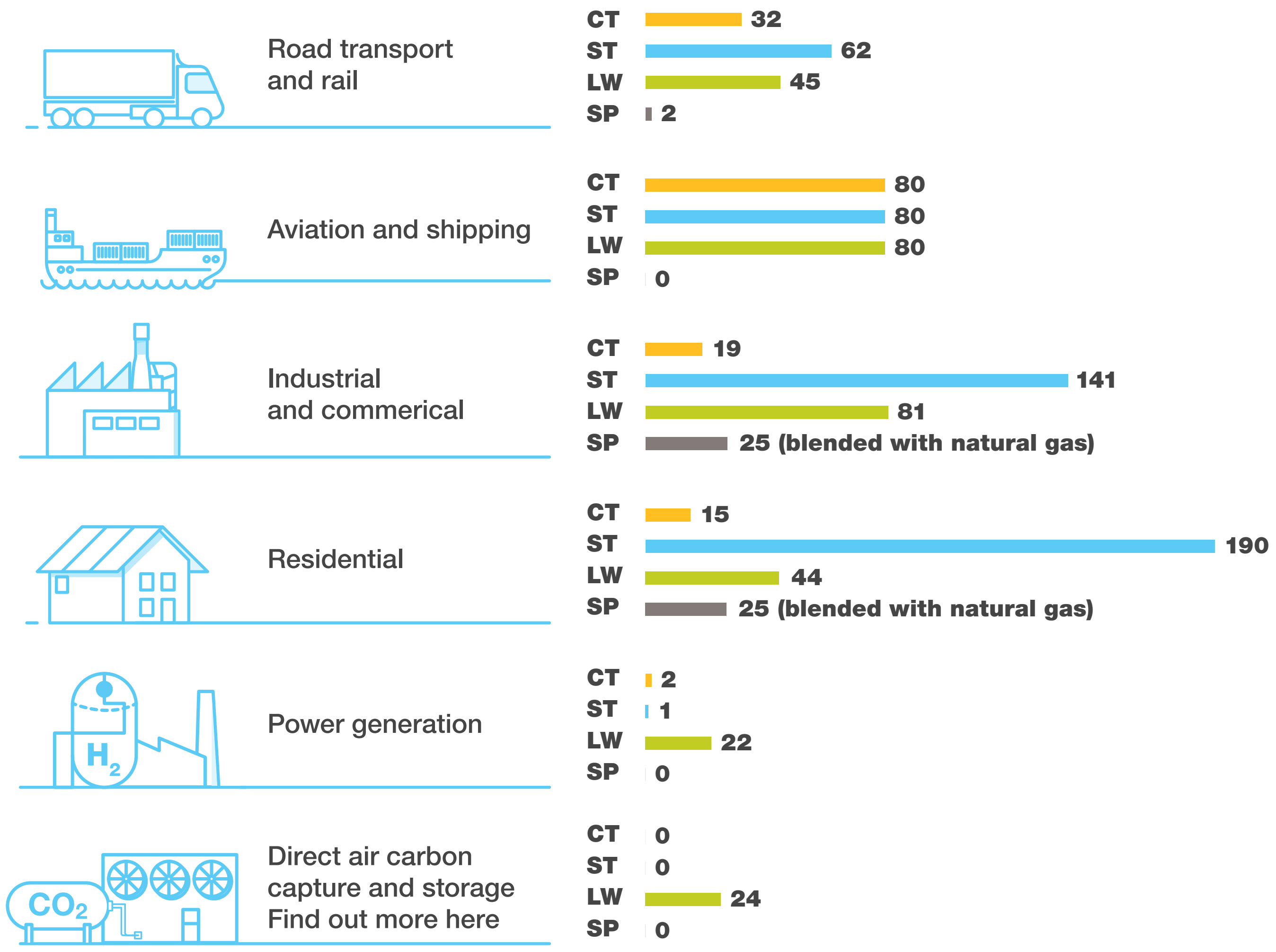
In the scenarios with lower societal change, where fewer end consumers electrify their energy needs, hydrogen can be used instead of natural gas to heat homes and buildings. It can provide a broadly similar consumer experience to natural gas and only requires changing the boiler and the gas hob. However, even in System Transformation, we have assumed energy efficiency retrofits to most buildings, as a way of reducing the overall demand for hydrogen as it’s likely to be more expensive than natural gas.

Direct Air Carbon Capture and Storage

Carbon dioxide can be removed from the atmosphere by stripping it from the air, after which it can be stored. We are using this process for the first time in FES this year in Leading the Way. It is an energy intensive process and requires heat (provided here by hydrogen), electricity and storage for the carbon dioxide.

System Transformation has the most hydrogen, predominantly for heating homes and buildings. The overall demand this year is lower than in our FES 20 results, as we have taken on feedback that more commercial end consumers are likely to switch to electricity than hydrogen for their heating. In all three net zero scenarios, hydrogen is used for aviation and shipping and for HGVs, although in Consumer Transformation there are a large number of electric lorries as well. In Steady Progression, hydrogen is blended with natural gas, which helps to reduce its carbon impact. Leading the Way is the only scenario with Direct Air Carbon Capture and Storage, the heat energy for which comes from green hydrogen.

Figure SV.12: 2050 Hydrogen demand (TWh)



FES 2021 / System View / Hydrogen Supply 182

What we've found

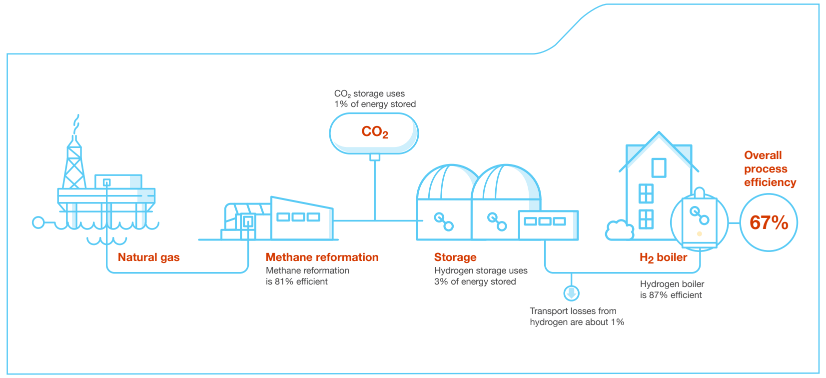
The whole energy system efficiency of using hydrogen to heat a home depends on the original feedstock, the production methods, transportation, storage and how the energy is used to generate heat. The illustrations here show the relative efficiency of the different processes to produce heat for a home or a building. 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.

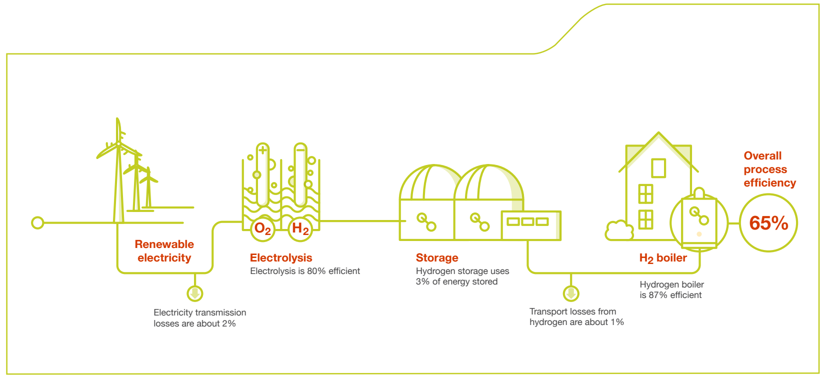
The costs of the different production methods are equally important. Assessing the potential costs of different technologies does form part of the initial FES modelling, however the full costing work is done separately to this scenario analysis.

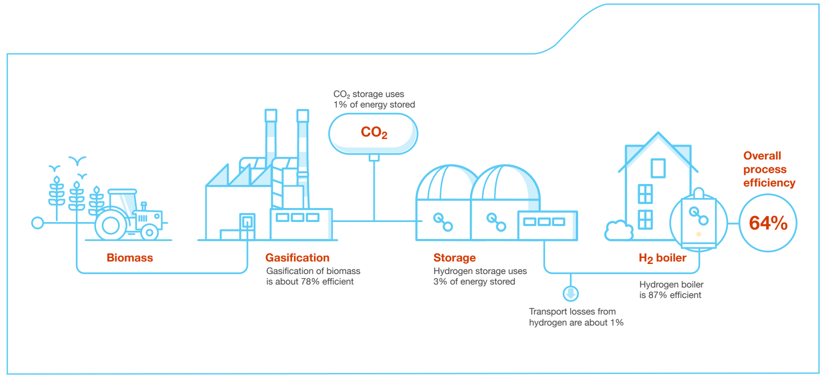
To provide context, we looked at external sources to find some indicative costs for the processes illustrated here. These articles show that currently, there is not a huge difference in costs between producing blue hydrogen, green hydrogen and biomass hydrogen (all in a range of 1.2 - 3.3 USD/kg of hydrogen)[1]. As technologies are scaled up over time, the differences may increase or decrease, but it is useful to note now that no single process is much cheaper than another.

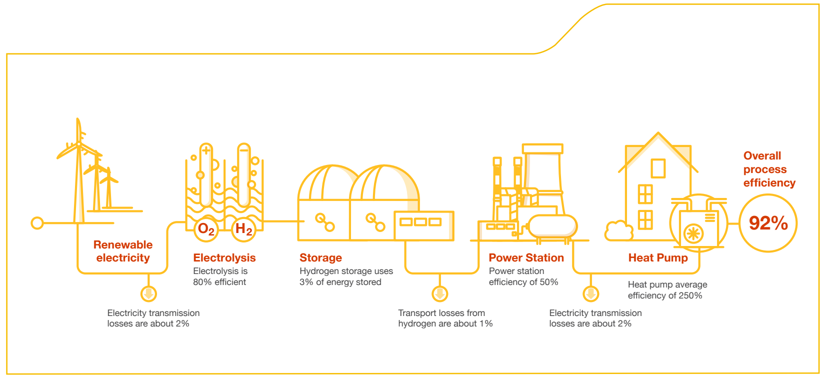
Efficiency of using hydrogen to heat a home[2]

There are different ways to produce hydrogen and illustrated here are some examples from the different net zero scenarios.









1 For more information see www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2050

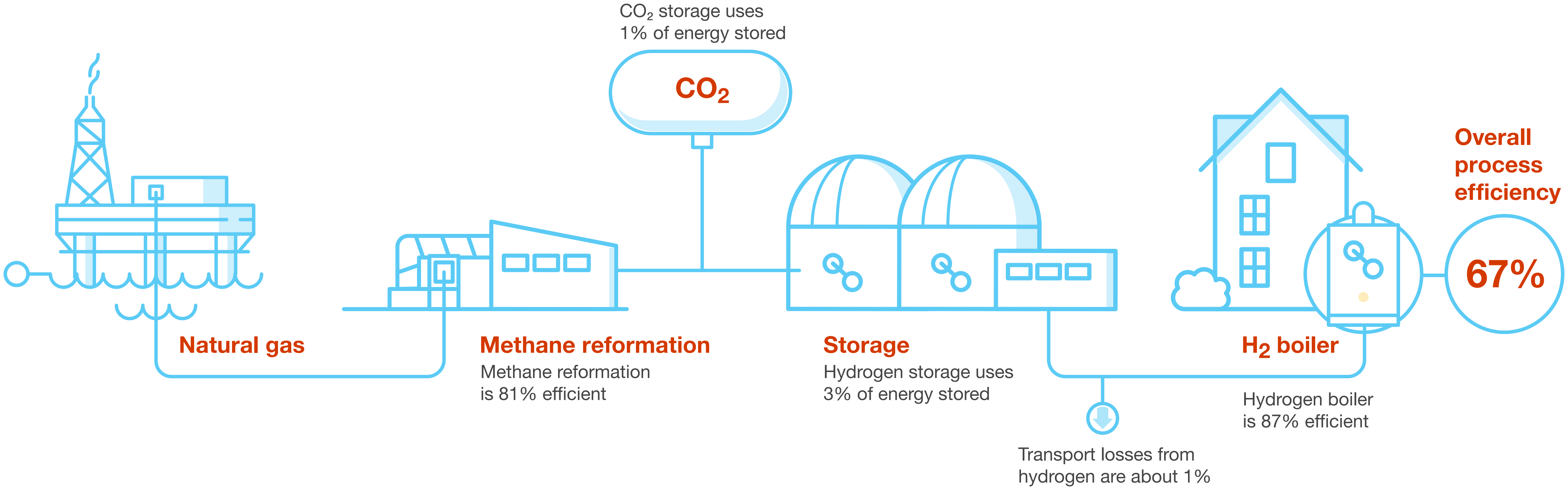
2 Steady Progression is not included as hydrogen is not used to heat homes in this scenario.

FES 2021 / System View / Hydrogen Supply 183

What we've found

System Transformation

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



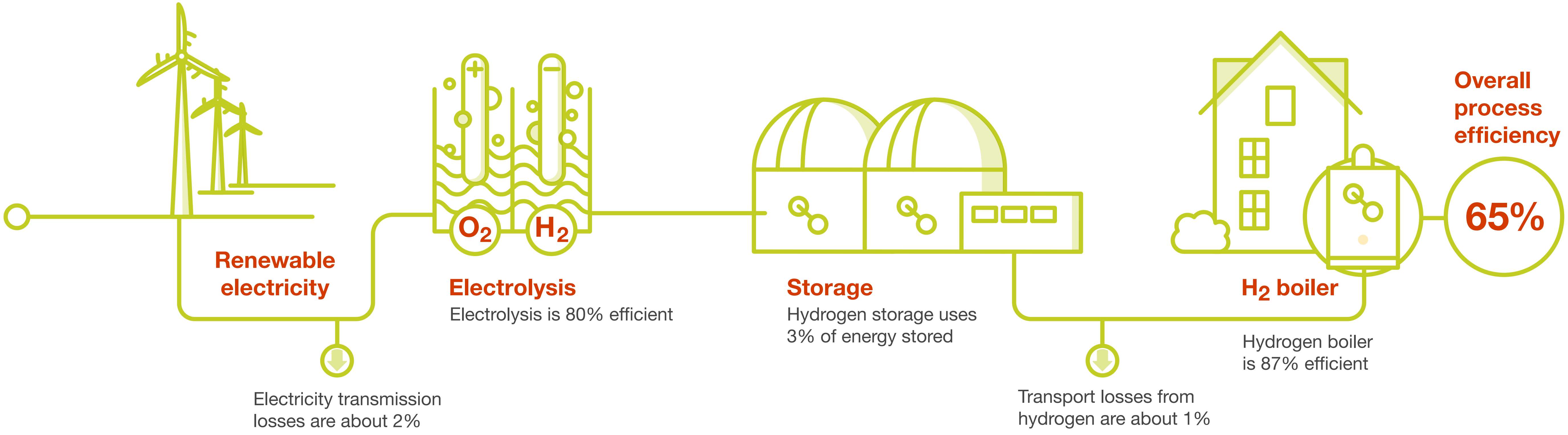
1 For more information see www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2050

2 Steady Progression is not included as hydrogen is not used to heat homes in this scenario.

FES 2021 / System View / Hydrogen Supply 184

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.

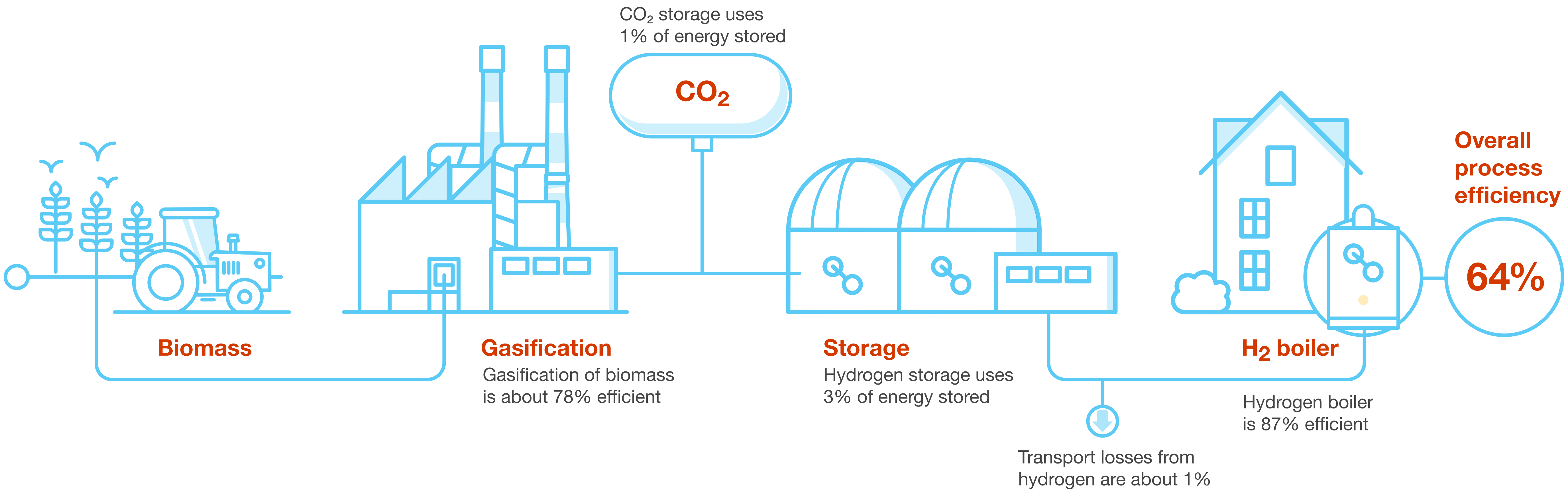


1 For more information see www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2050
2 Steady Progression is not included as hydrogen is not used to heat homes in this scenario.

FES 2021 / System View / Hydrogen Supply 185

What we've found

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

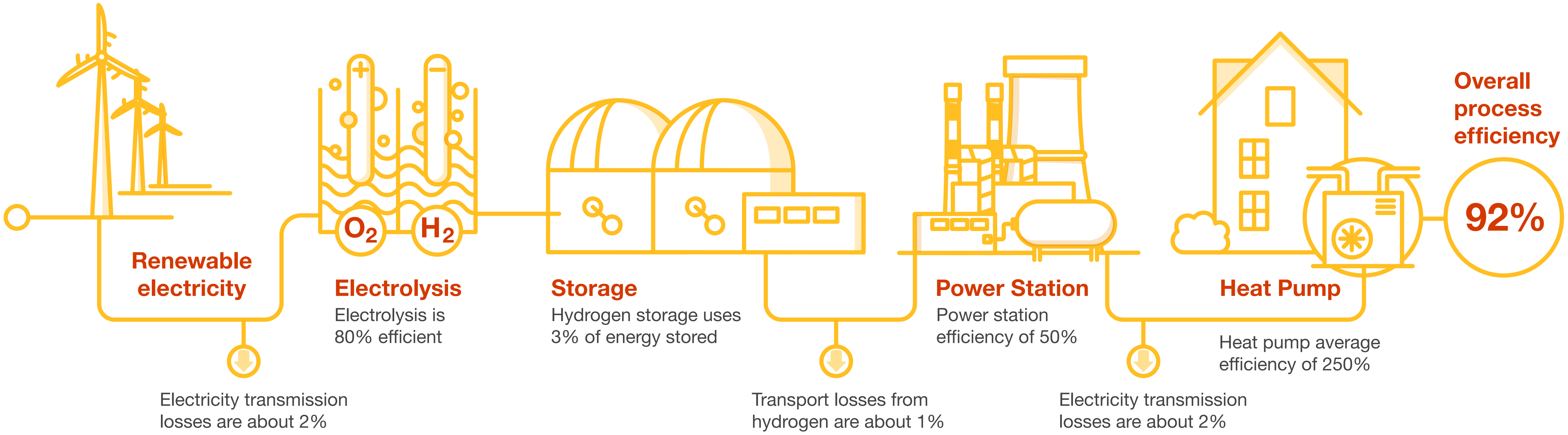


1 For more information see www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2050
2 Steady Progression is not included as hydrogen is not used to heat homes in this scenario.

FES 2021 / System View / Hydrogen Supply 186

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.



1 For more information see www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2050
2 Steady Progression is not included as hydrogen is not used to heat homes in this scenario.

FES 2021 / System View / Hydrogen Supply 187

What we've found

Transition to hydrogen

One of the big questions is how hydrogen could be used to heat homes instead of natural gas. It is not as simple as just using the natural gas pipe network to transport hydrogen. The rest of the infrastructure and governance need to be in place; producers, suppliers and network operators need to be ready and there needs to be sufficient demand, which will require government intervention.

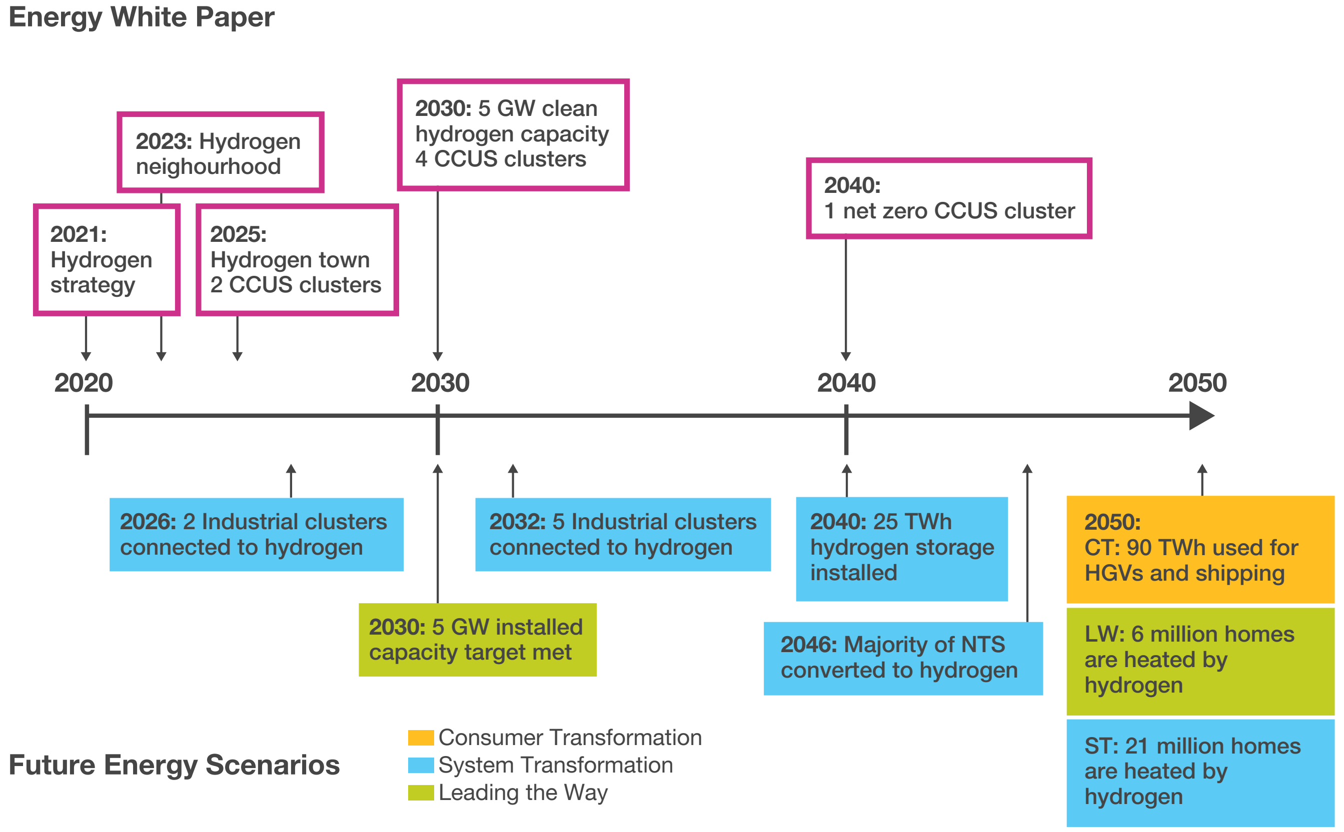
To meet the government's hydrogen target of 5 GW installed production capacity by 2030, there will either need to be a steep growth in demand over the 2020s or spare production capacity will need to be built in anticipation of demand at a later date. Demand could be increased by allowing some hydrogen to be blended into the networks at scale, however this would require new regulations and processes for supplying and billing end consumers.

In Leading the Way we have met this target by assuming that 5 GW of electrolysers will be built with government support but initially operating at a reduced load factor (i.e. not their maximum output). System Transformation reaches 5 GW capacity in 2032, also at reduced capacity. However, with government support to build capacity and demand, for example by enabling blending in the network or more incentivised use in transport and industry, the target could be met with higher load factors in these scenarios. In Consumer Transformation and in Steady Progression, the production capacity target is not met until later.

Where there are industrial clusters with a demand for hydrogen, we have assumed that these act as an anchor for hydrogen supply within a particular region. These hubs could be connected by a 'hydrogen backbone', which would supply and store hydrogen, supporting increasing use across the country (for more information, please click here). We have assumed that in System Transformation and Leading the Way, hydrogen supply to the wider region grows out from these hubs.

Having adequate hydrogen storage is as important as production, so it can provide additional energy at times of peak demand. Storage increases rapidly in System Transformation, to reach over 50 TWh by 2050, compared to 12 TWh in Consumer Transformation.

Hydrogen milestones in policy and our net zero scenarios



FES 2021 / System View / Hydrogen Supply 188

What we've found

Hydrogen Storage

Is an important piece of the net zero puzzle in all scenarios, helping to manage seasonal swings in demand for heating. Hydrogen production can soak up excess renewable electricity at times of low demand for quick release at times of peak demand. In our FES, we've assumed it would be stored predominantly in salt caverns, which are already being used to store natural gas. Currently, only 14 TWh of natural gas is stored this way in the UK.

A recent **study** indicated that there is a theoretical capacity of up to 3000 TWh of hydrogen storage, although if small sites are discounted, this drops to 200 TWh. However, the development of hydrogen storage capacity is likely to take some time, as there will be planning procedures, environmental impact assessments and geological engineering work to be completed.

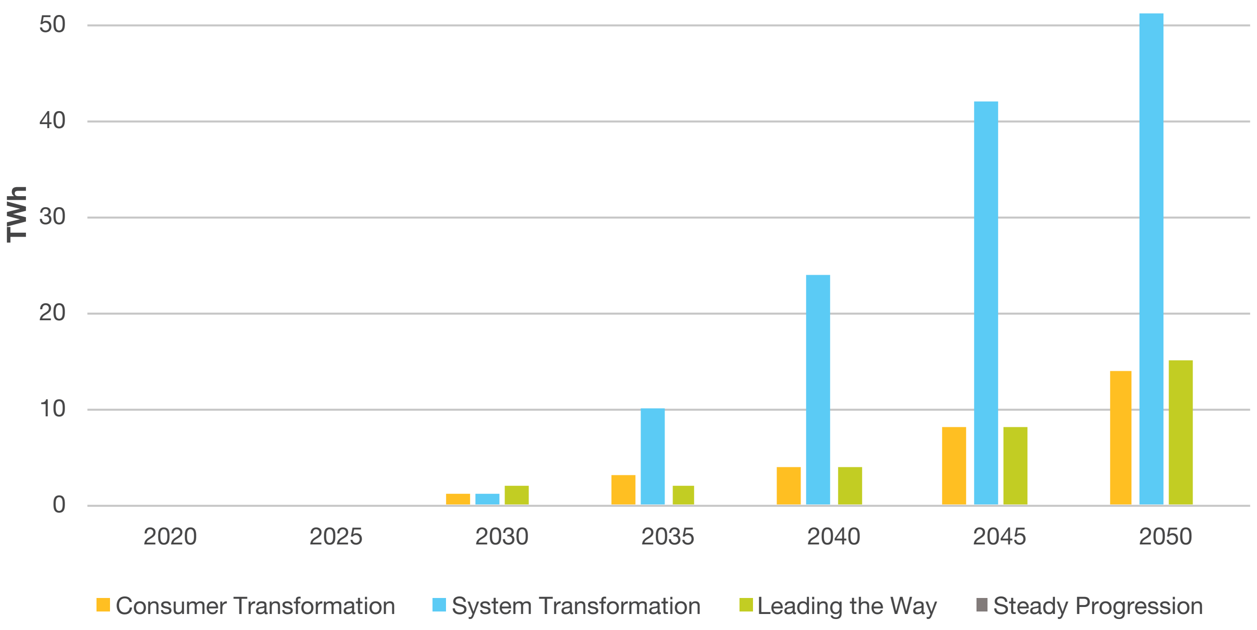
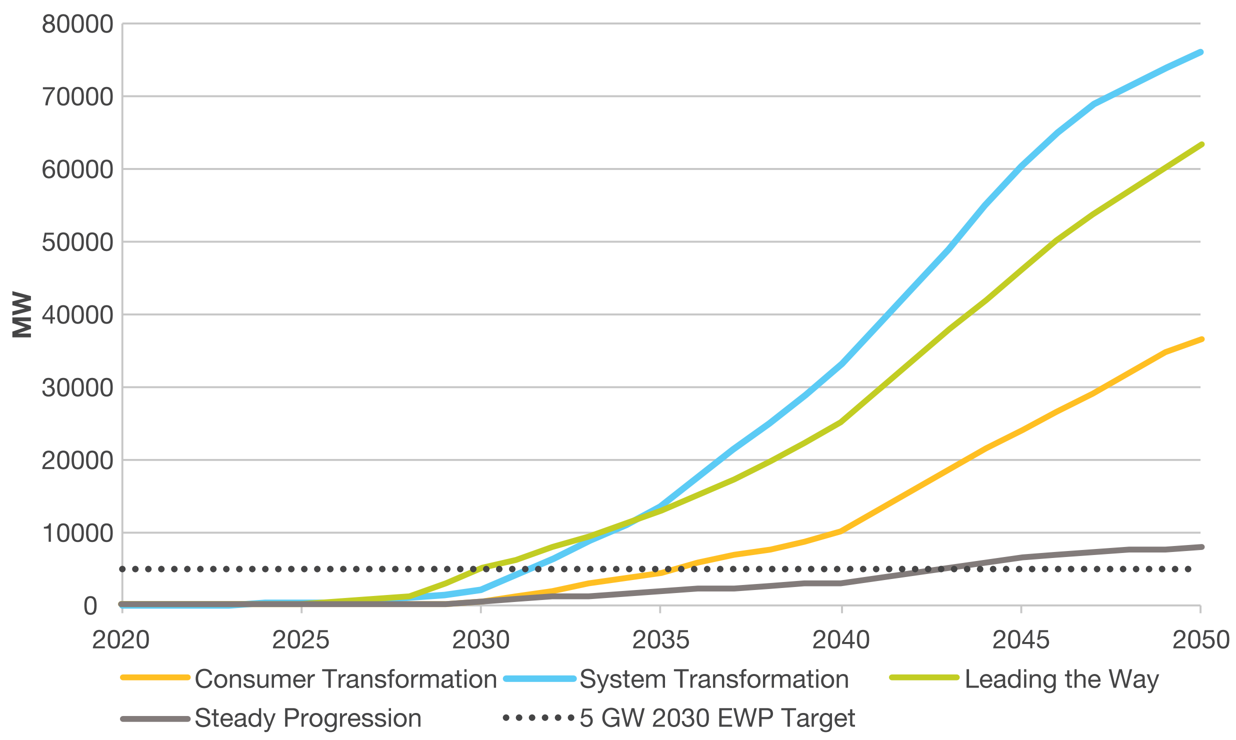


Figure SV.13: Total hydrogen production capacity in each scenario (MW)



FES 2021 / System View / Hydrogen Supply 189

What we've found

Hydrogen supply

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

We have used the range of production methods outlined earlier, making choices for each scenario based on the FES framework. System Transformation understandably has the highest levels of production from all sources, with the majority coming from the reformation of methane.

Nuclear energy combined with low temperature electrolysis has been modelled for the first time this year based on stakeholder feedback and is used in both System Transformation and Consumer Transformation. Electrolysis from wind or solar power is the main production source for Leading the Way and Consumer Transformation.

Figure SV.14: Networked Electricity[3] Demand for Electrolysis (TWh)

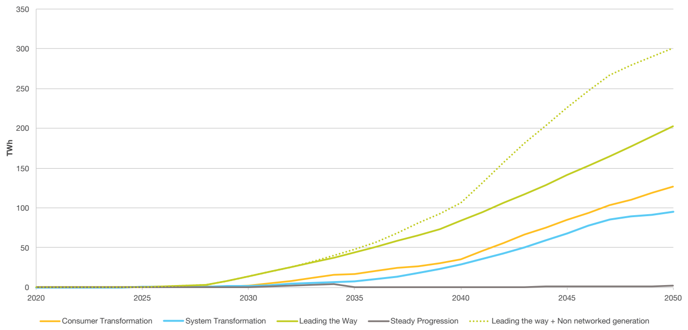


Figure SV.15: Natural Gas Demand for Reformation (TWh)

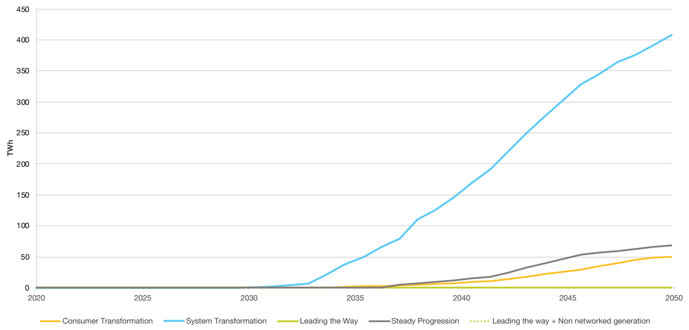


Figure SV.16: Nuclear Electricity Demand for Electrolysis (TWh)[4]

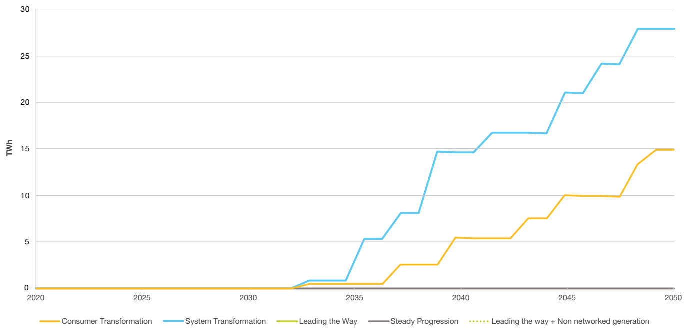
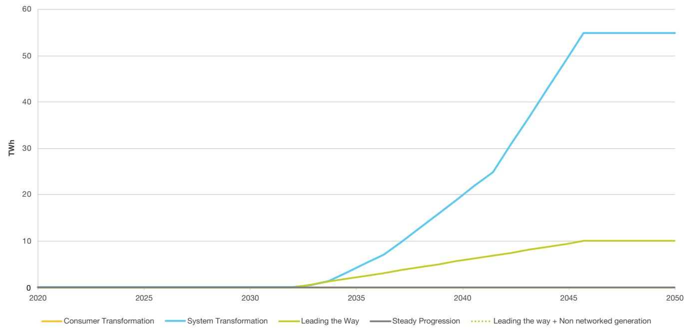


Figure SV.17: Bioresources Demand for Gasification (TWh)

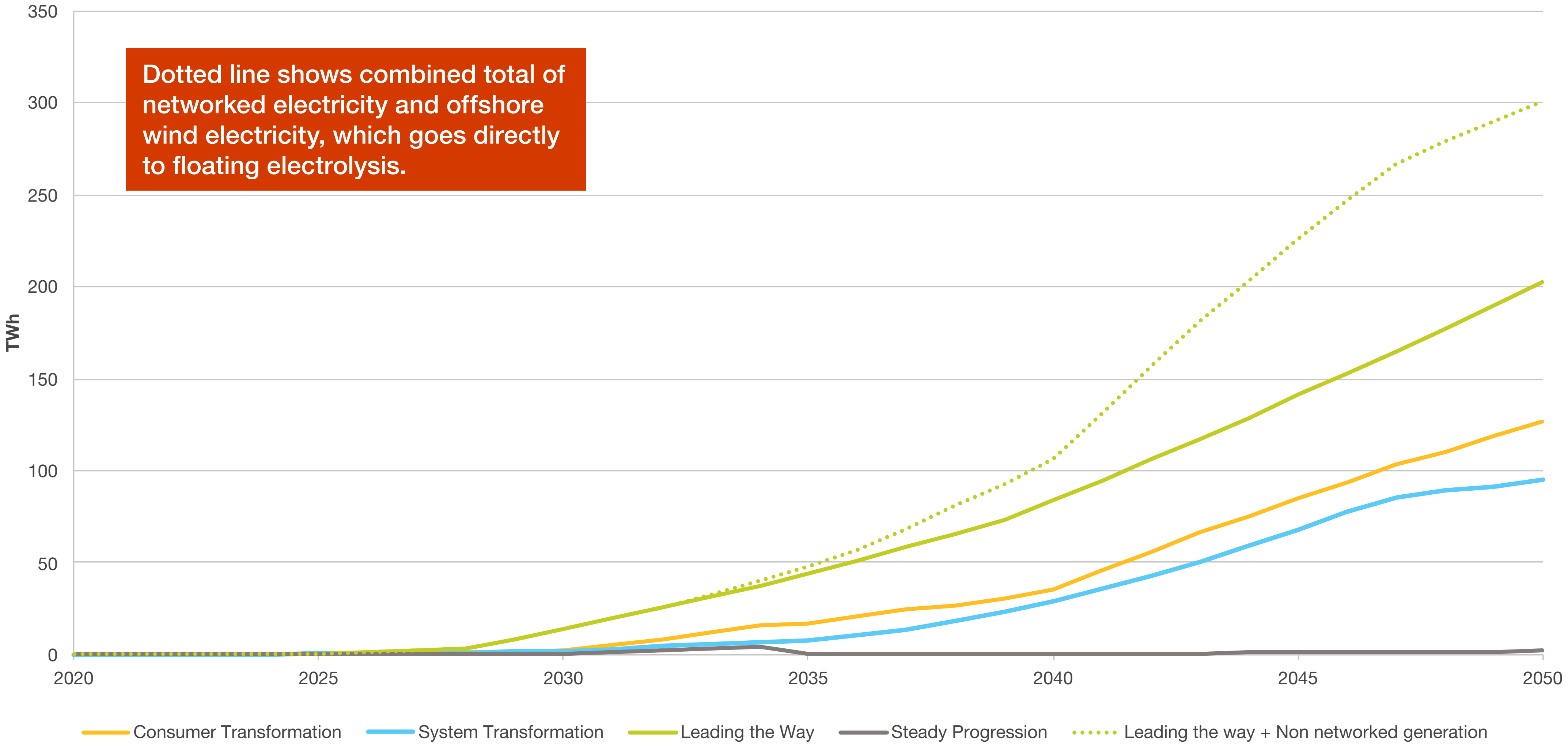


3 Electricity supplied over the electricity transmission or distribution network.
4 This is electricity from nuclear, which goes directly to electrolysis and not via the main electricity network.

