Department for
Energy Security
& Net Zero

Biomass Strategy

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Ministerial foreword

The green energy transition has never been more important. In recent years, global energy markets have been rocked by a pandemic, war in Europe, and by pressures on the cost of living across the globe. We have seen how dependence on fossil fuels can leave British citizens paying the price for rogue actions elsewhere in the world. All the while, we are witnessing the increasingly damaging effects of climate change, from rising sea levels to extreme temperatures.

That is why, in March this year, the newly formed Department for Energy Security and Net Zero published the Powering Up Britain strategy, setting out how we're going to build a truly green economy. As that strategy made clear, biomass has a major role to play.

Biomass is already a key component of our energy supply, with bioenergy generating 11% of total electricity supply in 2022. But its future potential is extraordinary: it is a renewable source that can be used across all three energy sectors (transport; heat; and electricity), as well as non-energy sectors. It can deliver low carbon energy, displace fossil fuel use in materials, and produce negative emissions when combined with carbon capture and storage. This strategy, which builds on the Biomass policy statement published in November 2021, explains how we aim to leverage that potential.

One of the most significant challenges is securing a sustainable supply of biomass, both from within the UK and from imports. We are committed to maintaining a strict approach to biomass sustainability and are planning to consult on a sustainability framework to support this approach.

Another challenge is the scaling up of domestic biomass supply, without compromising food security. That's why the government has awarded £36 million to projects across two phases of the Biomass Feedstocks Innovation Programme, funding innovative ideas that address barriers to domestic production.

At the same time, we will continue to develop policy measures to support the scale-up and deployment of biomass technology more generally.

In the decades ahead, biomass' unique potential as a carbon negative renewable energy source will prove ever more valuable in our efforts to reduce emissions, and this strategy explores how we can build this vital industry.

The Rt Hon Graham Stuart MP
Minister of State for Energy Security and Net Zero

Foreword

Professor Paul Monks
Department of Energy Security and Net Zero Chief Scientific Advisor

The United Kingdom has set an ambitious target to achieve net zero greenhouse gas emissions by 2050. Meeting this target will require a significant shift in our approach to energy and low carbon technologies. There has never been a more crucial time to take action, particularly considering the ongoing conflict in Ukraine, which adds to the challenge of decarbonising every sector of our economy while ensuring energy security. To tackle this, there is a need to invest in low carbon technologies and take comprehensive action across all fronts as we progress through the carbon budgets.

The decarbonisation challenge is a complex systems issue that encompasses various sectors, such as transportation, power generation, industry, residential emissions and agriculture. In the future there will be a need for negative emission technologies to compensate for areas where we cannot decarbonise completely. It is not enough to rely solely on technology to solve this challenge; we must actively engage people to ensure there is an understanding of the magnitude of the problem and confidence in the solutions.

Biomass can play a significant role in decarbonising nearly all sectors of the economy. The UK is already a global leader in biomass policy and technologies, with biomass accounting for 8.6% of our energy supply in 2022. This progress is driven by the effective biomass policies that have been in place for over 20 years. These policies have not only helped reduce the reliance on coal in our electricity system but have also stimulated substantial investment in low carbon technologies and fuels.

Meeting the net zero target will require a combination of strategies, including reducing demand, improving efficiency, and implementing low carbon solutions. Biomass is not a silver bullet, and neither is carbon capture. We will rely on a range of solutions to achieve net zero.

One crucial aspect to biomass is its intersection with the environment and how we interact with it. It is imperative that biomass is sourced and used sustainably. This requires clear criteria for what constitutes sustainable biomass and implementing robust monitoring, verification, and reporting processes. The UK was one of the first countries to develop and use sustainability criteria for biomass across various sectors, and we have worked actively internationally to enhance and refine them.

There is a need, as laid out in this strategy, to review and further strengthen the criteria.

There are no easy solutions to the decarbonisation challenge. As we progress towards net zero, we must prioritise low regrets options that allow us to move forward effectively and quickly. Placing sustainability as our top priority when utilising biomass will support this approach.

The following strategy outlines our assessment of the potential role of biomass in achieving our net zero target. It acknowledges that there is a finite supply of sustainable biomass, emphasising the need to carefully consider how we can direct its usage. The evidence suggests that we should prepare for a transition to a world where we deploy more carbon capture technologies. Through biomass, we can achieve both low carbon energy sources and some of the negative emissions necessary to reach net zero.

Executive Summary

The purpose of the Biomass Strategy is to set out the role biomass can play in reaching net zero, what government is doing to enable that objective and where further action is needed.

Biomass is defined as any material of biological origin, including the biodegradable fraction of products, crops, wastes and residues from biological origin. It is a versatile resource that can be used in multiple ways across different technologies and is an important component of many of our pathways to net zero. The Strategy restates the government's firm commitment to biomass sustainability. It reviews the potential future availability of sustainable biomass to the UK and considers how this resource could be prioritised strategically across the economy to help achieve the government's net zero target, and wider environmental and energy security commitments.

Biomass sustainability

Government has supported the use of biomass across the power, heat and transport sectors since the 2000s embedding world-leading sustainability criteria within its support schemes. Only biomass use that complies with strict criteria is considered to be low carbon and to deliver genuine CO_2 emissions savings. Government is minded to take a series of further actions to strengthen the UK's biomass sustainability criteria used in future schemes, to ensure they reflect the most advanced thinking on sustainability.

A key commitment of the Biomass Strategy is to develop and implement a cross-sectoral common sustainability framework, subject to consultation.

Biomass availability

The UK's ability to gain access to sustainable feedstocks at sufficient scale and acceptable prices will ultimately determine the overall contribution of biomass to net zero. As the biomass supply is so diverse, understanding future availability is complex and subject to significant uncertainties.

Biomass from domestic sources currently make up 66% of the total biomass used in renewable energy generation, with the rest deriving from international sources. The illustrative scenarios presented in this strategy show that both domestic and imported sustainable biomass supply are expected to be important in supporting biomass use across the economy.

Government, businesses, and biomass producers all have a role in introducing interventions that increase the supply of biomass and reduce supply costs. Domestic biomass cultivation and deployment will be considered in the context of the government's Food Strategy commitment to maintain current levels of food production and alongside our legally binding Environment Act 2021 targets.

We will continue to monitor the levels of biomass supply to ensure the UK can secure the necessary supply for increasing biomass use across the economy and we will consider interventions to remove barriers to increasing biomass supply if necessary.

Priority use of biomass

As sustainable biomass is a limited resource and future availability to the UK is uncertain, its use should be prioritised where it offers the greatest environmental, economic and social benefits. Opportunities for biomass use within each sector should be considered against other low carbon alternatives available to that sector. As a result, harder to decarbonise areas, technologies and sectors should be some of the priority uses of biomass.

In the **short term** (2020s) government will continue to facilitate sustainable biomass deployment through a range of incentives and requirements covering power, heat and transport.

In the **medium term** (to 2035) government intends to further develop biomass uses in power, heat and transport sectors to support the delivery of Carbon Budget 6, with a view to transition away from unabated emission uses of biomass where possible to uses such as Bioenergy with Carbon Capture and Storage (BECCS), which are critical to meeting net zero, as they are needed to balance the residual emissions from hard-to-decarbonise sectors.

Biomass use in the **long term** (to 2050) is difficult to predict owing to wide ranging uncertainties and evidence gaps. Current modelling indicates that biomass use combined with BECCS for power, heat and transport contribute the most towards net zero. Emerging bioeconomy products and markets beyond energy will continue to be reviewed.

Based on current analysis, the strategy sets out that biomass uses that can produce negative emissions (i.e., those that capture and store CO_2) should be prioritised in the long term to support UK's net zero target. Biomass could still play a role in hard to decarbonise sectors that may not be able to universally deploy BECCS but have limited alternatives. However, relative demand is expected to be lower than BECCS usage. New or existing biomass applications should therefore consider options and routes to deploy BECCS at their facilities in the longer-term.

Biomass with carbon capture and storage

Bioenergy with Carbon Capture and Storage (BECCS) is an engineered Greenhouse Gas Removal (GGR) technology that captures and stores CO_2 from biomass while producing low carbon energy, including electricity, heat, hydrogen and biofuels.

Alongside the Strategy, the government is publishing a report led by the Department for Energy Security and Net Zero Chief Scientific Adviser's Task and Finish Group which sought to establish an evidence-based position on the validity of BECCS as a GGR option to deliver negative emissions.

The report sets out how **"well regulated" BECCS can achieve its objective to deliver negative emissions and ensure positive outcomes for people, the environment, and the climate.**

Although BECCS is not currently operating at scale in the UK, the technology is operating elsewhere globally in demonstration plants and at commercial scale. The deployment of BECCS will come via several possible routes, each of which are at various stages of technology readiness.