FES 2021 / System View / Hydrogen Supply 190

What we've found

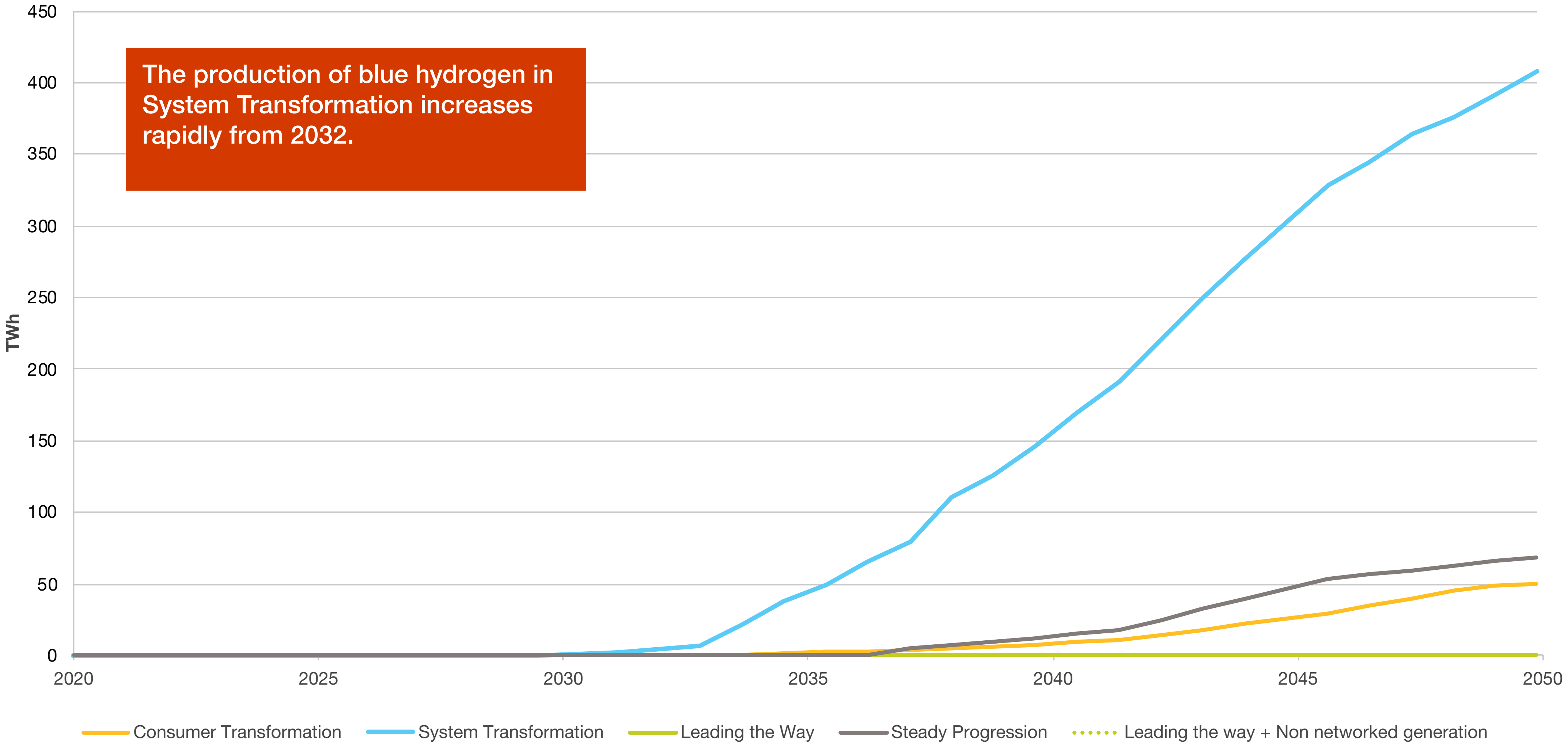
Figure SV.14: Networked Electricity[3] Demand for Electrolysis (TWh)



3 Electricity supplied over the electricity transmission or distribution network.

What we've found

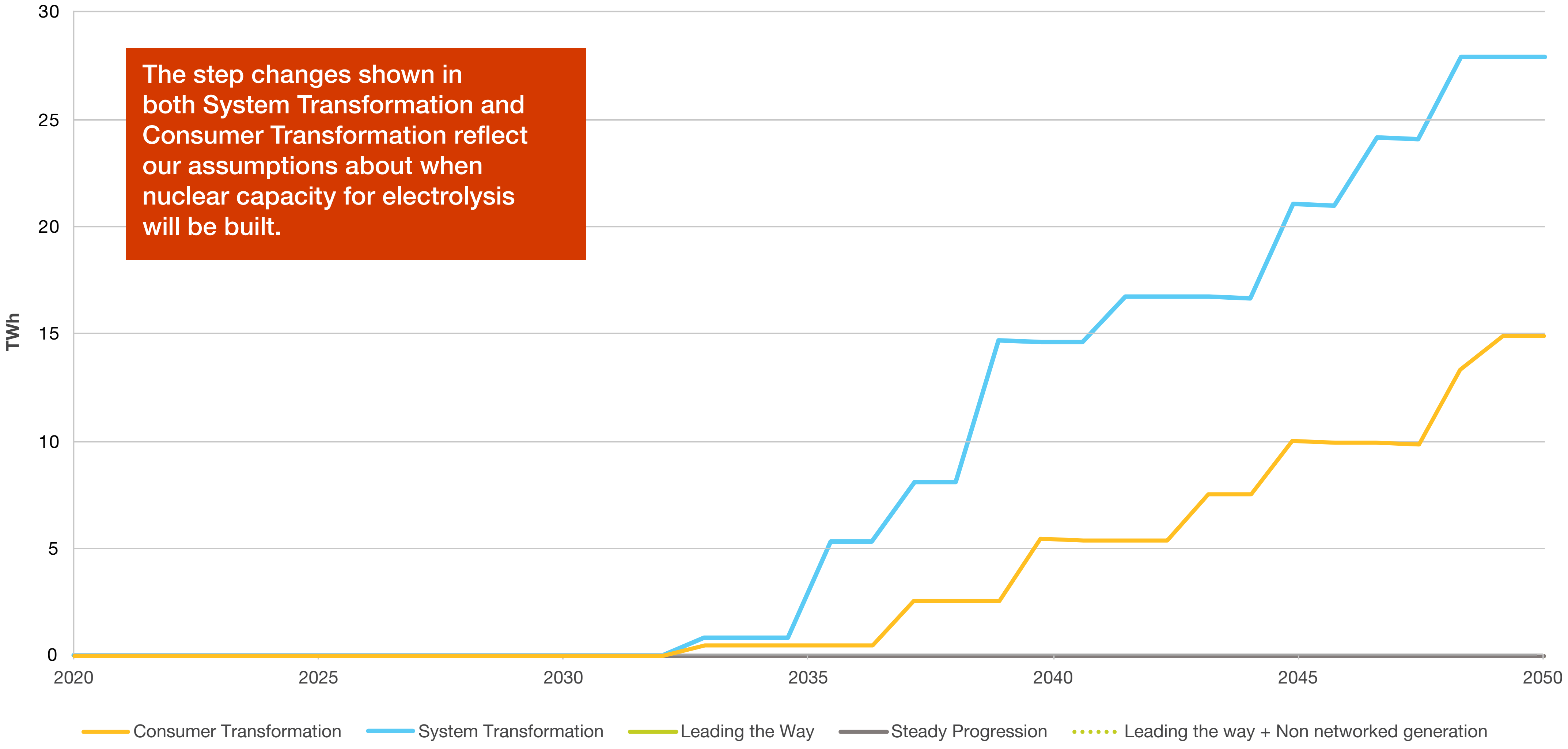
Figure SV.15: Natural Gas Demand for Reformation (TWh)



FES 2021 / System View / Hydrogen Supply 192

What we've found

Figure SV.16: Nuclear Electricity Demand for Electrolysis (TWh)[4]

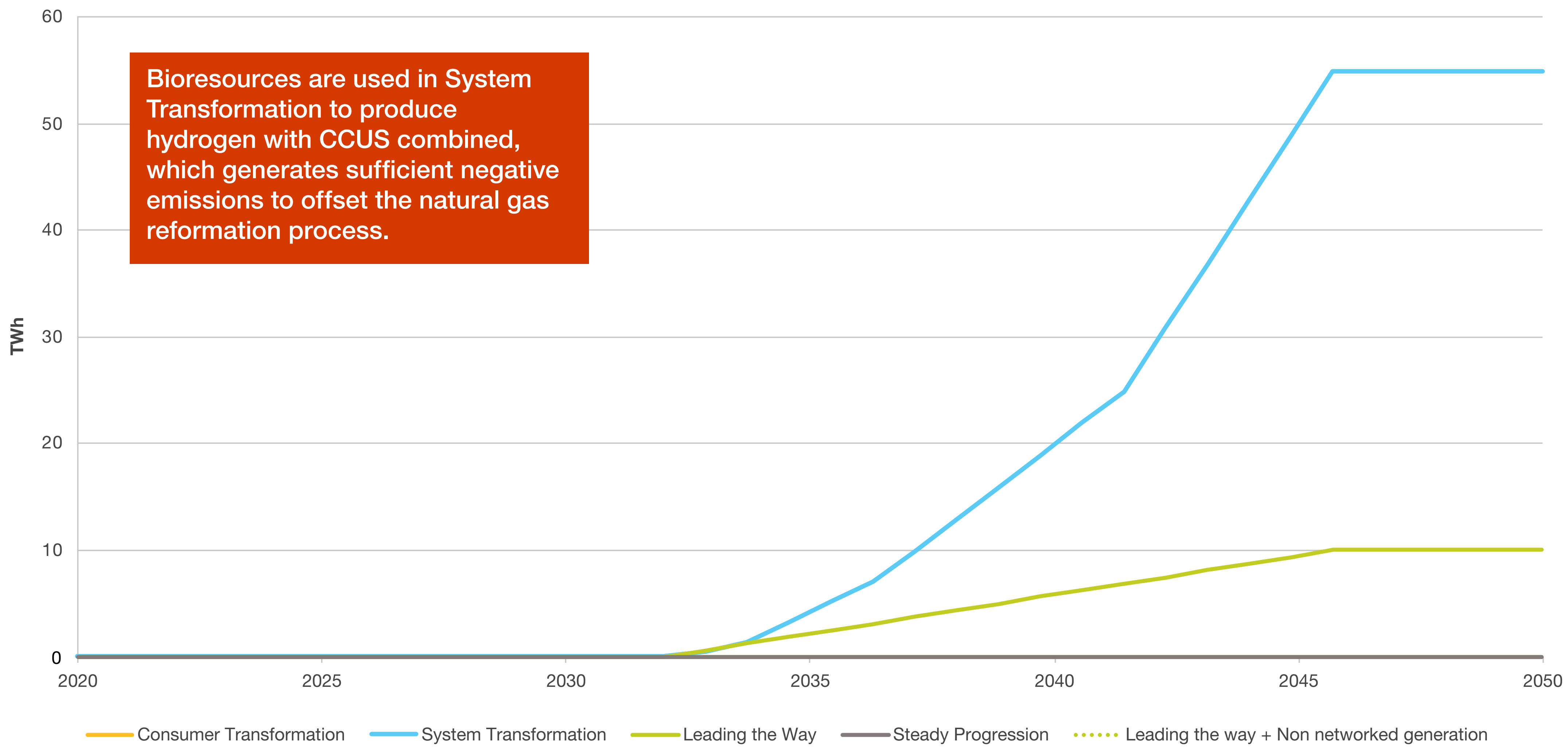


4 This is electricity from nuclear, which goes directly to electrolysis and not via the main electricity network.

FES 2021 / System View / Hydrogen Supply 193

What we've found

Figure SV.17: Bioresources Demand for Gasification (TWh)



FES 2021 / System View / Hydrogen Supply 194

Consumer Transformation

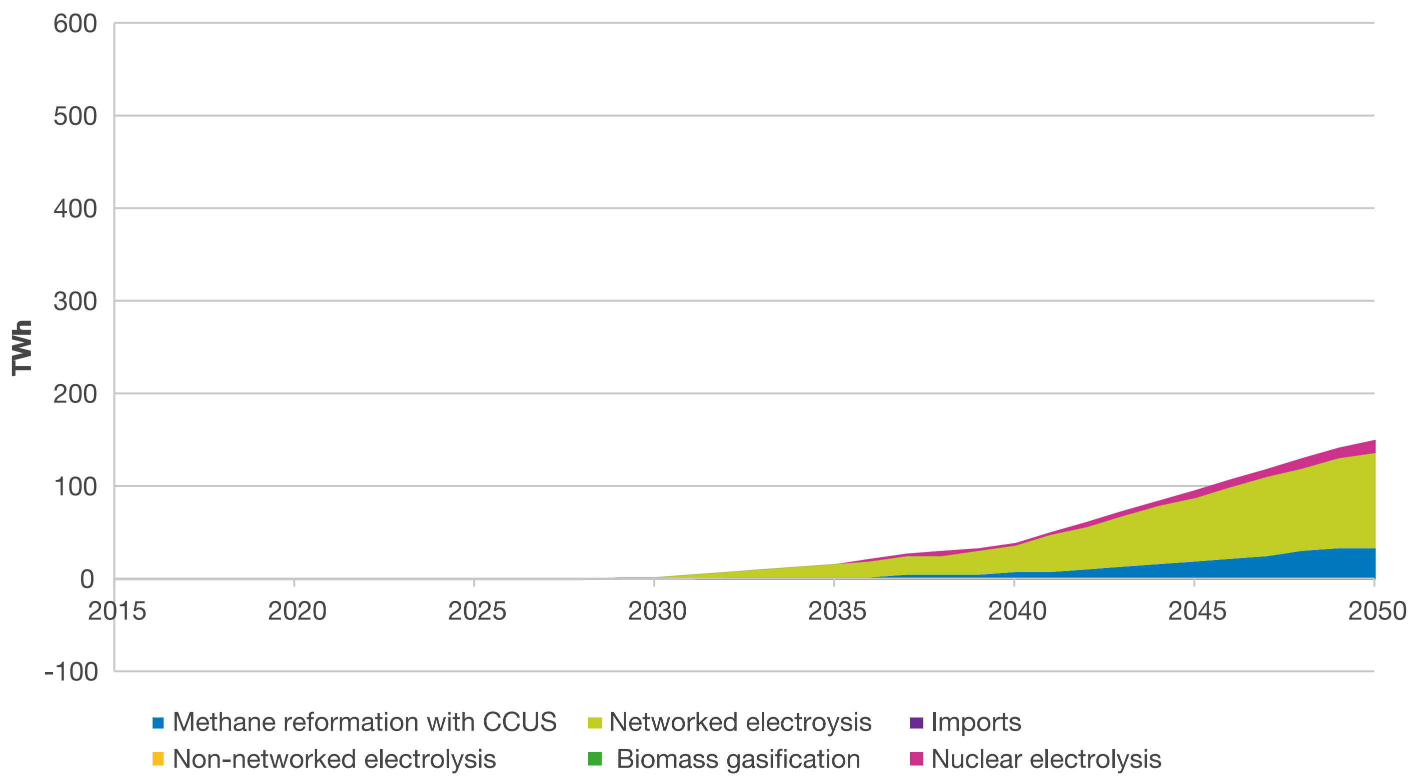
The route to 2050

Consumer Transformation has the least amount of hydrogen out of the three net zero scenarios and uses electricity for heating where feasible. This means the focus is on using renewable electricity to produce hydrogen, particularly when it would otherwise be curtailed. By 2035, the cost of electrolysis has dropped, due to lower wholesale power prices, so that it is cheaper to use than reforming methane. Nuclear energy combined with electrolysis is introduced in the 2030s.

What does 2050 look like?

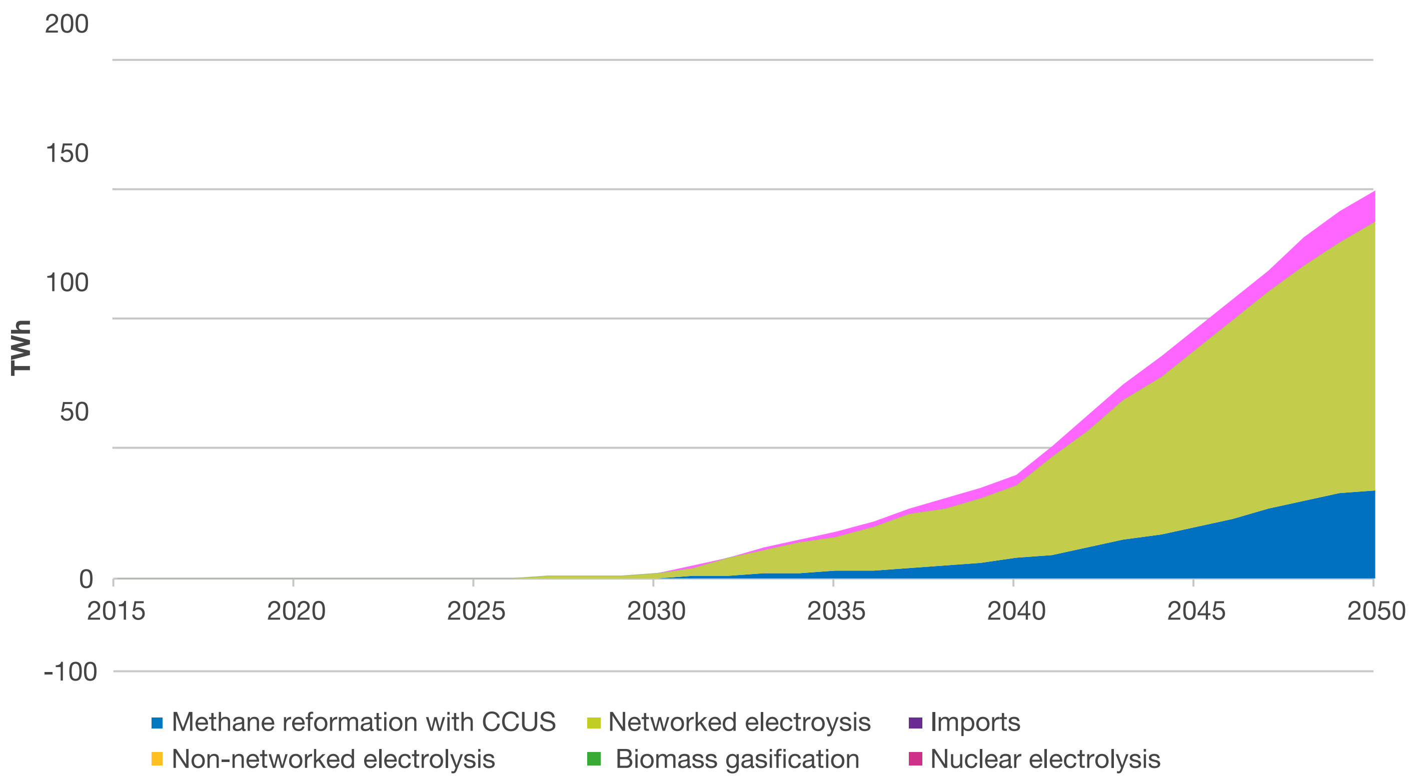
Green hydrogen from renewable electricity makes up almost 70% of total hydrogen supply in 2050 with 23% coming from methane reformation with CCUS. The hydrogen produced using excess renewable energy is stored until it is needed later, for example in peak demand when it is used in power stations. Hydrogen is also used in sectors where electrification is not possible or cost-effective: industrial applications, shipping and road haulage.
The electrolysers are located close to demand so the national gas network is not converted to transport hydrogen. There may be some localised areas close to the reformation facilities, where the gas network is converted or even expanded to transport hydrogen to heat homes and buildings, but this is not widespread.

Figure SV.18: Hydrogen supply in Consumer Transformation (TWh)



What we've found

Figure SV.18: Hydrogen supply in Consumer Transformation (TWh) - Scaled View



FES 2021 / System View / Hydrogen Supply 196

What we've found

System Transformation

The route to 2050

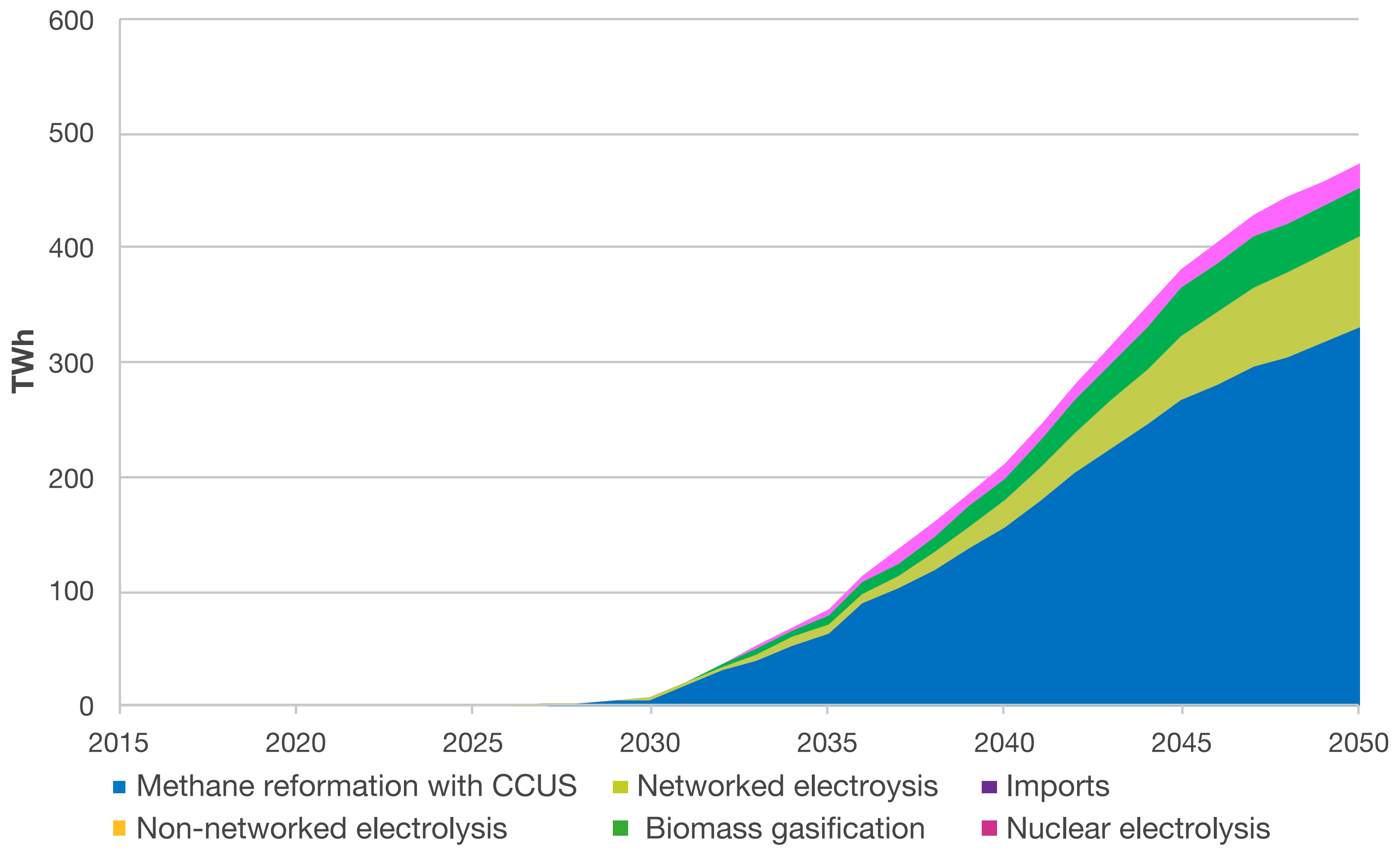
Government support for hydrogen is strong from the mid-2020s so supply and demand grow quickly over the 2030s. Industrial clusters start the transition, where blue hydrogen is produced. The first two clusters will have hydrogen supplies by 2026 and the following two by 2030. As these industrial hubs are connected to the converted gas network, hydrogen can be transported around the country easily and the carbon captured can also be transported to its storage location. 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 national gas transmission system. Most of the conversion work has been completed by 2045.

What does 2050 look like?

Almost 70% of hydrogen comes from methane reformation with green hydrogen, nuclear and biomass gasification providing additional volumes. The use of biomass with CCUS contributes almost 10% in 2050. We assume this is a commercially attractive way to produce hydrogen because there will be payments for negative emissions and it offsets the use of methane for hydrogen production. So in System Transformation, biomass is prioritised for gasification to ensure that sufficient negative emissions are produced to offset the methane used.

As hydrogen will be predominantly meeting heating demand, significant seasonal storage will be needed to ensure sufficient supply for winter peak and to store hydrogen produced by the methane reformers which operate at baseload throughout the year. This will be stored primarily in salt caverns and we expect 51 TWh of stored hydrogen to be available by 2050 (roughly equivalent to 10% of annual demand). Post-2050, assuming costs reduce, we could see more electrolysis for hydrogen in this scenario, as it replaces methane reformation plant.

Figure SV.19: Hydrogen supply in System Transformation (TWh)



What we've found

Leading the Way

The route to 2050

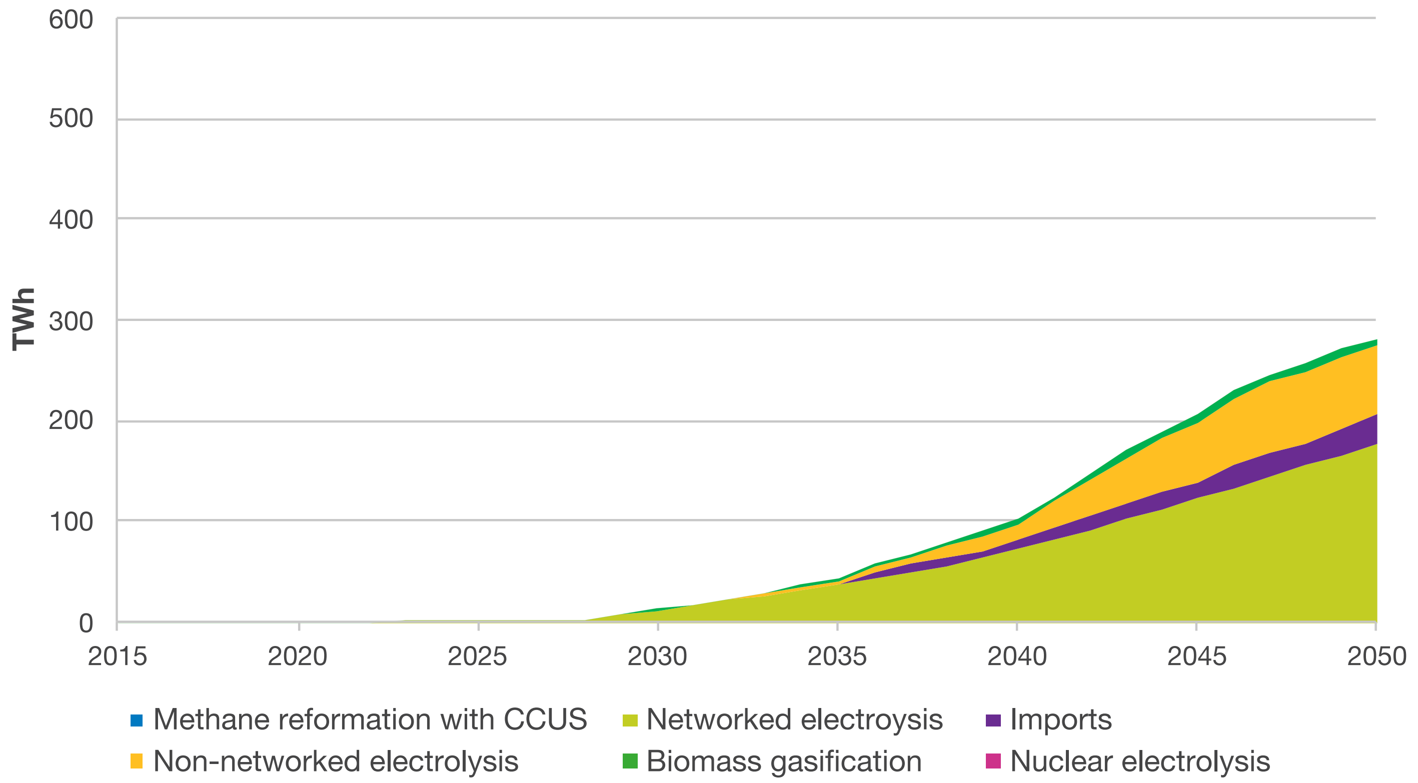
With swift decarbonisation as the primary goal, we expect hydrogen production capacity to be built over the 2020s with government support to reach the 5 GW target. Electrolysers will be built near where renewable electricity comes to shore to avoid creating congestion on the electricity network. These facilities will be connected to a local hydrogen transmission network so that the hydrogen can be used for heating, either as the sole fuel or as part of a hybrid solution with a heat pump. Offshore electrolysers will be also be built alongside wind farms in the 2030s, so that hydrogen is transported to shore rather than electricity.

We have also assumed that there is a similar approach around the world, so that there is a global market for hydrogen by 2040 and it can be imported. Leading the Way is the scenario with the second largest hydrogen supply but none of it from the continued extraction of fossil fuels.

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.

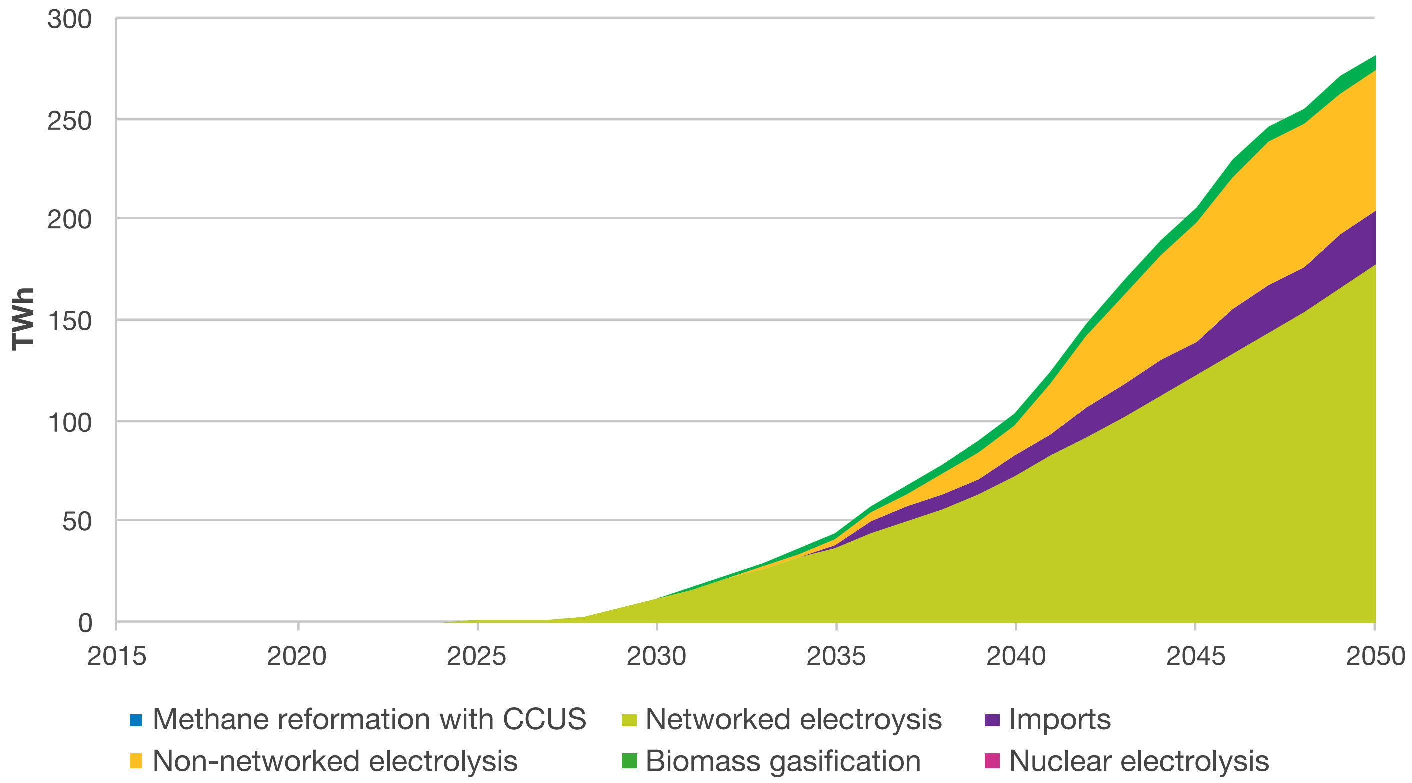
Figure SV.20: Hydrogen supply in Leading the Way (TWh)



FES 2021 / System View / Hydrogen Supply 198

What we've found

Figure SV.20: Hydrogen supply in Leading the Way (TWh) -Scaled View



FES 2021 / System View / Hydrogen Supply 199

What we've found

Steady Progression

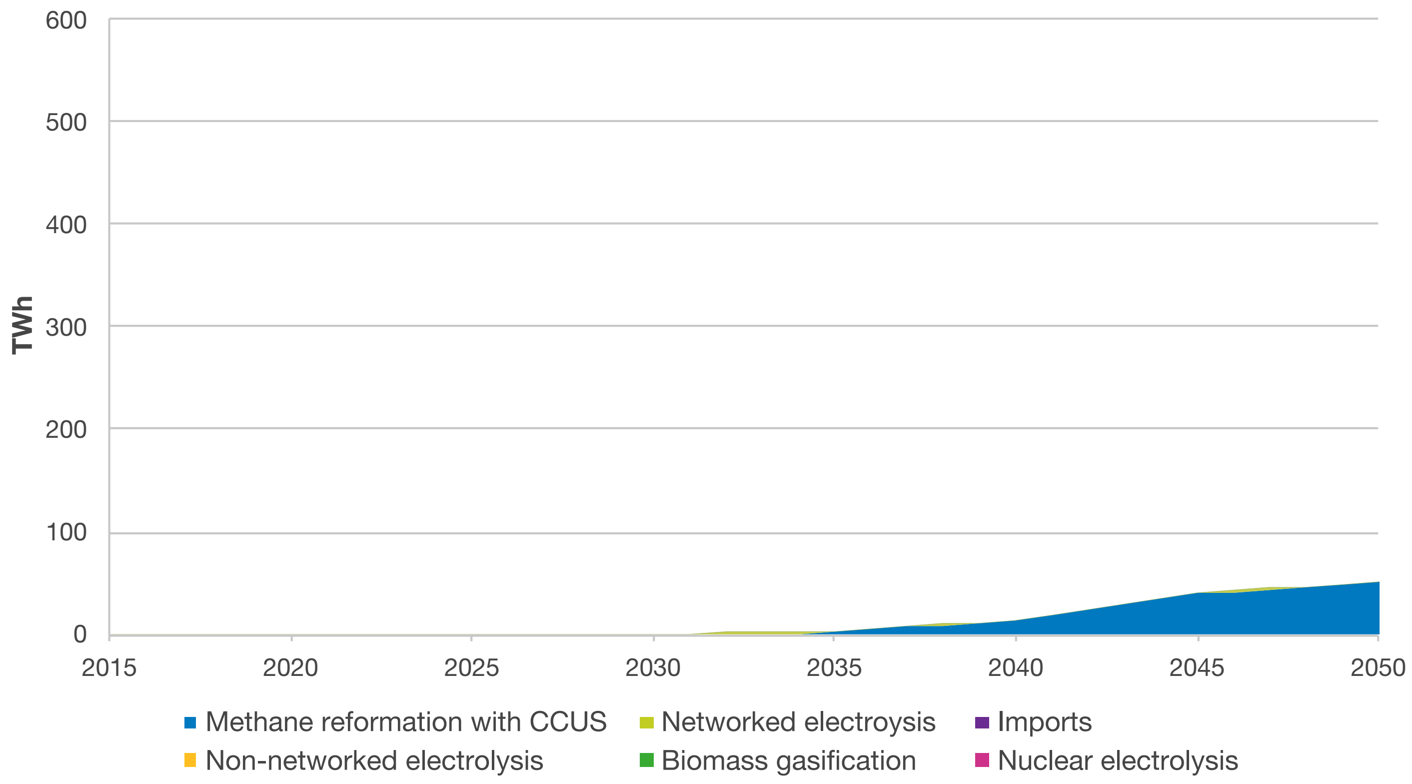
The route to 2050

Without a clear strategy from the Government, there is a lack of demand for hydrogen in Steady Progression and no reason to create a hydrogen transmission network. However, projects such as HyDeploy have shown that hydrogen blends of up to 20% (by volume) can be used in the gas network without significant effects on appliances. So we have assumed this route has been taken in Steady Progression to reduce the carbon impact of the supply of natural gas to homes and buildings for heating. This hydrogen comes from methane reformation with CCUS, with the first production and storage facility being built in the mid-2030s.

What does 2050 look like?

In 2050, natural gas is still being supplied to heat homes and buildings but it is mixed with 20% hydrogen (by volume), approximately 52 TWh per year. This hydrogen comes predominantly from methane reformation with an additional 2 TWh from electrolysis. This reduces the carbon impact of natural gas combustion. Hydrogen is not used in other applications.

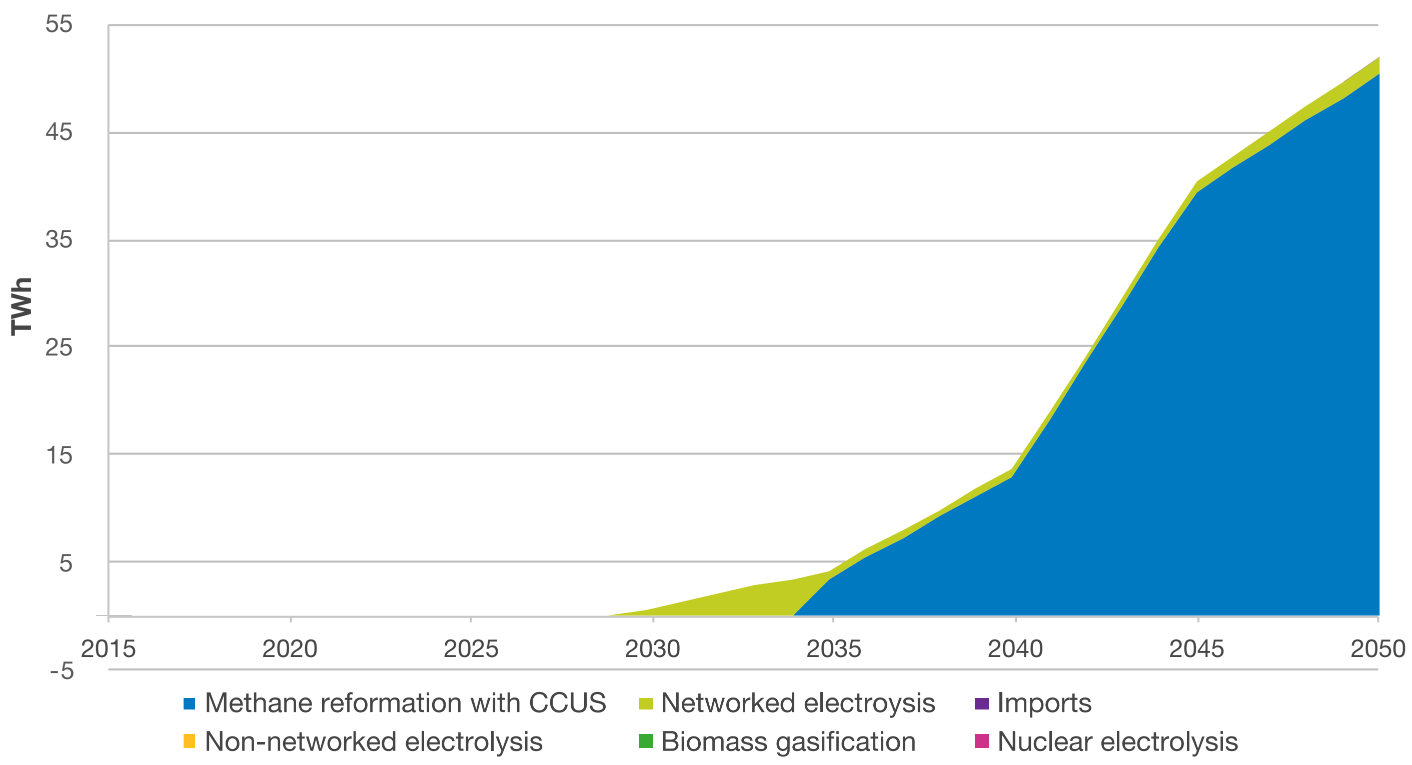
Figure SV.21: Hydrogen supply in Steady Progression (TWh)



FES 2021 / System View / Hydrogen Supply 200

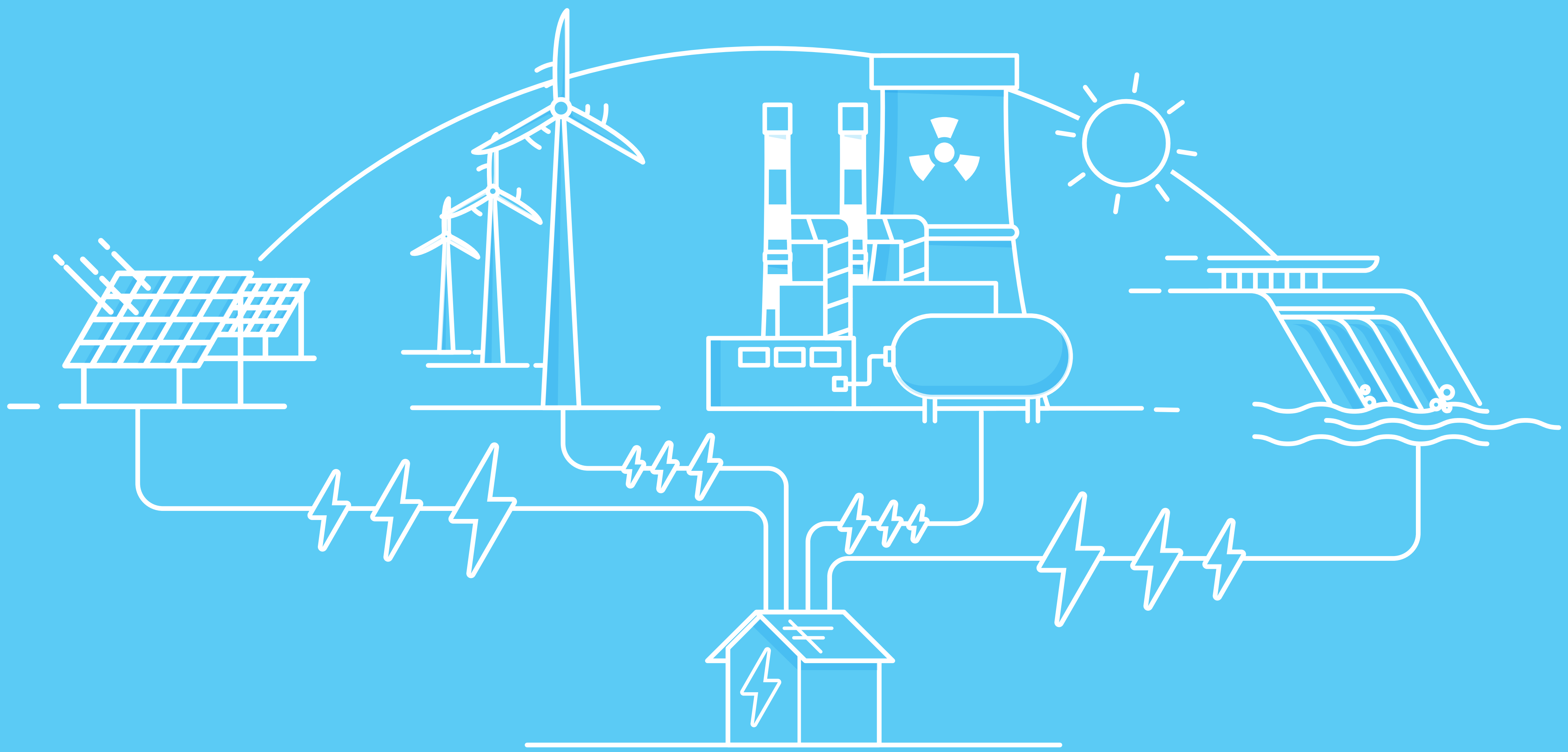
What we've found

Figure SV.21: Hydrogen supply in Steady Progression (TWh) - Scaled View



FES 2021 / System View / Hydrogen Supply 201

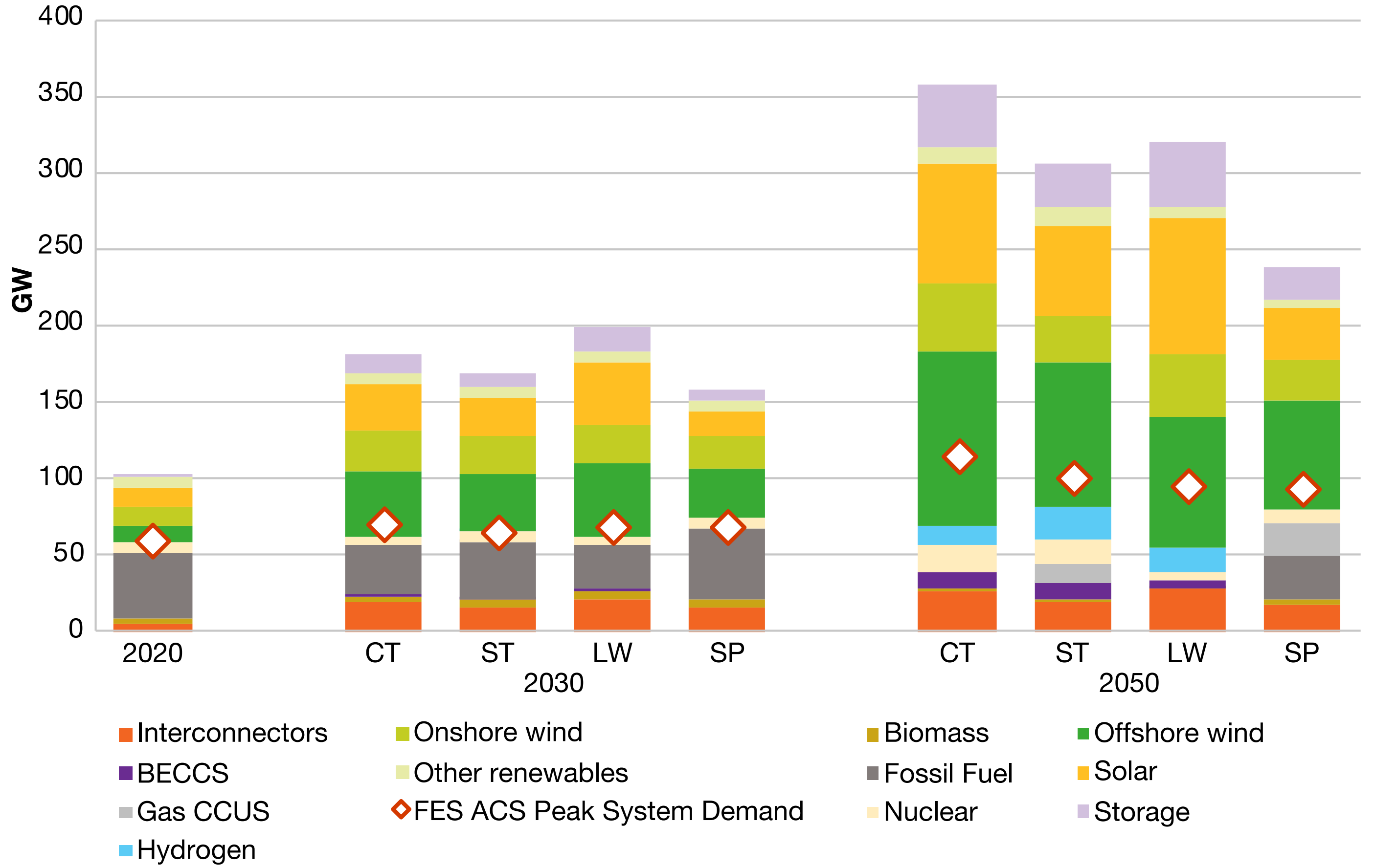
Electricity Supply



Key insights

- Rapid decarbonisation of the electricity sector is essential to meet net zero and enable the decarbonisation of other sectors such as heat and transport through electrification. The use of Bioenergy with Carbon Capture Usage and Storage (BECCS) means we can achieve overall net negative emissions in the power sector.
- Increased electricity peak demands compared to FES 2020 mean we will need more generation capacity, particularly renewables, as well as flexible technologies and demand side response.
- As unabated gas generation is phased out in the 2030s in the net zero scenarios, maintaining system security will be challenging. To achieve this we need to see accelerated uptake of zero carbon technologies and Carbon Capture Usage and Storage (CCUS).
- The profile of electricity supply is changing. We will see demand side response play a central role in flexibility, this will ensure security of supply in a more efficient way.
- Connecting high volumes of new renewable generation, particularly offshore wind, to the electricity system will be challenging in the short term due to the need for network reinforcement.

Figure SV.22: Installed electricity generation capacity, storage and interconnection to 2050



FES 2021 / System View / Electricity Supply 203

Where are we now

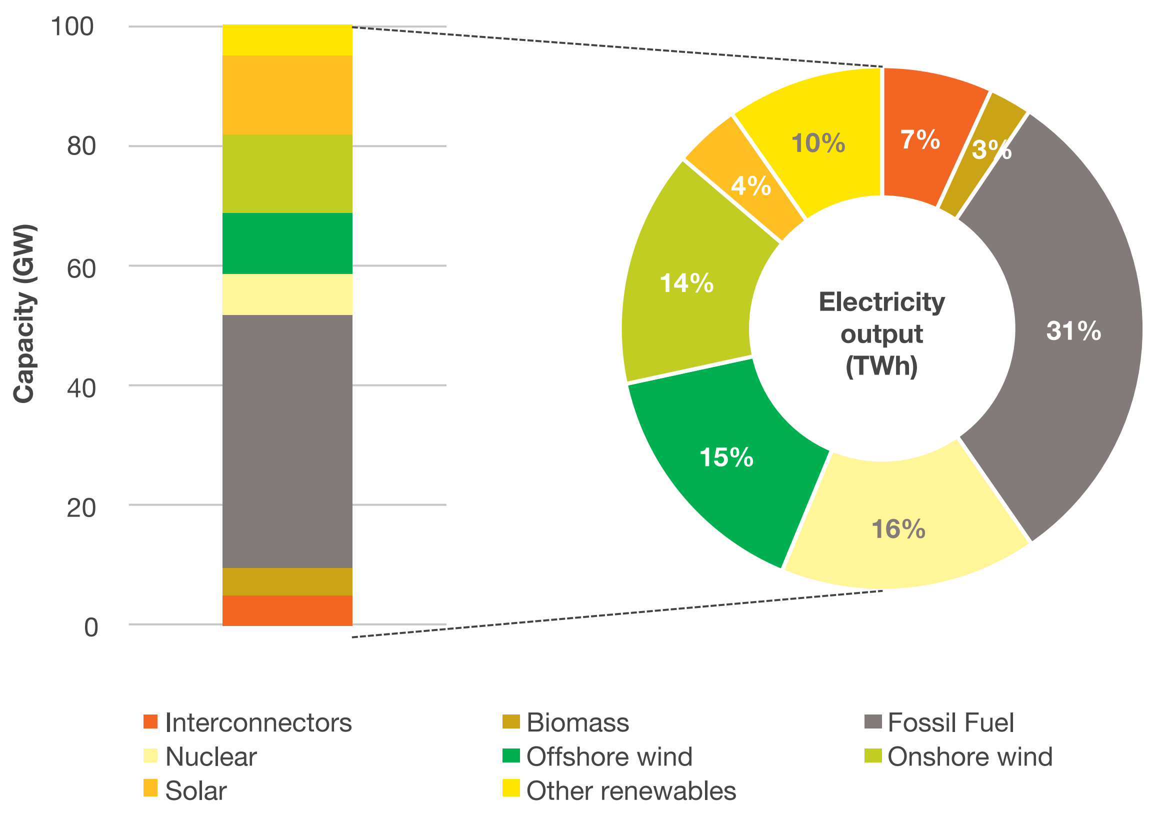
The electricity generation sector has seen the most progress made on decarbonisation, particularly in recent years. It started with the 'dash for gas' in the 1990s that saw natural gas displacing coal fired generation and continued more recently with the rapid growth in renewables.

Today's electricity mix is made up primarily of gas, renewables and nuclear, supplemented by a few other sources. In winter some coal generation plants have been used to help meet peak demand, coal use even in winter has been declining sharply in recent years.

Renewable generation capacity, primarily wind and solar, has increased fivefold over the past 10 years. This growth has been supported by government subsidies, such as the Feed-In Tariff and the Contracts for Difference scheme but has also been driven by rapid reductions in cost that have allowed them to start competing in a subsidy-free environment.

The latest auction for leases to operate offshore wind sites was held this year. Successful bids were for sites which could deliver a further 8 GW of offshore wind capacity to help meet the government's target of delivering 40 GW of offshore wind by 2030.

Figure SV.23: Electricity generation capacity and output in 2020



FES 2021 / System View / Electricity Supply 204

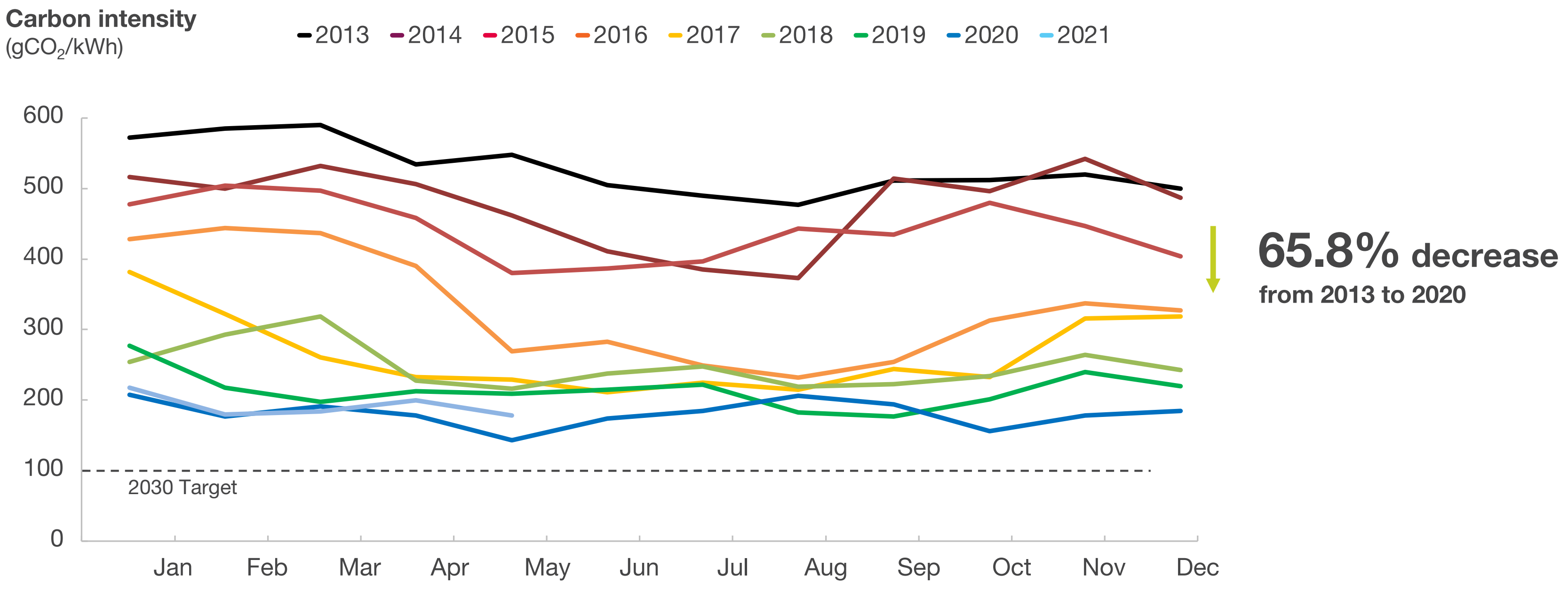
Where are we now

One of our major challenges in decarbonising the electricity system further is to replace fossil fuels as a source of flexibility on the electricity system. This will become increasingly important as we see more variable weather-driven sources of generation on the system.

The role of electricity generation within the whole energy system is changing. Historically it has been to deliver sufficient energy to meet demand and security of supply, however in future the electricity system will be supply-led, with renewable generators producing electricity when it is sunny or windy and flexible sources of demand adjusting to use and store this energy. Decarbonisation of the electricity system enables the decarbonisation of other sectors. Without decarbonisation of electricity, changes made by consumers such as use of electric vehicles and electrified home heating would not lead to a net reduction of emissions.

National Grid ESO aims to be able to operate the electricity system carbon free by 2025. This means alternative sources of inertia will need to be found, a commodity that helps to reduce the rate of change of frequency on the system that has historically been delivered as a by-product of fossil fuel generation.

Figure SV.24: Historic electricity supply carbon intensity reduction[1]



1 See live and historic carbon intensity data at https://www.carbonintensity.org.uk/

FES 2021 / System View / Electricity Supply 205

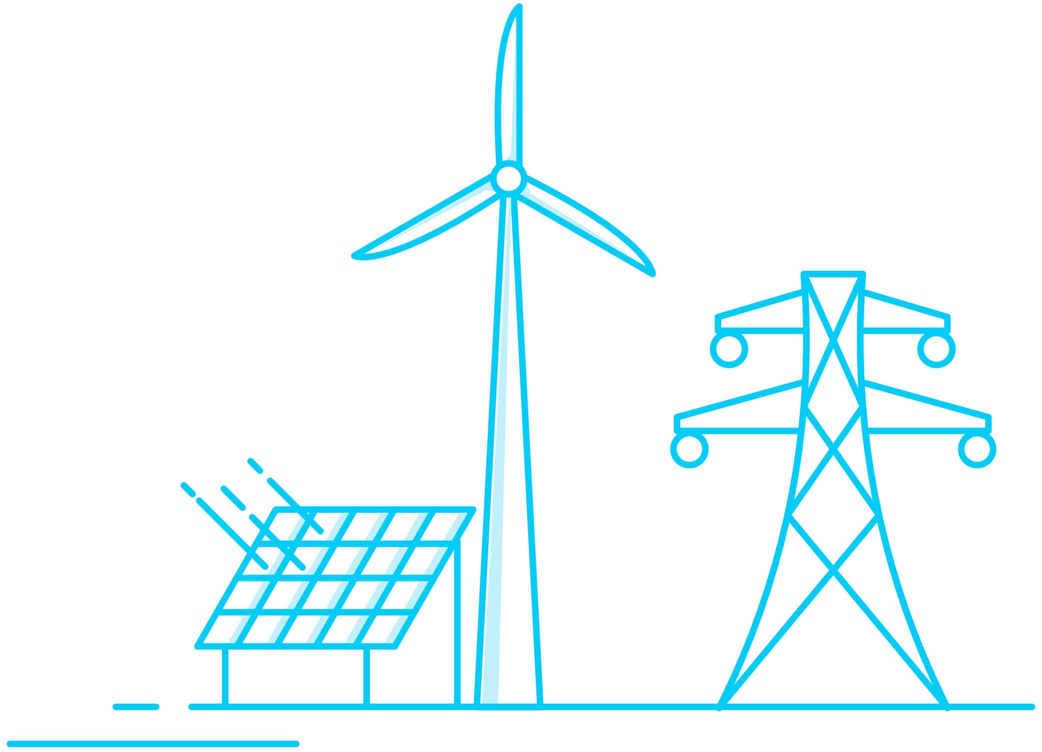
Where are we now

Networks

While the largest demands today are in the big cities, and particularly the south of England, electricity needs to be moved across the country from where it is generated to where it is needed. This means capacity on the electricity transmission network to move power across the country and between regions is an important factor. Today we already see high levels of power exported from Scotland into England at times of high wind generation, and in future we expect to see further significant power flows associated with new offshore wind. These power flows will need to be managed, today this often involves curtailing generation when network capacity is constrained. Work has been done to alleviate these constraints through transmission projects such as the Western Link running down the west coast (completed in 2017) and the under-development Eastern Links off the east coast.

The analysis underpinning our Future Energy Scenarios helps us understand these issues better and how they will change in the future. These challenges will become increasingly important as the system becomes more decarbonised, with many generation sources located further from demand than previously; for example onshore wind in Scotland and offshore wind in the North Sea. The development of local flexibility markets may also alleviate these issues, without needing this to be addressed at transmission-level.

Detailed discussion of these issues is beyond the scope of FES 2021; however they are considered in more detail in publications which build on our FES 2021 analysis: our Electricity Ten Year Statement, Network Options Assessment, and Offshore Coordination work.



FES 2021 / System View / Electricity Supply 206

What we've found

Electricity generation

The proportion of renewable generation increases across all scenarios, with offshore wind expected to provide the backbone of our electricity supply in 2050. Variable renewable technologies typically have a substantially lower load factor than fossil fuel generation. This means that generating an equivalent amount of energy requires significantly higher installed renewable generation capacity.

Higher peak and annual demands in this year's modelling compared to last year have led to greater electricity capacities across all scenarios compared to last year. Total installed capacity will need to increase at least three-fold by 2050 in the net zero scenarios, with more capacity needed in the scenarios with higher levels of societal change. These scenarios typically have higher levels of electrification, leading to increased annual and peak demands and greater need for renewable generation capacity. We assume sufficient generation capacity to achieve the security of supply standard of no greater than a 3-hour loss of load expectation in all scenarios. This could be through mechanisms such as the Capacity Market which incentivise generation capacity to be available at peak times.

We assume that the price of the new UK Emissions Trading Scheme (ETS) will be similar to the EU ETS and that the two will continue on a similar trajectory to 2050. We anticipate the GB Carbon Price Support will continue in line with government policy before gradually being phased out as the ETS increases.

System Transformation and Steady Progression have lower levels of decentralised generation; as high levels of transmission-connected offshore wind in particular offset increases in other distribution-connected technologies.

High levels of societal change in Leading the Way and Consumer Transformation lead to higher uptake of decentralised generation as local communities have greater appetite for renewable generation. There are lower levels of take-up of other renewable technologies, such as hydroelectric, marine and geothermal generation, more details can be found in the data workbook.

FES 2021 / System View / Electricity Supply 207

What we've found

Load Factor

The load factor or capacity factor of a technology refers to the electricity generated by a technology as a proportion of the maximum potential generation over the period. Variable renewable technologies typically have a substantially lower load factor than fossil fuel generation can provide due to the nature of the resources they are harnessing, for example solar PV generation is limited by hours of daylight.

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). 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 capacity 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.

Capacity Market

The Capacity Market ensures security of electricity supply by providing a payment for reliable sources of electricity capacity, alongside their electricity revenues, to ensure they deliver energy when needed. Participants can bid for contracts in auctions ahead of the delivery date for the capacity, and secure guaranteed revenue which can help support generators that may have low annual running hours.

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.

In a decentralised world, far more small-scale energy supplies connect to the distribution networks, including renewables and small-scale green gas. On a yet smaller-scale, consumers access technology to manage their own electricity needs in a more localised manner.

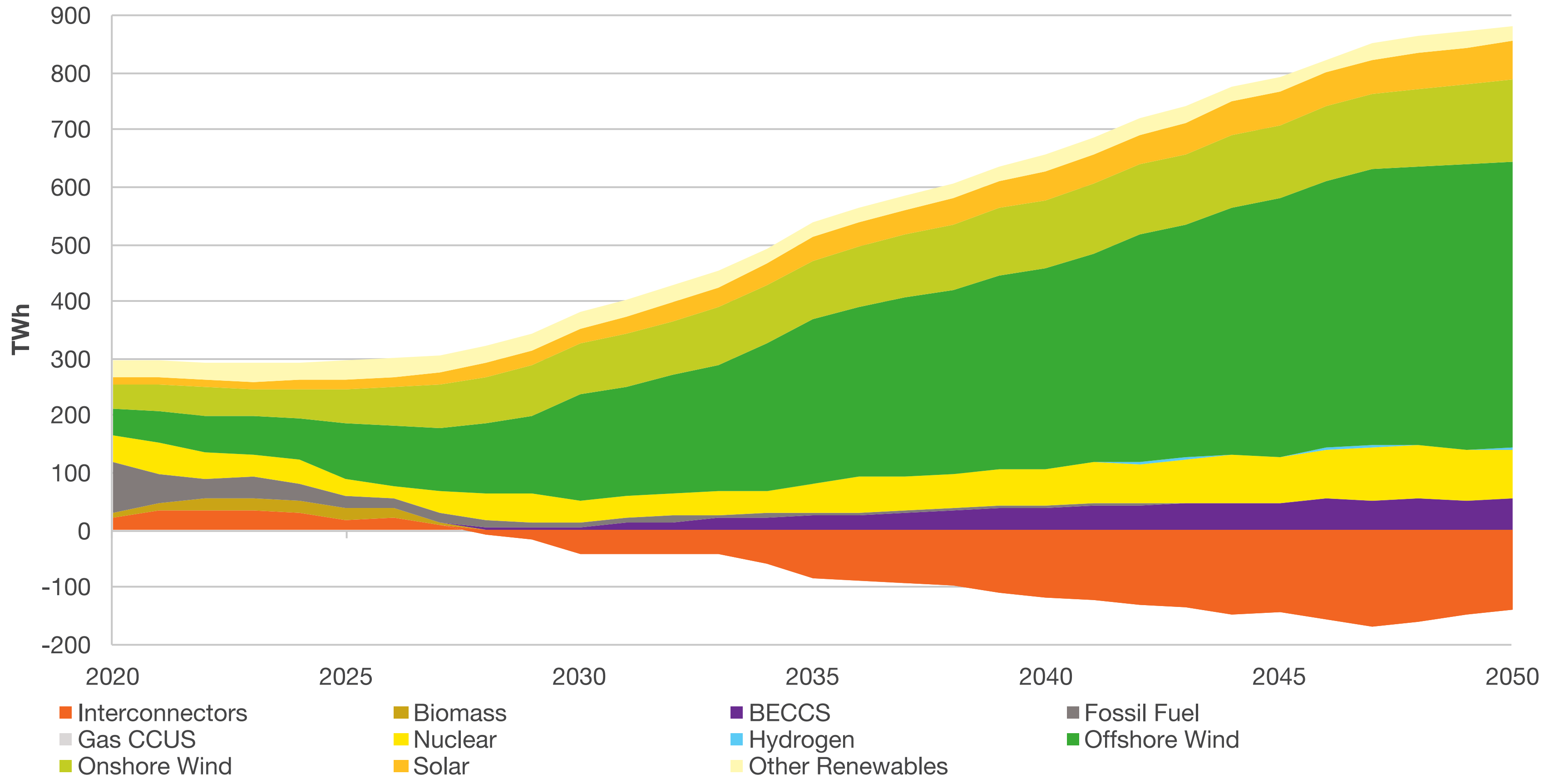
FES 2021 / System View / Electricity Supply 208

What we've found

Scenarios overview

Across all scenarios we see an increase in renewable generation, particularly offshore wind, which grows to make up over half of electricity supply by the late 2030s in all scenarios. 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 scenarios. Across the scenarios last year the highest generation output in 2050 was 691 TWh, this year there is a substantial increase to 882 TWh.

Figure SV.25: Electricity output by technology (excluding non-networked offshore wind generation)



Consumer Transformation

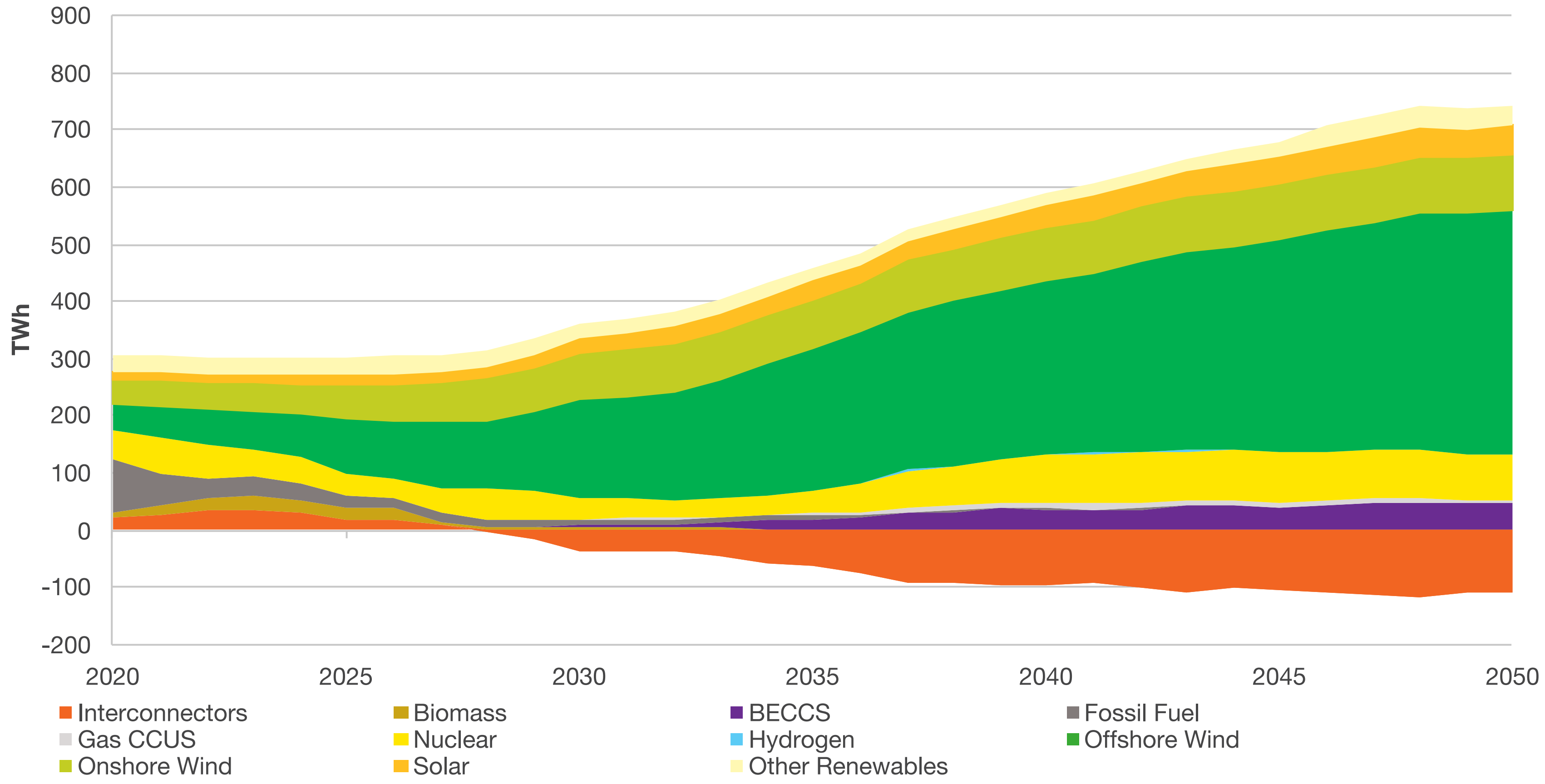
FES 2021 / System View / Electricity Supply 209

What we've found

Scenarios overview

Across all scenarios we see an increase in renewable generation, particularly offshore wind, which grows to make up over half of electricity supply by the late 2030s in all scenarios. 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 scenarios. Across the scenarios last year the highest generation output in 2050 was 691 TWh, this year there is a substantial increase to 882 TWh.

Figure SV.25: Electricity output by technology (excluding non-networked offshore wind generation)



System Transformation

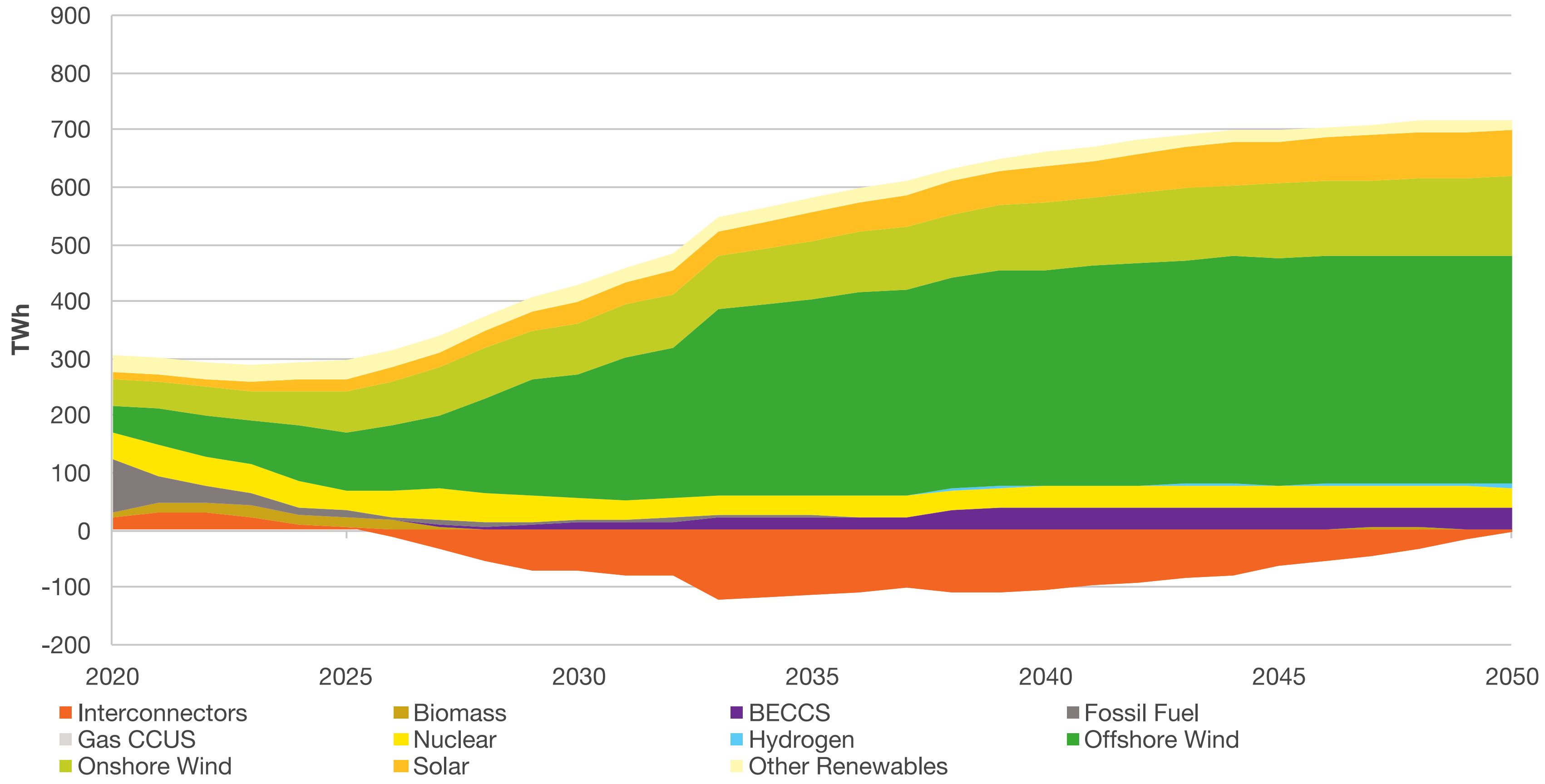
FES 2021 / System View / Electricity Supply 210

What we’ve found

Scenarios overview

Across all scenarios we see an increase in renewable generation, particularly offshore wind, which grows to make up over half of electricity supply by the late 2030s in all scenarios. 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 scenarios. Across the scenarios last year the highest generation output in 2050 was 691 TWh, this year there is a substantial increase to 882 TWh.

Figure SV.25: Electricity output by technology (excluding non-networked offshore wind generation)



Leading the Way

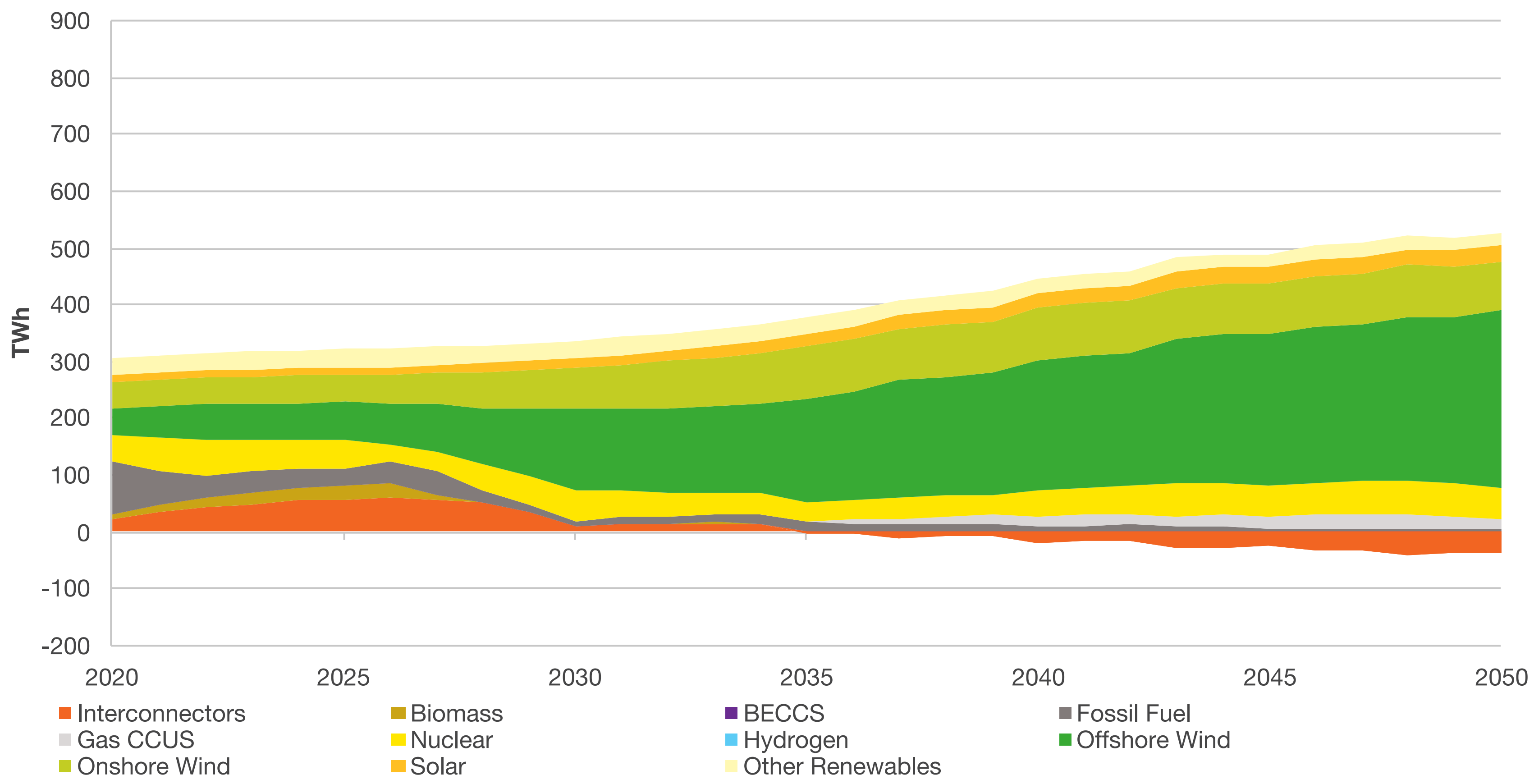
FES 2021 / System View / Electricity Supply 211

What we've found

Scenarios overview

Across all scenarios we see an increase in renewable generation, particularly offshore wind, which grows to make up over half of electricity supply by the late 2030s in all scenarios. 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 scenarios. Across the scenarios last year the highest generation output in 2050 was 691 TWh, this year there is a substantial increase to 882 TWh.

Figure SV.25: Electricity output by technology (excluding non-networked offshore wind generation)



Steady Progression

FES 2021 / System View / Electricity Supply 212

Scenarios overview: electricity supply

Consumer Transformation

The route to 2050

Consumer Transformation sees rapid uptake of renewable generation, particularly offshore wind and solar, to support a highly-electrified economy. The target of 40 GW of offshore wind by 2030 is met, and the 2020s see the development of the first BECCS and hydrogen powered generation. Gas generation reduces rapidly through the 2020s but is still used to support security of supply. Capacity declines in the 2030s, offset by continued increases in renewable and nuclear generation, including significant numbers of small modular reactors, growth in hydrogen generation capacity and BECCS. The power sector reaches net negative emissions in 2032. Storage and interconnection also play an increasingly important role, providing flexibility as fossil fuel capacity reduces.

What does 2050 look like?

Total electricity generation capacity is 290 GW, plus a further 68 GW of electricity storage and interconnection. Electricity generation output is nearly three times that of today at 883 TWh, with 141 TWh exported. Wind, solar, nuclear and BECCS provide 97% 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 net negative emissions, reaching a carbon intensity of -54 gCO_2/kWh.

FES 2021 / System View / Electricity Supply 213

Scenarios overview: electricity supply

System Transformation

The route to 2050

This scenario sees greater growth of large-scale technologies connected to the transmission network. The Government's 2030 offshore wind target is narrowly missed, reaching 40 GW in 2031, 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 come on stream post-2030 and play an increasingly important role. Interconnection and storage capacities increase steadily but provide a smaller share of flexibility.

What does 2050 look like?

Total electricity generation capacity is 258 GW, plus a further 47 GW of electricity storage and interconnection. Electricity generation output is well over twice that of today at 724 TWh, with 108 TWh exported. Wind, solar, nuclear and BECCS provide 95% of generation output, gas CCS and hydrogen provide less than 1% 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 and meet peak demand. The power sector delivers net negative emissions, reaching a carbon intensity of -55 gCO_2/kWh with negative emissions from BECCS more than offsetting residual emissions from gas CCUS.

FES 2021 / System View / Electricity Supply 214

What we've found

Scenarios overview: electricity supply

Leading the Way

The route to 2050

This scenario sees the most aggressive growth in renewable technologies, reaching 40 GW of offshore wind by 2029 and continuing to increase through the 2030s. It also sees high levels of onshore wind growth. BECCS generation is developed ahead of 2030. There is no growth in new nuclear after SMR demonstration plants in the early 2030s. Natural gas generation is phased out rapidly, with only limited capacity remaining post-2035 to support security of supply. Alternative technologies like hydrogen need to be ramped up rapidly ahead of this date.

What does 2050 look like?

Total electricity generation capacity is 248 GW, plus a further 71 GW of electricity storage and interconnection, meeting lower annual and peak demands than the other net zero scenarios. Electricity generation output is well over twice that of today at 701 TWh. Wind, solar, nuclear and BECCS provide 96% of generation output; these are supported by high levels of interconnection and storage and some flexible hydrogen generation to meet peak demands. Interconnectors continually import and export power with a net balance close to zero. The power sector delivers net negative emissions, reaching a carbon intensity of -43 gCO_2/kWh.

FES 2021 / System View / Electricity Supply 215

What we've found

Scenarios overview: electricity supply

Steady Progression

The route to 2050

Steady Progression sees more gradual decarbonisation of the power sector; growth in offshore wind continues, with 30 GW installed by 2030, but with more limited growth of onshore wind and solar. Post-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 42 gCO_2/kWh by 2030, and decline gradually after this point driven by the shift away from unabated gas. Interconnection capacity continues to grow up to 2035 while storage continues to gradually increase.

What does 2050 look like?

Total electricity generation capacity is 201 GW, plus a further 37 GW of electricity storage and interconnection. Electricity generation output is over 1.5 times that of today at 513 TWh, with 79 TWh exported. Wind, solar, nuclear and BECCS provide 92% of generation, the electricity system is dominated by renewables, particularly offshore wind, but fossil fuels still play a key role, with gas generation and gas CCUS generation providing flexibility to support renewable generation, along with interconnectors. Carbon intensity of electricity generation has fallen by over 90% from today to 14 gCO_2/kWh.

FES 2021 / System View / Electricity Supply 216

What we've found

Load factors

Load factors of electricity generation technologies vary across the scenarios according to their mix.

Hydrogen and gas CCUS generation operate with very low load factors in the net zero scenarios, as does unabated gas in Steady Progression, indicating their role is primarily to support security of supply. BECCS and nuclear typically run with higher load factors, running as baseload generation. The annual load factor of BECCS is reduced in Consumer Transformation and System Transformation by some units operating only in the winter months. 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, supported by a large increase in installed capacity. Load factors for renewable generation are capped by the variable nature of renewable energy resources.

Load Factor

The load factor or capacity factor of a technology refers to the electricity generated by a technology as a proportion of the maximum potential generation over the period. Variable renewable technologies typically have a substantially lower load factor than fossil fuel generation can provide due to the nature of the resources they are harnessing, for example solar PV generation is limited by hours of daylight.

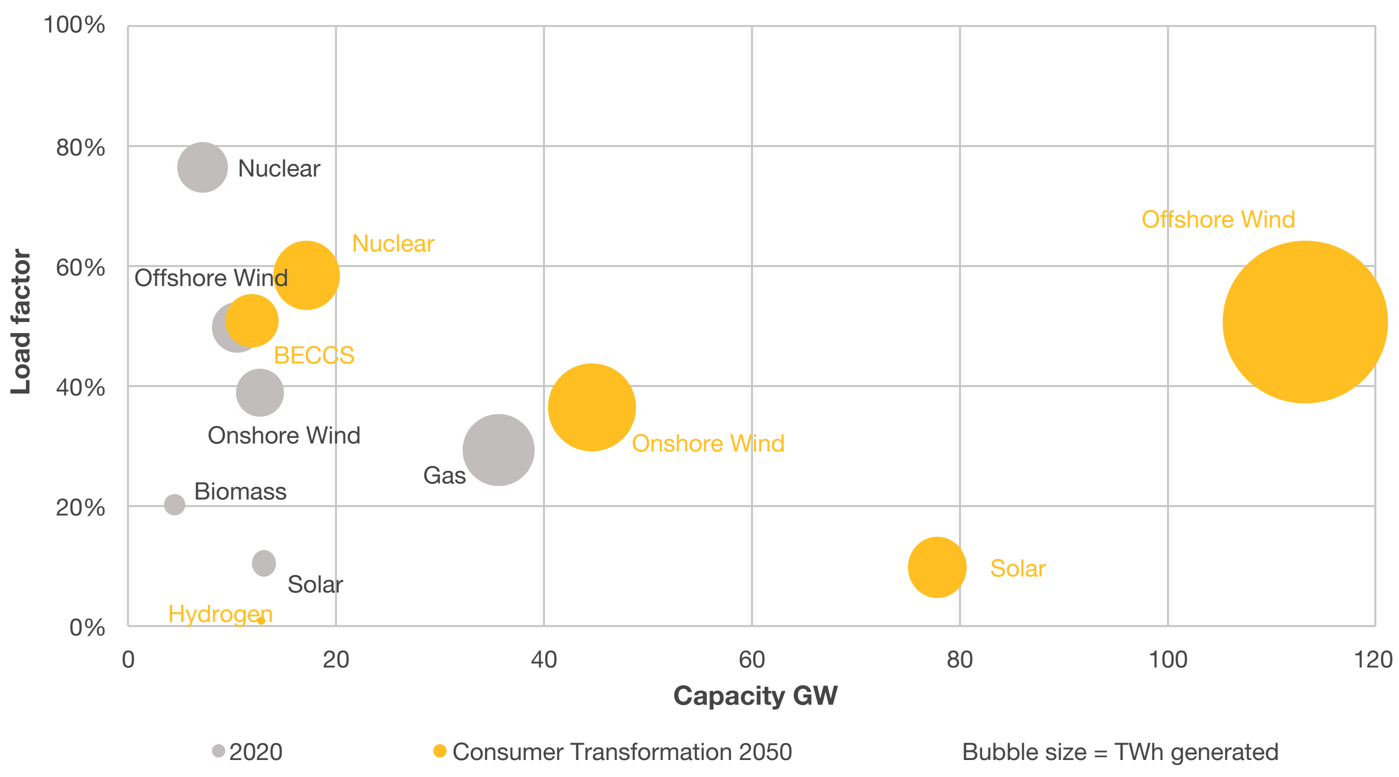
Average UK load factors over the last five years range from 11% for Solar PV, 27% for onshore wind and 40% for offshore wind through to 72% for plant biomass combustion (BEIS Energy Trends 2021). This means that generating an equivalent amount of energy to that currently coming from fossil fuels requires significantly higher installed renewable capacity.

Larger wind turbines, particularly those offshore, have higher capacity 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.