There is active work ongoing in government to support BECCS, including development of several business models to support it.

Biomass uses across the economy

Biomass for **renewable electricity generation** has played a significant role in decarbonising our power sector. Biomass electricity and power BECCS could provide either dispatchable or baseload power, offering valuable flexibility to complement the variability of other renewables. The role of biomass electricity is being explored in the Review of Electricity Market Arrangements (REMA).

Biomethane will continue to play an important role in optimising the path to net zero and increasing energy security; it can support decarbonising a number of sectors such as heat, transport and power, and the anaerobic digestion (AD) process is recognised as a recycling activity, creating a more circular economy. As part of this, we are taking a holistic approach to identify the barriers to the growth of the biomethane market and understand how best to address these.

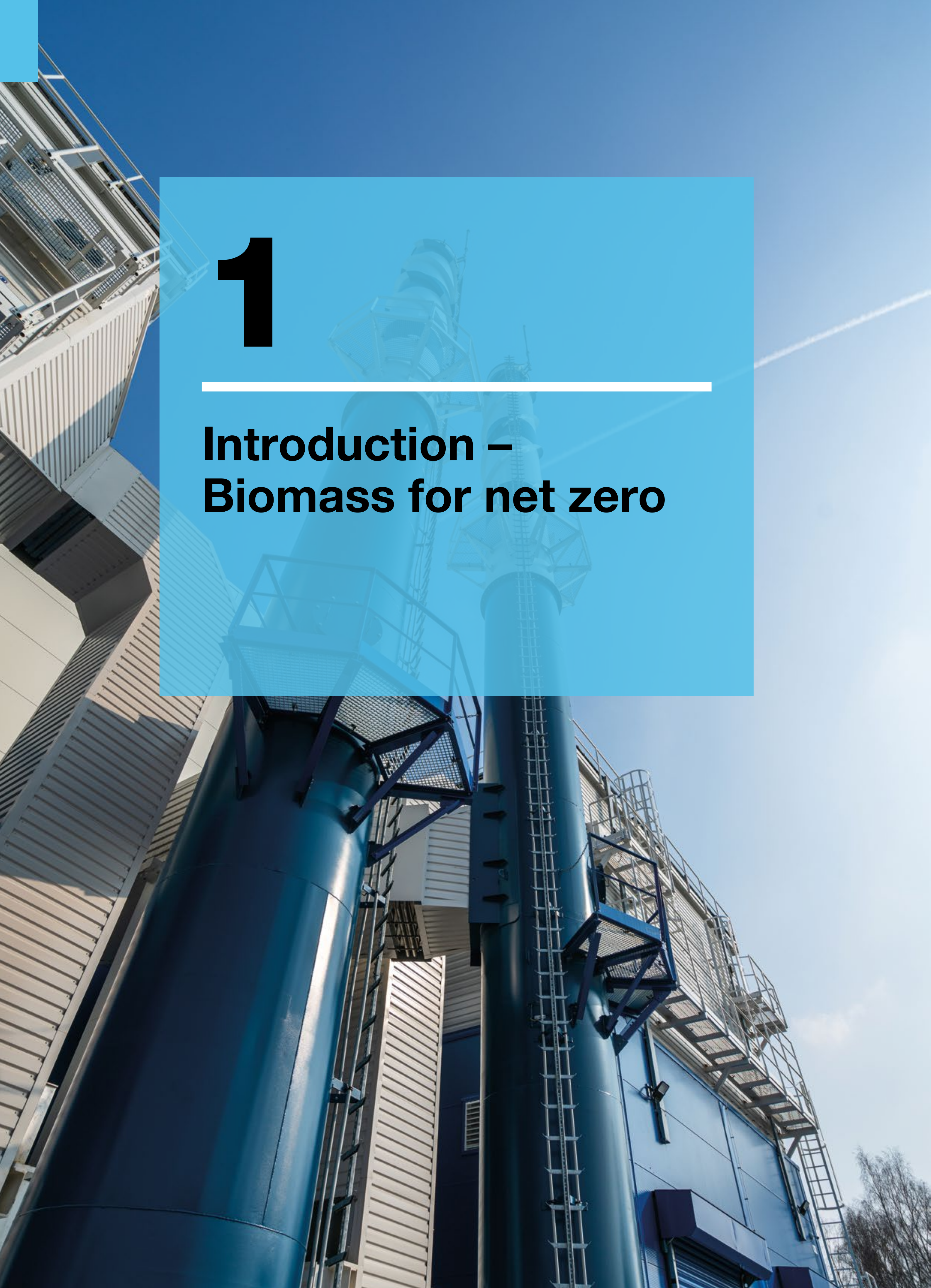
Biomass will likely have a role in **heating** in certain properties such as off-gas grid homes that are not readily suitable for heat pumps, and where appropriate mitigations can be set in place to minimise air quality impacts. The government is considering a range of options to decarbonise these types of properties.

Low carbon **transport fuels** include liquid and gaseous fuels produced from biomass. They play an important role in the decarbonisation of the transport sector, replacing the use of fossil fuels. Today we see their use in road vehicles, but as zero tailpipe emission technologies become commonplace their role will increasingly shift to transport modes with limited alternatives to the use of liquid and gaseous fuels, such as aviation and maritime. DfT will publish a Low Carbon Fuels Strategy which will set out how the deployment of low carbon fuels, including biofuels, may evolve in the period to 2050 across different transport modes.

Industrial decarbonisation – We are working to enable industry to meet the ambition of replacing 50TWh of fossil fuels with renewable energy sources by 2035. Biomass use in industry should be prioritised in combination with CCUS. In the absence of viable BECCS infrastructure, we will continue to support biomass use in industry where limited low carbon alternatives are available.

Biomass can be used directly as a feedstock for **low carbon hydrogen** through reformation, gasification, or pyrolysis technologies, and if carbon capture and storage is added this can provide negative emissions. The UK is committed to supporting multiple production routes to hydrogen.

Other uses of biomass – there is an increased interest globally and in the UK in the concept of the bioeconomy. The bioeconomy includes both energy uses and non-energy uses of biomass, such as wood-based products (e.g., timber, wood panels, etc), biochar, and bio-chemicals and biomaterials (bioplastics). Government will work with international and industry partners to better understand how the bio-based chemicals and materials sectors can form part of the long term priority use of biomass.



1

Introduction – Biomass for net zero

Biomass production and use in the UK today

When produced sustainably, biomass is a renewable, low carbon energy source and material. This is because its inherent energy comes from the sun, it absorbs carbon dioxide (CO_2) as it grows, and it can be used to directly displace fossil fuels such as oil, coal, and natural gas, for the production of energy or other products. Biomass can regrow in a relatively short time, unlike fossil fuels; and the carbon that is released from the organic material was sequestered recently from the atmosphere, compared to fossil fuels where the carbon was sequestered hundreds of millions of years ago. Many biomass feedstocks are wastes or residues that would be combusted or left to decompose, so it is more efficient to use that material and displace expensive, volatile fossil fuels in the process.

Biomass covers a broad and varied range of materials, and the current resource supply is diverse. We define biomass as any material of biological origin (including biodegradable fraction of products, wastes and residues from biological origin). Biomass feedstocks considered in this Strategy include purpose-grown biomass, biomass co-products, residual biomass, and biogenic waste, from both domestic and imported sources. Purpose-grown crops are mainly conventional food and feed crops, but they can also include perennial energy crops (Miscanthus and short-rotation coppice (SRC)), and short-rotation forestry (SRF). Co-products and residues include those from the agricultural and forest sectors. Biogenic wastes include those from the agricultural, commercial, industrial, and municipal sectors.

While the UK does produce around 66% of its biomass supply,[1] some is imported to the UK either as a final fuel, or as a raw or processed feedstock.

Sustainable biomass is a versatile, low carbon material that can be used as a low carbon alternative to fossil fuels for energy (heat, power, transport fuels), including as an energy source for industrial processes or as a raw material used to make products (such as bio-based plastics and materials from foundational industries). Biomass has played a prominent role in decarbonising the power, heat, and transport sectors. The latest energy statistics (2022) estimate that bioenergy provided 8.6% of the UK's energy supply,[2] most of which was supported by government. Not only does biomass offer a decarbonisation tool to various sectors in the UK, but it can also provide skilled jobs, boost the economy, and provide a route to utilise some of the resources the UK has, or has access to, which are often low value and problematic to dispose of.

The use of biomass in the power, heat and transport sectors has largely been supported by policies aimed at achieving renewable energy targets since the 2000s. These have been successful in establishing the industries, infrastructure, and the supply chains, and have helped reduce the UK's reliance on fossil fuels. However, the current policy landscape is undergoing changes considering the net zero target, of which biomass is expected to make a significant contribution. This strategy sets out the objectives and priorities that should govern the use of biomass in line with this target.