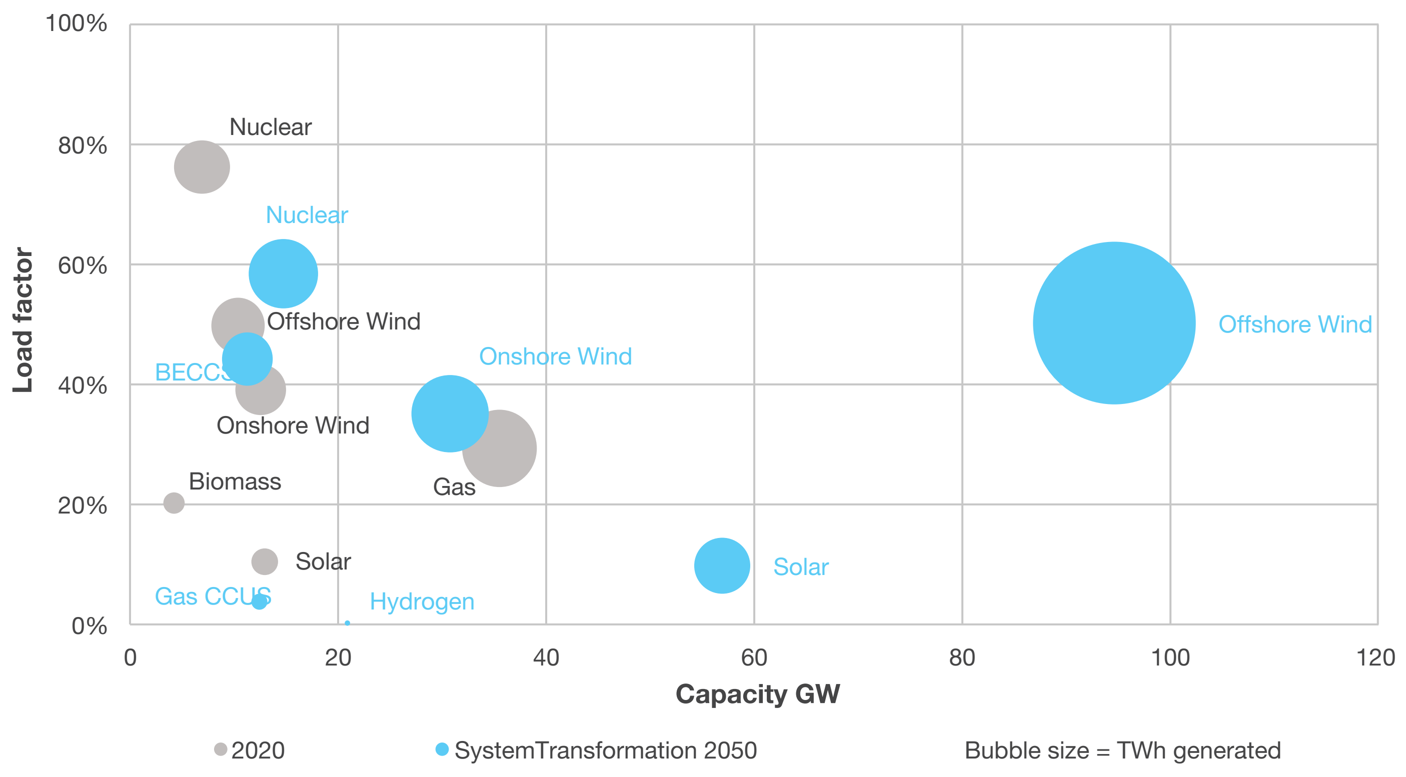
FES 2021 / System View / Electricity Supply 217

What we've found

Figure SV.26: Load factors of electricity generation



Consumer Transformation

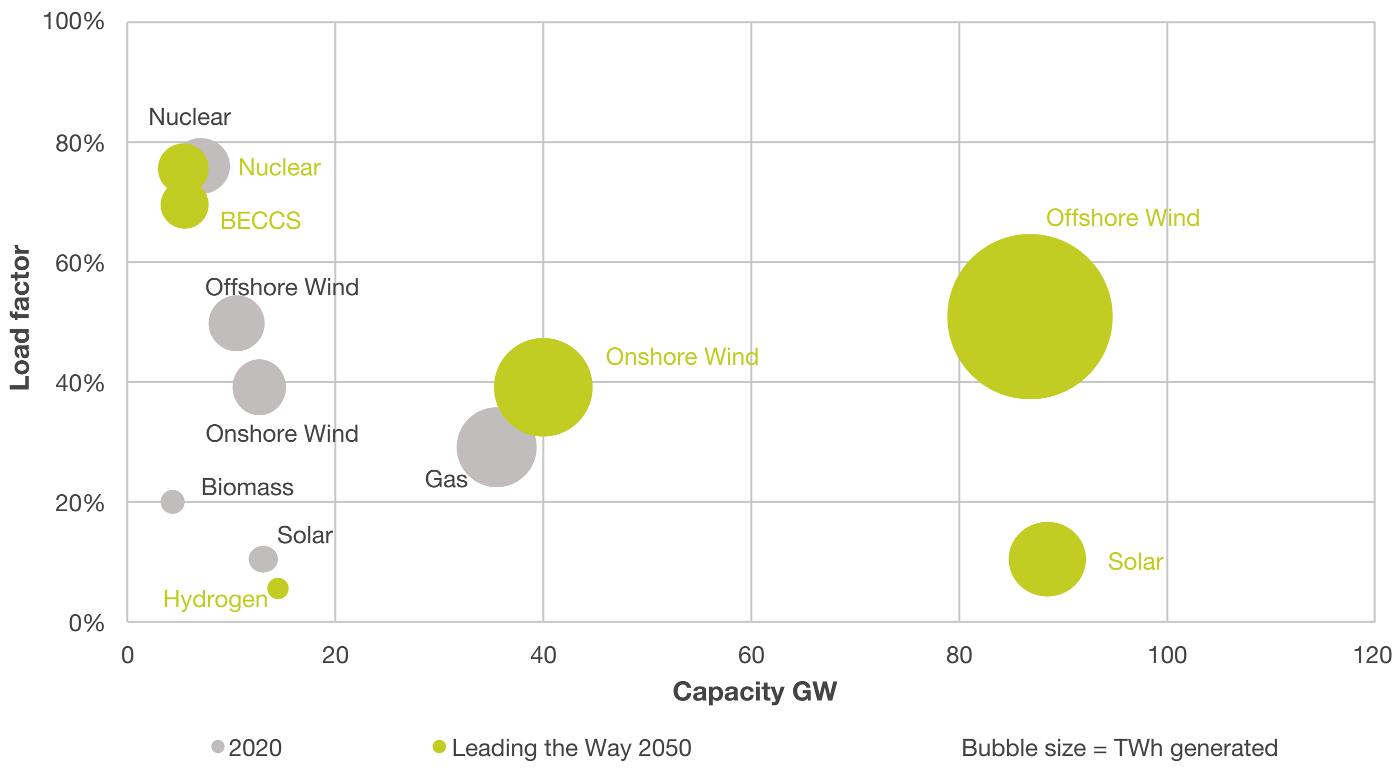


System Transformation

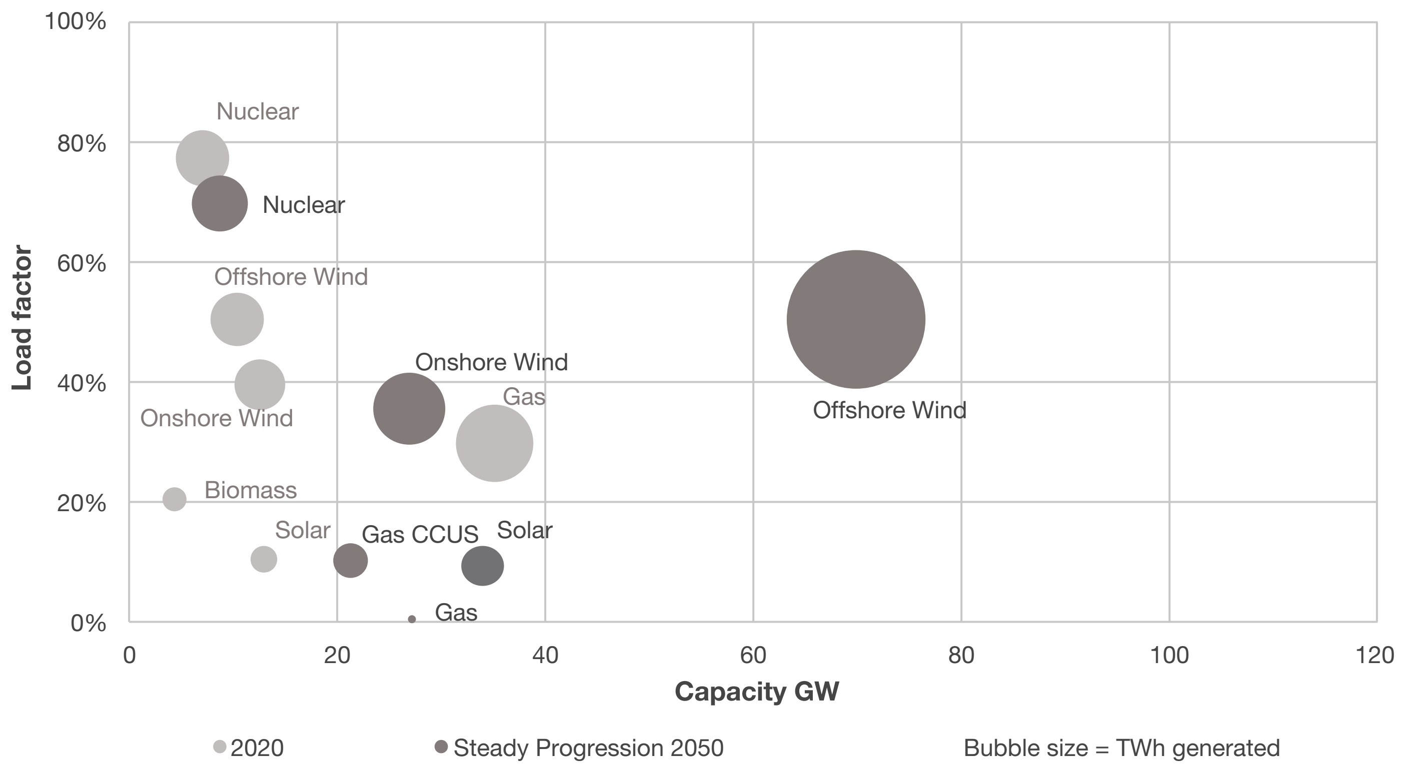
FES 2021 / System View / Electricity Supply 218

What we've found

Figure SV.26: Load factors of electricity generation



Leading the Way



Steady Progression

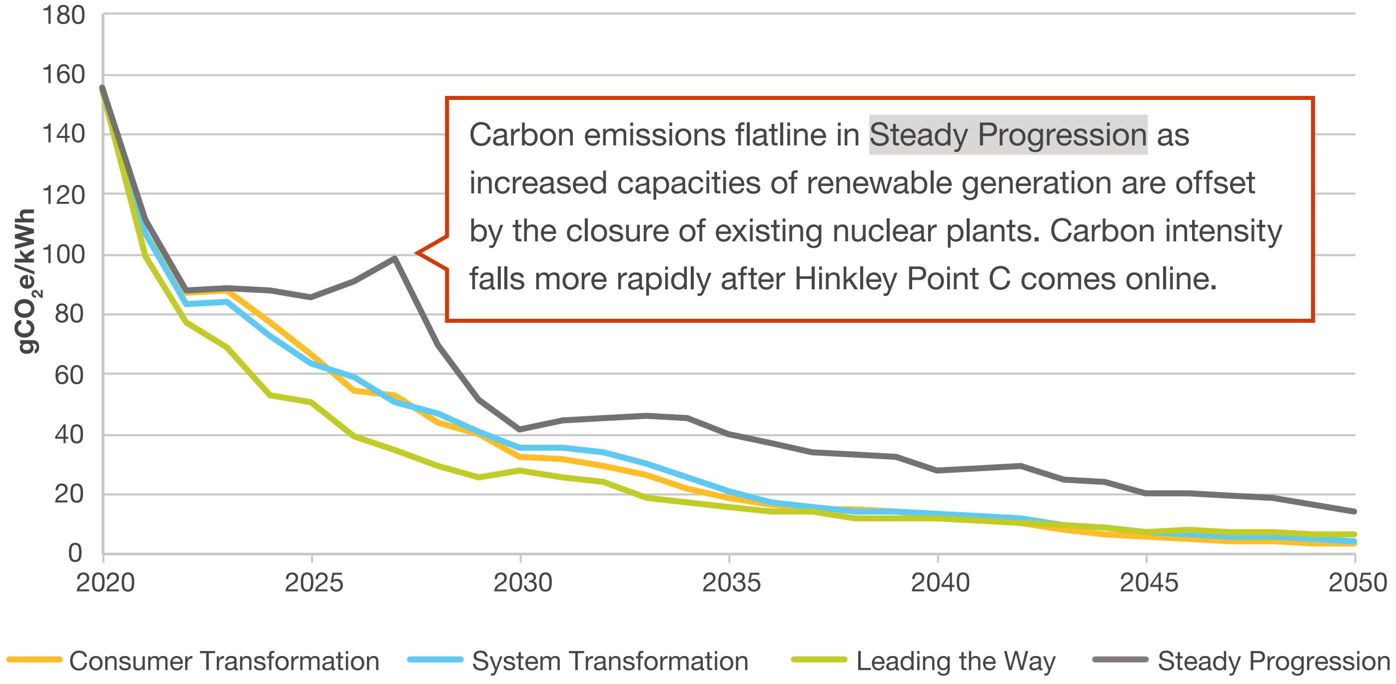
FES 2021 / System View / Electricity Supply 219

What we've found

Electricity sector carbon emissions

Power sector carbon emissions are expected to fall rapidly in the early 2020s in all scenarios.

Figure SV.27: Power sector carbon intensity excluding negative emissions from BECCS



The commissioning of Hinkley Point C contributes to emissions falling further in the mid to late 2020s. In the net zero scenarios, gas generation continues reducing rapidly through the 2020s and 2030s. The late 2020s also see the first BECCS plants commissioned in the net zero scenarios, delivering negative emissions. These negative emissions can be attributed to the electricity sector, but as the carbon intensity of other generation sources fall further these negative emissions then overwhelm the residual emissions from the power sector. BECCS plays an important role as one of the sources of negative emissions that can offset low residual emissions from electricity generation and other sectors. The role of negative emissions is discussed in more detail in the net zero chapter.

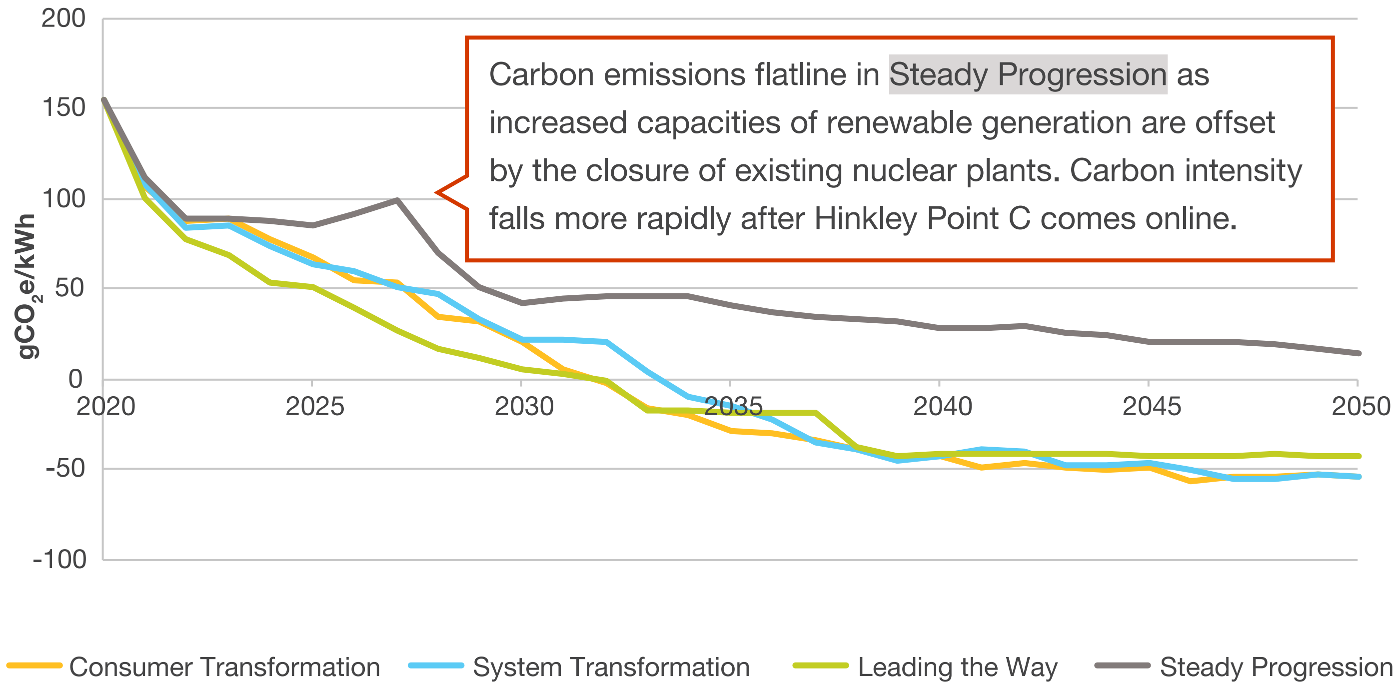
Excluding BECCS, emissions in the power sector fall below 10 gCO_2/kWh by 2043 in all net zero scenarios. These are from sources with low levels of annual output such as energy from waste and in System Transformation some residual emissions from gas CCUS generation. In Steady Progression emissions decline gradually from 2030 and fall below 15 gCO_2/kWh by 2050. 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.

FES 2021 / System View / Electricity Supply 220

Electricity sector carbon emissions

Power sector carbon emissions are expected to fall rapidly in the early 2020s in all scenarios.

Figure SV.27: Power sector carbon intensity



FES 2021 / System View / Electricity Supply 221

What we've found

Wind

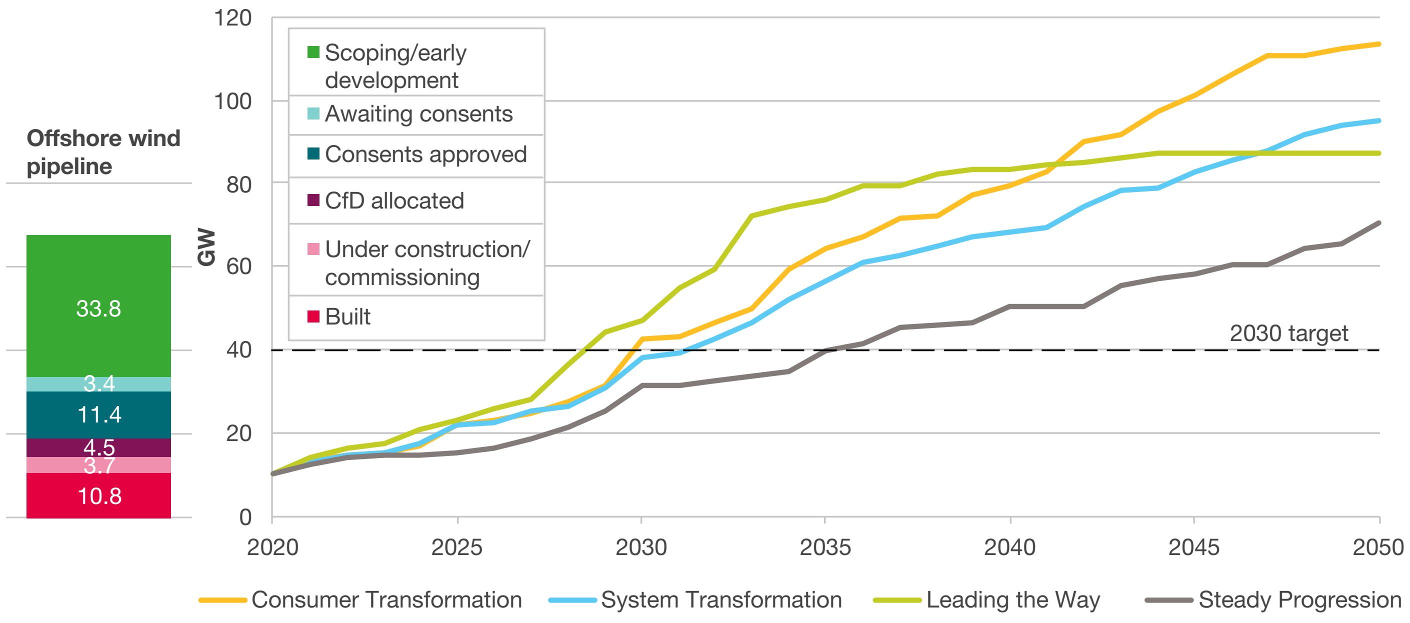
The past year has seen increased ambition around offshore wind, with the Government's Ten Point Plan re-affirming the commitment to reaching 40 GW by 2030. This target is met in Leading the Way and Consumer Transformation, by 2031 in System Transformation, and not until 2035 in our slowest decarbonising scenario, Steady Progression. Nevertheless, this is faster than we saw in FES 2020. The target is still extremely challenging and requires rapid development of the offshore wind supply chain, and in Consumer Transformation we see further increases through the 2030s to reach 80 GW by 2040 and 113 GW by 2050.

The fourth round of leasing for offshore sites from the Crown Estate has included projects from a wider range of sites around Britain's coastline than in previous auctions. The pipeline of potential wind projects has continued to increase, underlining its potential for providing the future backbone of GB electricity supply.

The past year has also seen developments in floating wind, with the Government having the ambition to deliver 1 GW by 2030; this could significantly increase our wind resource through the use of deep-water sites. Floating wind is included within our total offshore wind figures in SV.28.

Achieving the 40 GW target for offshore wind by 2030 will be difficult, both in scaling up of technology and the network, as offshore generation requires infrastructure to bring the power onshore and also to move it from coastal landing points to demand centres. Our work on Offshore Coordination will streamline the process, with offshore connections reducing the need for individual cables coming to shore for each wind farm.

Figure SV.28: Offshore wind generation capacity and pipeline[2]



We expect most future onshore wind to be connected to distribution networks, although there is also some growth in transmission-level onshore wind, particularly in Scotland. This take-up happens much more rapidly in the scenarios with higher levels of societal change, with Consumer Transformation doubling capacity to 26 GW by 2030 and reaching 44 GW in 2050. Development of onshore wind is more limited in the lower societal change scenarios of System Transformation and Steady Progression, but still increases to exceed 27 GW by 2050 in all scenarios. This is due to factors such as onshore wind facing greater local opposition and making planning permission more difficult to achieve in lower societal change scenarios.

2 This excludes any non-networked offshore wind used to produce hydrogen offshore.

What we've found

Figure SV.29: Onshore wind generation capacity

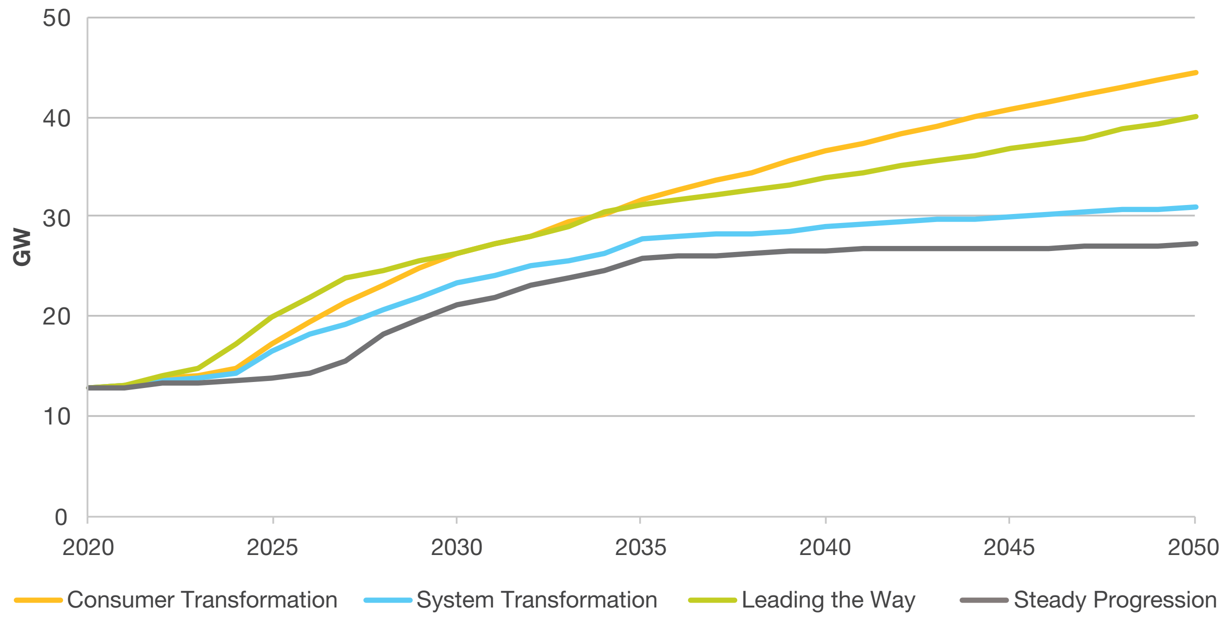
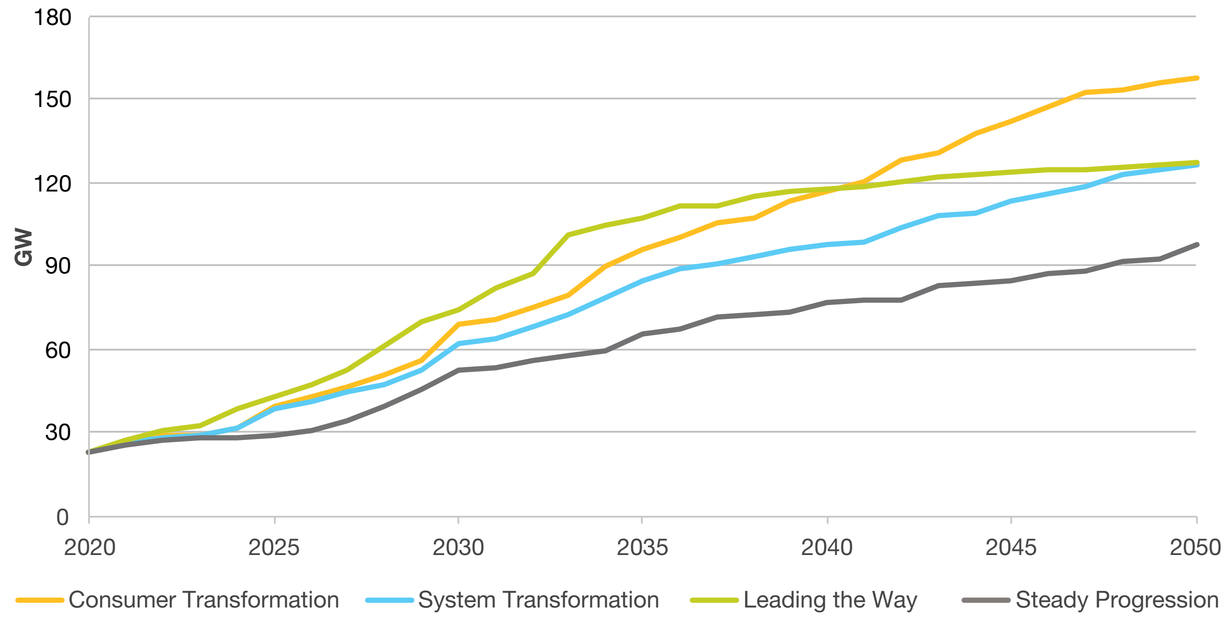


Figure SV.30: Total wind generation capacity (onshore and offshore)[2]



2 This excludes any non-networked offshore wind used to produce hydrogen offshore.

What we've found

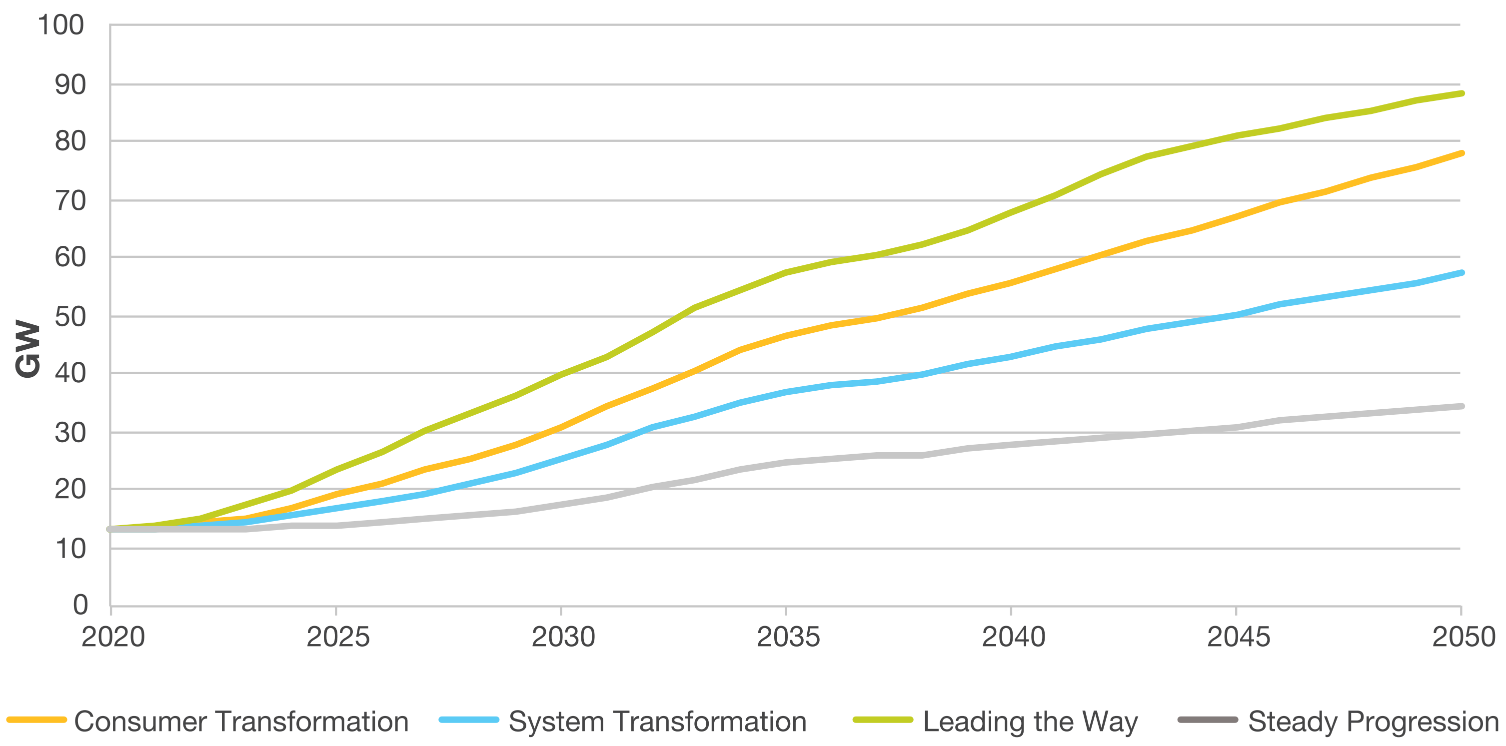
Solar

We expect continued price reductions to increase the uptake of solar panels through the late 2020s, although this is more limited in Steady Progression.

There is a wide range of outcomes for solar development across our scenarios, depending on factors including price reductions of solar panels and electricity network capacity.

Our maximum uptake for solar generation has increased substantially since FES20. In Leading the Way this is paired with flexible technologies like electrolysis producing hydrogen that can mitigate the impact of low daytime power prices when there may be too much renewable generation. There is co-location of solar with electrolysis to produce hydrogen. This is additional to high take-up of domestic solar by highly-engaged consumers.

Figure SV.31: Solar generation capacity



FES 2021 / System View / Electricity Supply 224

What we've found

Fossil fuel generation

Gas fired generation continues to play an important role in our electricity mix, with significant capacity providing flexibility throughout the 2020s. There is limited opportunity for any unabated gas if we are to meet decarbonisation targets, and the Climate Change Committee (CCC) have called for a complete end of unabated gas for power generation by 2035, subject to meeting security of supply. To meet this challenging target requires immediate action on deployment of CCUS, hydrogen and other long duration storage. In Leading the Way gas generation makes up 0.5% of electricity supply in 2050, and installed gas capacity falls to 0.9 GW by 2038. Gas capacity is phased out more slowly in the other net zero scenarios, however its use decreases significantly, providing less than 1% of electricity supply in 2035, as it is still mainly used to ensure security of supply.

Steady Progression sees reduced power sector emissions compared to FES 2020 as a significant proportion of gas plant is converted to run with carbon capture and storage post 2035. System Transformation also uses relatively high levels of gas CCUS, as increased demands lead to a greater need for gas generation and improved economics compared to hydrogen turbines, which operate more effectively as peaking plant.

Coal generation continues to decrease as we see all remaining coal fired generation plants come off the system by 2023 in all scenarios.

Did you know: 2025 zero carbon operation

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 will mean that there will be times when no fossil fuel generators will be running on the system, when sufficient zero carbon generation is available to meet 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.

FES 2021 / System View / Electricity Supply 225

What we've found

Figure SV.32: Unabated gas generation capacity

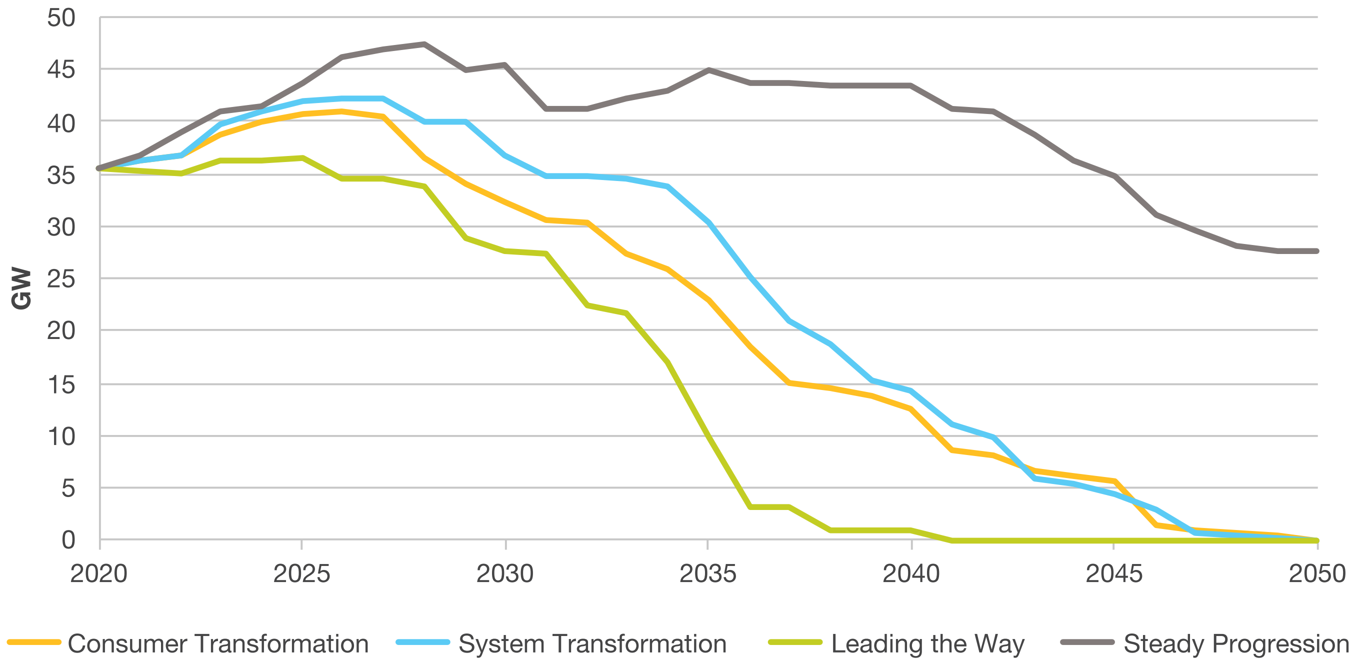
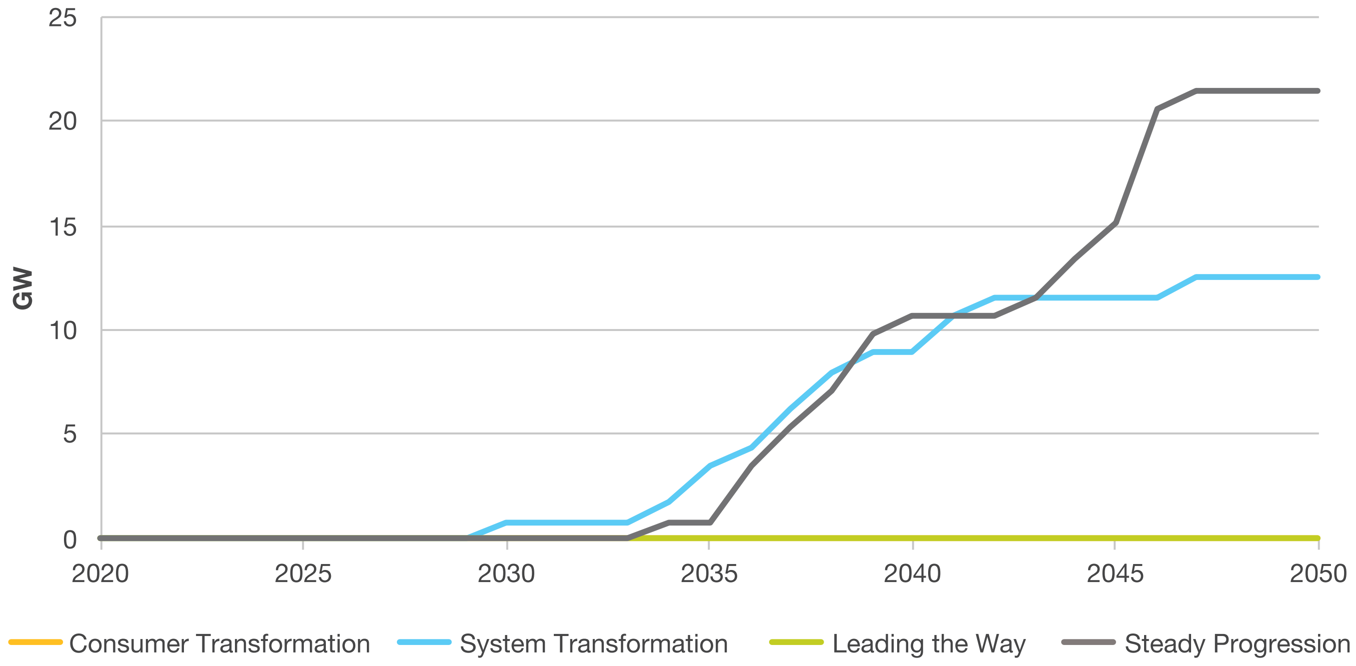


Figure SV.33: Gas CCUS generation capacity



FES 2021 / System View / Electricity Supply 226

Bioenergy and bioenergy with carbon capture and storage

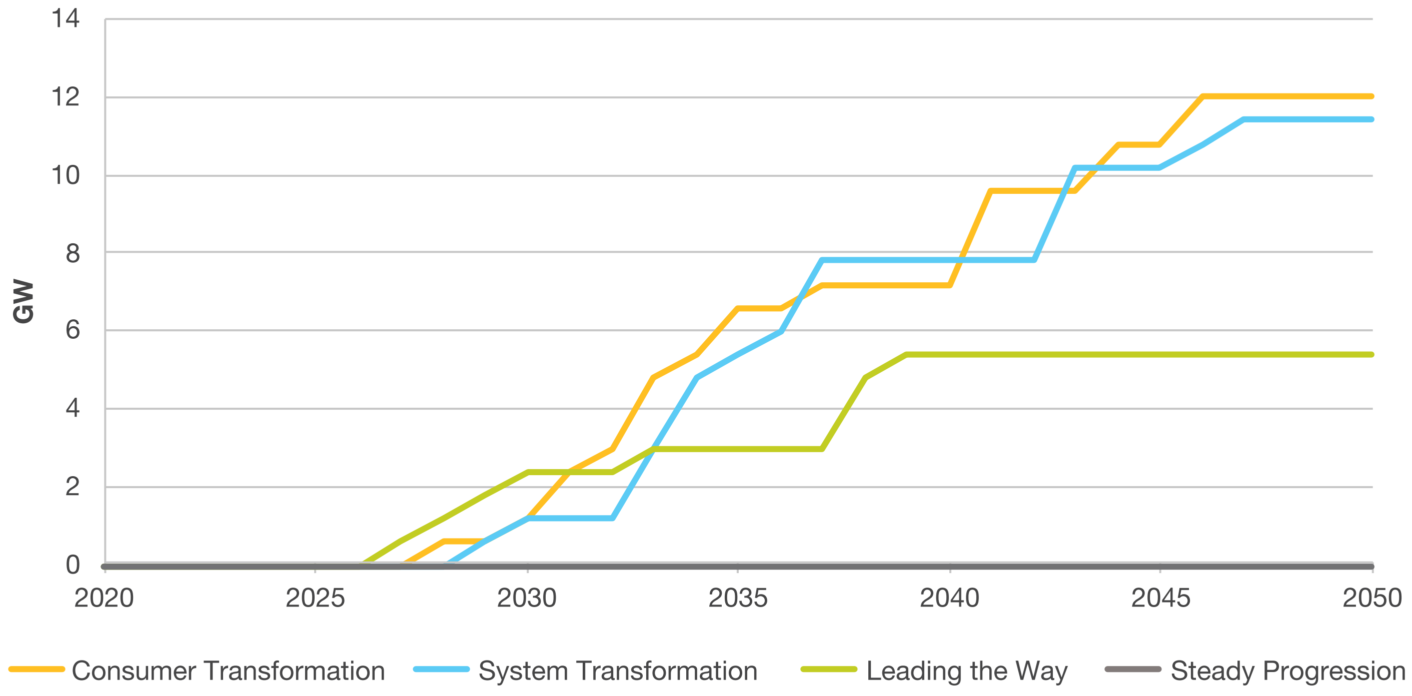
Delivering negative emissions by using sustainable bioenergy with carbon capture and storage continues to be an important part of the pathway to net zero. While BECCS alone cannot meet our decarbonisation ambitions, and it is important to focus on rapid decarbonisation of the whole economy, it can offset some residual emissions from areas that are particularly challenging to decarbonise such as some industrial processes.

We see the development of BECCS across the net zero scenarios in the late 2020s, after carbon capture and storage technology has been scaled up. There continues to be some biomass 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.

BECCS is important in supporting security of supply in winter, helping to meet higher peak demands, while also delivering negative emissions. System Transformation and Consumer Transformation have more BECCS capacity than in FES 2020; we expect these to run with a lower overall load factor, using a similar amount of bioresource and delivering a similar level of negative emissions as seen in FES 2020. Negative emissions delivered from different sources are explored in more detail here. In 2050 we expect BECCS plant to operate at full output to achieve maximum efficiency, but with more units being brought online in the winter months.

Figure SV.34: BECCS generation capacity



What we've found

Sustainability of supply chains

On paper the use of biomass for heat, transport or electricity is carbon neutral; at scale, however, many issues need to be addressed to make sure it is both carbon neutral and sustainable. Its classification as carbon neutral is not universally accepted; some commentators argue that using trees for power generation creates a 'carbon debt' as their ability to absorb carbon cannot be immediately replaced, taking several years until a young tree absorbs as much carbon as a larger, older tree.

Another aspect is the impact of the rising demand for biomass from countries like the UK without their own large forestry industry. Sustainability standards for forestry management can be very hard to implement and enforce internationally. There is a danger that climate critical forests in all parts of the world will be felled to meet this demand. Additionally, trees could be grown on farmland instead of food, which in turn could make food more expensive. These issues have led the Netherlands to ban the import of biomass for the production of heat and power[3].

There are ways to manage the supply chain to avoid these problems. Firstly, by prioritising the use of waste biomass, such as by-products from industry or from farms and homes. Secondly, by sourcing as much biomass as possible from within the UK, where its production can be more closely monitored. For wood pellets specifically, sustainable forest management is required to ensure enough trees are planted to replenish those being felled and that they are allowed to grow before being harvested. Global monitoring of forestry will require stringent sustainability standards and strict enforcement; biomass buyers will need to make sure they are buying from responsible and sustainable sources. Germany is considering a 'tree premium'[4], a payment for each hectare of forest absorbing carbon. On a global scale this could help developing countries avoid felling untouched forests.

3 https://www.euractiv.com/section/energy/news/the-dutch-have-decided-burning-biomass-is-not-sustainable/
4 https://www.euractiv.com/section/biomass/news/berlin-and-brussels-mull-forest-protection-as-climate-change-takes-its-toll/

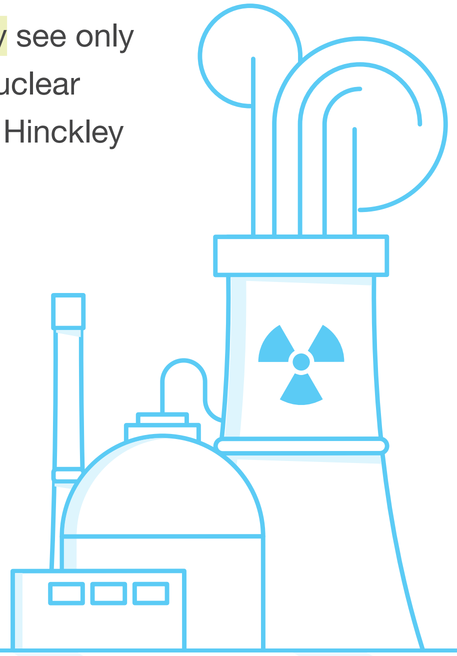
FES 2021 / System View / Electricity Supply 228

What we've found

Nuclear

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 mid-2020s which helps offset some of this decline, but nuclear capacity doesn't recover to current levels in any scenario until post-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.

Consumer Transformation relies primarily on small modular reactors, 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 see only very limited new nuclear development after Hinckley Point C.



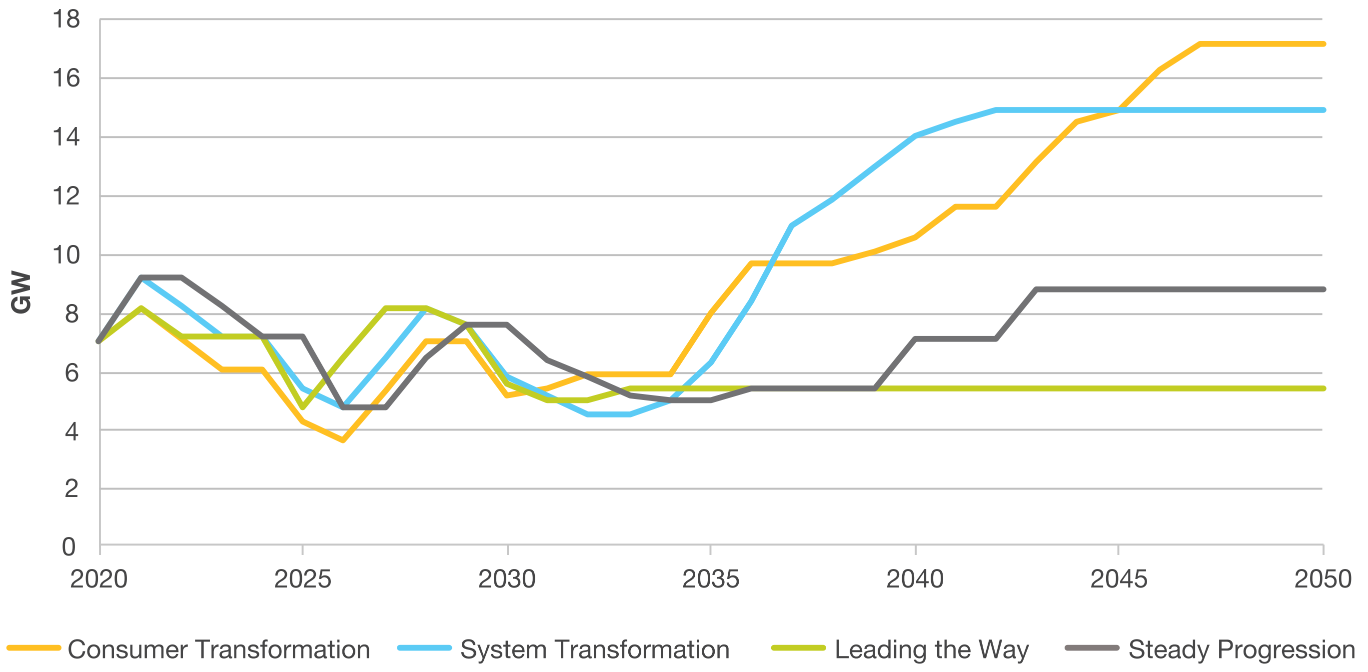
Small modular reactors

Small modular reactors offer an alternative approach to delivering nuclear power generation. These are smaller in capacity than traditional nuclear plant, around half a gigawatt, compared to 1-3 GW for existing sites. These could be delivered by a range of competing designs, though none are yet operational. They are assumed to be located on existing sites of nuclear generation and connected to the transmission system.

FES 2021 / System View / Electricity Supply 229

What we've found

Figure SV.35: Nuclear generation capacity

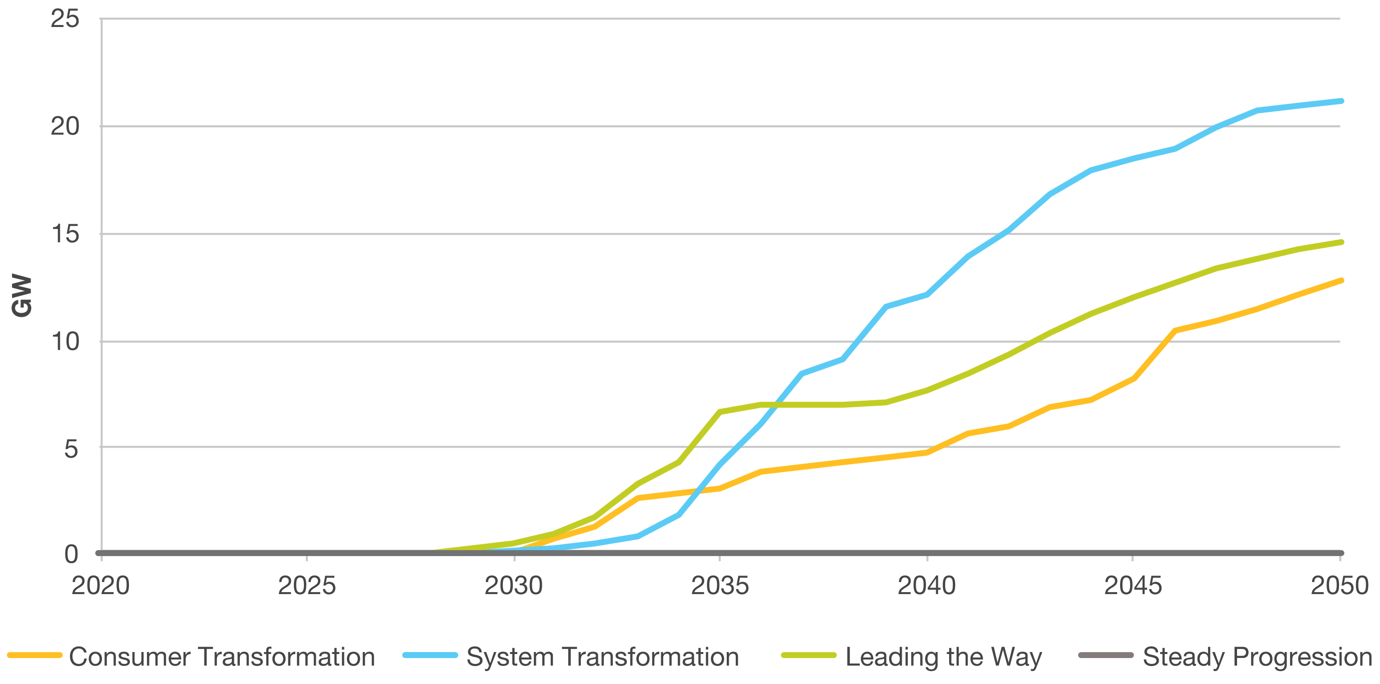


FES 2021 / System View / Electricity Supply 230

Hydrogen generation

Higher peak demands in FES 2021 see greater need for dispatchable peak generation, and a corresponding increase in hydrogen generation in the net zero scenarios compared to FES 2020. There is no hydrogen generation in Steady Progression as high levels of gas generation remain available.

Figure SV.36: Hydrogen generation capacity



As seen in Figure SV.36, hydrogen generation does not contribute significantly to meet demand in any of the scenarios, but is crucial to helping to manage periods of high demand and low renewable generation, particularly as natural gas generation is phased out.

The overall process of hydrogen production and combustion for generation has a low efficiency; however this is offset by low load factors and low annual running hours. High electricity prices when hydrogen turbines are running will make it competitive, but some form of capacity-based support like the current Capacity Market would probably be needed to deliver enough generation capacity.

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 carbon capture and storage technology; however this balance shifts as annual output requirements increase. In System Transformation the gas transmission networks are 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 as well as gas CCUS in 2050 is important due to the lower levels of flexibility provided by engaged consumers as the scenario sees lower levels of societal change.

In Consumer Transformation and Leading the Way hydrogen networks are not widespread, although 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. Besides this, hydrogen generation needs to be carefully sited close to sources of hydrogen production and storage sites.

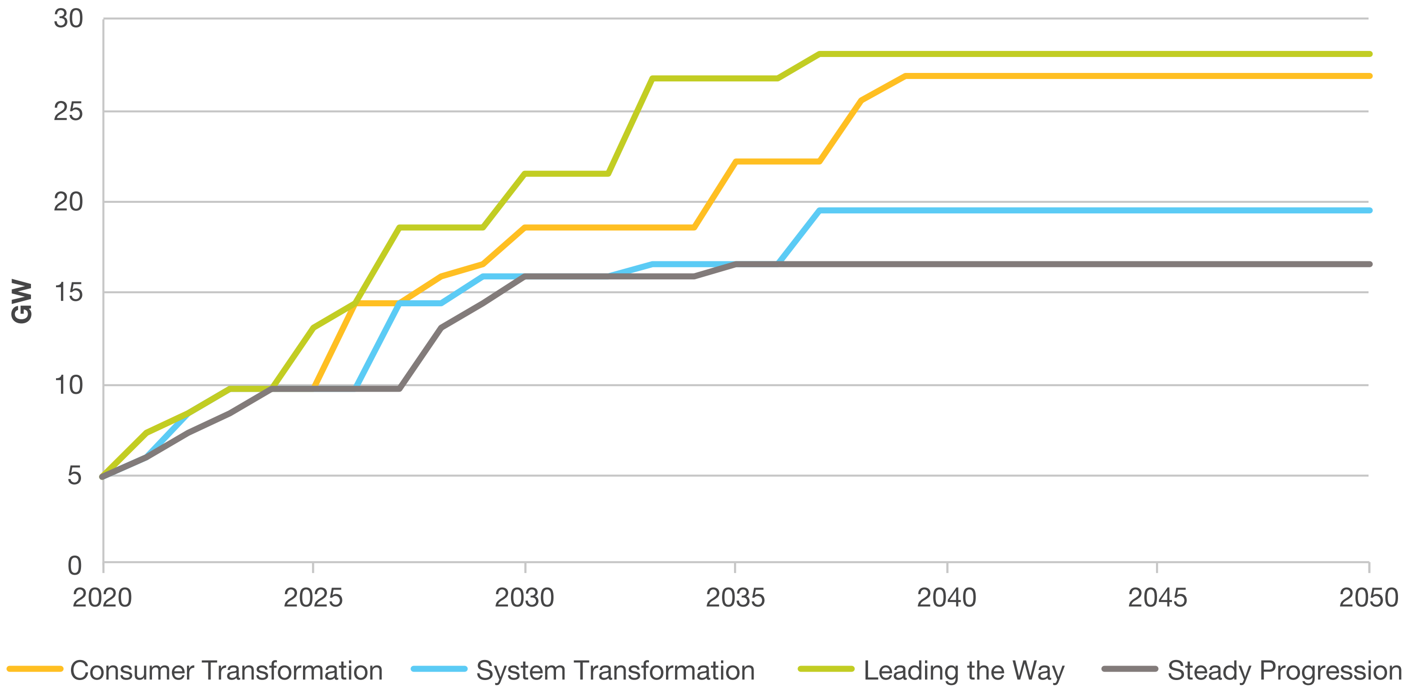
Electricity interconnector capacity

There are a lot of interconnector projects in the pipeline, with two due to commission before the end of 2021. We expect to see continued growth in this area, with Capacity Market agreements secured by new projects providing greater certainty in the near term. The high flexibility needs of Leading the Way and Consumer Transformation mean these see the biggest growth in interconnection capacity, with interconnectors used in all scenarios for trading electricity with continental neighbours. They export electricity when GB renewable generation is high and import electricity when European countries have an excess.

The different countries that GB has or will interconnect with have different generation mixes, with low carbon generation from hydroelectricity or nuclear meaning interconnectors can operate differently to those connecting to markets dominated by renewables.

Interconnectors will be an increasingly important part of our generation mix to help meet peak electricity demands. Flows across interconnectors between GB and continental Europe are discussed in more detail in the **flexibility chapter**.

Figure SV.37: Connected interconnector capacity



FES 2021 / System View / Electricity Supply 232

Electricity storage capacity

Electricity storage will become increasingly important as levels of renewable generation increase. Nevertheless, the degree of storage varies significantly across our net zero scenarios as its need is affected by flexibility demands on the system and the uptake of other flexible technologies such as interconnection capacity, vehicle to grid (V2G) and hydrogen production and generation. In this section we discuss electricity storage technologies including batteries, compressed air storage, liquid air energy storage and pumped hydro storage projects, but exclude V2G capacity and electricity used to produce and store hydrogen.

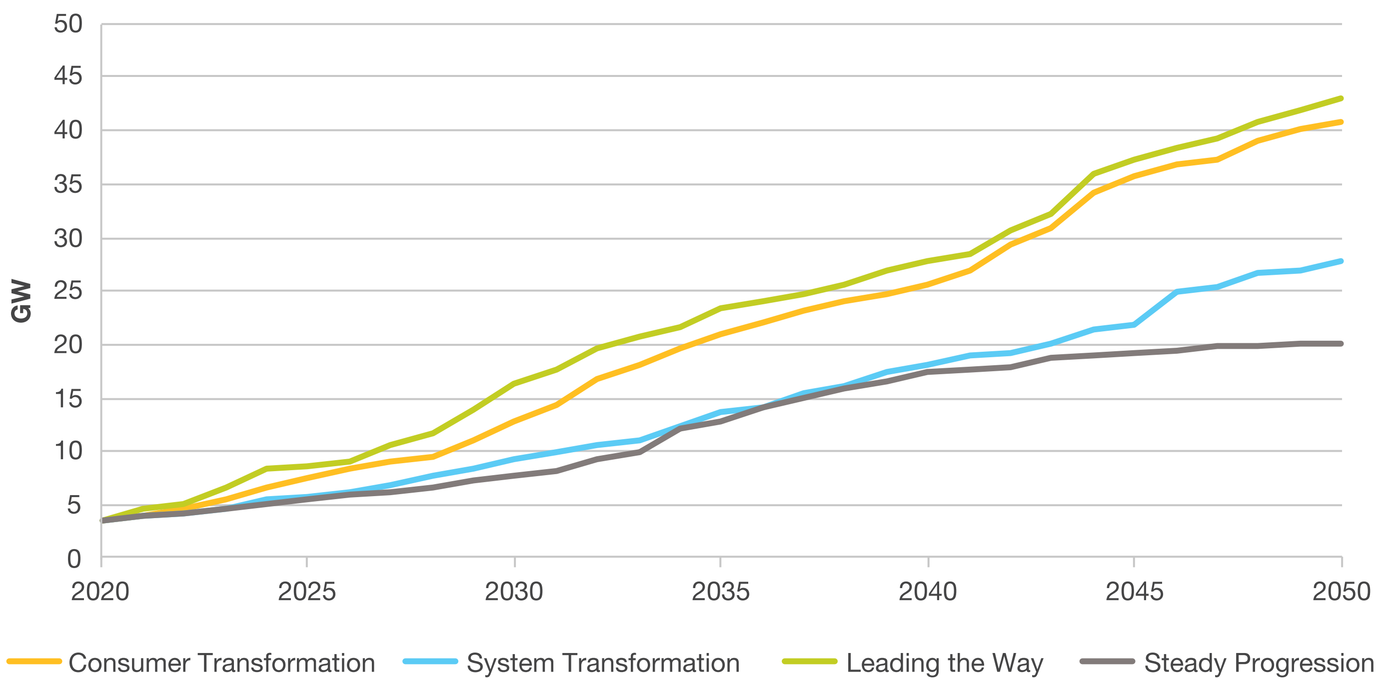
Leading the Way sees rapid growth in electricity storage in the 2020s, reflecting increasing amounts securing Capacity Market contracts. The other scenarios see more modest growth in the early 2020s before an acceleration after 2025 and particularly post-2030 as the need for flexible technologies increases.

While we see some increase in large-scale developments, such as pumped hydro in some scenarios, overall we expect battery storage to make up the largest share of capacity. We also expect more of this capacity to be associated with storage with an increased duration than in FES 2020.

Falling costs of batteries and changing system needs mean we expect greater use of batteries that can deliver maximum power output for two to four hours. This increases the use of battery storage for shifting demand within the day and managing constraints on the network.

Storage will play a key role in managing renewable generation output and meeting peak demands on the electricity system; this is discussed in more detail in the flexibility chapter.

Figure SV.38: Electricity storage capacity (excluding V2G)



FES 2021 / System View / Electricity Supply 233

Flexibility

Introduction

Flexibility is crucial to operating the energy system where the supply and demand of energy needs to be balanced over different timescales.[1]

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. Supply depends on factors like the availability of fuels, natural resources, or on the weather conditions affecting renewable generation output.

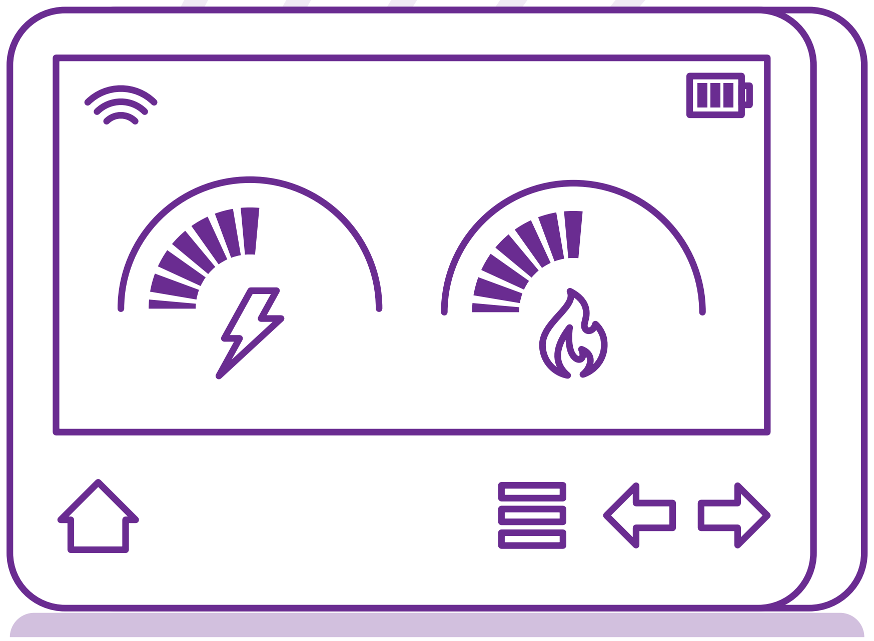
The whole energy system includes networked fuel such as electricity and gas, alongside other fuels such as oil and coal. For electricity, balancing needs to happen constantly; supply and demand need to be exactly matched to keep system voltage and frequency stable. The gas system, however, can match supply and demand over a longer timescale throughout a day, due to storage and production flexibility which make it easier to manage short term fluctuations. Flexibility in other energy sources such as oil, coal or biomass are supported by local storage at sites like petrol stations or power stations. In FES 2021 we explore the flexibility needed to balance energy across a range of fuels and demands.

It is also important to consider interactions between different forms of energy on the system. Current peak heat demands in winter are several times higher than peak electricity demands and so natural gas provides a significant amount of flexibility by meeting most of this heat demand.

To meet net zero carbon emissions, flexibility will become more important due to factors such as growth in renewable generation, increasing electrification of heat and transport, and changes in consumer behaviour.

What is flexibility?

In FES we focus on the flexibility needed to balance supply and demand. Flexibility for system operation at very short timescales is managed using a range of tools explored in our System Operability Framework.



1 A more detailed discussion of energy system flexibility can be found here.

FES 2021 / Flexibility 235

Introduction

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 electricity, a reliability standard is set by the Secretary of State – currently three hours per year loss of load expectation (LOLE[2])
- 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[3]) even if the single largest piece of supply infrastructure were to fail

Our analysis considers how these standards can be met in all years and all scenarios. In future, 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 have seen in Texas this year, extreme weather events can be extremely challenging for energy systems and careful planning is needed to prepare for them.

Historically, flexibility has been predominantly about adjusting energy supply to meet demand which means the focus on security of supply is the winter peak demand period. However, in the future this will include other periods as security of supply will be driven not just by high demand but also by high and low supply as our energy system becomes more dominated by variable renewable generation. The concept of peak electricity demand and how it affects system operation is also changing as the ability of demand to ramp up to take advantage of low prices increases. We may see periods of high renewable generation output that have higher demands than our traditional winter peak demand.

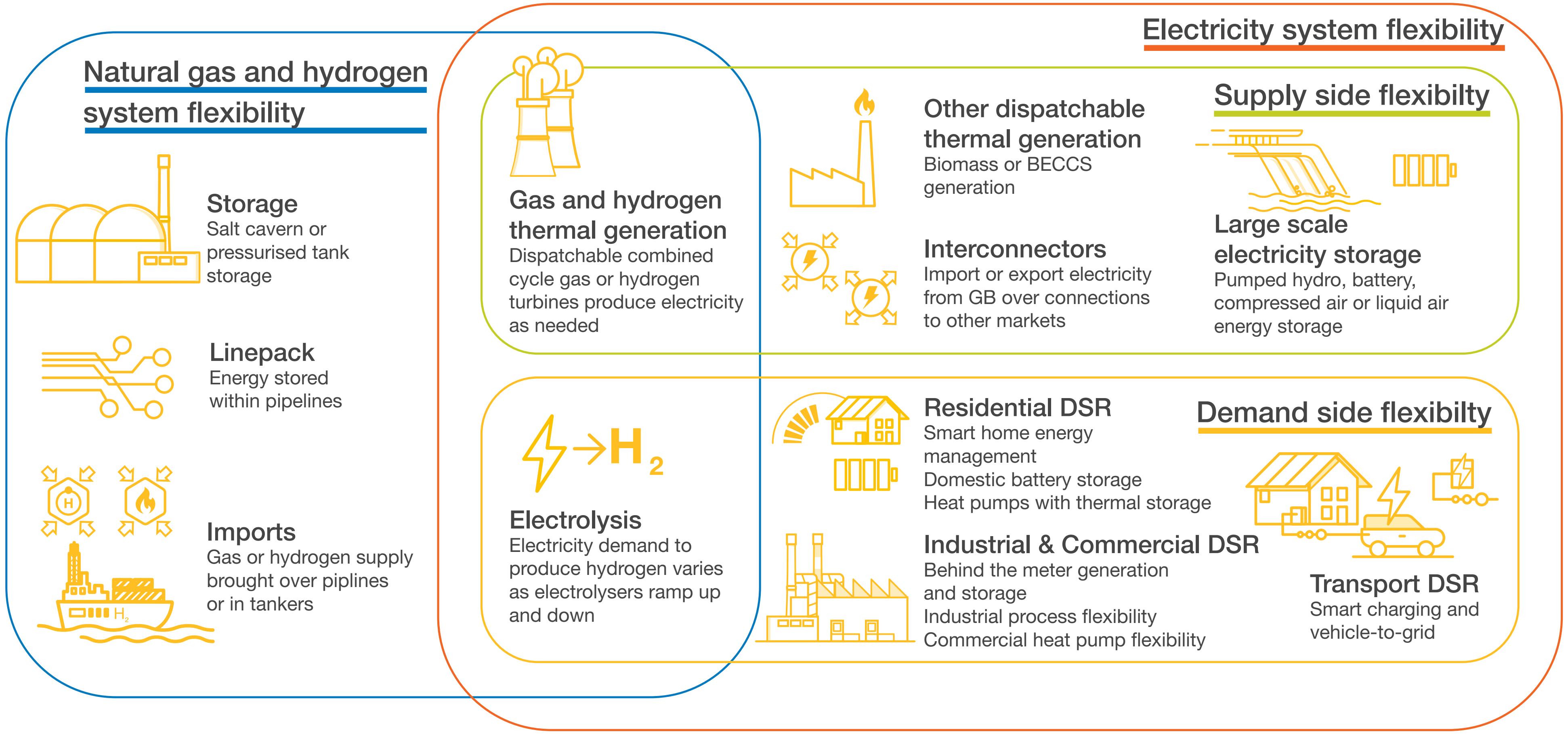
As more of our energy demand is electrified this makes flexibility more important in keeping costs down by minimising peak demand. The increased level of weather dependent generation also creates a flexibility challenge whereby the most efficient solution would be to reduce demand rather than to keep increasing generation capacity. Therefore, in future, flexibility moves from being a supply-side consideration to being essential for both energy demand and supply. The development of new sources of flexibility brings opportunities. In some scenarios we can use hydrogen for flexibility, absorbing excess wind and storing energy to meet peak demand. It can also help address network investment and operability constraints, reducing the need for electricity network reinforcement by producing hydrogen close to generation and then moving the hydrogen around the country.

2 An approach used to describe electricity security of supply. For detailed definition, please refer to glossary.
3 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.

FES 2021 / Flexibility 236

Key insights

- In future the electricity system will be supply-led. Demand will adjust to use or store energy from variable renewable generation. Solutions will include electrolysis, interconnection, demand side response and storage, particularly in the 2-4 hour range.
- As electrification of the economy increases across all scenarios, flexibility becomes increasingly important to help manage peak electricity demands and reduce the need for additional electricity generation capacity.
- The flexibility provided today by the gas transmission system will significantly reduce in Leading the Way and Consumer Transformation in 2050. These scenarios will need significantly more flexibility from consumers than System Transformation which retains the transmission system to transport hydrogen.
- Large-scale interseasonal energy storage is essential to meeting net zero, our net zero scenarios use hydrogen to meet this need. No sites currently exist, so the right policy and economic incentives for investment need to happen to bring this forward.
- Appropriate price signals and incentives will be needed from policy and the energy market to encourage the types of flexible demand-side response behaviour that a net zero world requires from consumers.



FES 2021 / Flexibility 237

Gas system flexibility

Other flexibility is delivered today primarily through the gas system. This is supported by storage on the gas network from linepack, but also by additional connected storage sites and the ability to vary upstream production of gas. Storage capacity for gas is substantially higher than for electricity. Stored electricity is less than 0.2% of the energy stored in natural gas today. At the end of 2020 there was approximately 15,000 GWh of gas in storage, and a minimum 3,800 GWh of linepack in the gas network; there is less than 30 GWh of electricity storage capacity, of which 96% is from pumped hydro storage sites, with around 4% from other forms like batteries.

Gas storage capacity has declined over the last 10 years with the closure of the major storage site, Rough, in 2016. In recent years, capacity has increased slightly to 1.5 bcm. The need for dedicated storage sites has reduced with security of gas supply supported by import from Norway, the Netherlands and Belgium, and the use of continental European gas storage, but also increasingly through import of Liquefied Natural Gas (LNG). More detail on this can be found in the gas supply section.

The economics for developing new GB gas storage sites are very challenging. However, close to 9 bcm of potential new sites have secured planning permission but not yet reached final investment decision, covering both medium-range fast-cycle facilities and long-range seasonal storage. In the longer-term conversion of these types of storage sites to store hydrogen will become increasingly important as the role of natural gas diminishes towards net zero. Finding a regulatory model that supports the development of sufficient hydrogen storage will also be crucial.

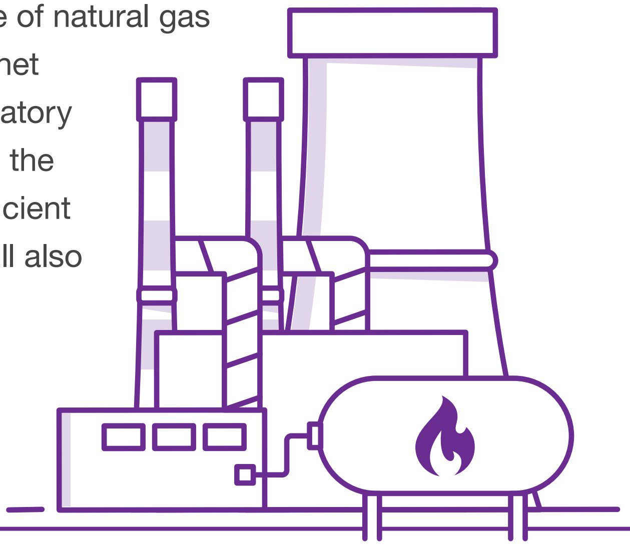
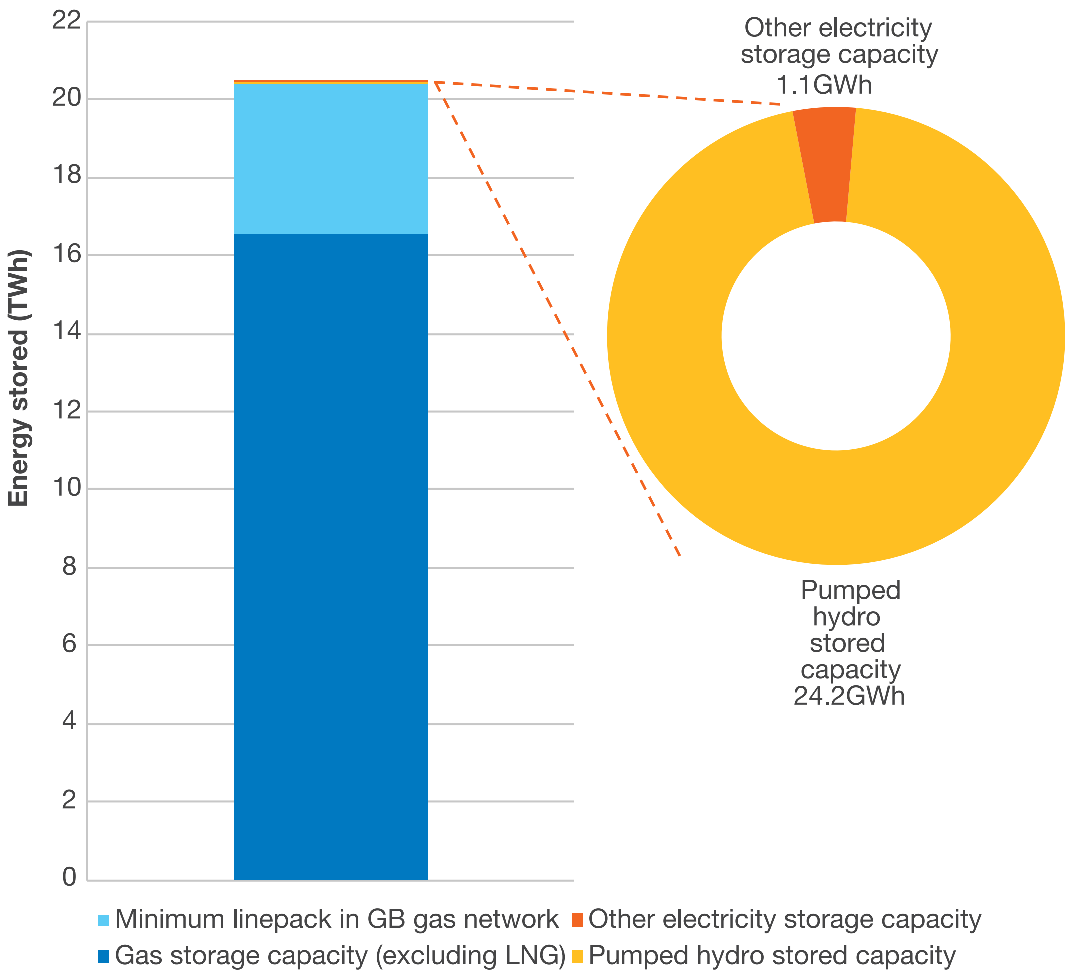


Figure FL.1: Electricity and gas storage capacity in 2020



Where are we now?

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 gas day, supply and demand are 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.

BCM

For gas, in Great Britain, a good guide for converting from energy in watt hours to gas volume in cubic metres (or from TWh to bcm) is to divide by 11.

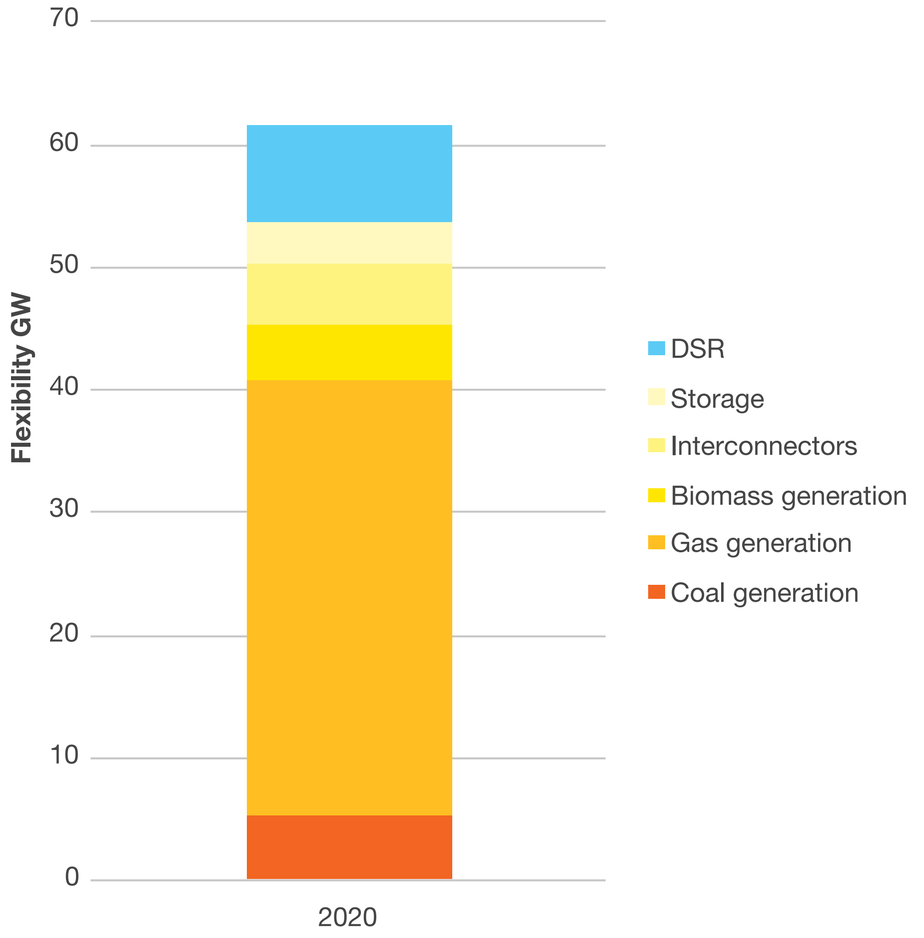
FES 2021 / Flexibility 239

Electricity system flexibility

Electricity system flexibility today is predominantly delivered on the supply side. As demand varies through the day, different sources of electricity are brought online. Some like nuclear operate more as 'baseload' generation, running constantly, other than for periods of maintenance, while others such as natural gas turbines are more flexible.

Sources of flexibility are shown in Figure FL.2. 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.1. It shows that demand side flexibility makes up a small proportion; the majority of electricity system flexibility today also comes from natural gas, with gas power stations able to modulate up and down, supported by gas network flexibility.

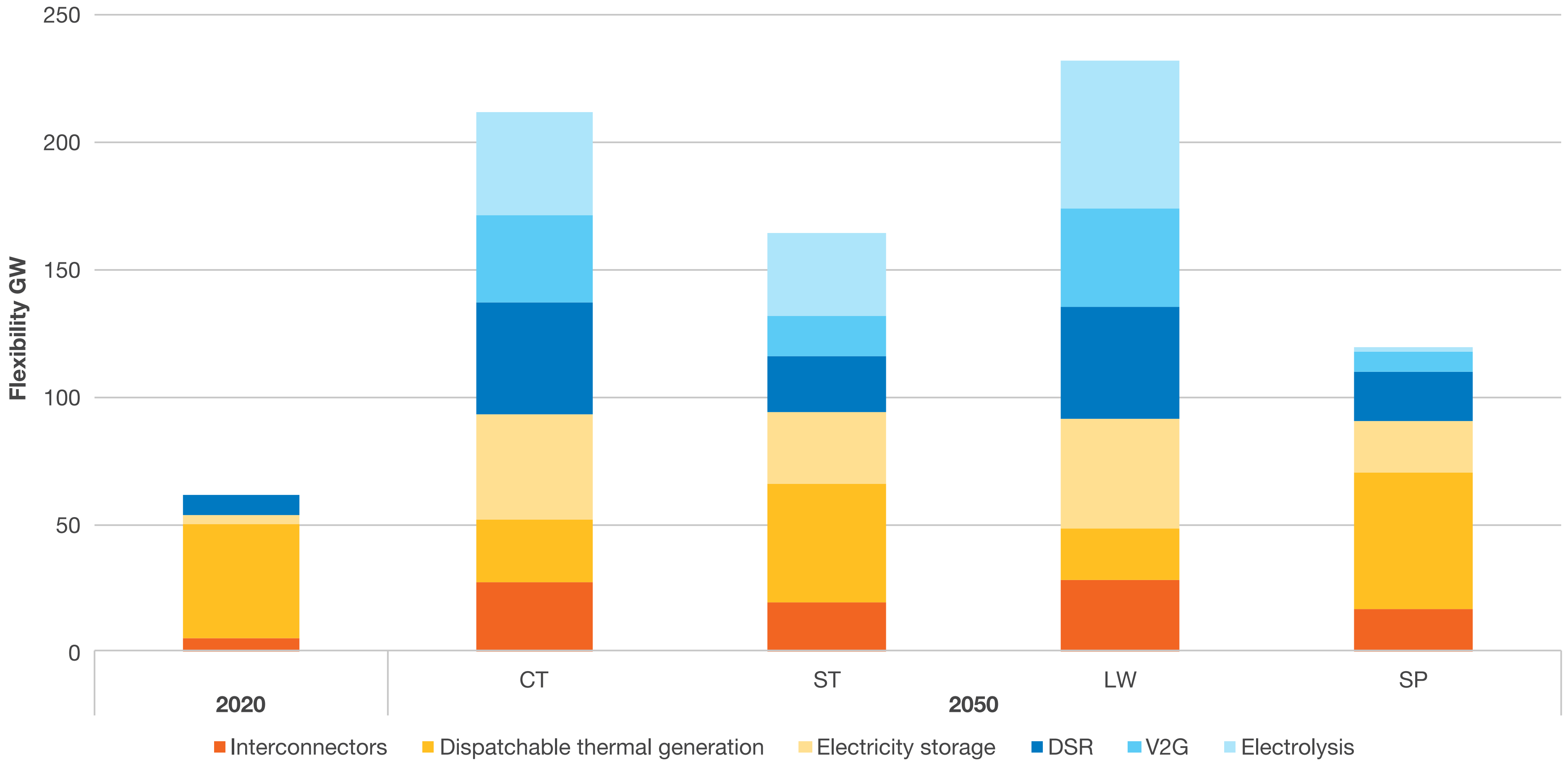
Figure FL.2: Power output of flexible electricity technologies in 2020



FES 2021 / Flexibility 240

Scenarios overview: flexibility

Figure FL.3: Supply and demand flexibility in 2050



FES 2021 / Flexibility 241

Scenarios overview: flexibility

Consumer Transformation

The road to 2050

- Peak electricity demands start to increase from the early 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 starts to increase, helping mitigate demand growth
- Natural gas generation is phased out with other forms of dispatchable generation filling the gap
- Hydrogen storage starts to play a role growing to 12 TWh by 2050 amidst growth in electrolysis and hydrogen generation capacity, while natural gas demands fall sharply
- By the 2040s smart automation has become the norm, with demand side response and vehicle to grid technology helping reduce peak demands by over 45 GW in 2040

What does 2050 look like?

Demand side flexibility dominates over supply side flexibility, and is the single largest source of flexibility on the electricity system. A combination of electrolysis, hydrogen generation and storage offer high levels of whole energy system flexibility and high net exports over interconnectors help manage renewable generation output.

FES 2021 / Flexibility 242

Scenarios overview: flexibility

System Transformation

The route to 2050

- Peak electricity demands increase more rapidly post-2025 led by electrification of transport
- Contribution from demand side response to mitigate these is limited, with the largest contributions from the transport sector post-2035, reaching over 22 GW from smart charging and V2G by 2040
- Hydrogen storage is developed at scale from the early 2030s, reaching over 20 TWh by 2040; the gas network is repurposed to transport hydrogen
- Post 2035 sees the growth of hydrogen and gas CCUS generation, offsetting the decrease in unabated gas generation on the supply side
- Interconnection capacity reaches 15 GW by 2030 and just under 20 GW by 2040

What does 2050 look like?

Total supply side flexibility is similar to demand side flexibility. Widespread use of hydrogen keeps peak electricity demands lower, although lower consumer engagement limits the contribution of demand side response. Dispatchable thermal generation from gas CCUS and hydrogen support security of supply. High 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 interseasonally.

FES 2021 / Flexibility 243

Scenarios overview: flexibility

Leading the Way

The route to 2050

- Peak electricity demands fall in the short term, but start to increase rapidly post-2025 as the economy electrifies
- Rapid early take-up of demand side response and vehicle to grid sees a reduction in peak demand of 20 GW by 2030 and 55 GW by 2040
- 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, in line with the CCC target of no unabated gas generation by 2035. This is mitigated by growth in interconnection, storage and hydrogen generation and additional demand reduction from demand side response technologies
- Interconnection capacity increases rapidly, reaching 13 GW by 2025 and 21 GW by 2030, and net exports are seen over the interconnectors between 2026 and 2050

What does 2050 look like?

Demand side flexibility dominates over supply side flexibility. High levels of energy efficiency and greater consumer engagement limit peak demands through demand side response and vehicle to grid 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, with only a low level of net export across the interconnectors.

FES 2021 / Flexibility 244

Scenarios overview: flexibility

Steady Progression

The route to 2050

- Peak electricity demands increase steadily through the 2020s and more rapidly post-2030
- Demand side response take-up is low as is consumer engagement, reaching only 9 GW by 2030 and 13 GW by 2040, with very minimal engagement in V2G
- A limited role for hydrogen across the economy sees only slow growth in electrolysis and no large-scale storage
- Natural gas continues to play a significant role backing up renewable generation and meeting security of supply, with some displaced by gas CCUS post-2035
- Growth in interconnection capacity is slow but still reaches 15 GW by 2030 before plateauing

What does 2050 look like?

Supply side flexibility continues to dominate over demand side flexibility. Peak electricity demands are capped by limited electrification of the heat sector; relatively low levels of consumer engagement in demand side response means this only has limited impact. 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 are low.

FES 2021 / Flexibility 245

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.

Electricity peak demands have historically occurred on winter weekday evenings, when demand for industrial and commercial premises overlaps heating, and lighting in homes. The nature and timings of peak demand is likely to change as the country decarbonises; the peak demands shown here may not always represent the highest demands on the system at any time. 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 boosted by up to 58 GW of electrolysis and 19 GW of electric vehicle charging. 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.

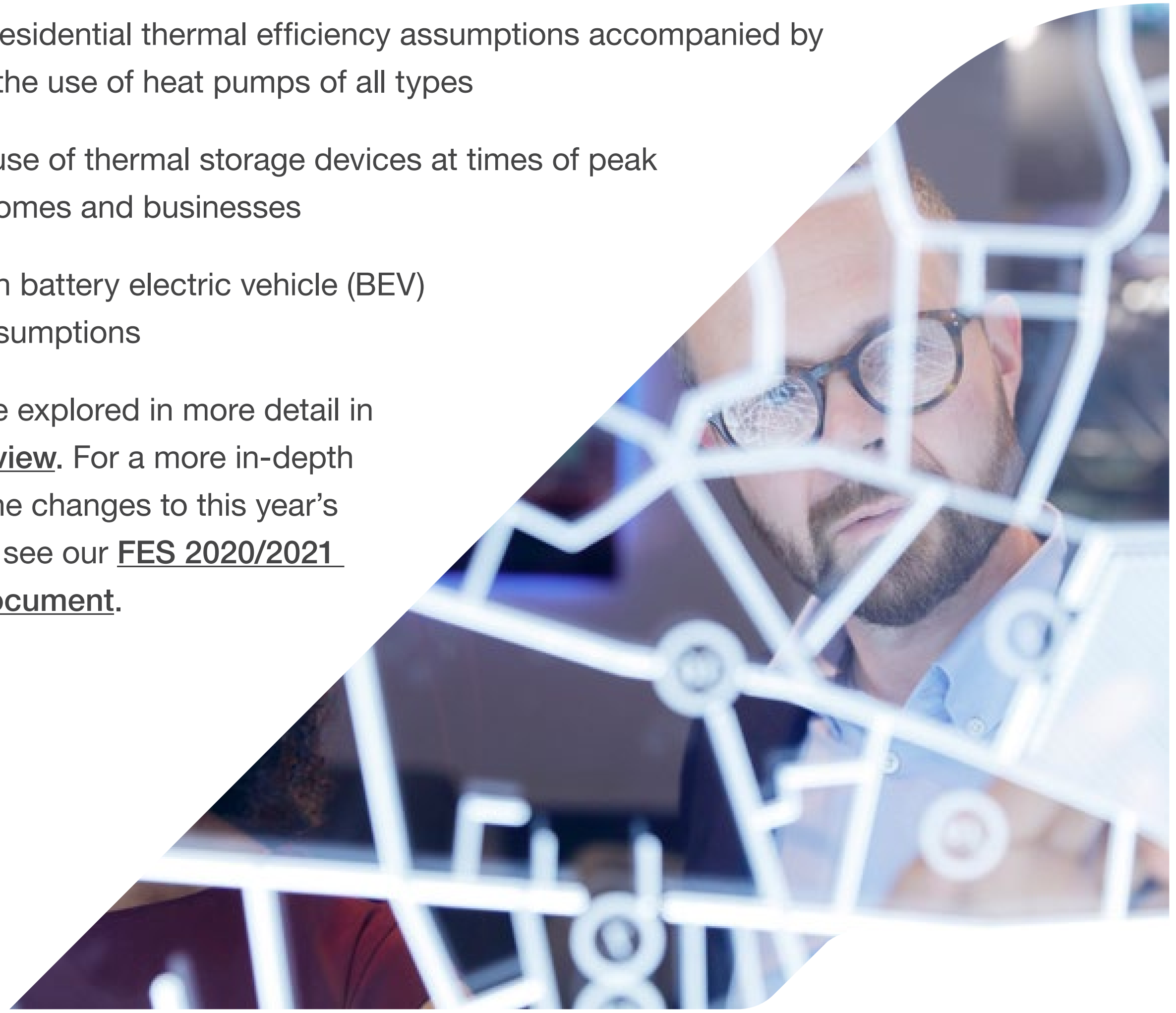
Consumer Transformation is the most electrified scenario. In Figure FL.4 you can see the peak demand for electricity increase rapidly from the late 2020s. This is slower in the other scenarios where many sectors, but particularly heat, see lower electrification.

The peak demands presented here are average cold spell (ACS)[4], which include the impact of residential demand side response. A breakdown of peak demands in 2050 before and after all types of demand side flexibility have been accounted for is shown in Figure FL.8, with more detail in the data workbook.

Compared to FES 2020, this year's electricity peak and annual demands have increased across all scenarios. This reflects stakeholder feedback and modelling updates and includes:

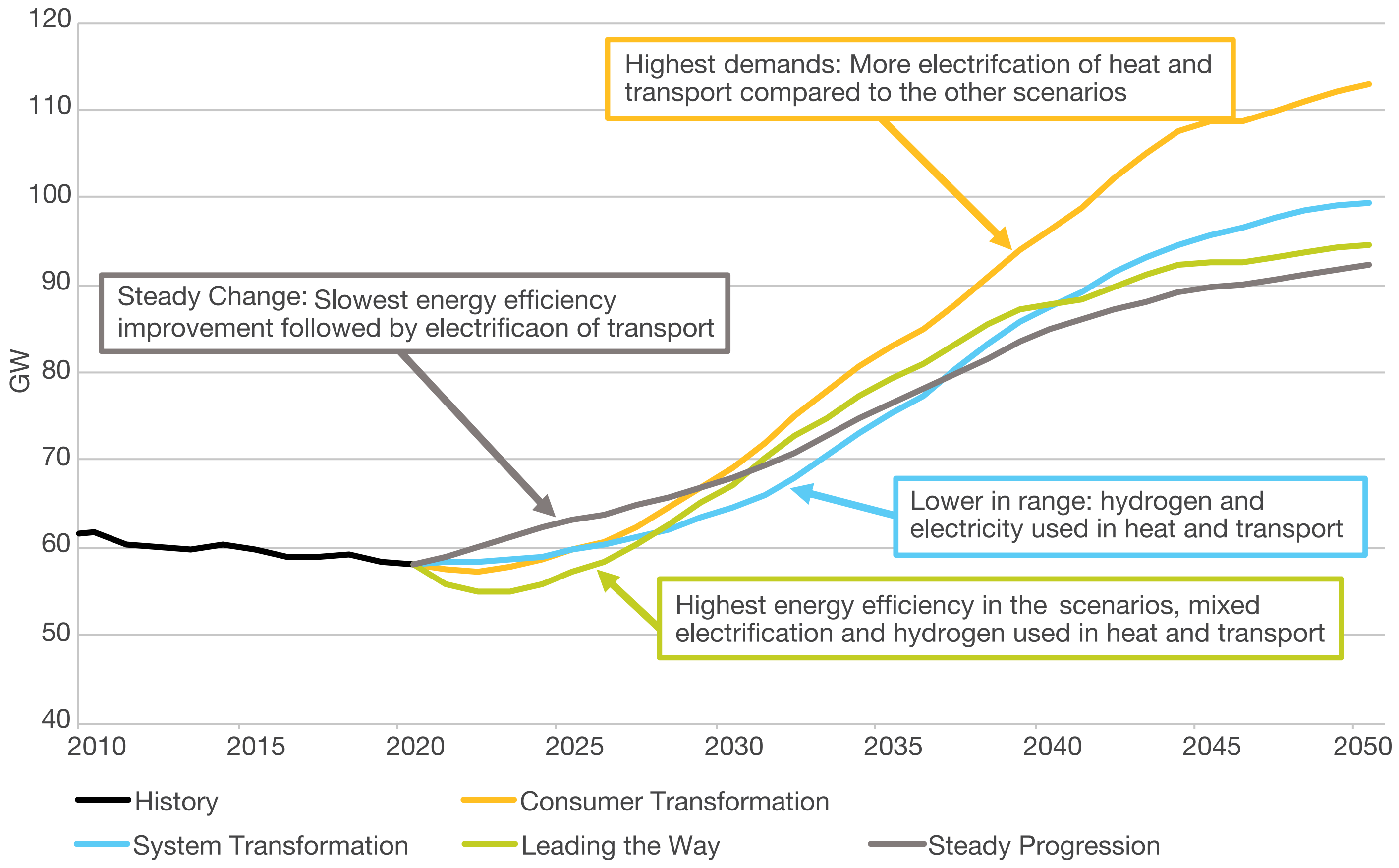
1. Changes in fuel switching and thermal or appliance assumptions in the I&C sectors
2. Changes to residential thermal efficiency assumptions accompanied by increases in the use of heat pumps of all types
3. Changes to use of thermal storage devices at times of peak demand in homes and businesses
4. Reductions in battery electric vehicle (BEV) efficiency assumptions

These areas are explored in more detail in the consumer view. For a more in-depth discussion of the changes to this year's FES modelling, see our FES 2020/2021 comparison document.