1 DUKES 2023 renewable sources of energy: https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes Table 6.1.

2 DUKES 2023: https://www.gov.uk/government/statistics/energy-chapter-1-digest-of-united-kingdom-energy-statistics-dukes Table 1.1.

Policy context

The 2012 Bioenergy Strategy introduced a set of principles for future government policies on bioenergy. It specified that bioenergy should deliver genuine greenhouse gas (GHG) reductions, should make a cost-effective contribution to UK GHG emission objectives, and any increased production should consider the impact on food security and biodiversity, amongst others. These principles remain central to government's approach to biomass, though it must be built upon to ensure that biomass makes the best possible contribution to delivering net zero.

More recently, the Net Zero Strategy: Building Back Greener[3] set out that the UK needs to continue to move away from fossil fuels and expand the production of innovative low carbon fuels, reduce the demand for energy and carbon-intensive resources, and increase our resource use efficiency. Biomass has a role to play in all these areas.

The Net Zero Strategy also identified that Greenhouse Gas Removal (GGR) technologies (including Bioenergy with Carbon Capture and Storage) will be essential, as they are required to balance the residual emissions from hard-to-decarbonise sectors while providing new economic opportunities. A diverse mix of GGR technologies will be required to meet our targets, reduce reliance on any single technology, and deliver a resilient negative emissions market that can support decarbonisation at the lowest cost while maximising the benefits to the UK economy.

In this context, Bioenergy with Carbon Capture and Storage (BECCS) will be a major route for delivering engineered GGRs, as it combines the use of biomass to provide low carbon energy and products with carbon capture and storage. This means the CO_2 contained within the biomass, which was removed from the atmosphere during plant growth, is captured and placed into long term storage.

The Net Zero Strategy presented illustrative scenarios for achieving net zero. Within these, biomass use is scaled up considerably from today's level, largely as a result of BECCS development, particularly hydrogen BECCS. As negative emissions are key for delivering net zero, we expect biomass use in BECCS to increase in the future as these new technologies deploy over time.

Almost all biomass uses could deploy some level of BECCS if optimally sited or used at an appropriate scale. Carbon capture and storage (CCS) technology has been operating safely in locations around the world since the 1970s. There is active government work taking place to develop business models to support various routes of BECCS, as well as commitments made to deploy carbon capture usage and storage (CCUS) infrastructure.

3 https://www.gov.uk/government/publications/net-zero-strategy

Alignment between Strategies

Biomass production and use spans many sectors of the economy; it features in various government strategies including more recently:

- The recently published **Powering Up Britain: Net Zero Growth Plan**[4] (2023) reiterated the **Net Zero Strategy** (2021) ambition to deploy at least 5 $MtCO_2$/yr of engineered GGRs by 2030, which could potentially rise to 23 $MtCO_2$/yr by 2035. It also restated the government's ambition to achieve 50 TWh of industrial fuel switching to low carbon fuels by 2035. We expect this primarily to be reached via switching from fossil fuels to electricity and hydrogen, though bioenergy could enable additional carbon savings.
- The 2030 **Strategic Framework for International Climate and Nature Action**[5] (2023) set out a high-level framework to guide the UK's international climate and nature policy through to 2030 taking an integrated approach to climate (including mitigation, adaptation and resilience) and nature.
- The **Powering up Britain – Energy Security Plan**[6] (2023) outlined how the government plans to secure our energy system by ensuring a resilient and reliable supply, increase our energy efficiency, and bring bills down through decisive actions to increase Britain's low carbon domestic electricity supply. It continues UK leadership in securing the economic benefits of the energy transition, including through major investment in Carbon Capture Utilisation and Storage (CCUS). It also set out that increasing volumes of domestically produced biomethane will be injected into the gas grid through the Green Gas Support Scheme (GGSS) which will reduce carbon emissions, decrease reliance on natural gas and provide diversity in gas supply.
- The **Jet Zero Strategy**[7] (2022), sets out the government's plan for achieving net zero aviation by 2050, through rapid technology development. The Strategy sets out a multi-measures approach and includes ambitious targets of net zero domestic UK aviation and zero emission airport operations in England by 2040. The government has also committed to having at least five UK SAF plants under construction by 2025, supported by the £165 million Advanced Fuels Fund, and to introduce a SAF mandate targeting at least 10% SAF in the UK aviation fuel mix by 2030. A second consultation on the mandate's design and options for setting targets beyond 2030 was published in March 2023.
- The **British Energy Security Strategy**[8] (2022) set out an ambition to deliver up to 10GW of low carbon hydrogen production capacity by 2030, subject to affordability and value for money.

4 https://www.gov.uk/government/publications/powering-up-britain/powering-up-britain-net-zero-growth-plan
5 https://www.gov.uk/government/publications/2030-strategic-framework-for-international-climate-and-nature-action
6 https://www.gov.uk/government/publications/powering-up-britain
7 https://www.gov.uk/government/publications/jet-zero-strategy-delivering-net-zero-aviation-by-2050
8 https://www.gov.uk/government/publications/british-energy-security-strategy

- The **UK Hydrogen strategy**[9] (2021) highlighted that low carbon hydrogen is a critical component of our strategy to deliver energy security, drive economic growth and support net zero. It has the potential to help to bring down emissions in vital UK industrial sectors and provide flexible energy for power, heat, and transport. To reach the scale and cost reductions required to help deliver net zero, we are supporting multiple production routes, including via biomass.
- The **Industrial Decarbonisation Strategy**[10] (2021) acknowledges that low carbon technologies required for decarbonising industries are at different stages of development. The Strategy outlines a comprehensive approach to support the deployment of low carbon technologies, drive innovation, and ensure the long term competitiveness of industries while transitioning towards a net-zero future.
- The **Heat and Buildings Strategy**[11] (2021) set out how the UK will decarbonise its homes, and commercial, industrial and public sector buildings, as part of setting a path to net zero by 2050. This considered the role that bioenergy can play in helping to decarbonise the sector. It recognised that increased production of biomethane would be needed to decarbonise the gas grid, as well as how bioenergy can be used in decarbonising difficult-to-treat properties off the gas grid. The strategy also acknowledged the need to ensure that environmental standards are not adversely affected (e.g., air quality and feedstock sustainability).
- The forthcoming **Low Carbon Fuels Strategy** (due 2023) will set out how low carbon fuels, including biofuels, could be deployed across transport modes in the period to 2050. It follows on from the Net Zero Strategy and the earlier Transport Decarbonisation Plan which set out plans for the transport sector to achieve net zero, including through use of low carbon fuels such as biofuels.
- The **England Trees Action Plan**[12] (2021) set out ambitious tree planting aspirations, highlighted the importance of forestry in the green economy and recognised the need to develop the evidence base for woodland and tree cover expansion, including species choice for short rotation forestry.

The devolved administrations have also published several strategies and plans where production and use of biomass in individual sectors is reflected. References to these have been made where relevant in the Strategy.

These strategies outlined how individual sectors are expected to contribute to climate mitigation and adaptation, with all touching on either the production or use of biomass. Therefore, the Biomass Strategy is an opportunity to bring these strategies across all areas of government together and provide an overview of the prioritisation of biomass use, and updated information on the availability of sustainable biomass to the UK.

9 https://www.gov.uk/government/publications/uk-hydrogen-strategy
10 https://www.gov.uk/government/publications/industrial-decarbonisation-strategy
11 https://www.gov.uk/government/publications/heat-and-buildings-strategy
12 https://www.gov.uk/government/publications/england-trees-action-plan-2021-to-2024

Public engagement

Alongside this Strategy we have published the summary of the Biomass Strategy Call for Evidence,[13] where government sought the public's view on the role of biomass in achieving net zero. The Call for Evidence received 144 unique responses from a range of sectors, covering biomass users, suppliers, trade associations, utility companies, academics and non-profit organisations. It overall highlighted the diverse and often opposing views on the use and sustainability of biomass, and we have used the information gathered through this, and through focused industry stakeholder engagement sessions, to inform the Strategy.

To understand the views of the wider public, a Biomass Public Dialogue Project was commissioned in April 2022 to engage a diverse group of participants, broadly reflective of the UK public, on the sources and uses of biomass. Views gathered from this project have helped to inform this Biomass Strategy, and learnings from the project have been reflected throughout this document.

Participants heard a range of perspectives and whilst most participants thought biomass should play a role in achieving net zero, views were varied on how large a role it should play due to concerns about the potential environmental impact.