4 FES uses the Average Cold Spell (ACS) definition of electricity demand which is consistent with the treatment of demand in the electricity Capacity Mechanism.

Figure FL.4: Electricity peak demand



Natural gas peak demand

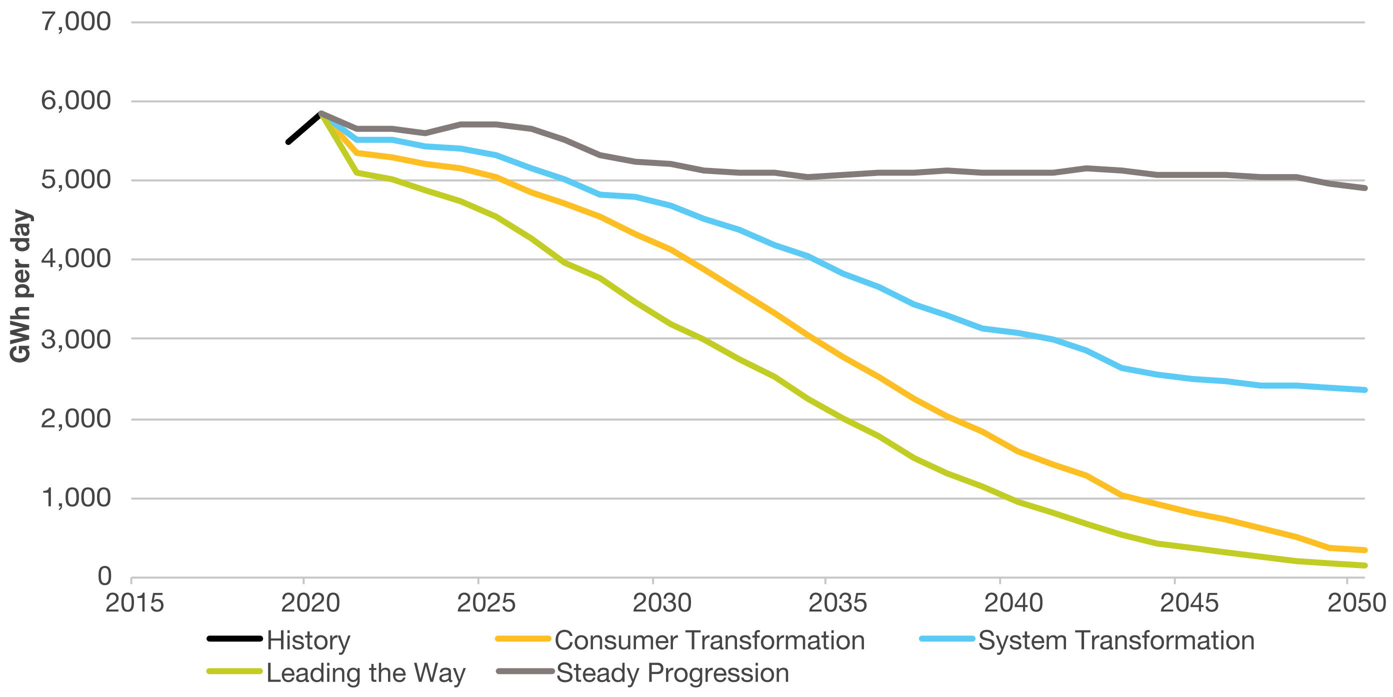
Natural gas peak demands[5] are expected to decline in line with the reduced use of natural gas in the net zero scenarios. Peak demand for natural gas is linked to annual demand particularly driven by heat demand for residential homes. On cold winter evenings this will continue to be high while large 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.

Steady Progression makes limited progress in decarbonising heat, with many homes still using gas boilers, and with gas still being used in the power sector. As such natural gas peak demands continue at a similar level to today.

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. 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.

5 This is a 1-in-20 demand which means that statistically, in a long series of winters, it would be exceeded in one out of twenty winters.

Figure FL.5: Natural gas peak demand



Annual demand

Trends in peak natural gas demand generally mirror 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 2021 / Flexibility 248

Digitalisation

Digitalisation is essential to managing an energy system with smart flexible demand.

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, not just nationally, but also on a regional and local level across distribution networks and right down to street level. For example, a whole street of electric vehicles all drawing power from or feeding power back to the grid at maximum output could cause local network issues. 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 2020/21 Bridging the Gap programme explored how data and digitalisation, technology and markets can help meet the new challenges of a decarbonised electricity system.

FES 2021 / Flexibility 249

What we've found

Markets

To deliver higher levels of flexibility, we need sharper market signals to incentivise the right outcomes.

We see up to 43 GW of electricity storage across our scenarios in 2050, compared to 3.5 GW today, 44 GW of demand side response, compared to 6 GW today and 58 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 driven by revenues for ancillary services that support system operation whereas, in future, signals should 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).

Markets for flexibility should be based on our market design principles and be:

1. Competitive and accessible
2. Transparent
3. Fair
4. Coherent

Our scenarios support the work we are doing on market change, and feed into our Market Strategy which looks ahead to develop a clear 10-year vision. National Grid ESO is working closely with industry and the Government to enhance the role of flexibility in the Capacity Market. We are working with stakeholders to understand what future markets need to look like and how changes can be implemented.

For more information see our Markets Roadmap. In addition, we are also working to better understand how interactions between National Grid ESO and Distribution System Operators (DSOs) can ensure the best use of residual flexibility.

FES 2021 / Flexibility 250

Ancillary services

These are services we procure to balance demand and supply and maintain security of electricity supply across Britain's transmission system. They manage a range of issues, including:

Response: used to position generating units into their frequency sensitive mode;

Reserve: to manage overall imbalance in the system, based on generation and demand outturns, forecasting and available margin (headroom and footroom);

Thermal: to manage congestion constraints in the network;

Voltage: to manage the voltage level by controlling the volume of reactive power that providers can absorb or generate;

RoCoF/inertia: to manage a safe system, we have sometimes to reduce the largest loss/gain and/or to increase the number of synchronous generation units.

The Balancing Mechanism (BM) currently manages system operation in real time. Existing ancillary services procured by the ESO include Dynamic Containment, Optional Downward Flexibility Management, Short Term Operating Reserve, Fast Reserve and Firm Frequency Response. Our Markets Roadmap sets out our future vision for the markets we own and operate.

FES 2021 / Flexibility 251

Whole energy system flexibility

The type of flexibility natural gas provides will continue to be important to the future energy system and as its use diminishes, alternative solutions will be needed in the net zero scenarios. Urgent focus is needed to optimise the energy system infrastructure changes needed to deliver zero-carbon energy to consumers.

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 power stations or to meet end user demand. In Steady Progression we assume the continued use of natural gas will lead to gas network storage, linepack and upstream supply variability playing a similar role to today in terms of whole energy system flexibility.

Producing hydrogen through electrolysis offers demand side flexibility and burning it in turbines offers supply side flexibility to the electricity system. If hydrogen is not used for heat or transport, it can be compressed and stored, in potentially very large volumes, for months. While 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.

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. A strategic approach to its development 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. Optimising for the minimum level of hydrogen storage will lead to different outcomes than for the best whole energy system outcome. These figures will depend on the future potential revenue streams for flexibility and the support available to develop hydrogen storage sites. The level of storage needed in System Transformation is affected by methane reformation production of hydrogen across the year. If production is ramped up in the winter and reduced in the summer, lower levels of interseasonal storage will be 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. The level of hydrogen storage required in Leading the Way is mitigated by the presence of some hydrogen import.

FES 2021 / Flexibility 252

What we've found

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 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 imports/exports 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.

Hydrogen import

Hydrogen could be imported through converted gas interconnectors, new offshore hybrid wind and electrolysis hubs or shipping to converted LNG terminals. The development of an international hydrogen market for import and export is highly uncertain at this stage.

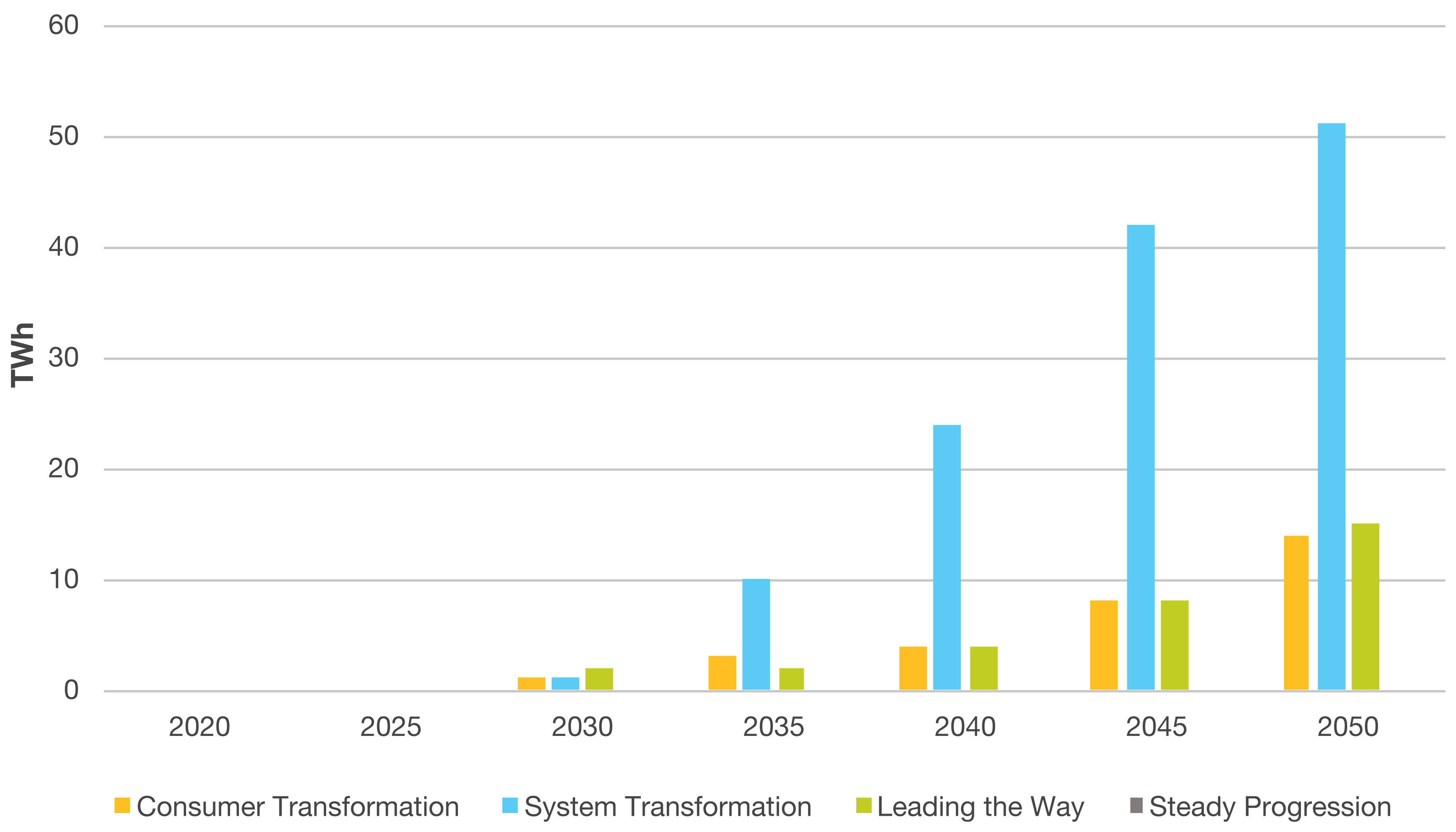
FES 2021 / Flexibility 253

Whole energy system flexibility

Despite a huge increase in electricity storage capacity in the net zero scenarios, the energy it stores is dwarfed by that of hydrogen storage, demonstrating the value of the latter to the whole energy system. Both types of storage are needed to meet different energy system needs. In 2050 the capacity of electricity storage (excluding vehicle to grid) in each scenario represents 1.1% of the 15 TWh of hydrogen storage in Leading the Way, 1.3% of the 12 TWh in Consumer Transformation and 0.2% of the 51 TWh in System Transformation.

In 2050, hydrogen storage capacity needed in Consumer Transformation and Leading the Way is comparable to gas storage capacity today, while in System Transformation it is substantially higher, although still lower than gas storage capacity in the recent past, which was as high as 52 TWh in 2015. The lower energy density of hydrogen may mean larger volumes are needed than the equivalent energy storage for gas; this will depend on the actual storage facilities and the pressures at which it can be stored.

Figure FL.6: Hydrogen storage capacity requirements



FES 2021 / Flexibility 254

Whole energy system flexibility

Figure FL.7 shows the modelled daily level of hydrogen in storage over the year in 2050 for the net zero scenarios. System Transformation has the greatest interseasonal 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 Consumer Transformation and Leading the Way the interseasonal relationship is weaker, due to lower heating requirements and more production coming from electrolysis. Nevertheless, storage plays a crucial role through the year helping to match hydrogen supply and demand.

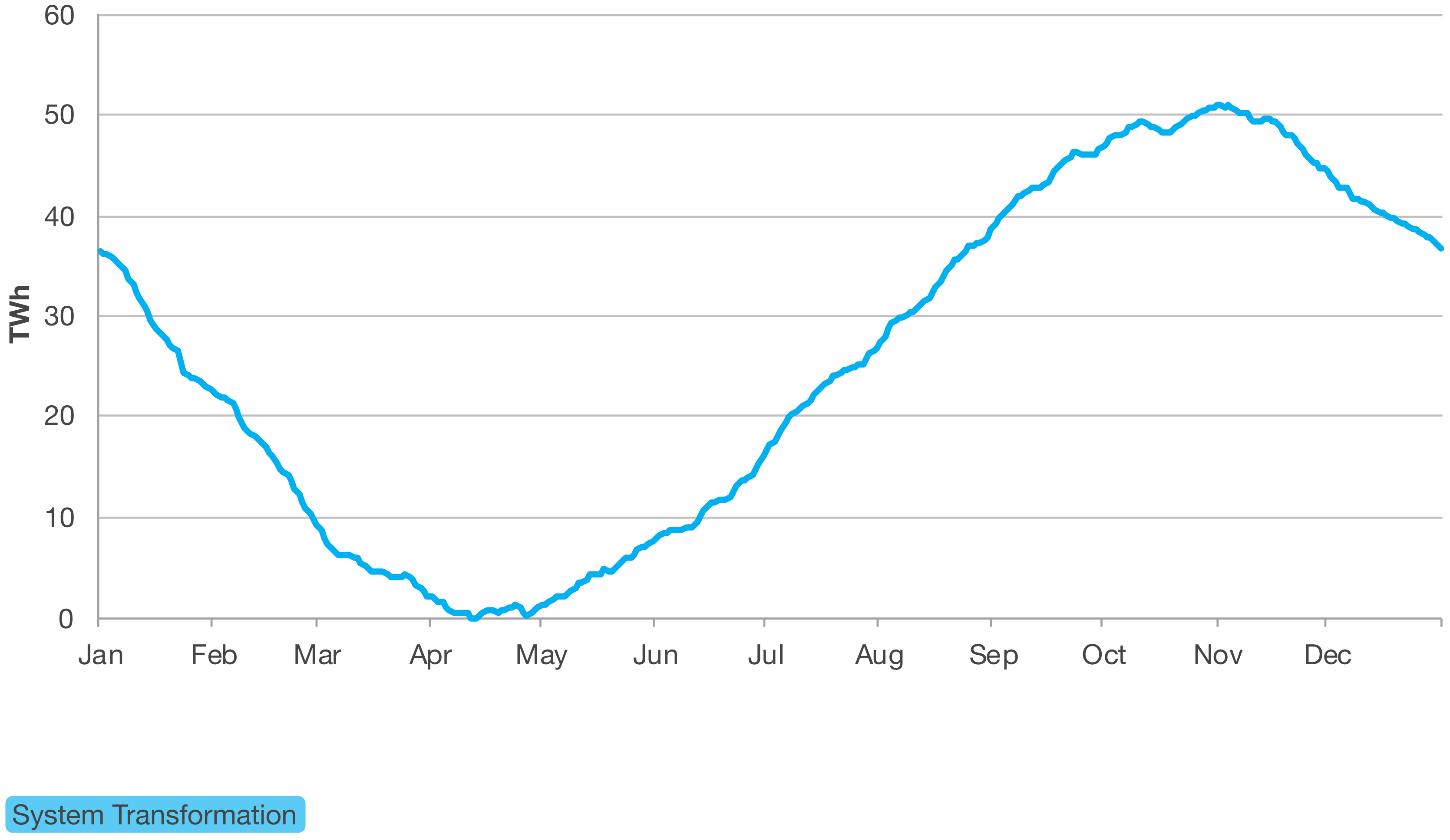
Figure FL.7: Levels of hydrogen in storage in 2050

Consumer Transformation

Whole energy system flexibility

Figure FL.7 shows the modelled daily level of hydrogen in storage over the year in 2050 for the net zero scenarios. System Transformation has the greatest interseasonal 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 Consumer Transformation and Leading the Way the interseasonal relationship is weaker, due to lower heating requirements and more production coming from electrolysis. Nevertheless, storage plays a crucial role through the year helping to match hydrogen supply and demand.

Figure FL.7: Levels of hydrogen in storage in 2050



FES 2021 / Flexibility 256

Whole energy system flexibility

Figure FL.7 shows the modelled daily level of hydrogen in storage over the year in 2050 for the net zero scenarios. System Transformation has the greatest interseasonal 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 Consumer Transformation and Leading the Way the interseasonal relationship is weaker, due to lower heating requirements and more production coming from electrolysis. Nevertheless, storage plays a crucial role through the year helping to match hydrogen supply and demand.

Figure FL.7: Levels of hydrogen in storage in 2050

Leading the Way

FES 2021 / Flexibility 257

Electricity system flexibility

Electrification across sectors leads to increasing peak demands from the mid to late 2020s in all scenarios. Demand side response (DSR) will play an important role in mitigating peak demand increases.

Figure FL.4 shows ACS[6] peak demands per scenario, represented by the central bar in Figure FL.8. Unmanaged peak demand can be reduced by up to 24% down to ACS peak through smart charging, and residential heat flexibility. Industrial and commercial DSR, non-heat residential DSR and Vehicle to Grid (V2G) response are not included in the ACS peak calculation and can reduce the peak demand by up to 35% below this.

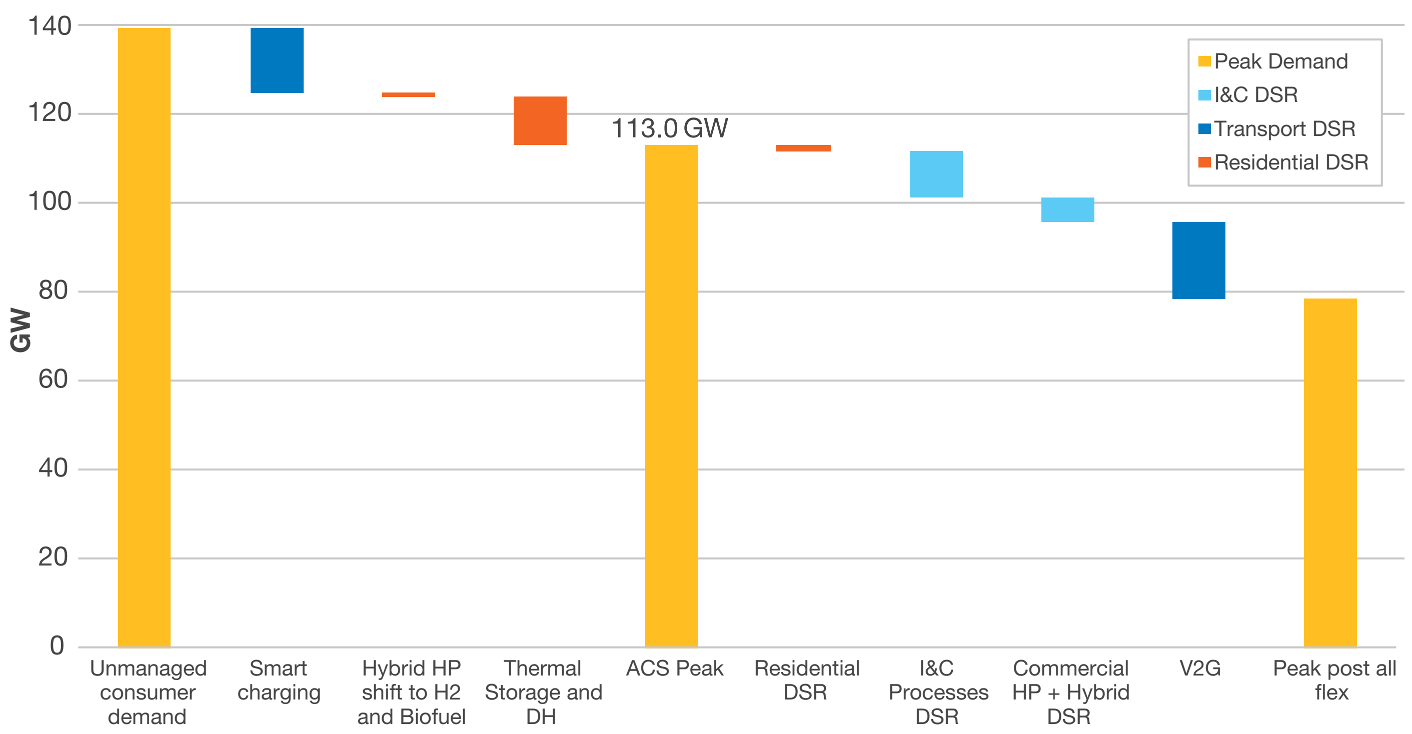
While all these forms of flexibility are important, across the scenarios the take-up of different flexible technologies varies. The uptake rates and the relative impact of each technology are explored in more detail in the following sections.

Consumer Transformation and Leading the Way have highly engaged consumers, and can see total peak demands reduced by over 43% due to DSR. Demand side flexibility take-up is lower in System Transformation and Steady Progression which have less consumer engagement, however they still see over 20% total peak demand reduction from DSR.

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.8 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 electric vehicle 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.

Figure FL.8: Impact of flexible DSR on peak demands in 2050 Consumer Transformation



Consumer Transformation

6 FES uses the Average Cold Spell (ACS) definition of electricity demand which is consistent with the treatment of demand in the electricity Capacity Mechanism.

What we've found

Figure FL.8: Impact of flexible DSR on peak demands in 2050 System Transformation

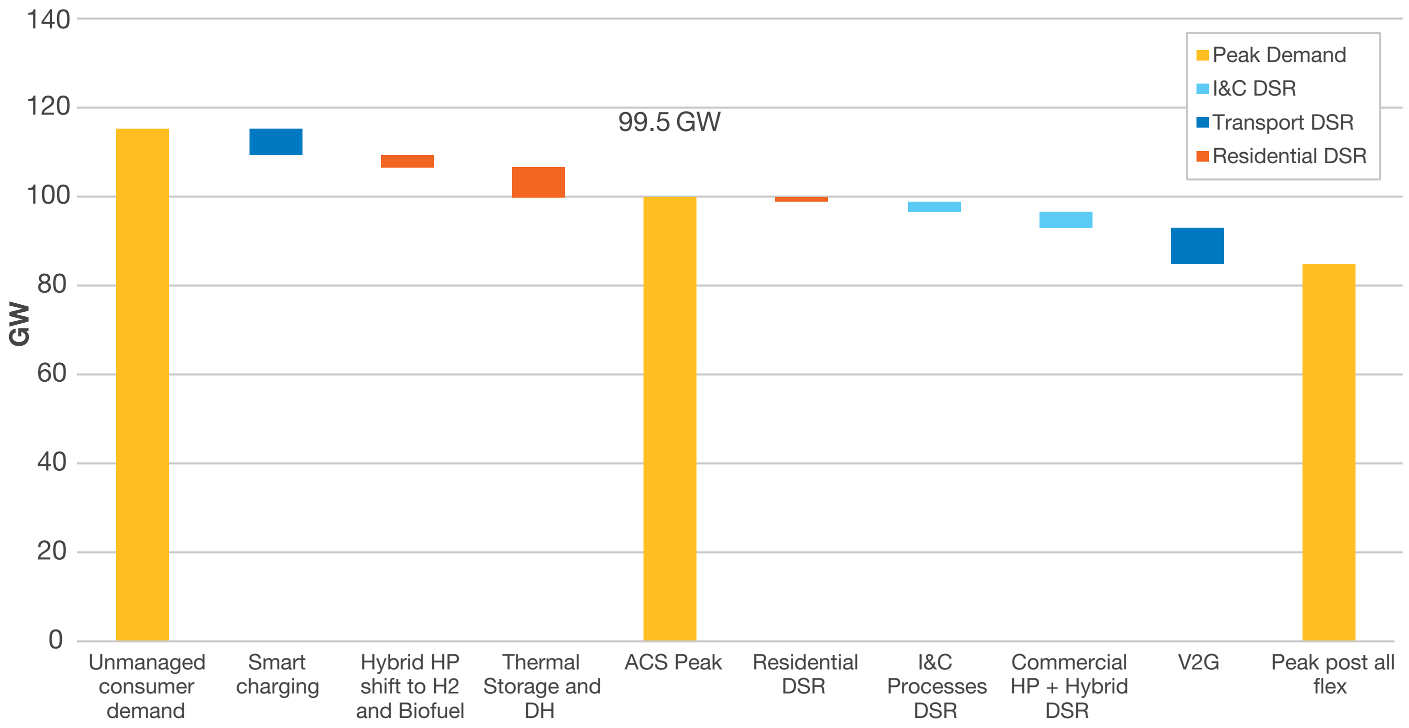
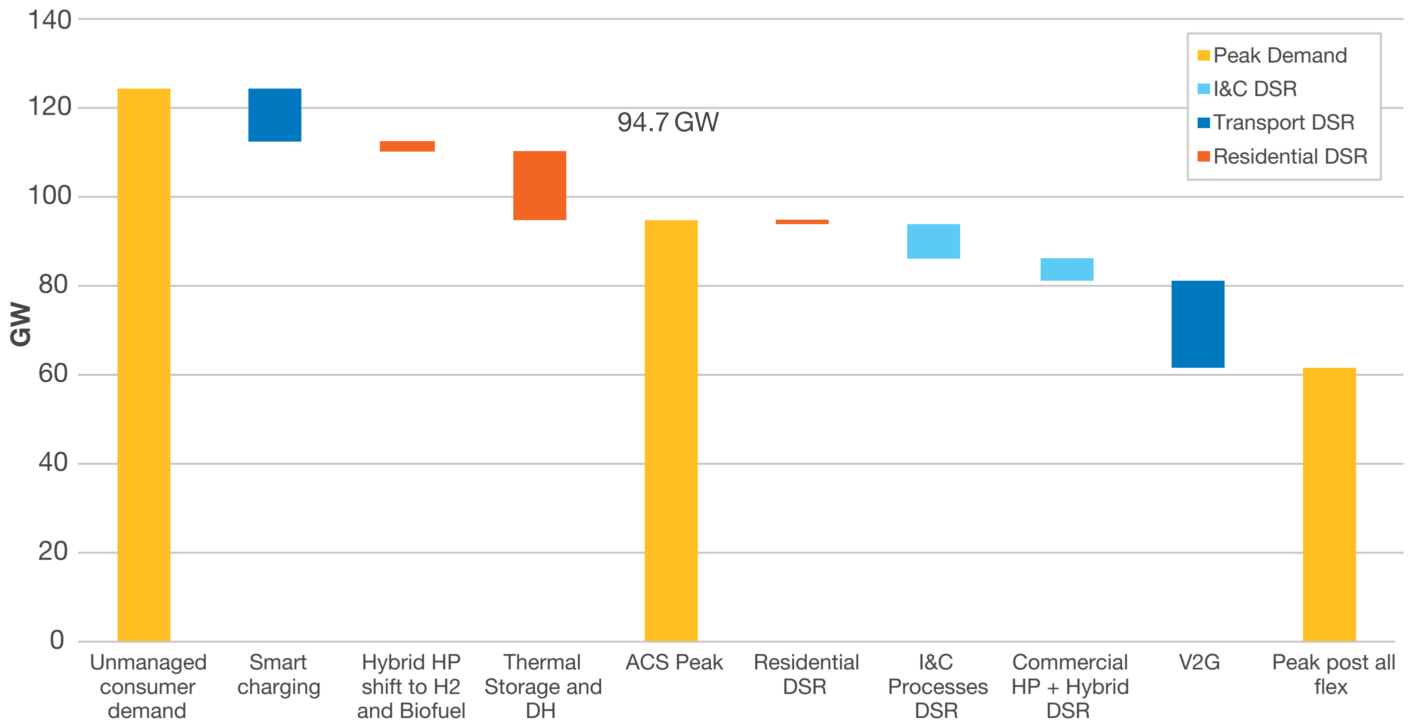
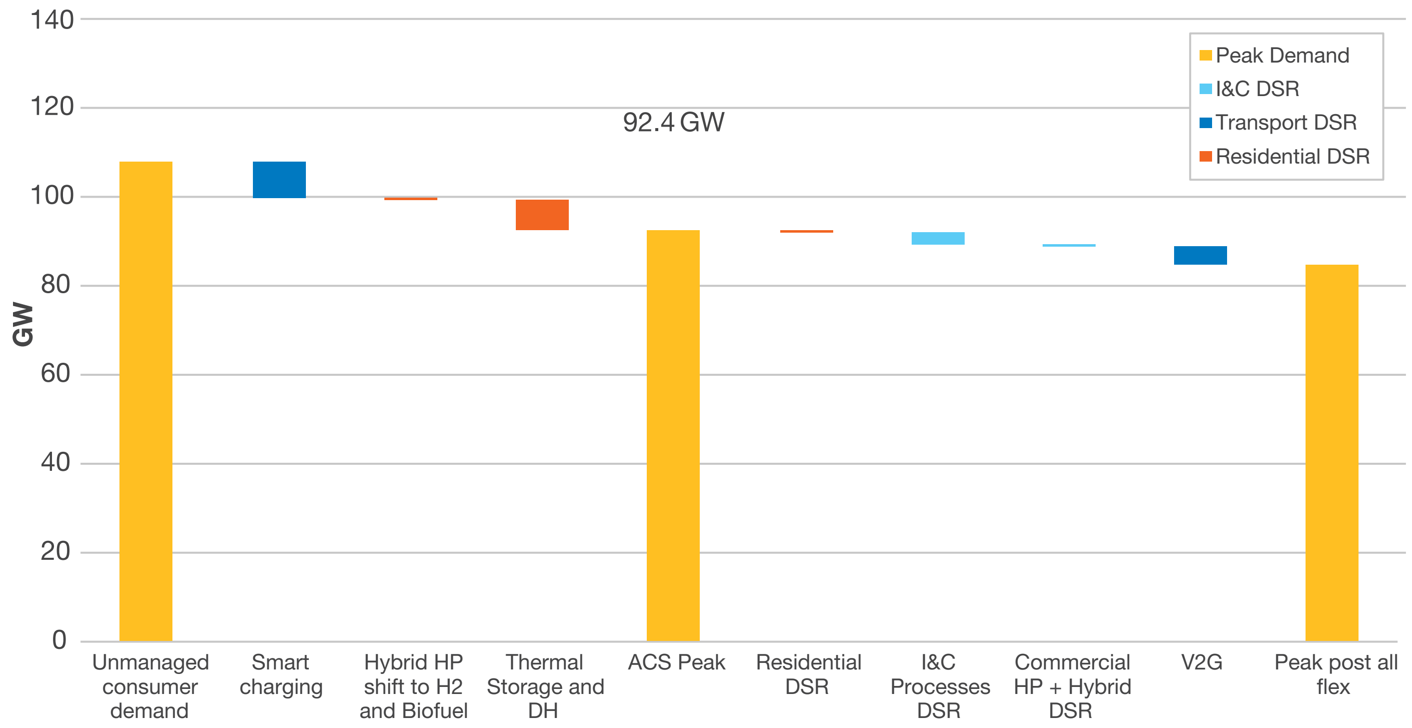


Figure FL.8: Impact of flexible DSR on peak demands in 2050 Leading the Way



FES 2021 / Flexibility 259

Figure FL.8: Impact of flexible DSR on peak demands in 2050 Steady Progression



FES 2021 / Flexibility 260

Industrial and commercial demand flexibility

The industrial and commercial sectors are expected to offer increased levels of demand flexibility, with significant opportunity for demand side response.

We expect load shifting of demand for industrial processes to increase across all scenarios, with greater acceleration from the mid-2020s. The rise of smart technology and the developing market for DSR in the net zero scenarios see the rewards for participating increase while the barriers to entry are eased.

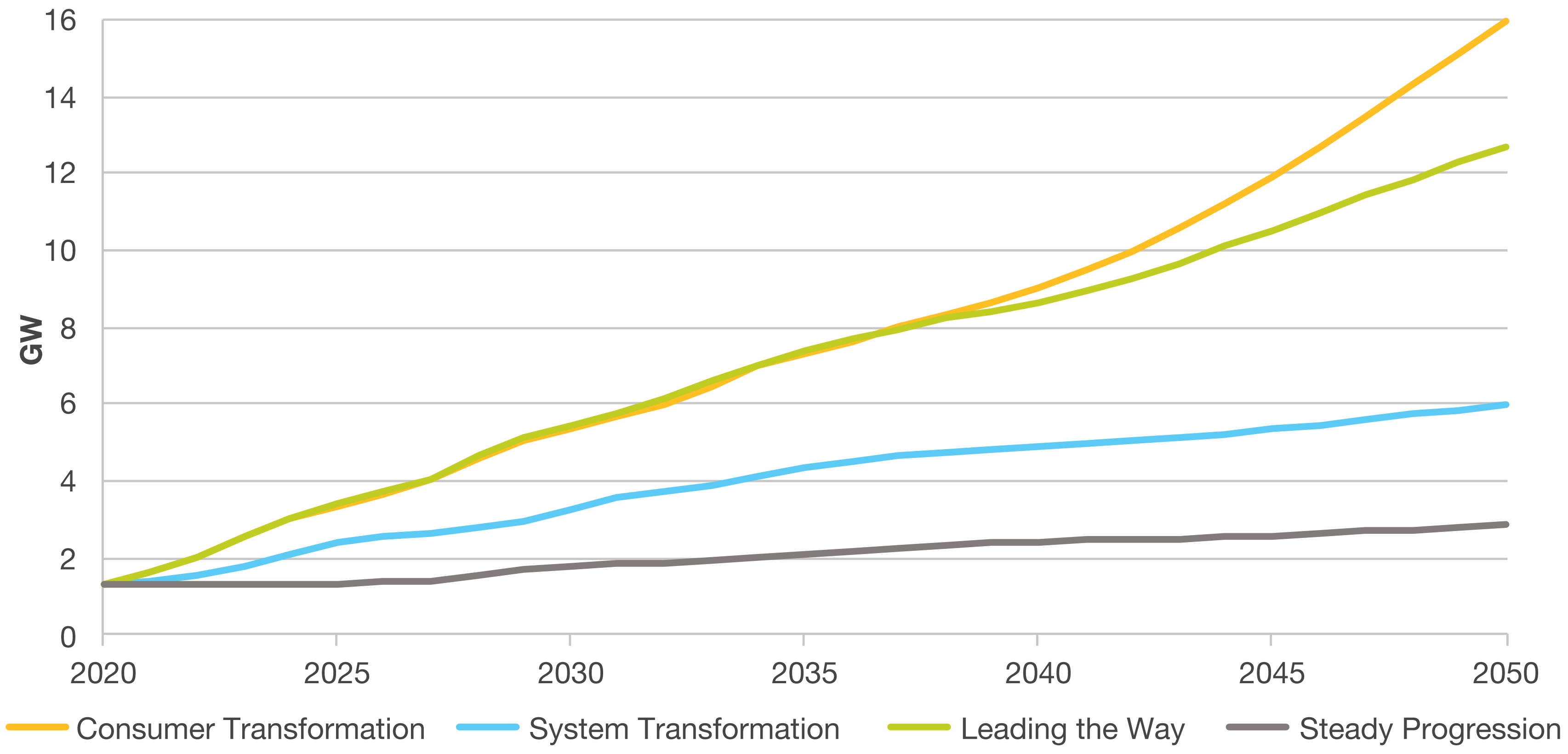
Across the net zero scenarios we expect increased electrification of heat to lead to increased opportunity for thermal load shifting, reaching up to 6 GW by 2050. This is split between some load shifting from thermal storage alongside heat pumps, and a larger share from smart storage heaters. There is very little growth in thermal flexibility in Steady Progression due to limited consumer engagement and lower levels of electrification of heat.

Demand side response

In FES we define I&C DSR as the turning up or down, or off or on, of electricity consumption in response to external signals. In our scenarios we model end-use demand. If a consumer chooses not to reduce their demand, but instead switches to an alternative energy source such as an onsite diesel generator or batteries, this is captured in other areas of the analysis (for example, distributed generation and storage). To avoid double counting, this is not included in our definition of I&C DSR.

FES 2021 / Flexibility 261

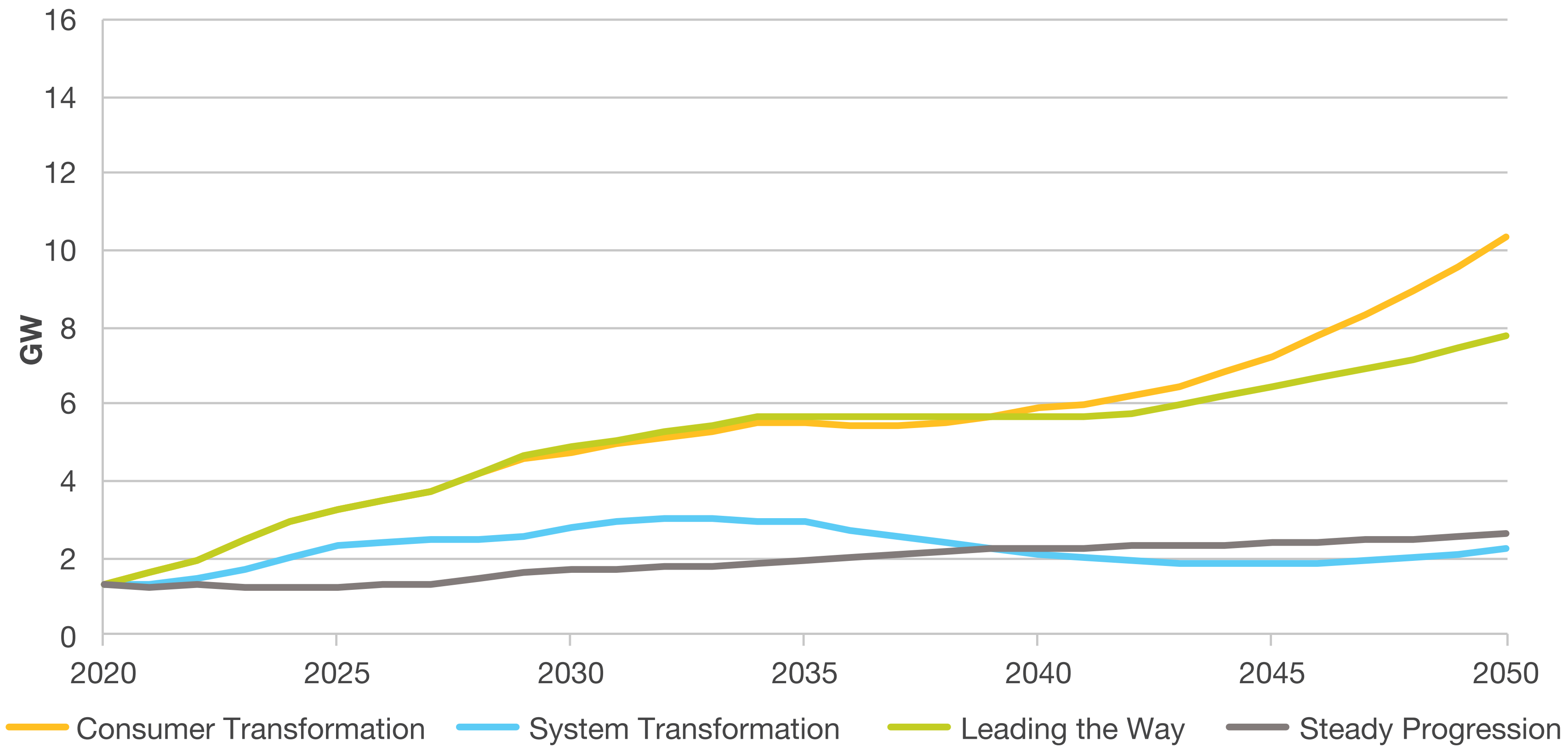
Figure FL.9: Industrial and commercial demand side response, total



FES 2021 / Flexibility 262

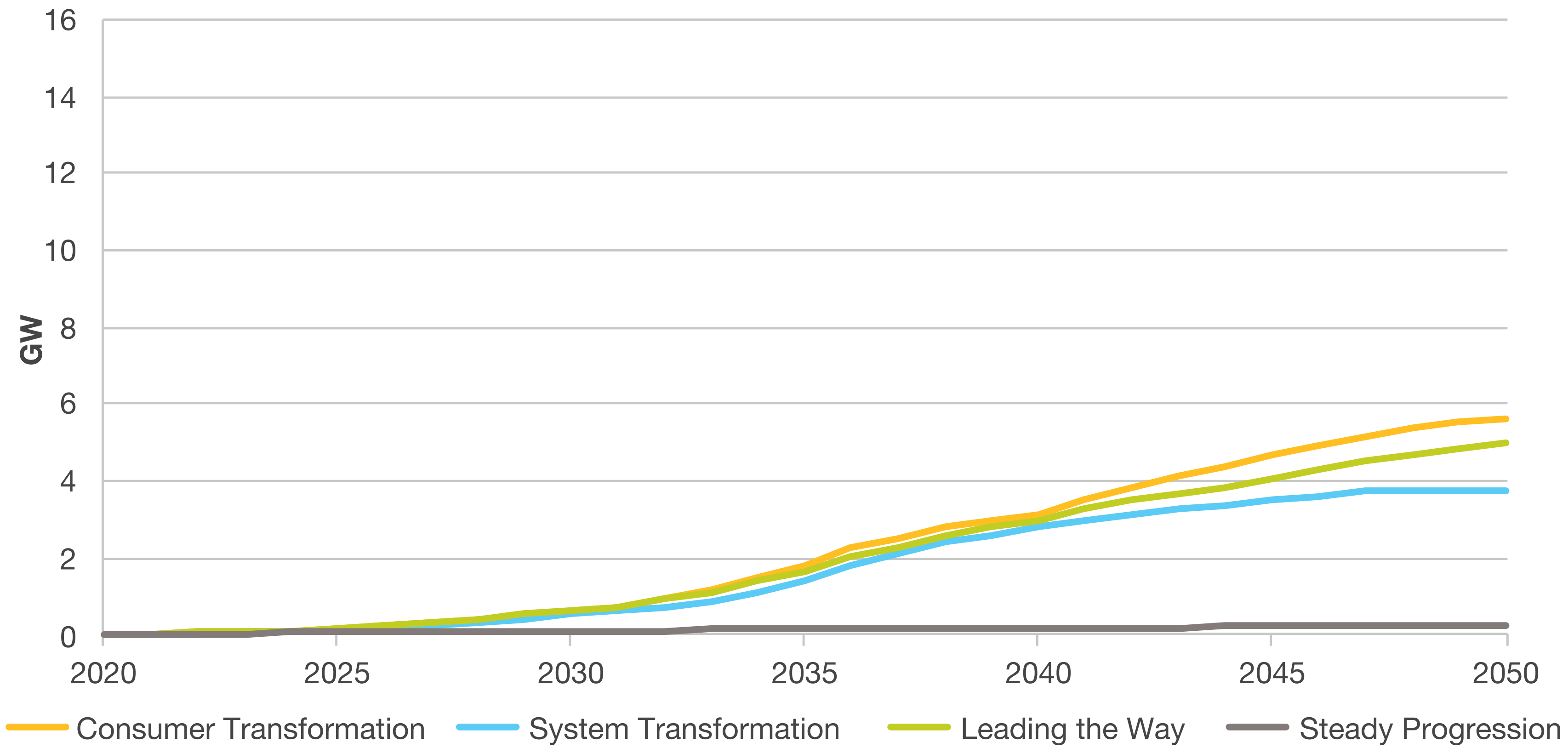
What we've found

Figure FL.9: Industrial and commercial demand side response from processes



FES 2021 / Flexibility 263

Figure FL.9: Industrial and commercial demand side response from heat



FES 2021 / Flexibility 264

What we've found

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 is covered in the transport flexibility section below. Much of this flexibility will be delivered without direct consumer involvement – consumers would simply opt in and use flexible devices in their homes, then load-shifting and optimisation of demand profiles would take place in the background. 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 time of use tariffs could shift electricity demand away from peak periods from appliances such as washing machines, dishwashers and even for short periods of time refrigerators or freezers. Up to 1.3 GW of peak demand could be shifted away from peak times, with the highest amounts in the scenarios with the highest levels of societal change. We expect the move to flexible EV charging to act as a trigger point for consumers to begin to engage in this type of load shifting as elements such as time of use tariffs are already in place.