Participants remained sceptical about the concept of 'sustainable biomass' and were initially ambivalent about the role of BECCS in achieving net zero. Participants wanted more information on the conditions under which biomass sourcing, use and production can be proven as a sustainable energy source; and information on how biomass use may influence daily lives. Chapters 2 and 5 reflect on these conditions and how they are applied to the sustainability criteria review and priority use assessment. The full Public Dialogue on the Role of Biomass in Achieving Net Zero: Final Report' is published alongside this Strategy.[14]

Biomass in Scotland, Wales and Northern Ireland

The Biomass Strategy takes a cross-cutting approach to delivering a comprehensive view on biomass for net zero across the UK and might therefore touch on policy areas that are devolved. All parts of the UK have a significant role to play in delivering net zero, and the devolved administrations have a range of plans and policies in place to reach their own targets and contribute to the UK's net zero target:

- In 2021, the Welsh Government published its Net Zero Wales plan, which focuses on Carbon Budget 2 (2021-2025) and sets out the pathway to net zero by 2050.[15] The plan noted that during Carbon Budget 2, there is a need to clarify the role of biomass in reaching net zero.
- The Northern Ireland Assembly passed NI's first Climate Change Act in 2022.[16] The Act contains a commitment for NI to achieve net zero emissions by 2050. To do this, a Climate Action

[13] https://www.gov.uk/government/consultations/role-of-biomass-in-achieving-net-zero-call-for-evidence
[14] https://www.gov.uk/government/publications/biomass-strategy
[15] https://www.gov.wales/net-zero-wales-carbon-budget-2-2021-2025
[16] https://www.legislation.gov.uk/nia/2022/31/contents/enacted

Plan is being developed which will be the delivery vehicle for NI's first carbon budget.

- Scotland's climate change legislation sets a target date for net zero emissions of all greenhouse gases by 2045.[17] The Scottish Government's Draft Energy Strategy and Just Transition Plan (published January 2023) set out their aim to see bioenergy used only where it can best support Scotland's journey towards net zero.[18] It also states that decisions over use of bioenergy should also align with and support Scotland's goals for protecting and restoring nature.

We will continue to work with the devolved administrations as we develop the policies and proposals set out in the Strategy to support research and innovation, and the deployment of biomass technologies and biomass production.

In the Strategy, we commit to consult on the detail and actions required to implement a cross sectoral sustainability framework. Some of the proposals in the consultation may fall within an area of devolved responsibility in Scotland, Wales and/or Northern Ireland and this would limit the extent to which these proposals could be implemented, subject to agreement. We will continue to work with the devolved administrations as we develop the consultation.

We also recognise that some policies related to biomass use may fall within an area of devolved responsibility in Scotland, Wales and/or Northern Ireland. While we would encourage devolved administrations to consider the biomass priority use assessment, they are not bound to take it into account when considering the development of policies that are within their competence.

Principles of biomass use

The Biomass Strategy Policy Statement[19] outlined the government's strategic view on the priorities for biomass use across the UK economy in the medium- to long term. It included a series of guiding principles to inform the priority uses of biomass, developed through consultation with stakeholders. The principles include:

- **Sustainability**, which focuses on ensuring that biomass used in the UK is sustainable and is in line with our climate and environmental goals.
- **Air quality**, aimed at minimising any public health impacts from the use of biomass.
- **Net zero**, to ensure that biomass uses contributes towards the UK's net zero target.
- **Circular economy & resource efficiency**, to ensure that these wider benefits from biomass use to the UK economy are realised wherever possible, in line with government goals.

This Strategy built on these principles and presents a priority use assessment that reflects on the best use of biomass to support the UK's net zero target. This assessment includes analysis of the current biomass use landscape (short term view), analysis of the role of biomass

17 https://www.legislation.gov.uk/asp/2019/15/contents/enacted
18 https://www.gov.scot/publications/draft-energy-strategy-transition-plan/pages/0
19 https://www.gov.uk/government/publications/biomass-policy-statement-a-strategic-view-on-the-role-of-sustainable-biomass-for-net-zero

to meet Carbon Budget 6 (medium term view) and a series of illustrative scenarios to outline the potential role of biomass for net zero (long term view). As part of this assessment, we also considered the wider strategic context around energy security and economic growth.

Structure of this document

Chapter 2 focuses on **biomass sustainability** criteria that are in operation in the UK across various biomass support schemes. It provides an overview of the work done and proposals to develop and implement a cross-sectoral biomass sustainability framework, subject to consultation.

Chapter 3 discusses the impacts of biomass use on **air quality and the regulatory requirements on biomass**. It also details related policy development and research and development projects.

Chapter 4 provides an assessment of the **amounts of sustainable biomass** that is used in the UK now and could potentially be available in the future. It presents some illustrative biomass availability scenarios and provides an overview of the innovation opportunities for scaling up domestic biomass supply.

Chapter 5 sets out a **priority use assessment** that informs the best use of biomass resources across the UK economy in the short (2020s), medium (2035) and long term (2050) towards our net zero target, based on our existing evidence base.

Chapter 6 focuses on **Bioenergy with Carbon Capture and Storage**. Including a review of the role of BECCS in meeting net zero, and an overview of the BECCS technology landscape. It reviews the latest innovation funding for BECCS and the recent Department for Energy Security and Net Zero Chief Scientific Advisor's Task and Finish Group report on BECCS. It also includes information on the potential of biochar to deliver greenhouse gas removals.

Chapter 7 provides details on **sector-specific policy plans** and action to support biomass use in the short, medium and longer-terms. It is split to cover the main policy areas in government, and includes electricity, biomethane and greening the gas grid, biomass with combined heat and power, transport, industry, low carbon hydrogen production and non-energy uses of biomass.

Alongside this strategy we are also publishing:

- **Public Dialogue on the Role of Biomass in Achieving Net Zero: Final Report** – a summary of a project to engage a diverse group of participants, broadly reflective of the UK public, on the sources and uses of biomass.
- **Task and Finish Group Report: The ability for BECCS to generate negative emissions** – a report led by the Department for Energy Security and Net Zero Chief Scientific Adviser's Task and Finish Group which sought to establish an evidenced based position on the validity of BECCS as a GGR option to deliver negative emissions.
- **Analysis of Responses to the Call for Evidence for Biomass Strategy on the Role of Biomass in Achieving Net Zero** – a summary report on the analysis of the responses to the 2021 Call for Evidence, which sought information and evidence from stakeholders on how sustainable biomass should be sourced and used to best support our net zero target.

2

Biomass Sustainability: ensuring sustainable biomass use across the economy

Our Key Commitments

- **To develop and implement a cross-sectoral sustainability framework, subject to consultation.**
- We will **consult on the detail and actions** required to implement such a cross-sectoral sustainability framework.
- We will set out next steps, based on the consultation, for implementing a common sustainability framework in the government response.

Sustainable biomass is a versatile low carbon resource that is needed to meet the UK's net zero target, helping to displace the use of fossil fuels in hard-to-decarbonise parts of the economy and by delivering negative emissions.

Government is clear that the main principle for biomass use is sustainability. Sustainable biomass can be derived from a range of sources: from purpose-grown crops to wastes and residues of other products and activities. The decarbonisation potential of biomass goes beyond the displacement of fossil fuels and needs to be considered as part of a wider system of sustainable land and resource use. This will need to take account of the natural capital and ecosystems services potential of land used for biomass as well as wider social and food security considerations. The Intergovernmental Panel on Climate Change (IPCC) in their most recent reports[20] have outlined that bioenergy and Bioenergy with Carbon Capture and Storage (BECCS) can contribute towards our global climate goals; but only if the biomass is from sustainable sources.

We already have stringent and globally leading biomass sustainability criteria in place in government support schemes to ensure biomass genuinely contributes to the UK's decarbonisation efforts. We only consider biomass that complies with these criteria to be low carbon and to deliver genuine GHG emission savings. The biomass sustainability criteria also cover wider aspects of sustainability, including environmental and social impacts, which ensure that biomass use is in line with the UK's climate and environmental goals. Our ambition is to remain at the forefront of sustainability across the bioeconomy, strengthening our already strict criteria where required to ensure consistency across the bioeconomy and to continue delivering genuine GHG savings and in future, deliver negative emissions.

This chapter focuses on the current sustainability criteria and regulatory landscape of biomass use in the UK, and how these criteria and governance mechanisms may be strengthened in the future. We set out the analyses and stakeholder engagement conducted to understand where there may be opportunities to strengthen requirements to ensure our sustainability criteria for biomass remain globally leading and aligned to the most up-to-date scientific evidence.

20 https://www.ipcc.ch/report/ar6/wg3

2.1 Biomass sustainability requirements in the UK today

To ensure biomass use delivers its role in the UK's decarbonisation goals, the UK has already set mandatory stringent sustainability criteria in the power, heat and transport sectors.

Meeting these criteria are the gateway to market or government support mechanisms. The criteria relate to environmental, social, and economic conditions which are used to distinguish between desirable and undesirable forms of biomass.

The current biomass sustainability criteria are defined in sector-specific legislation, such as the Renewable Obligation Order (RO),[21] Renewable Heat Incentive (RHI),[22] Green Gas Support Scheme (GGSS),[23] Renewable Transport Fuel Obligation (RTFO),[24] UK Emissions Trading scheme (UKETS),[25] and private law contracts within the Contracts for Difference scheme (CfD),[26] and in the Low Carbon Hydrogen Standard[27] (LCHS) for hydrogen producers. The criteria set out for each scheme contain broadly similar overarching criteria but vary in their exact requirements as set out below. In all schemes, support payments are subject to compliance with the criteria set out in the scheme.

The sustainability criteria in the sector-specific schemes contain a range of requirements under 'Land' and 'Greenhouse Gas (GHG)' criteria (Figure 2.1: Summary of Land and Greenhouse Gas Criteria across the UK Biomass Sustainability criteria).

The **Land criteria** stipulate that all feedstocks should be legally sourced according to the laws in the country of harvest. They also set requirements for sustainable harvesting that account for protection for biodiversity and highly biodiverse areas, high carbon stock lands such as wetlands and peatlands, nature conservation, endangered species, ecosystem services such as soil, water and air quality. They also cover land rights that span the traditional, legal or customary land rights of local communities; labour rights cover health and safety of workers, right to collective action, training, minimum age of work, and dispute mechanisms.

The **GHG criteria** require life cycle GHG emissions associated with biomass use (including production, cultivation, harvesting or collection, transportation, and processing) are included in emission calculations. Operators must meet set thresholds (which tighten over time) to ensure a minimum GHG saving is achieved against a fossil fuel reference.

21 Renewables Obligation Order: https://www.legislation.gov.uk/uksi/2015/1947/contents
22 Renewable Heat Initiative: https://www.legislation.gov.uk/uksi/2018/611/contents
23 Green Gas Support Scheme: https://www.legislation.gov.uk/uksi/2021/1335/contents
24 Renewable Transport Fuel Obligation: https://www.legislation.gov.uk/uksi/2007/3072/contents
25 UK Emissions trading scheme: https://www.legislation.gov.uk/uksi/2020/1265/contents
26 Contracts for Difference: https://www.gov.uk/government/publications/contracts-for-difference/contract-for-difference
27 Low Carbon Hydrogen Standard: https://www.gov.uk/government/publications/uk-low-carbon-hydrogen-standard-emissions-reporting-and-sustainability-criteria

The different government support schemes are operated separately and have well-established arrangements for updating their sustainability criteria. As a result, they have diverged from each other to respond to particular sustainability issues. For example, the RTFO and GGSS have introduced limits on the use of arable (food and feed) crops in order to respond to concerns over direct competition with food markets and avoid indirectly distorting existing markets that could result in direct or indirect land use change. This also prevents negative impacts on food security and on the final GHG savings biomass provides.

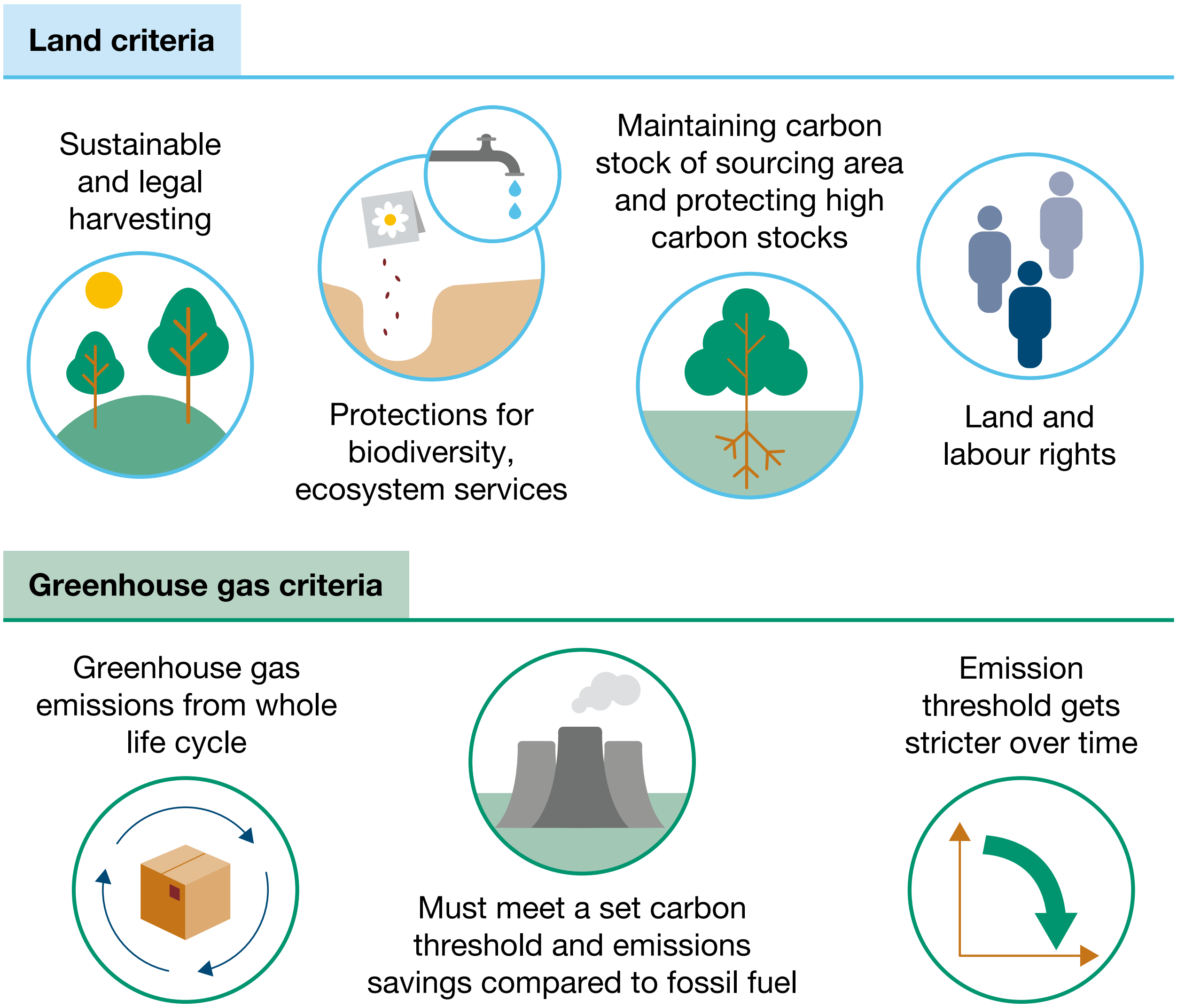


Figure 2.1: Summary of Land and Greenhouse Gas Criteria across the UK biomass sustainability criteria

A detailed comparison between the schemes can be found in Table 2.1, however, the main differences between the schemes are:

- **Indirect Land use change:** The RTFO and LCHS have provisions for Indirect Land Use Change (ILUC) reporting.
- **GHG thresholds:** There are differences in the emission thresholds applied across the schemes, with the lowest, 8 gCO_2e/MJ, within CfD Allocation Round 4, and subsequent rounds.
- **Crop Cap:** The RTFO currently has a crop cap which is decreasing annually from 4% in 2020 to 2% in 2032.
- **Waste use (as per waste categories defined in scheme legislation):** GGSS has a minimum waste use threshold of 50%. The RTFO rewards twice the amount of Renewable Transport Fuel Certificates (RTFCs) per litre to biofuels derived from certain wastes and residues.

Table 2.1 Summary of existing UK biomass sustainability criteria[28]

Sector	Transport	Energy
Scheme	**Renewable Transport Fuel Obligation (RTFO)**	**Renewables Obligation Order (RO)**
Criteria		
Land Use	Indirect Land Use Change (ILUC) factors added for crop-based biofuels, and Direct Land Use Change (DLUC) included in criteria.	DLUC included.
GHG emission target	Installations before 5th Oct 2015 must achieve 55% GHG saving, after that date 65% GHG saving, relative to a fossil fuel comparator of 94 gCO_2e/MJ.	Bioliquids: 60% emissions savings for installations post-2015, 50% emissions saving for pre 2015 installations. Solid and gaseous: post 2013 dedicated biomass station threshold is 66.7 gCO_2e/MJ, from April 2020 the threshold is 55.6 g CO_2e/MJ, from 2025 it is 50 gCO_2e/MJ.
Ecosystem Services	No legal requirements but the sustainable land use standard mentions water quality, air quality, and preservation of natural landscape.	Ecosystem health, vitality and productivity need to be maintained as per Timber Standard for Heat & Electricity.
Biodiversity	Adhere to national regulations, no sourcing from highly biodiverse areas.	Protection for biodiverse areas as per Timber Standard for Heat & Electricity. No sourcing from highly biodiverse areas.
Protection of carbon stocks	No sourcing from high carbon stock areas. Source from permitted sourcing only. Soil carbon criteria require management of carbon stocks where agricultural residues are used to make biofuels.	No sourcing from high carbon stock areas. Source from permitted sourcing only.
Crop Cap threshold	For 2023, 3.50% (the cap decreases annually from 4% in 2020 to 2% in 2032).	No.