Across all scenarios we expect increased electrification of heat, primarily from greater use of heat pumps. Consumer Transformation and Leading the Way see the highest level of electrification of heat, and therefore the highest electricity peak heat demands. However, they also see the highest levels of engagement in demand side flexibility to shift some of this load away from peak times.

What we've found

Residential flexibility

Our new spatial heat model has given us a more granular view of residential heat and opportunities for moving heat demand within the home. This analysis, combined with more conservative insulation assumptions across our scenarios this year, has led to higher peak demands in our modelling and increased the importance of domestic heat flexibility.

One well-established source of heating flexibility is from the use of storage heaters. These were widely adopted in the 1960s and 70s to make the most of surplus electricity overnight, when demands were lower. They were incentivised through a dual rate tariff known as Economy 7 that offered cheaper prices for seven hours overnight. While 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 6 GW of nominal peak shaving in 2020, they are mostly ‘dumb’ devices with only basic controls that cannot adjust according to system needs and only operate on set patterns. A new generation of ‘smart’ storage heaters is now available that could unlock greater flexibility in future, with a similar proportion of households to today expected to be using some form of storage heaters in 2050.

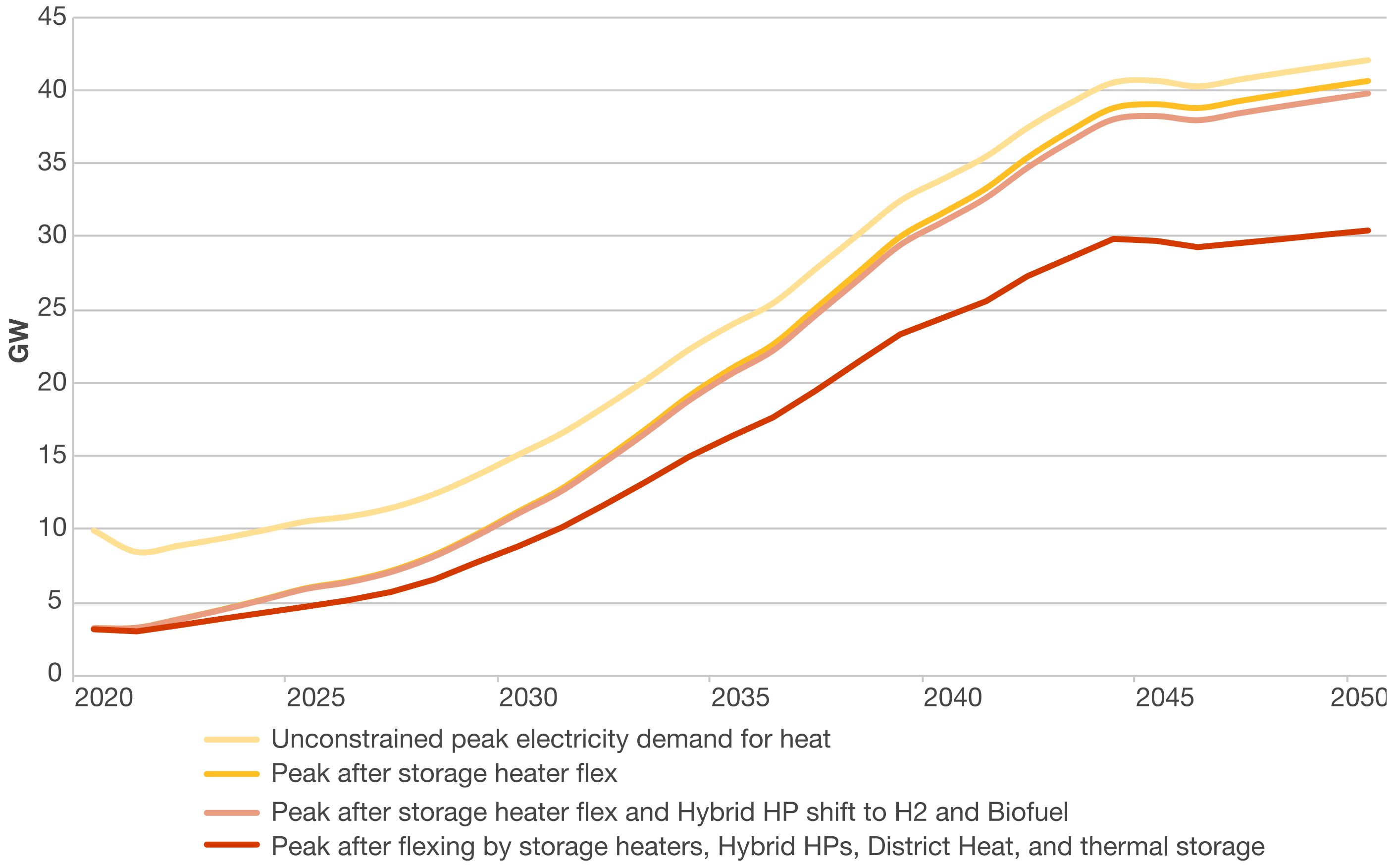
Other forms of thermal flexibility include hybrid heat pumps and thermal storage. At times of peak demand hybrid heat pumps can switch from electricity to hydrogen for heating. Demand can also be load shifted using thermal storage; a heat pump charges up a hot water tank or a dedicated thermal store when prices are low, this then supplies heat to the house for 3-4 hours over the peak evening period. In highly insulated homes the heating can be switched off completely for short periods over peak times without leading to a loss of temperature.

On very cold days some households using air source heat pumps without thermal storage may switch to a resistive heating mode, operating at less than half their usual efficiency and increasing their electricity demand. Figure FL.10 shows the net demand reduction effect of thermal flexibility after taking account of this.

FES 2021 / Flexibility 266

Residential flexibility

Figure FL.10: Residential winter peak electricity demand for heating and flexibility from heating technologies



Consumer Transformation

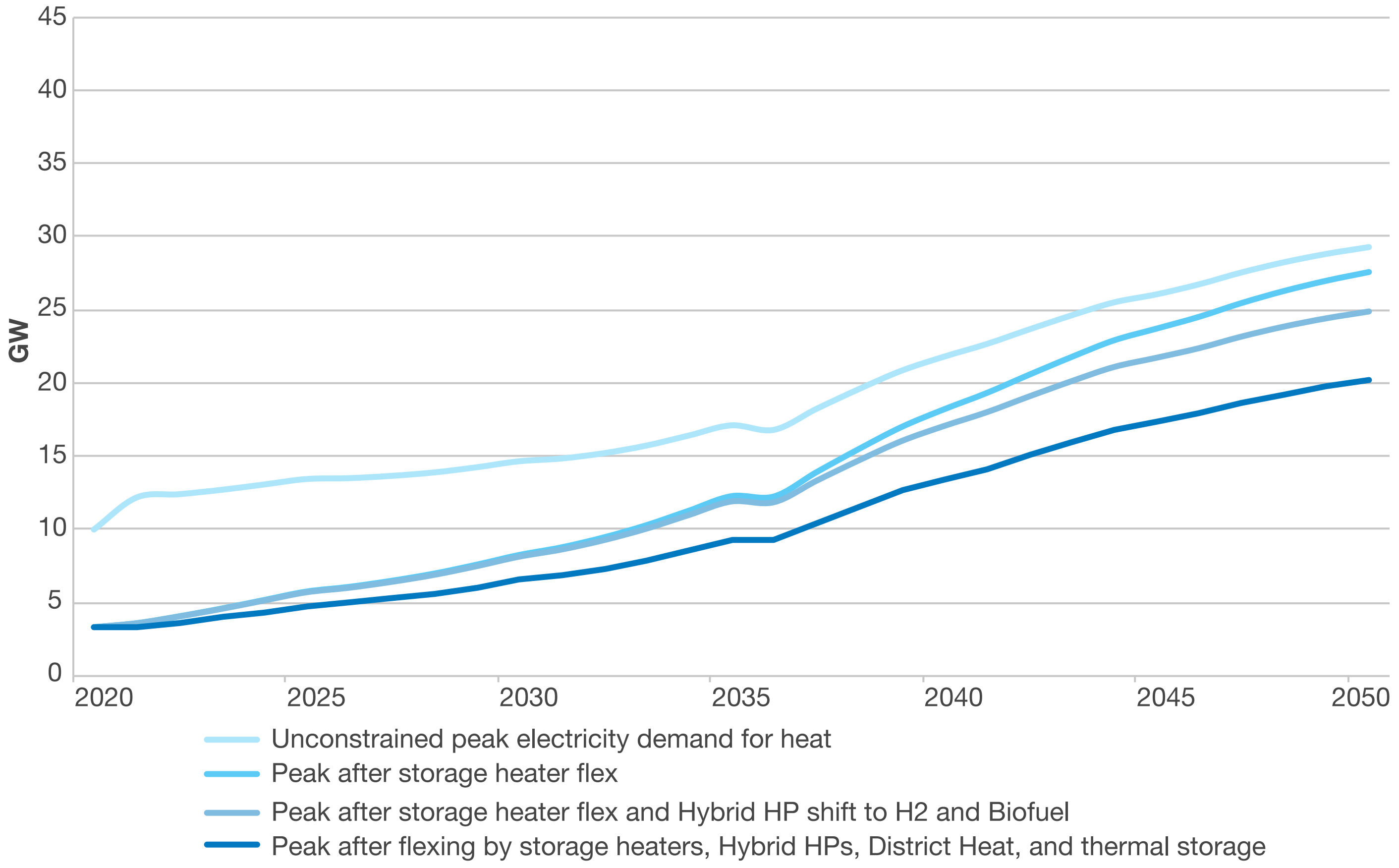
High levels of electrification of heat from the mid-2020s increase peak demand, with load shifting from thermal storage playing a large role in reducing peak demand from 2030 onwards.

Total peak demand shaving reaches 11.7 GW / 28% in 2050.

FES 2021 / Flexibility 267

Residential flexibility

Figure FL.10: Residential winter peak electricity demand for heating and flexibility from heating technologies



System Transformation

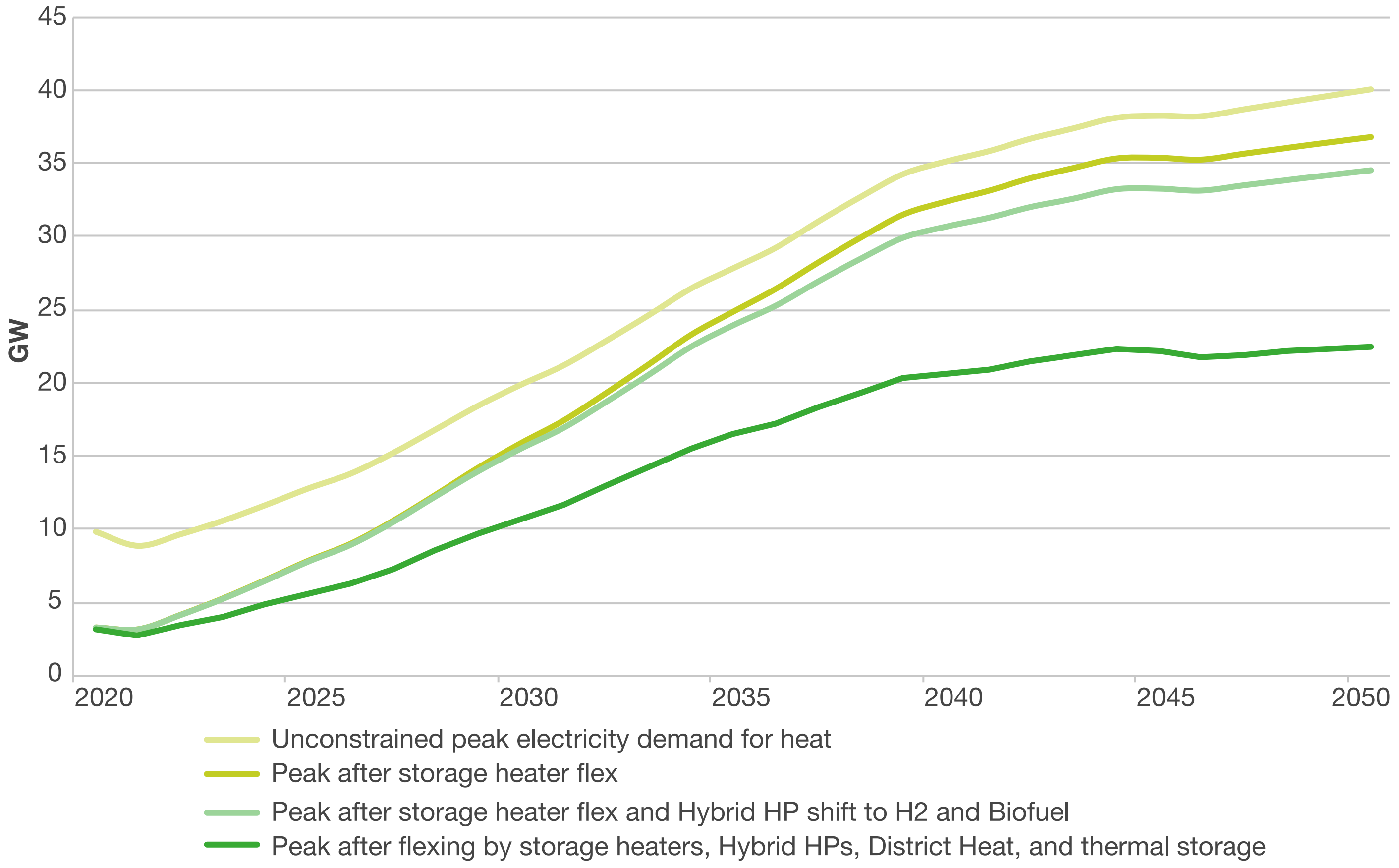
Slower take-up of heat pumps leads to a lower residential peak demand for heat, with flexible demand reduction split between hybrid heat pumps and thermal storage.

Total peak demand shaving reaches 9.2 GW / 31% in 2050.

FES 2021 / Flexibility 268

Residential flexibility

Figure FL.10: Residential winter peak electricity demand for heating and flexibility from heating technologies



Leading the Way

Peak electricity climbs sharply from the early 2020s.

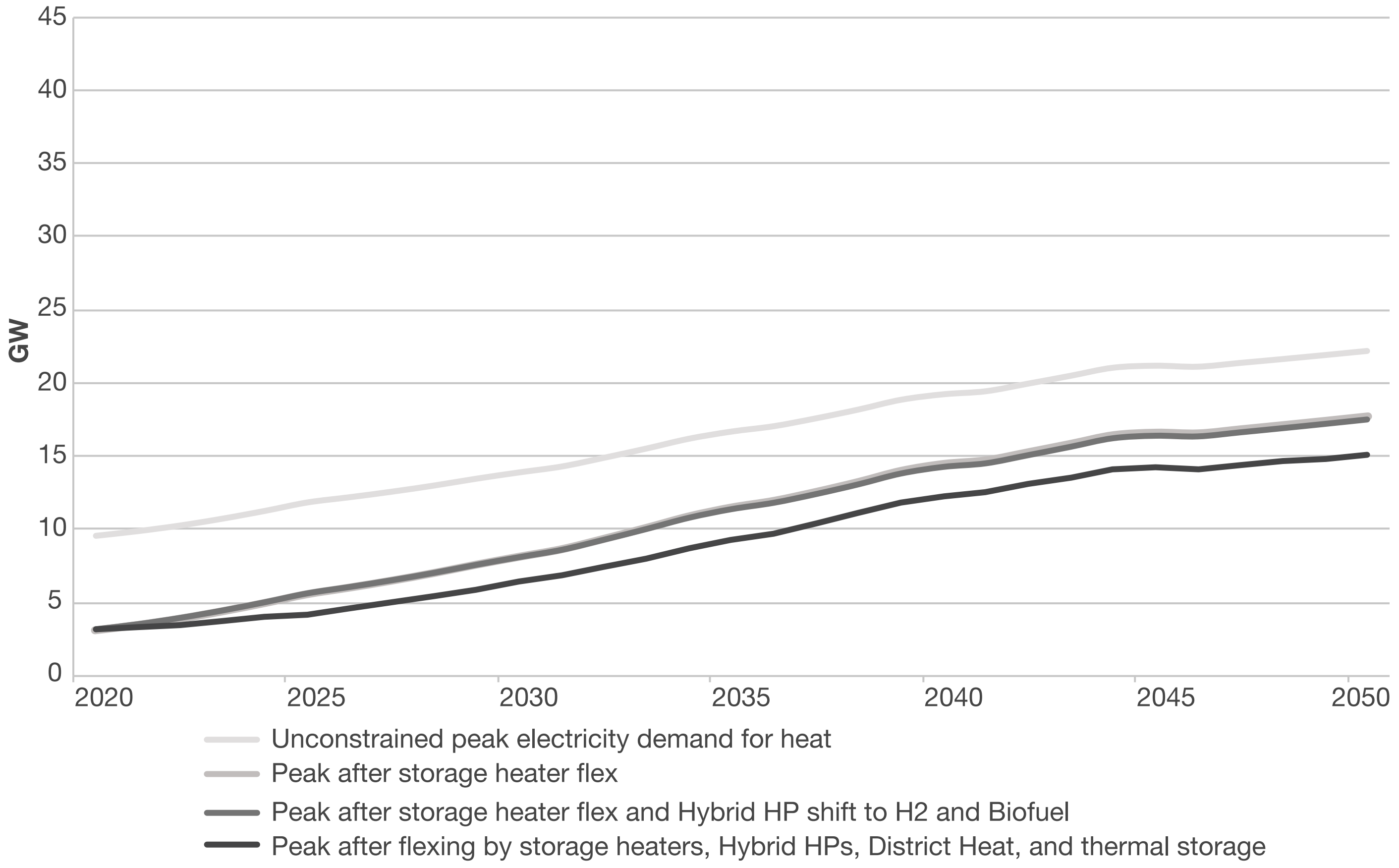
Over 12 GW of load shifting from thermal storage from homes and heat networks in 2050.

Total peak demand shaving reaches 17.7 GW / 44% in 2050.

FES 2021 / Flexibility 269

Residential flexibility

Figure FL.10: Residential winter peak electricity demand for heating and flexibility from heating technologies



Steady Progression

Peak demand for heat rises steadily, with some reduction seen from thermal storage, but storage heaters remain the largest source of flexibility.

Total peak demand shaving reaches 7.3 GW / 32% in 2050.

FES 2021 / Flexibility 270

What we've found

Transport flexibility

Smart charging and vehicle-to-grid (V2G) behaviour will play an important role in the future energy system.

Across all scenarios, cars are primarily electrified, increasing electricity demands and raising questions about how they will be charged. However, while electric vehicle charging represents a challenge, it is also an opportunity to increase flexibility. With suitable incentives and automation, drivers will be able to reduce their costs at the same time as reducing the costs of operating the energy system.

Figure FL.11 shows total electricity flexibility from electric vehicles at times of evening peak demand. Most of this comes from vehicles charging at home; 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 these 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 fuel costs low; providing flexibility from smart charging and vehicle to grid can support this. Increasing daytime or overnight demand through smart charging could be as valuable to the energy system as reducing peak demands.

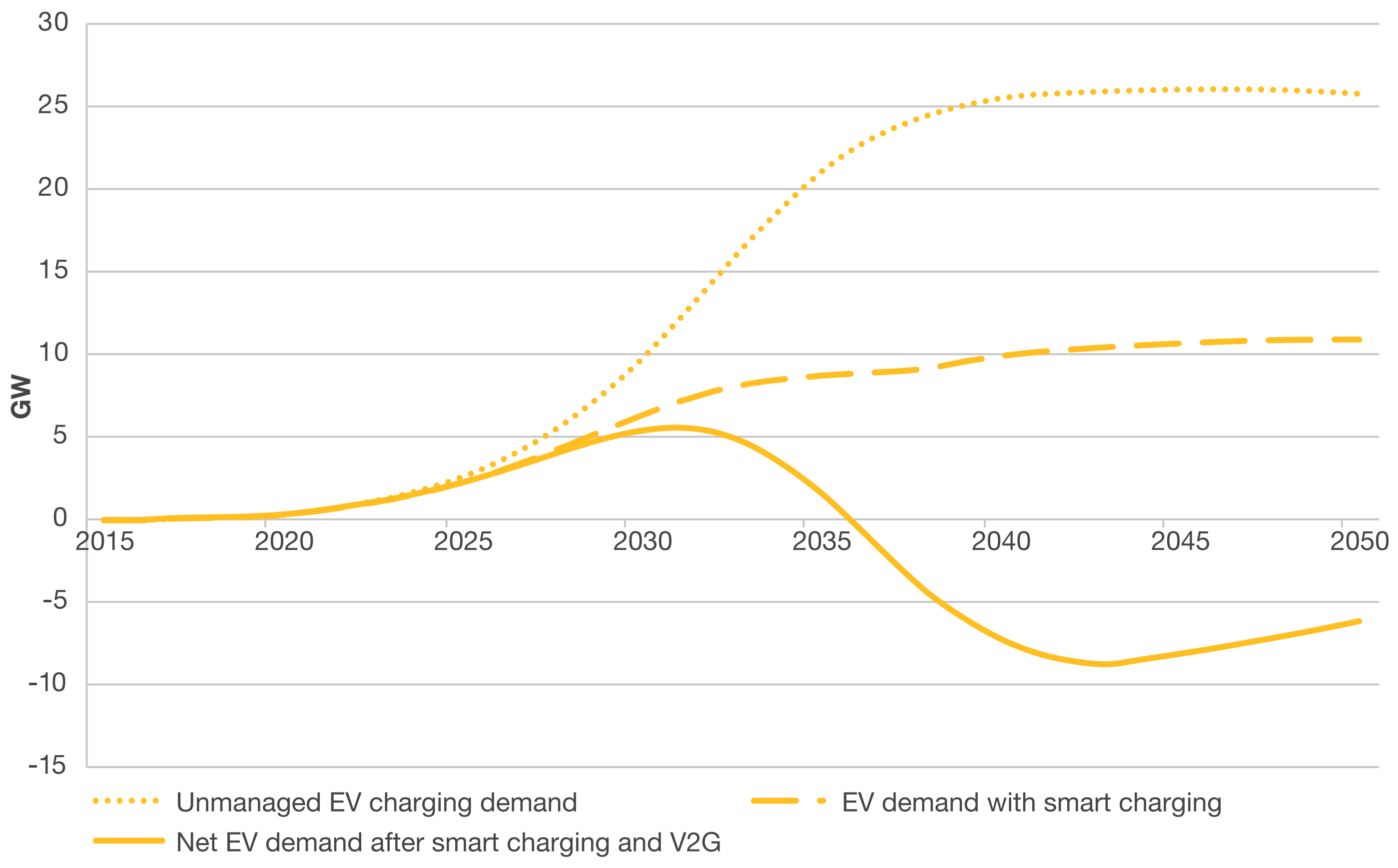
We expect high take-up of smart charging in households with off street parking and their own home chargers. Government and industry impetus suggest this is likely to be widespread. Smart meters, time of use tariffs and automation will make the experience simple for the consumer. We expect smart charging to keep additional peak electricity demand from electric vehicles to between 7 and 16 GW, lower in the scenarios with high levels of consumer engagement.

FES 2021 / Flexibility 271

Transport flexibility

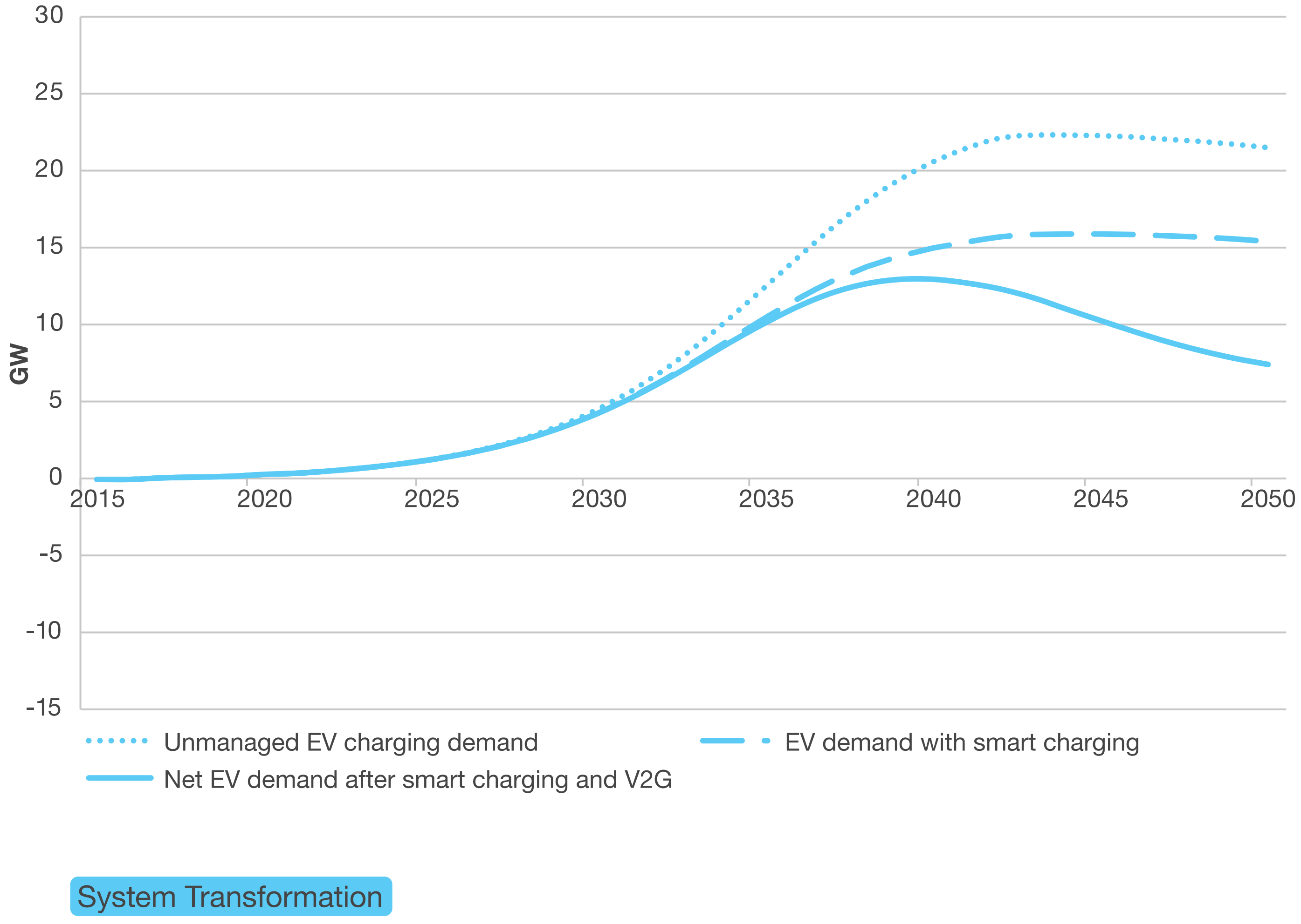
The impact of V2G on the electricity system is uncertain, with a wide range of outcomes across our scenarios. System Transformation and Steady Progression see limited take-up of vehicle-to-grid, however post 2040 this still represents a potential peak shaving of up to 8 GW in System Transformation. In 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 electric vehicles than is used to charge them. This impact is limited somewhat in the 2040s as autonomous vehicles start to increase market share and individual car ownership falls, particularly in Consumer Transformation and Leading the Way. While we would not expect autonomous vehicles to be typically charging at time of tight system margins, neither are they likely to be plugged in and able to respond to a V2G signal.

Figure FL.11: Electric vehicle charging behaviour at ACS winter peak system demand



Consumer Transformation

Figure FL.11: Electric vehicle charging behaviour at ACS winter peak system demand



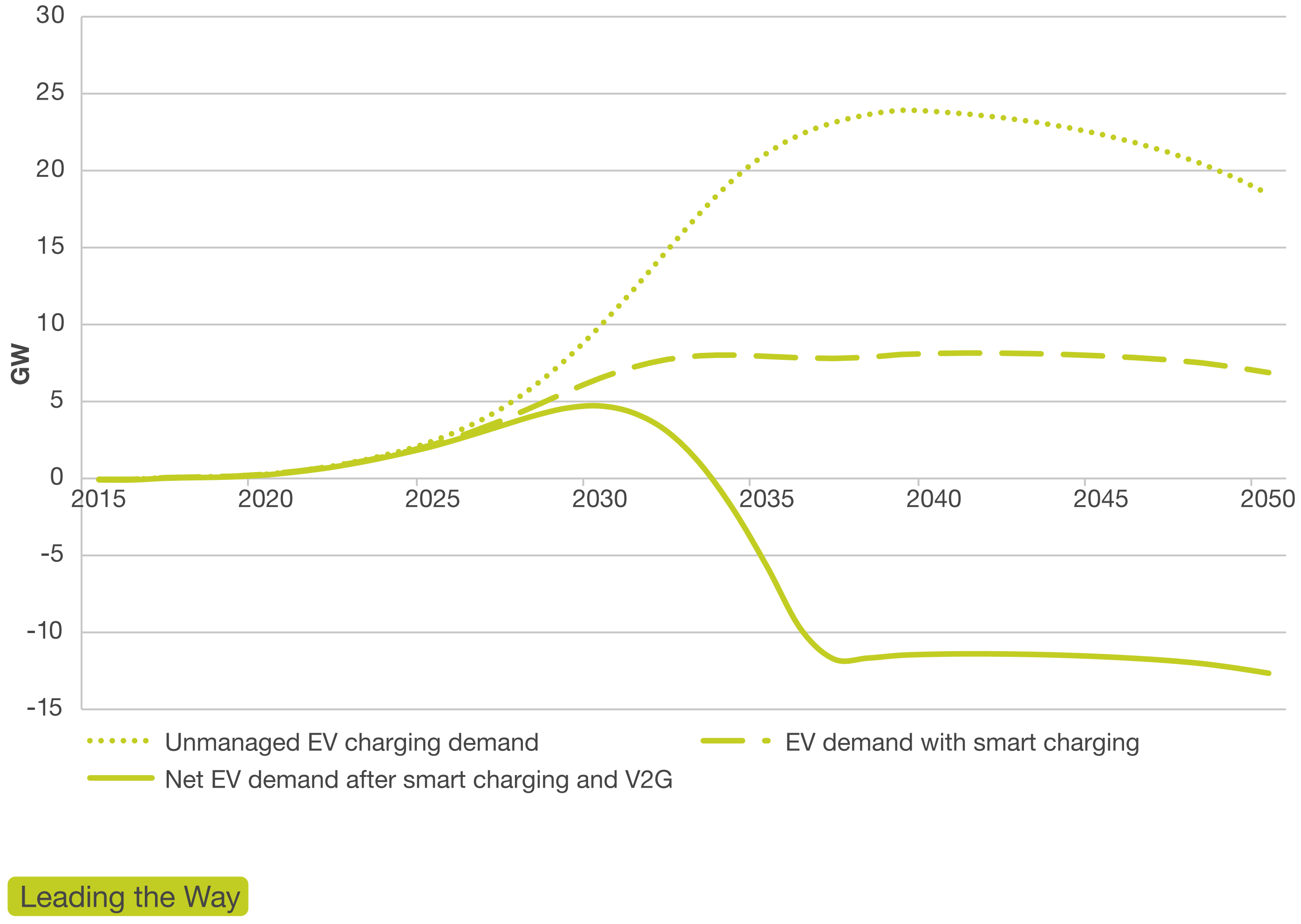
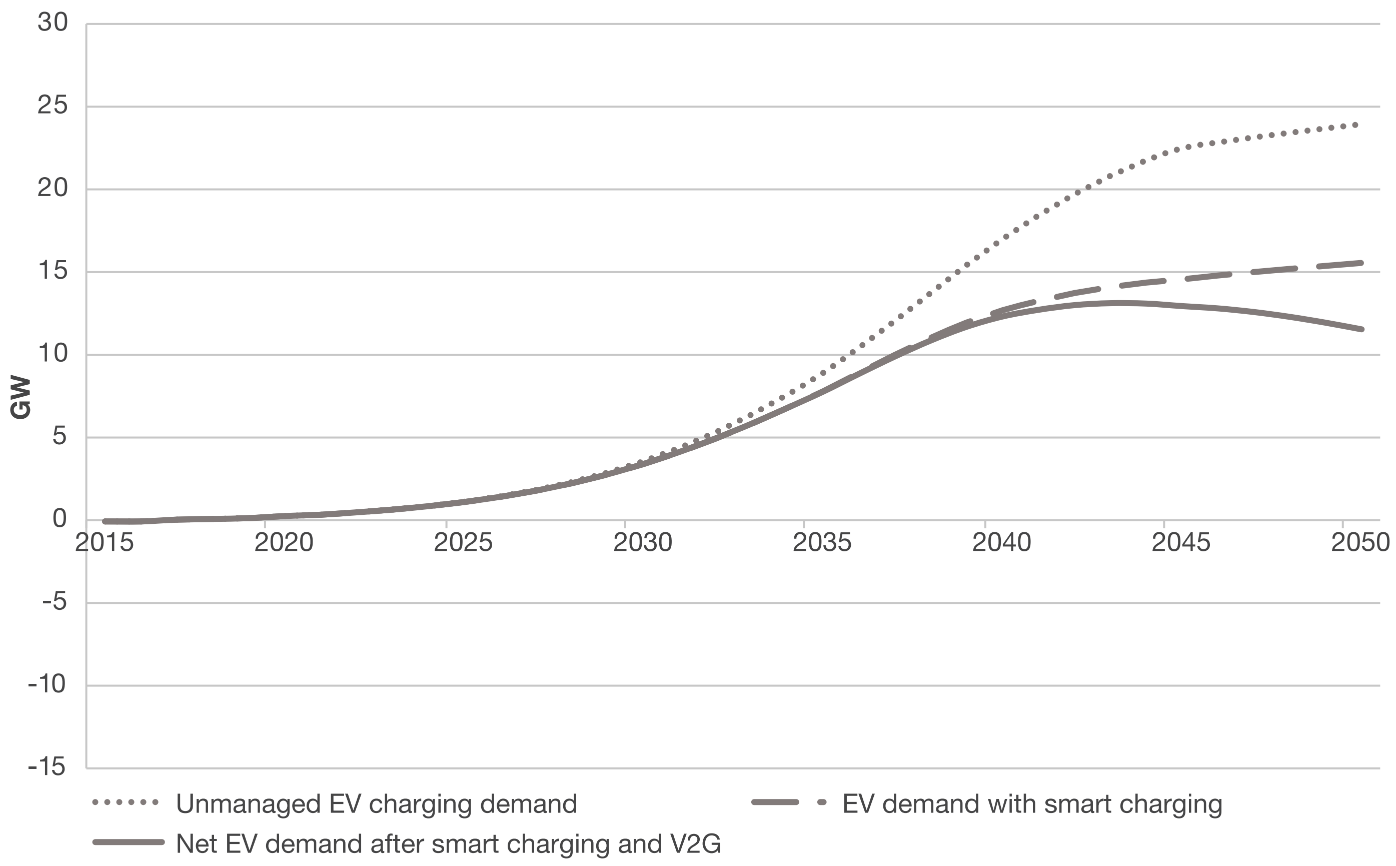


Figure FL.11: Electric vehicle charging behaviour at ACS winter peak system demand



Steady Progression

Electrolysis

Electrolysis plays an important role as a source of flexibility in the net zero scenarios, able to ramp up demand rapidly to match renewable output and producing hydrogen that can be stored until it is needed.

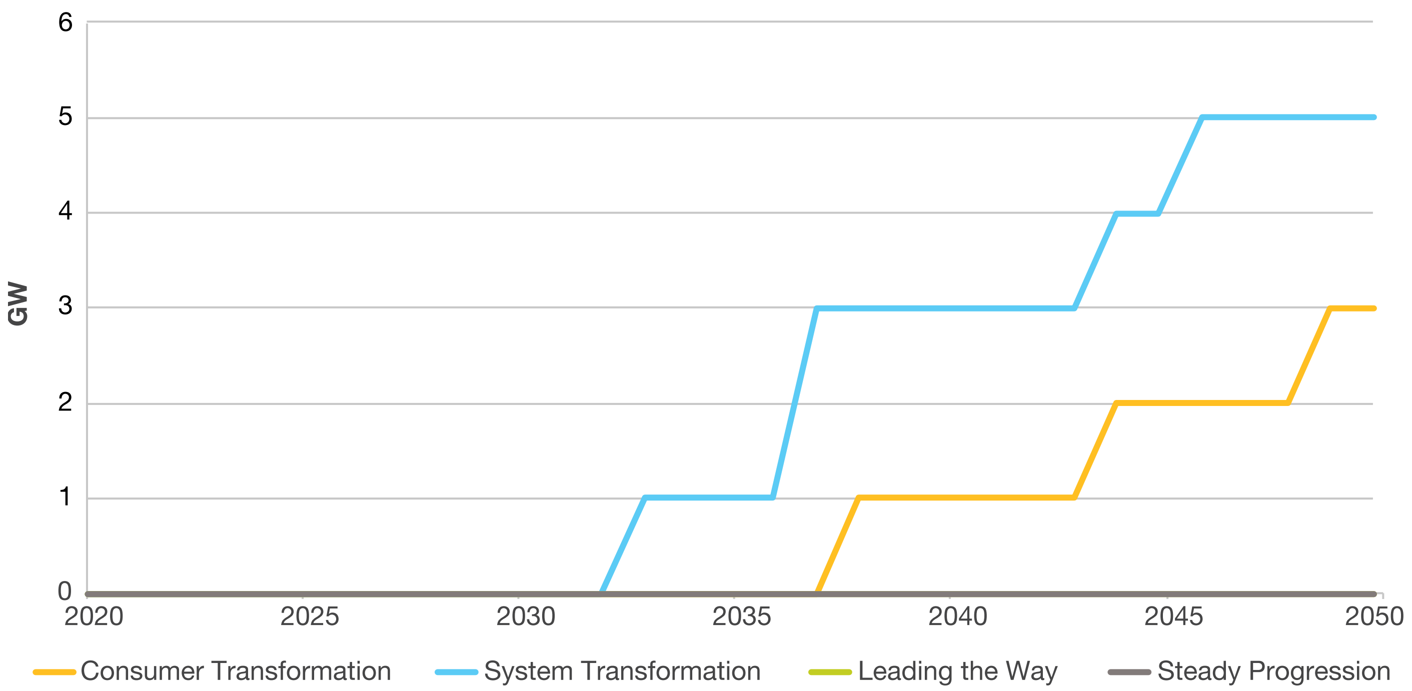
Leading the Way sees the earliest development of significant electrolysis capacity, reaching over 10 GW by 2034, followed by the other net zero scenarios by 2041. There is only limited development of electrolysis production in Steady Progression due to limited demand for hydrogen and because the electricity sector is not decarbonised, hydrogen produced from electrolysis is not zero carbon.

In Consumer Transformation and System Transformation some electrolysis capacity developed in the 2030s is connected directly to new nuclear generation, allowing these generators to operate in baseload. At times of low demand, nuclear-connected electrolysis increases to absorb excess power from the reactor. This makes up a relatively small proportion of total electrolysis capacity in these scenarios in 2050; 7% in Consumer Transformation and 14% 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. Electrolysis will be incentivised to operate and respond to electricity prices and market conditions. We don't expect it to run at times of peak demand unless it is matched with 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.

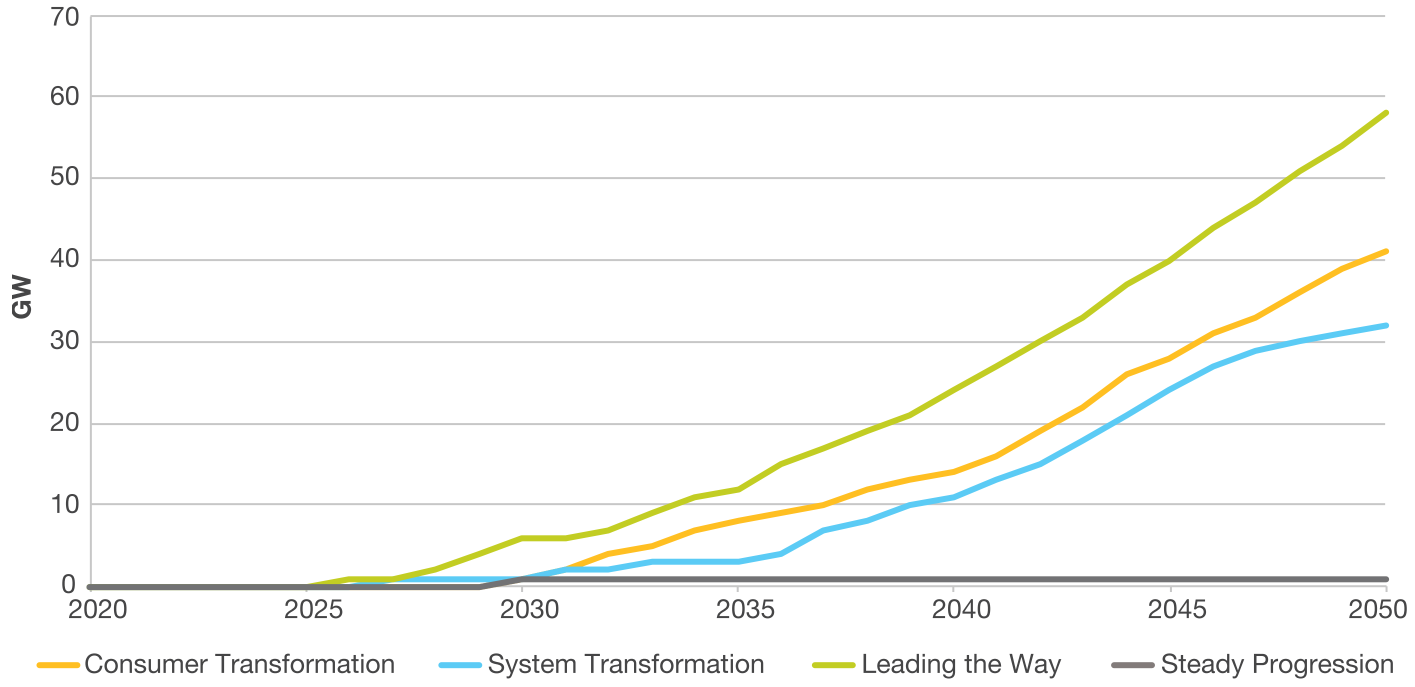
The locations of electrolysers need to consider a range of factors to maximise value to the energy system. There must be hydrogen storage on site or nearby and the connection to a network or infrastructure to transport the hydrogen. Locating electrolysers close to renewable generators could also minimise the need for electricity network reinforcement to transport this energy. However, sub-optimal siting could potentially increase network costs and constraints.

Figure FL.12: Nuclear connected electrolysis capacity



What we've found

Figure FL.12: Total onshore electrolysis capacity (network connected and nuclear connected)



FES 2021 / Flexibility 276

Dispatchable sources of supply

We see increased dispatchable sources of supply across all scenarios compared to FES 2020.