[28] The UK ETS has its own sustainability criteria; further information is available in the government response to the consultation on Developing the UK Emissions Trading Scheme: https://www.gov.uk/government/consultations/developing-the-uk-emissions-trading-scheme-uk-ets

	Heat	Energy	Heat	Hydrogen
	Renewable Heat Initiative (RHI)	**Contracts for Difference (CfD)**	**Green Gas Support Scheme (GGSS)**	**Low Carbon Hydrogen Standard (LCHS)**
	DLUC included.	DLUC included.	DLUC included.	ILUC factors reported on for crop derived hydrogen, DLUC included.
	Biomass fuel at least 60% emissions savings. Emissions limit is ≤34.8g CO_2e/MJ.	April 2020-21 March 2035 55.6 gCO_2e/MJ. April 2025 to end of term 50 gCO_2e/MJ. From 2021 8 gCO_2e/MJ.	Life cycle GHG emissions criteria for biomethane produced: less than or equal to 24g of CO_2e/MJ.	GHG emissions to the point of production (‘cradle-to-gate’): less than or equal to 20 gCO_2e/MJ LHV hydrogen.
	Ecosystem health, vitality and productivity need to be maintained as per Timber Standard for Heat & Electricity.	Land criteria set out maintenance of productivity, biodiversity, soil and water impacts as per Forest Europe criteria.	Land criteria includes regulations related to ecosystem protection and maintenance.	Aligned to RTFO.
	Protection for biodiverse areas as per Timber Standard for Heat & Electricity. No sourcing from highly biodiverse areas.	Protections as per Forest Europe Sustainability criteria.	Protection for biodiverse areas as per Timber Standard for Heat & Electricity. No sourcing from highly biodiverse areas.	Aligned to RTFO.
	No sourcing from high carbon stock areas. Source from permitted sourcing only.	No sourcing from high carbon stock areas. Source from permitted sourcing only.	No sourcing from high carbon stock areas. Source from permitted sourcing only.	Aligned to RTFO.
	No.	No.	No.	No.

Sector	Transport	Energy
Scheme	Renewable Transport Fuel Obligation (RTFO)	Renewables Obligation Order (RO)
Criteria		
Waste Use threshold	No, but the use of wastes and residues is incentivised by awarding of additional certificates.	No.
Legal sourcing	Legal sourcing: Forest criteria requires all forest biomass is legally harvested.	100% legally sourced. Adherence to national regulations in country of harvest.
Social criteria: Workers rights, Land rights	No legal requirements but sustainable land use standard includes adherence to national regulations in country of harvest.	Criteria require adherence to national regulations in country of harvest.

	Heat	Energy	Heat	Hydrogen
	Renewable Heat Initiative (RHI)	**Contracts for Difference (CfD)**	**Green Gas Support Scheme (GGSS)**	**Low Carbon Hydrogen Standard (LCHS)**
	For Non-Domestic Renewable Heat Incentive (NDRHI) only minimum of 50% of biogas yield (by energy content) must be produced using waste or residue feedstock.	No.	Minimum of 50% of biogas yield (by energy content) must be produced using waste or residue feedstock.	Aligned to RTFO.
	100% legally sourced. Adherence to national regulations in country of harvest.	100% legally sourced. Adherence to national regulations in country of harvest.	100% legally sourced. Adherence to national regulations in country of harvest.	Aligned to RTFO.
	Criteria require adherence to national regulations in country of harvest.	Criteria require adherence to national regulations in country of harvest.	Criteria require adherence to national regulations in country of harvest.	Aligned to RTFO.

2.2 Biomass governance structures and requirements in the UK today

As only sustainable biomass is considered low carbon, governance mechanisms are crucial to ensuring our sustainability criteria reduce and mitigate any risks or impacts associated with biomass production or use.

To ensure compliance with sustainability criteria (summarised in Section 2.1) and regulate biomass use, the UK has robust multi-tiered governance structures in place.

Biomass support schemes regulatory frameworks

Governance bodies

The UK regulatory framework utilises the sector-specific support scheme structures for biomass with sector-specific regulatory bodies in place (Figure 2.2). Four main bodies are involved in the sector-specific regulatory processes:

1. **Office of Gas and Electricity Markets (Ofgem):** Regulating RO, RHI, GGSS
2. **Low Carbon Contracts Company (LCCC):** administers CfD, with technical oversight from Ofgem.
3. **RTFO Unit:** An in-house unit within the Department for Transport (DfT) which regulates the RTFO.
4. **UK ETS Authority:** The governing body for the UK Emissions Trading Scheme, consisting of the UK Government, Scottish Government, Welsh Government and the Department of Agriculture, Environment and Rural Affairs for Northern Ireland (DAERA).

Operators must demonstrate compliance with the relevant sustainability criteria to the relevant regulator or administrator to receive financial payments. The regulators require evidence collected to be independently audited to ensure accurate and verified information is supplied.

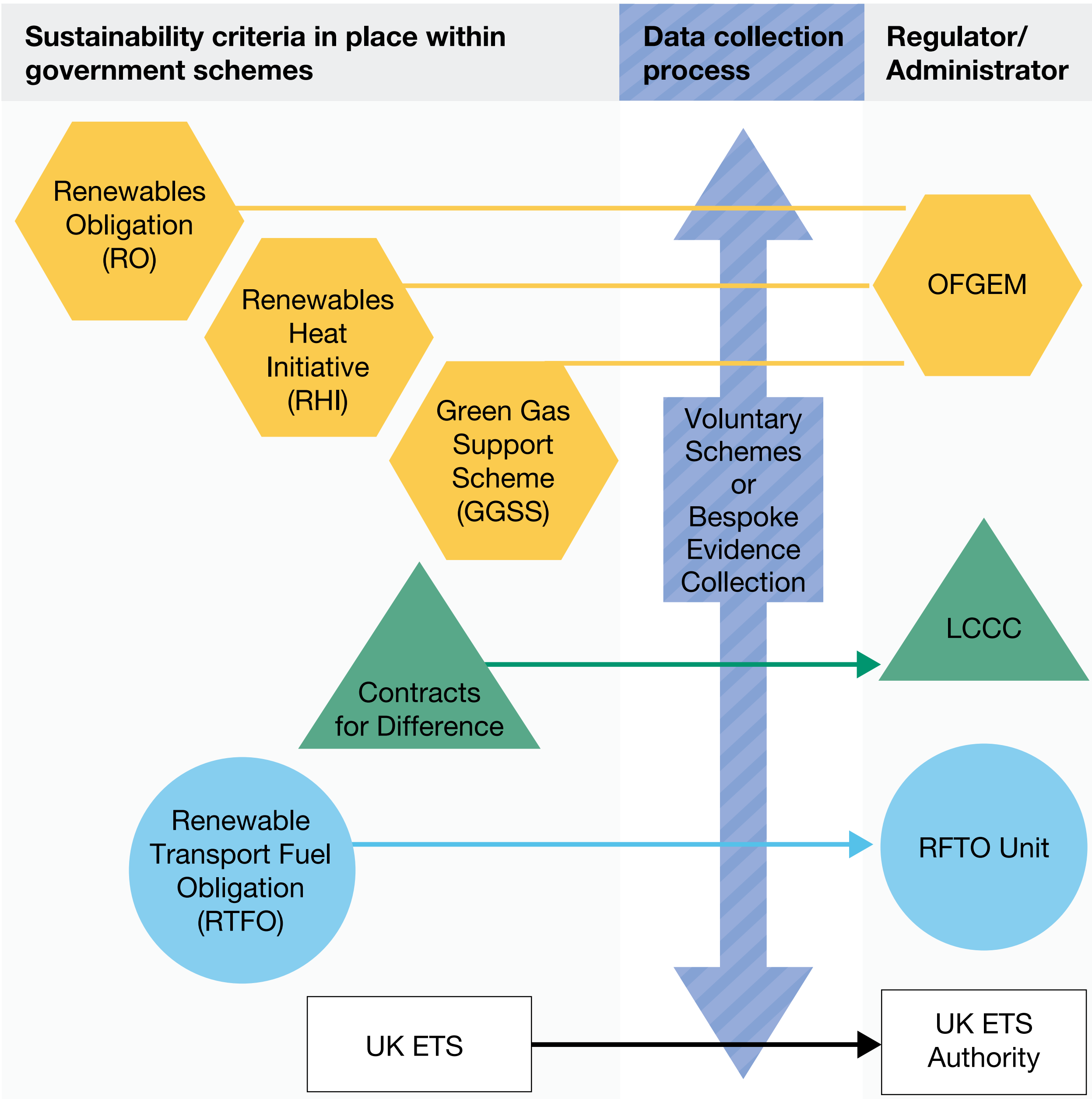


Figure 2.2: Summary of UK biomass regulatory framework for sector-specific schemes within the power, heat and transport sectors, and UK ETS

Compliance process

Although the compliance requirements vary slightly across schemes (See Annex A), the existing sustainability governance structure allows compliance to be demonstrated to regulators via multiple evidence collection pathways:

1 **By using recognised third-party Voluntary Certification Schemes:** UK biomass support schemes allow the use of approved third-party voluntary certification schemes

to demonstrate compliance.[29] The approved certification schemes are benchmarked by the government against the UK's biomass sustainability criteria. Certification schemes have their own internal auditing processes which are conducted by an independent third party to verify the certification and associated evidence. The existence of this third-party auditing is a requirement for using voluntary certification schemes to demonstrate compliance with the sustainability criteria. As biomass sustainability criteria evolve, the certification schemes themselves must evolve too to provide the necessary evidence and confidence that the criteria are being met.

2 **By using approved suppliers:** Generators can show they are sourcing sustainable feedstock to the regulator by using an approved supplier, e.g., RHI Biomass Suppliers List (BSL).[30] Suppliers on the BSL are audited in accordance with RHI regulations covering, for example, fuel quality and sustainability criteria facing suspension from the BSL should they fail to meet the strict requirements. The BSL administrator is required under the terms of the contract to provide regular updates to the Department for Energy Security and Net Zero of their performance against contract Key Performance Indicators (KPIs).

3 **Collecting bespoke evidence:** Generators can also collect bespoke evidence from the wider regulatory landscape (e.g., via permitting regulations) to demonstrate compliance to the regulator through self-reporting against the sustainability criteria of the appropriate government support scheme.

All support schemes require participants to demonstrate they meet the GHG criteria by using the respective scheme's GHG emission calculation methodologies and reporting processes. For the Land criteria, participants can demonstrate compliance using the allowed options within the scheme in question. Regulators require that data submitted as part of the compliance process be independently audited and verified by an independent third party which provides assurance to regulators that the criteria have been met.

Other domestic regulatory frameworks

Depending on supply chain and application, some biomass will need to comply with UK environmental, planning and waste regulations outside of the specific sustainability criteria associated with the government support scheme. The main interactions will be

29 Guidance on the use of approved third-part voluntary certification schemes is available:
a) RTFO recognised voluntary schemes: https://www.gov.uk/government/publications/renewable-transport-fuel-obligation-rtfo-voluntary-schemes/rtfo-list-of-recognised-voluntary-schemes
b) RHI guidance documents: https://www.ofgem.gov.uk/publications/non-domestic-rhi-main-guidance
c) RO guidance documents: https://www.ofgem.gov.uk/environmental-and-social-schemes/renewables-obligation-ro/applicants/biomass-sustainability
d) CfD guidance documents: https://www.lowcarboncontracts.uk/publications/lccc-sustainability-criteria-guidance
e) GGSS guidance documents: https://ofgem.gov.uk/publications/green-gas-support-scheme-guidance

30 RHI Biomass Suppliers List: https://www.gov.uk/find-fuel-supplier

with agricultural and forestry policies, waste regulations across devolved administrations, air quality regulations, environmental permitting regulations, and planning policies. Details on domestic regulation interactions with biomass policies are provided in Annex A and B.

International sourcing and global governance

International sustainability governance is essential to facilitate the trade of sustainable biomass and bioproducts such as biofuels. Combined with the existing strict sustainability criteria and strengthening of the criteria over time, we recognise that policy actions in the UK can play an important role in driving up best practice internationally.

The international governance arena covering biomass is complex (Figure 2.3), with a large range of governance mechanisms set in place. The UK already engages in a range of activities through policy mechanisms, targeted engagement, and international leaderships in relevant forums, which have either direct or indirect impacts on the sustainability governance of imported biomass.

Internationally recognised best-practice and certification schemes

The UK sustainability criteria are linked to international governance mechanisms through alignment with international biomass related policies, certification schemes and best practices.

Examples of links between UK's biomass sustainability requirements and international governance include:

- **Sustainability criteria are aligned to internationally recognised criteria:** UK's stringent sustainability criteria align with many internationally recognised criteria of biomass sustainability, such as the Forest Europe Sustainability Criteria and those set out in the EU's Renewable Energy Directive (RED).
- **Use of internationally recognised voluntary certification schemes & best practice:** As set out above, the UK support schemes allow for third-party voluntary schemes. These schemes set out criteria against which certifying bodies can conduct third-party audits of supply-chain operators to ensure that sustainability criteria and traceability requirements are met. These rely on assessing environmental risks within a region and mitigate based on local and national laws in country of harvest, or company policies and/or internationally agreed conventions, often whichever may be at a higher standard. Examples of such schemes eligible in the UK include the Sustainable Biomass Program (SBP), Forest Stewardship Council (FSC), Roundtable on Sustainable Palm Oil (RSPO), Roundtable on Sustainable Soy, International Sustainability and Carbon Certification (ISCC), and standard bodies such as the International Standards Organisation (ISO) 13065. These certification schemes and standard bodies use multi-stakeholder structures involving all relevant stakeholders along the supply chain throughout the different stages of the governance process, such as criteria development and enforcement.

Climate change and net zero related international agreements
e.g., the Paris Agreement

UK's net zero targets	**International schemes on timber or forestry** e.g., Forest Europe Sustainable Forest Management criteria, WWF Timber Scorecard	**International certification schemes for biomass** e.g., benchmarked schemes used to show compliance with UK sustainability criteria	**International platforms related to biomass** e.g., Biofutures Platform and Global Bioenergy Partnership
UK's climate change and environmental regulations e.g., environmental permitting regime	**Domestic regulations for timber or forestry** e.g., UK Timber Regulations, Felling licenses, UK FLEGT	**Domestic biomas regulations** e.g., sustainability criteria in support scheme	

Figure 2.3: UK domestic and international sustainability governance mechanisms for imported biomass. The colours of the boxes correspond to 1) Climate and net zero related agreements, platforms or regulations (blue), 2) Biomaterials related platforms, regulations and standards (yellow), and 3) Biomass related platforms, standards and regulations (green).

In the international biomass and net zero policy and best practice landscape, there is increased interest in multilateral organisations and initiatives as well as in the certification landscape to follow the circular bioeconomy model.[31] The cascading use of biomass is at the heart of the circular economy. This principle ensures that resources are re-used sequentially in the order of the specific resource quality at each stage of the cascade chain. For example, high-grade roundwood should first enter the timber market (e.g., for construction or furniture), and after this it should ideally be prepared for reuse, then recycled as composite boards. Throughout the process, wastes should also be recycled and, where this is not possible diverted to bioenergy or biofuels. For example, feedstock assessments under the RTFO take into account broader diversionary impacts from use as fuels, ensuring that an additional incentive is targeted towards waste feedstocks that have limited alternative uses, such as animal feed. This reduces the need for additional resource extraction and reinforces the Waste Hierarchy.

[31] https://www.ieabioenergyreview.org

The cascading use principle also encourages an efficient use of biomass by providing multiple products and services. However, local economic, environmental and social factors at sourcing may affect the pathways of material use, such as location and access to processing mills or changing market demands. Overall, the cascading use of biomass helps maximise the environmental, societal and economic value and benefits of the biomass resource,[32] but location-specific requirements of biomass sourcing systems must be considered. For example, this mechanism is already in place informally within the forestry sector, where forestry products are allocated to uses based on quality, value and local economic needs. As stated above, for waste and residues used in fuels production similar principles are also in place.

Following on from the 2015 ILUC Directive, which required EU member states to have due regard to the waste hierarchy and cascading principle for biomass in relation to biofuels, the EU in March 2023 provisionally agreed to adopt a cascading use approach within an update to the bioenergy sustainability criteria of the Renewable Energy Directive;[33] the details of how this will be implemented are under development. The UK is committed to moving towards a more circular economy: minimising waste, keeping resources in use as long as possible, extracting maximum value from them and promoting resource efficiency.

Further assessment is needed on how best to adopt and regulate the cascading use of biomass in the UK, where it is not already applied, to ensure we continue to champion best practices within a circular bioeconomy.

International platforms and organisations focused on biomass

The UK has a strong track-record in international collaboration and coordination of action across science, innovation, finance, and trade. We support the work of multilateral initiatives and platforms, such as the Global Bioenergy Partnership (GBEP),[34] a Commission on Sustainable Development Partnership that received its mandate from the G7 and supported by the G20, and the Clean Energy Ministerial (CEM)'s Biofuture Initiative,[35] among others.