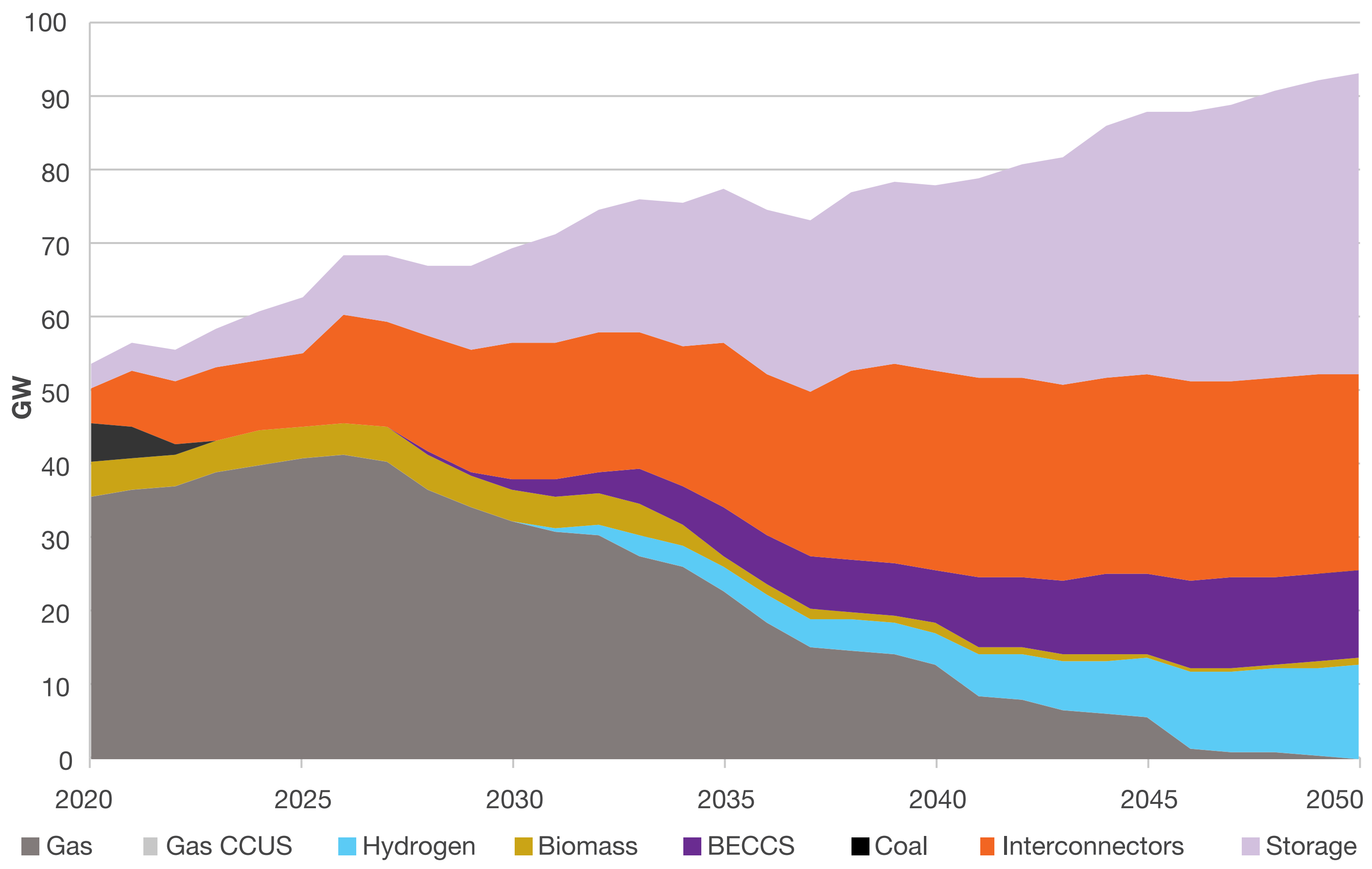
Demand side response will be crucial to help manage peak demands, as shown in Figure FL.8, but the residual demands need to be met by sources of supply under all conditions, even when renewable generation output is low.

Today the bulk of dispatchable capacity comes from thermal generation like gas and coal, in future a much greater share will come from other sources, such as electricity storage and interconnection with other countries and electricity markets.

Unabated fossil fuel generation declines to zero well ahead of 2050 in the net zero scenarios and baseload output from these technologies reduces earlier still; however some level of capacity needs to be retained to meet security of supply and provide resilience. 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, the rapid closure of unabated gas generation capacity in the 2030s sees a net reduction in dispatchable sources of supply at a time when renewable generation capacity is increasing sharply, highlighting some of the challenges that will be faced in operating the system. In System Transformation and Consumer Transformation, the slightly slower closure of unabated gas generation sees a continued trend of net increases in dispatchable capacity out to 2050. In Steady Progression, gas and gas CCUS generation capacity plays the biggest role in ensuring security of supply all the way to 2050.

Figure FL.13: Dispatchable electricity supply sources Consumer Transformation



What we've found

Figure FL.13: Dispatchable electricity supply sources System Transformation

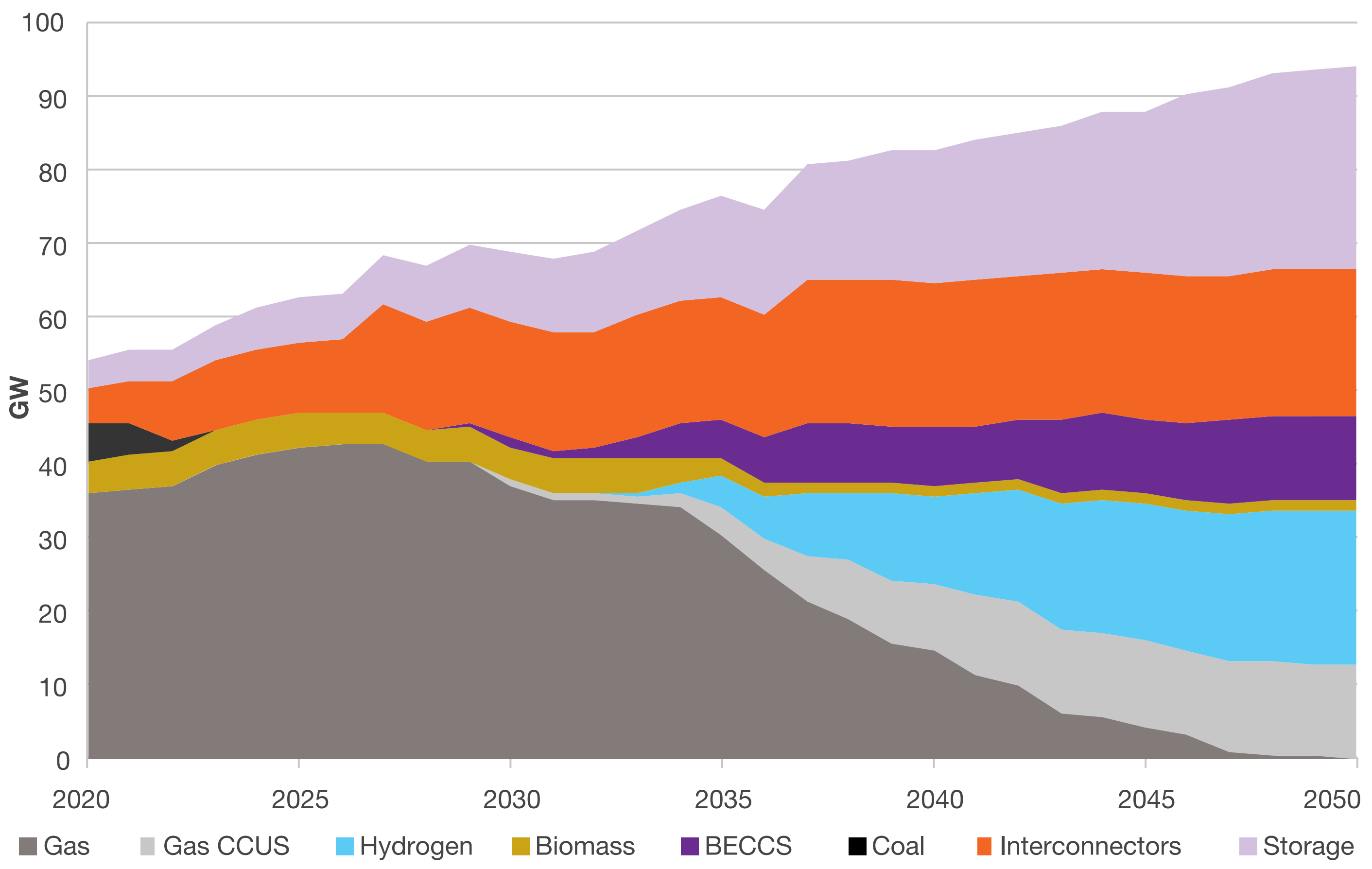
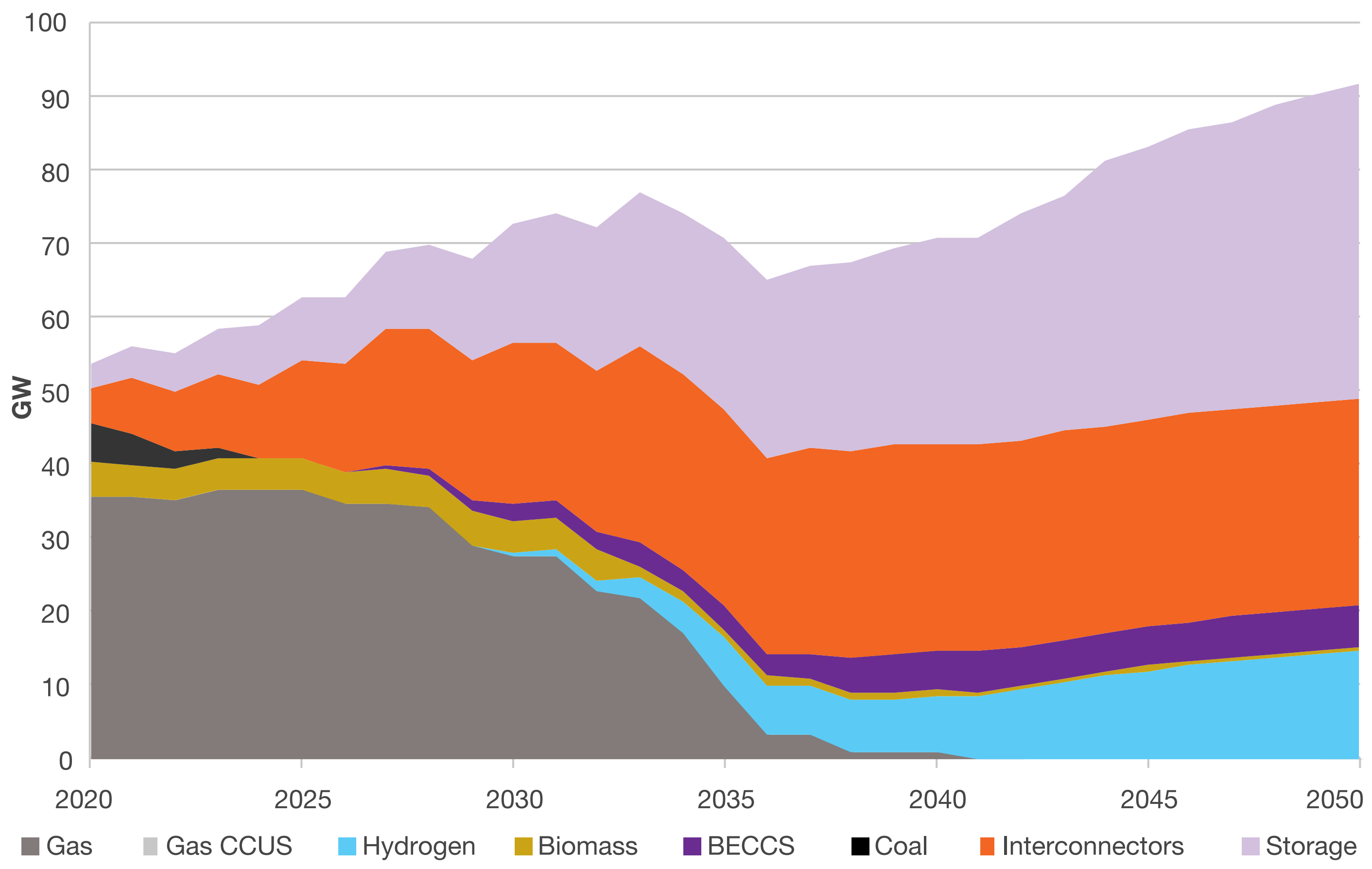
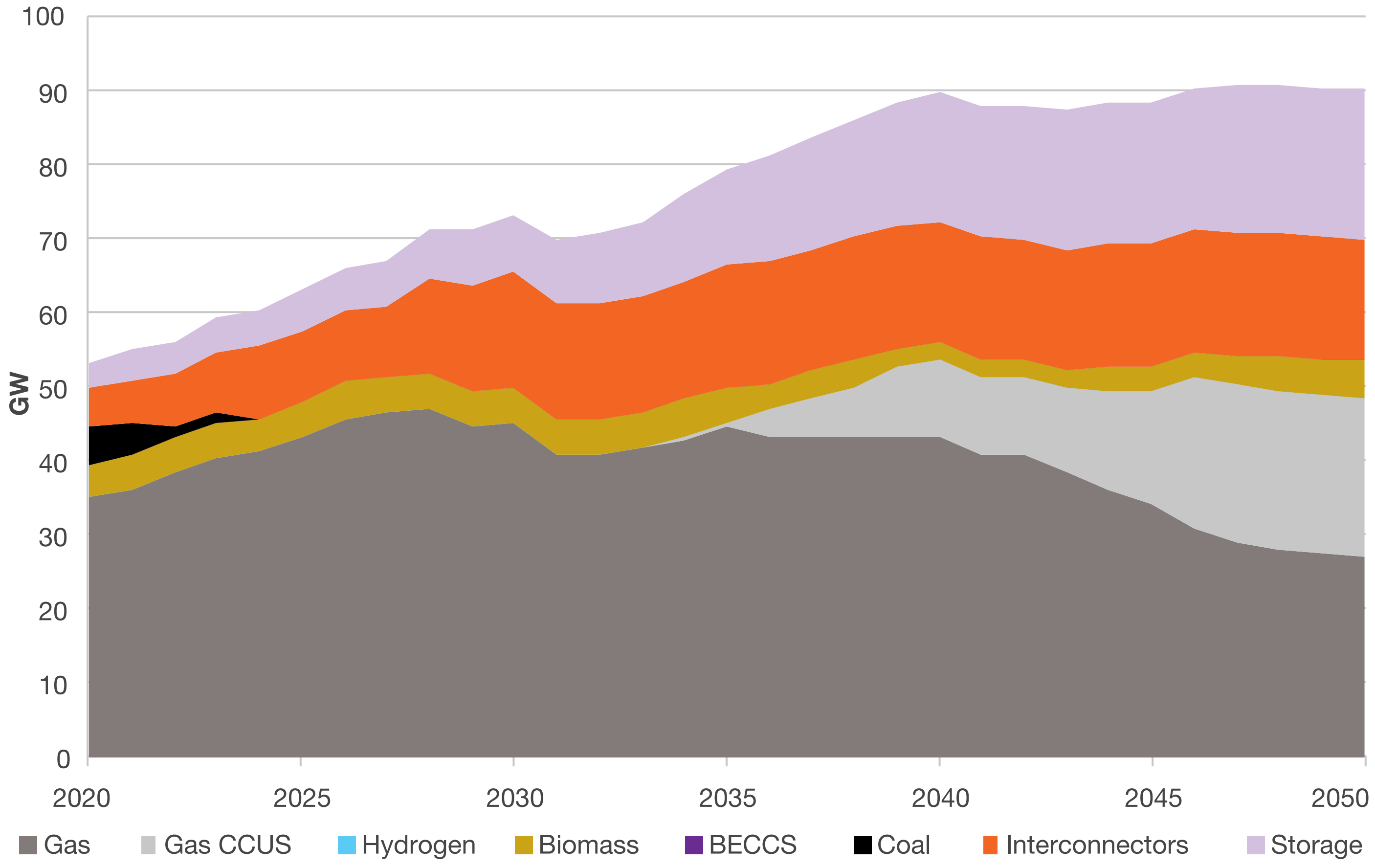


Figure FL.13: Dispatchable electricity supply sources Leading the Way



FES 2021 / Flexibility 278

Figure FL.13: Dispatchable electricity supply sources Steady Progression



FES 2021 / Flexibility 279

Electricity storage

Electricity storage capacities, both GW and GWh, will need to increase significantly to support the decarbonisation of our electricity system. This includes pumped hydro, large-scale, residential and industrial behind-the-meter batteries, and compressed air energy storage (CAES) and liquid air energy storage (LAES).

We see the largest growth in battery storage, which is expected to make up the largest share of power output in GW of any electricity storage technology. We expect to see continued innovation in battery chemistry improving energy density and reducing costs of batteries and supporting higher levels of take-up. Battery storage makes up a smaller share of total energy stored in GWh however. Batteries most commonly have a one to one or two to one ratio of power output to energy storage, pumped storage, CAES and LAES all typically see much more energy stored compared to power output and so are able to charge or discharge at maximum output for a longer period of time.

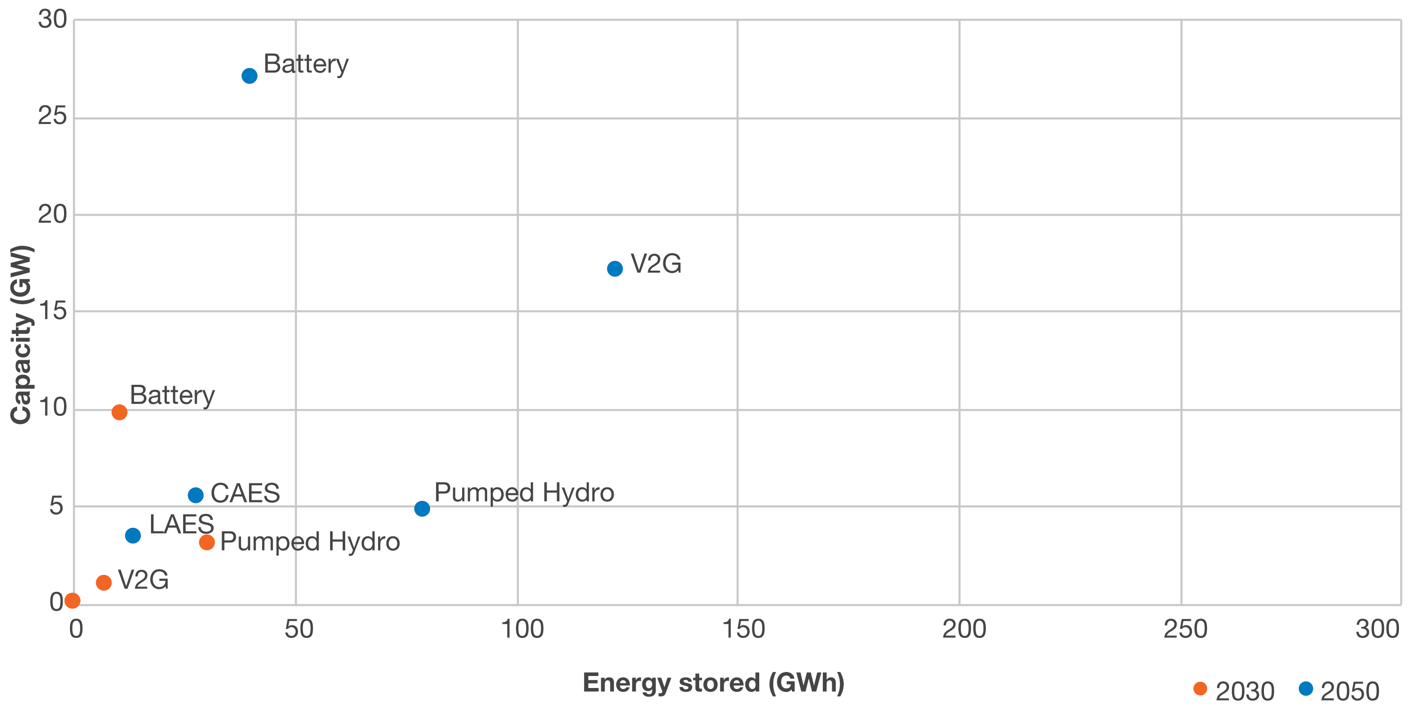
Consumer Transformation and Leading the Way see a relatively larger share of storage connected to distribution networks or co-located with renewable generation, while System Transformation and Steady Progression see higher levels of projects connected to the transmission network. Different durations of energy storage provide different benefits to the energy system. Two to four-hour storage typically helps meet short periods of peak demand, excess supply or support grid stability. Longer duration storage can help secure the system over longer periods of high or low renewable generation output. Non-electrical storage in other fuels such as hydrogen or gas is better suited to very long term or interseasonal storage. This is covered in the whole energy system flexibility section.

The policy and regulatory 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.

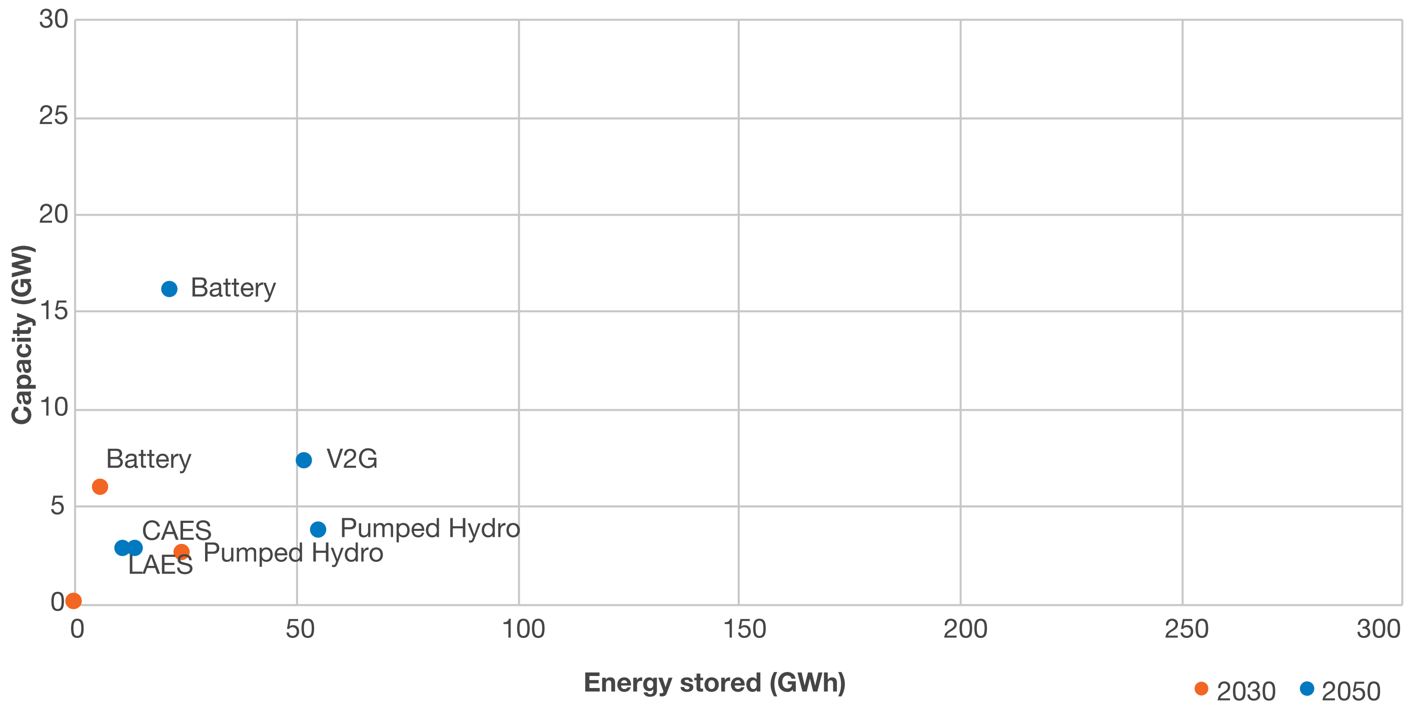
FES 2021 / Flexibility 280

Electricity storage

Figure FL.14: Power and energy outputs of electricity storage types in 2030 and 2050[7]



Consumer Transformation



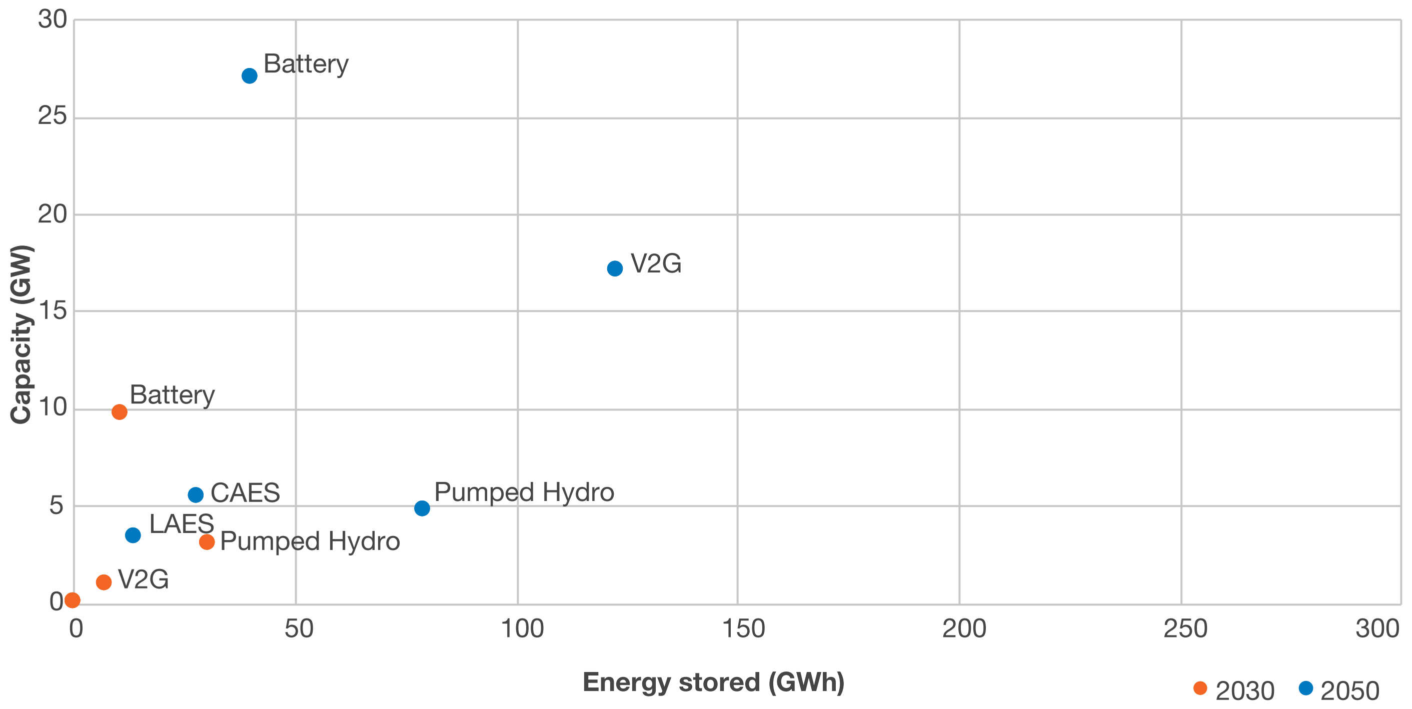
System Transformation

7 Vehicle-to-grid capacity and energy stored represents availability at peak (5-6pm), energy stored assumes 50 kWh of useable battery storage per vehicle in 2050.

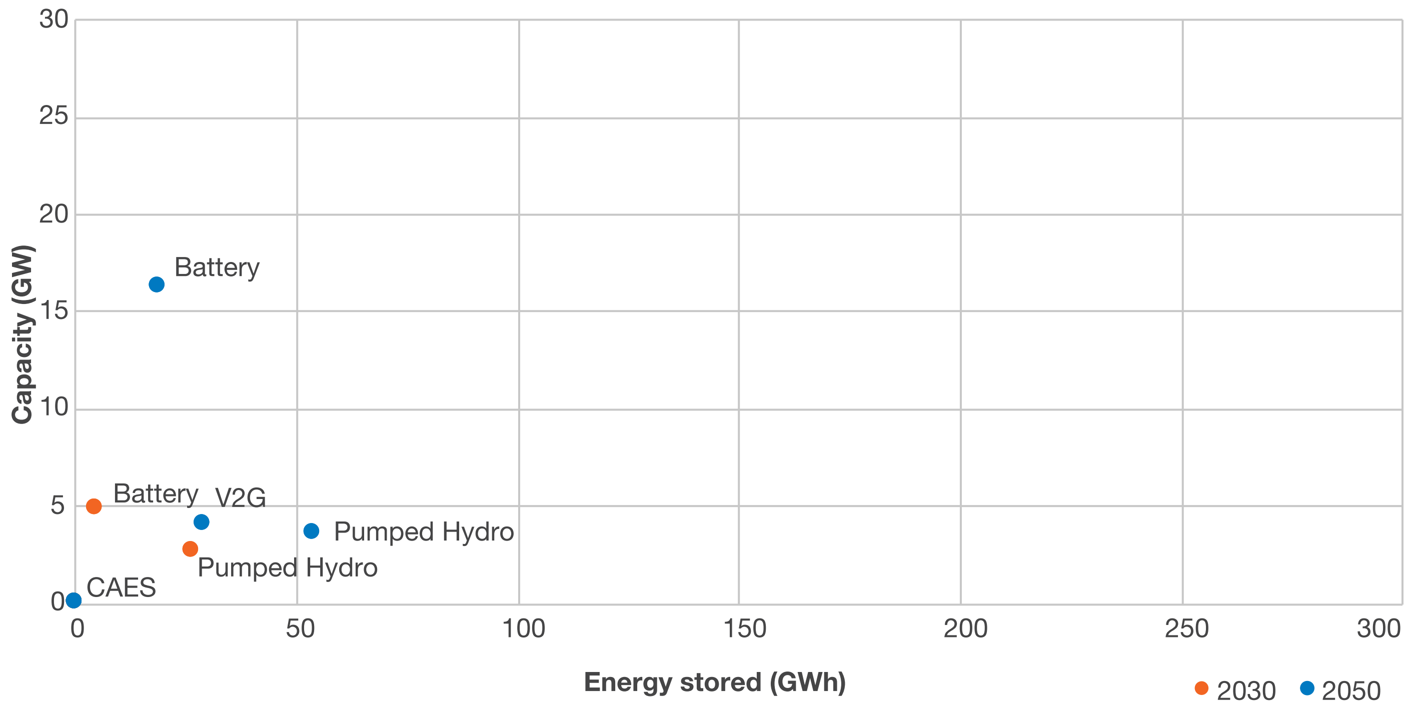
FES 2021 / Flexibility 281

Electricity storage

Figure FL.14: Power and energy outputs of electricity storage types in 2030 and 2050[7]



Leading the Way



Steady Progression

7 Vehicle-to-grid capacity and energy stored represents availability at peak (5-6pm), energy stored assumes 50 kWh of useable battery storage per vehicle in 2050.

Electricity storage

Figure FL.15: Total electrical energy storage (excluding vehicle-to-grid)

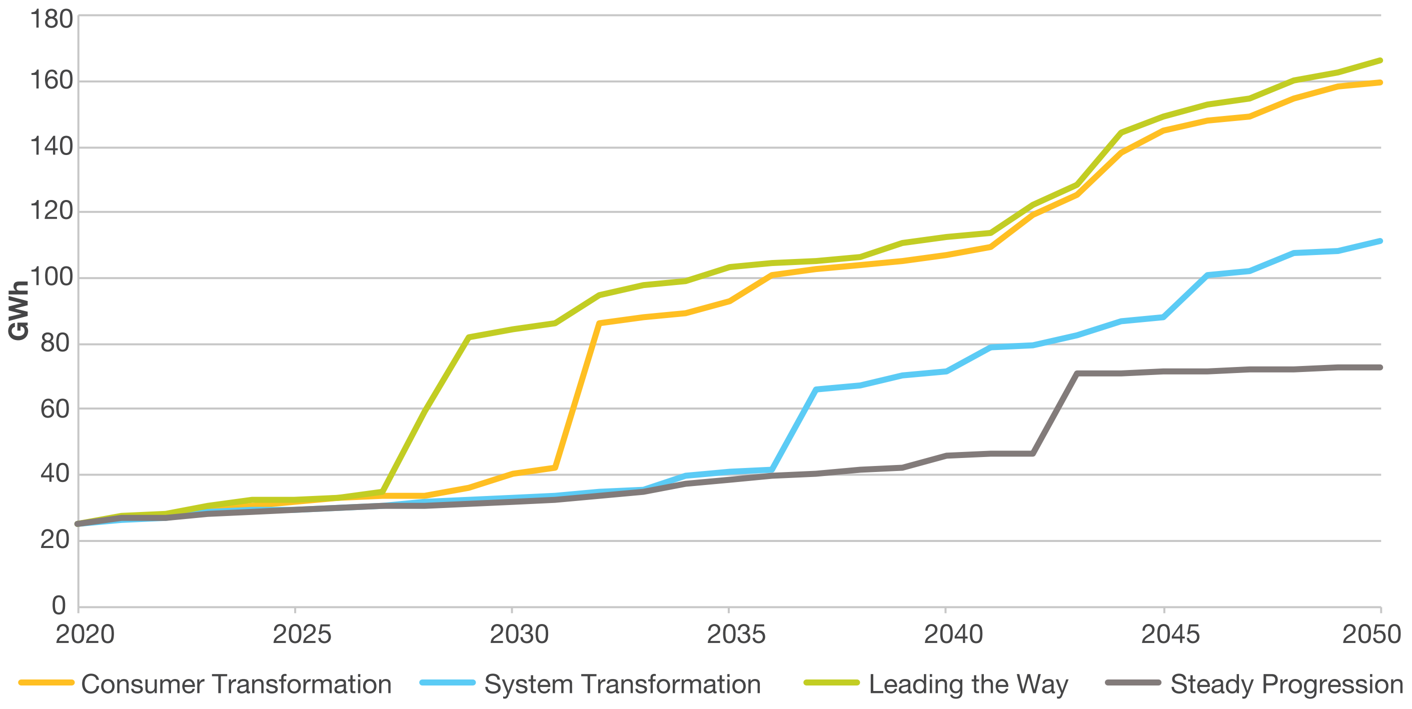
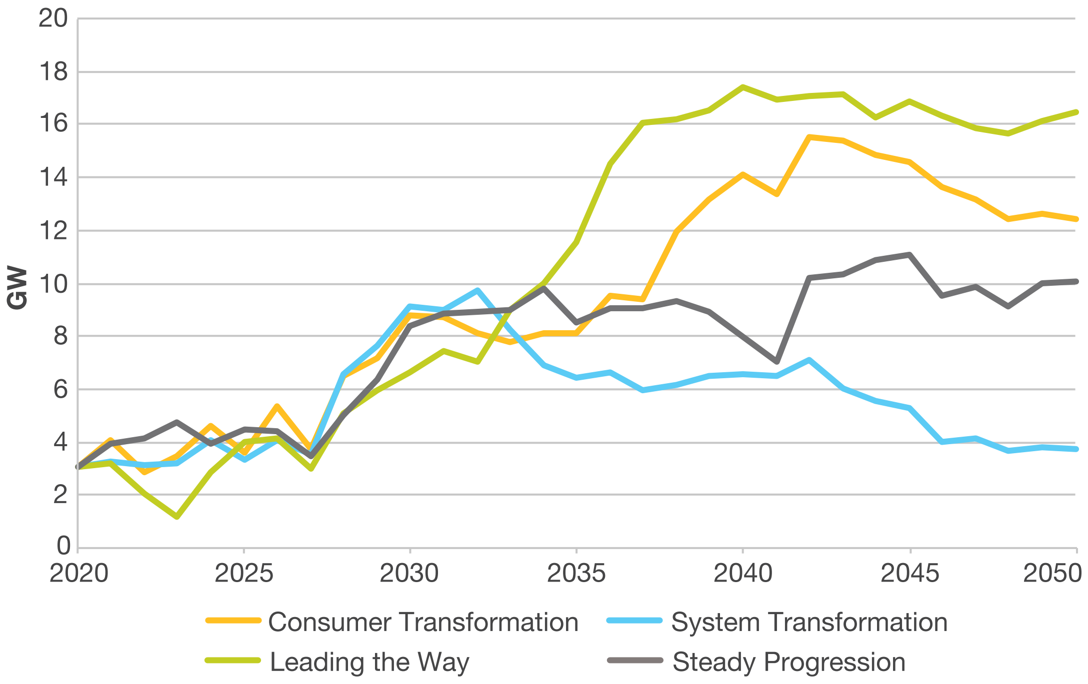


Figure FL.16: Interconnector peak flows[8]



Interconnector flows

We expect imports over the interconnectors with continental Europe to increase over peak in all scenarios through the 2020s as interconnector capacity grows.

Today there are 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.

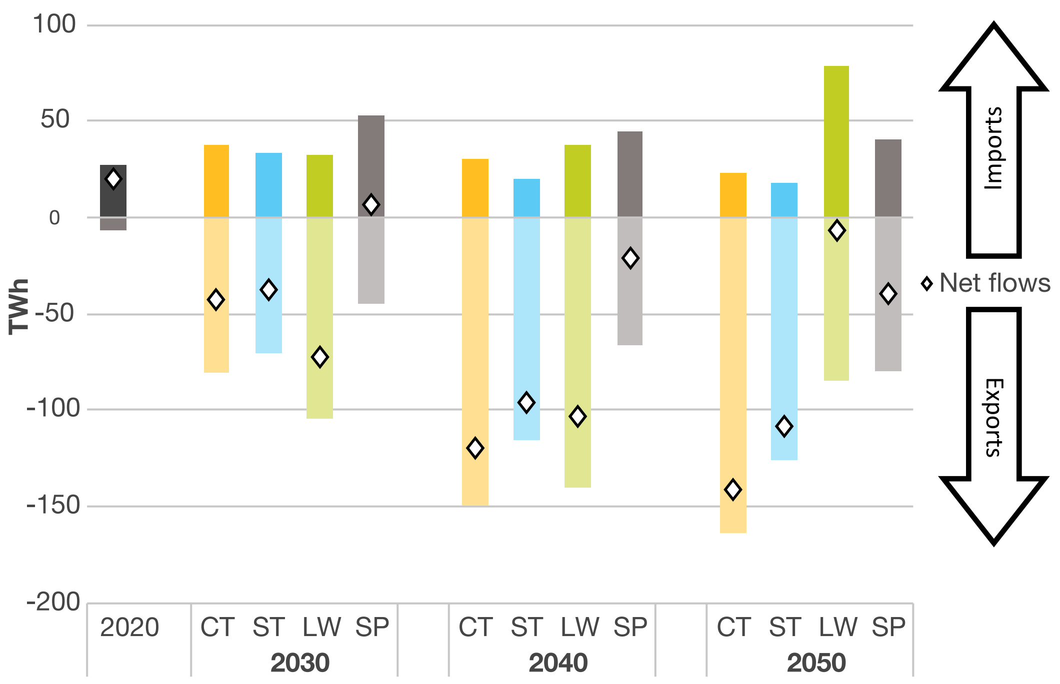
In Consumer Transformation and Leading the Way, peak flows increase through the 2030s as interconnector capacity continues to rise, fossil fuel capacity is phased out and peak electricity demands grow as the economy electrifies. Interconnectors still play an important role in Steady Progression in 2050, despite lower levels of capacity, meeting a greater share of peak demand than today. We consider the security of supply implications of relying on interconnectors to meet peak demand in our modelling using the same approach in our Capacity Market modelling as part of our Electricity Capacity Report, more details of which can be found **here**.[9]

Interconnectors are also used to move energy between GB and its neighbours throughout the year. When there is excess renewable generation in GB, more than 25 GW of interconnection to other electricity markets can be used to export this excess power in Consumer Transformation and Leading the Way in 2050. While operation over the year varies, we do see changing trends in net flows. From the late 2020s to the early 2040s Consumer Transformation and System Transformation see an increasing net export of electricity over the year; the high levels of variable renewable generation, particularly offshore wind, in these scenarios often exceed demand and so power is exported to the continent. Higher levels of electrolysis and demand side response in Leading the Way reduce the need to export power, although interconnectors still play an important role trading electricity throughout the year.

The movement of power over the interconnectors will continue to be primarily driven by price differentials between electricity markets. 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.

8 These are the interconnector flows we have modelled over the hour with the highest peak winter demand.
9 We apply a 'de-rating' factor to all forms of electricity generation as we do not assume that 100% of capacity will be available 100% of the time.

Figure FL.17: Interconnector net annual flows



FES 2021 / Flexibility 285

Thanks for your attention and we hope you found the FES 2021 document interesting and useful!

Continuing the Conversation

In terms of what's next, we now move into our main stakeholder engagement stage of the FES cycle, building on your comments and questions about FES 2021 to inform our new analysis and insight.

Keep an eye out for any surveys, thought-pieces or engagement opportunities via our FES Newsletter. If you are not already subscribed, you can do so via the ESO website or the FES email address opposite.

Also, in a similar fashion to the previous two years, we will be using FES 2021 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.

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 get in touch.

Access our current and past FES documents, data and multimedia at: 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: nationalgrideso.com

Write to us at:

Energy Insights & Analysis
Electricity System Operator
Faraday House
Warwick Technology Park
Gallows Hill Warwick
CV34 6DA

FES 2021 / 286

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 places without oxygen, for example anaerobic digestion which produces methane from biomass.

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 outturn 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 elicit 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 CO_2 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 2021 / Glossary 287

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.

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.

Carbon Pricing
Applying a cost to the emission of each tonne of carbon dioxide.

FES 2021 / Glossary 288

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 Cycle Gas Turbine (CCGT)
A power station that uses the combustion of natural gas or liquid fuel to drive a gas turbine generator to produce electricity. The exhaust gas from this process is used to produce steam in a heat recovery boiler. This steam then drives a steam turbine generator to generate more electricity.

Combined Heat and Power (CHP)
A system where both heat and electricity are generated simultaneously as part of one process. Covers a range of technologies to achieve this. A CHP plant is able to supply both electricity and heat to local buildings.

Climate Change Committee (CCC)
The Climate Change Committee is 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 (CAES) is a way to store energy for later use using compressed air.

Contract for Difference (CfD)
A contract between the Low Carbon Contracts Company (LCCC) and a low carbon electricity generator, designed to 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 is being hosted by the UK this year (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 2021 / Glossary 289

Dispatchable Electricity Supply
Dispatchable supply refers to sources of electricity (e.g. thermal generation or storage) that can be modulated up and down based on market needs or at the request of power grid operators.

Distributed Generation
Generation that is connected to the distribution networks (i.e. at lower voltage than the transmission network). Sometimes referred to as embedded generation.

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.

Electrolysis
Electrolysis is the process of using electricity to split water into hydrogen and oxygen.

Embedded Solar (EMB)
Solar photovoltaic (PV) generation that is connected at distribution level or behind the meter (i.e. rather than to the high voltage transmission network).

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
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.

Future Homes Standard (FHS)
Government policy that requires new homes, built during and after 2025, to have high energy standards. This includes the installation of energy efficiency measures, as well as low carbon heating technologies.

FES 2021 / Glossary 290

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.

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.

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 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.

Industrial Cluster
Hub for industry all using the same local infrastructure e.g. hydrogen supply or carbon capture and storage plant.

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.

Inflexible / Less Flexible Generation
Types of generation that require longer notice periods to change their output or have obligations that influence when they can generate.

Interconnectors
Transmission assets that connect the GB market to markets in other countries and allow suppliers to trade electricity or gas between these markets.

Intermittent 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.

FES 2021 / Glossary 291

Internal Combustion Engine (ICE)
Traditional engine used in transport sector which is powered by fossil fuels such as petrol or diesel.

Interoperability
The ability of a product or system to cooperate with other products or systems to share resources and maximise efficiency (e.g. 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.

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.

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 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.

FES 2021 / Glossary 292

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 networks which 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.

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.

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 Market.

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.

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

Peaking Plant
Electricity generators that operate only at times of peak demand when electricity prices are high.

Plug-in Hybrid Electric Vehicle (PHEV)
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.

FES 2021 / Glossary 293

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)
An 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
An mode of operation an electric heat pump can switch to in order to provide heat when it is very cold, providing around one unit of heat output for every unit of electricity input, compared to around 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.

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.

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
Charging units (e.g. for electric vehicles) which have two way communication ability and that can react to external signals.

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 (Solar PV)
The conversion of energy from the sun into electricity using photovoltaic panels (solar panels).

Steam Methane Reforming (SMR)
Steam reforming or Steam Methane Reformation (SMR) produces most of the world's hydrogen through a chemical reaction between hydrocarbons (typically methane) and steam. This also produces Carbon Monoxide, which can be released into the atmosphere (grey hydrogen) or captured and stored (blue hydrogen).

Supply Side Flexibility
Electricity generators or market participants adjusting electricity supply to meet demand.

FES 2021 / Glossary 294

Synfuels
Synthetic fuel is a liquid, or sometimes gaseous, fuel obtained from syngas, a mixture of carbon and hydrogen. 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.

System Operability Framework (SOF)
The SOF combines insight from FES with technical assessments to identify medium-term and long-term requirements for electricity system 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 as well as the corresponding system in England and Wales, which is owned by National Grid Electricity 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.

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 UK 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 elicits 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 75 g of CO_2/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 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.

Wet Waste
Waste which is a by-product from wet processes such as sewage treatment or brewing.

FES 2021 / Glossary 295

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 (potentially including hydrogen in the future).

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 across the wider economy associated with provision of energy and/or the emission of greenhouse gases; including systems such as transport, water, waste, hydrogen.

Whole Energy 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 2021 / Glossary 296

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 content 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 2021 / 297