The Biofuture Initiative aims to lead global action to accelerate development, scale-up, and deployment of sustainable bio-based alternatives to fossil-based fuels, chemicals, and materials, coordinated by the International Energy Agency. It promotes developing an evidence-based understanding of sustainable biomass production, provides a forum for policy dialogue and collaboration among its participants, and aims to foster consensus on biomass sustainability, availability, governance, and biomass use to help achieve net zero and climate-smart development goals.

32 https://www.ieabioenergy.com/blog/publications/cascading-of-woody-biomass-definitions-policies-and-effects-on-international-trade-2
33 https://ec.europa.eu/commission/presscorner/detail/en/IP_23_2061
34 https://www.globalbioenergy.org
35 https://biofutureplatform.org

The UK plays an important role within the premier forum for international economic cooperation, the Group of Twenty (G20). Biomass is an area of increasing focus for the G20 and has been discussed as a priority area in both the Environment and Climate Sustainability Working Group (ECSWG) and the Energy Transition Working Group (ETWG) as part of the G20 process in 2023. The UK is also promoting international collaboration on biomass, including on establishing sustainability criteria, as part of sector-specific initiatives, such as the International Civil Aviation Organization (ICAO) and International Maritime Organization (IMO).

International agreements covering climate change and environmental protections

The UK has been at the centre of global efforts to tackle climate change and transition to a global net zero economy. We continue to drive international collaboration and action on areas that will have the biggest impact, building on international agreements and alliances covering climate change and environmental protection such as the Paris Agreement, UN's Sustainable Development Goals (SDGs), Glasgow leader's Declaration on Forests and Land Use, and the UN Programme on Reducing Emissions from Deforestation and Forest Degradation (REDD+), among others, to accelerate the global net zero transition.

2.3 Review of existing biomass sustainability criteria

As part of our assessment of the biomass sustainability criteria, we held extensive stakeholder engagement via our 2021 Biomass Strategy Call for Evidence[36] and through several workshops. We collected information about evidence gaps, stakeholder views, needs and concerns from academia, industry, trade associations, NGO's, think tanks, and members of the public to support policy development in this complex policy space. The evidence and views gathered were considered alongside the wider evidence base from existing and ongoing research.

Biomass call for evidence

Analysis of responses to the Call for Evidence highlighted diverse and often opposing views and concerns about the sustainability of biomass.

- **38% viewed the existing sustainability criteria to be sufficient and robust**, and noted that the criteria had evolved over time to become more comprehensive. These responses also highlighted that stricter criteria or governance could reduce investment and innovation in the bioeconomy.

36 https://www.gov.uk/government/consultations/role-of-biomass-in-achieving-net-zero-call-for-evidence

- **38% regarded the existing sustainability criteria to be insufficient** and suggested that non-GHG criteria or indicators should be included in the net zero landscape. However, there was a lack of evidence on how the requirements may be improved in practice.
- **24% of responders did not indicate whether the existing sustainability criteria were robust enough or not.**

The main themes highlighted by stakeholders within the call for evidence are summarised below.

- **A need for standardisation across sectors.** Respondents highlighted inconsistencies in domestic biomass monitoring and reporting requirements and processes across existing government support schemes. Cross-sectoral legislation was proposed as a main mechanism for providing consistency. Some responses noted a need to improve Life Cycle Assessment (LCA) methodologies to ensure the full biomass value chain is captured in all schemes. Opinion on the role of voluntary certification schemes was divided, with some seeing it as a useful mechanism to help administer policy while others expressed a lack of trust in these schemes citing lack of transparency as a reason.
- **Monitoring and reporting:** Some stakeholders raised concerns on the impartiality of existing governance mechanisms, the lack of data sharing between them, and a lack of a standardised LCA methodology. Industry stakeholders highlighted that existing data collection already goes beyond the regulatory requirements and that more granular data could be reported but would require a proportional approach to balance commercial sensitivity and administrative burdens. Trust in current voluntary certification schemes appeared low outside of industry, and these stakeholders highlighted a need to establish an independent regulatory or auditing body.
- **Carbon life cycle assessments and carbon accounting:** Concerns were raised about the accuracy of carbon accounting, and whether carbon emissions are accurately reflected in the correct sectors (e.g., whether emissions from land use change can be verified to be accounted for in the Land Use, Land Use Change and Forestry (LULUCF) sector for imported feedstock). A full LCA accounting for temporal and spatial variations in carbon emissions was required by some stakeholders. The need to introduce accounting for negative emissions in GGR technologies, such as BECCS, was also raised.
- **Domestic versus Imported feedstock:** Some stakeholders highlighted a strong preference for domestic biomass sourcing. This was raised alongside concerns on the sustainability of forestry operations overseas, which was perceived by stakeholders outside of industry to be poor. Stakeholders raised potential large-scale felling of highly biodiverse forests as the main concern.
- **Sustainability outside of carbon:** Stakeholders supported a holistic approach to sustainability which includes carbon and non-carbon criteria, such as biodiversity. Some stakeholders suggested that current non-carbon criteria, such as social impacts within biomass supply chains, could be strengthened.

- **International consensus:** Stakeholders highlighted a need to align with internationally recognised sustainability requirements in place in other regions, such as wider Europe, recognising that biomass is a globally traded commodity and users often operate across borders. Respondents also raised the need to reach international consensus on biomass sustainability criteria to ensure transparency across international trade.

Biomass sourcing case studies

International sourcing of biomass, particularly of woody biomass, is a main area of interest for stakeholders, due to the potential risks associated with the complex supply chains. Stakeholders raised concerns that unsustainable feedstocks may be used in operations because of the existing minimum 70% threshold in certain schemes for the portion of woody biomass feedstocks that must be proven sustainable.

This minimum 70% sustainable sourcing threshold for woody biomass derives from the existing Timber Procurement Policy (TPP),[37] recognising that forest-derived woody biomass is part of the wider forestry sector, and is applicable within the RO, RHI, GGSS, and CfD.

We are committed to ensuring biomass sourcing and use is in line with our domestic and global climate and environmental goals. Strict biomass sustainability criteria have been in place for over a decade, including protections for biodiversity and land use (Section 2.1). We have set out actions that could be taken to strengthen criteria related to woody biomass in Section 2.4. Our sustainability criteria for woody biomass set out requirements for sustainable forest management practices, which can vary depending on location-specific needs and risks.

To demonstrate the robust risk-based forest management practices already in place within the forestry sector, two forestry case studies covering a domestic timber sourcing region and a US-based timber and woody biomass sourcing region are presented here. These case studies demonstrate the importance of expert local understanding of forestry systems for the management of healthy and productive forests, highlighting differences in local and regional conditions, such as climatic conditions and risks, leading to different choices and actions in forest management practices.

[37] Timber Procurement Policy Framework for Evaluating Category B (Fourth Edition): https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/510456/Cat_B_Framework_4th_Ed_-_Final.pdf

Case study: Louisiana and Mississippi Forestry Sector, US

Forestry management practices in many parts of the US South are focused on producing sawlogs for lumber mills, which provide the main source of income from the forests for landowners. Within this system, biomass for energy is a low-grade product in economic terms, produced from wastes and residues of the conventional forestry operations. To produce good quality sawlogs, the forest requires careful management over the lifespan of the stand (25-30 years for the loblolly pine stands visited) from planting to harvest. This generally requires fertilisation, pest management and two rounds of thinning. The forest landscape is also extensively managed to ensure a range of tree ages across the landscape (Figure 2.4), as well as the presence of a diverse range of wildlife habitats, such as streamside management zones and open areas surrounded by cover (e.g., a young stand next to a mature stand). Thinning of trees provides wildlife benefits by preventing the closure of the tree canopy; something that would have occurred in a natural system by periodic wildfires.

State regulatory bodies in the US oversee air and environmental impacts, wildlife, and land management practices. Extensive targeted help is provided to landowners, including through Best Management Practices for water quality, and by state forestry agencies to ensure good management of forest land. As US private forest land ownership is very high (>80% in both Louisiana and Mississippi, and 86% across the US South), the objectives of the landowners and local market conditions have a significant impact on the forestry sector. Through the targeted help provided to landowners, the state forestry agencies' aim is to ensure forests are well managed, and that a healthy market for forestry products can provide a source of income for landowners that incentivises keeping forests as forests.

State and national level regulations on air quality and environmental impacts must be met by forest products mills, with a stringent protocol in place for addressing any issues, and avenues for engagement with local populations who live close to industrial sites.

Figure 2.4: Sustainable forestry cycle showing the different stages of sustainable forest management

Case study: Kielder, UK

Kielder is the largest working forest in England, constituting 60,000 hectares. The forest is sustainably managed for people, nature and economy outcomes. Managed by Forestry England, the forest planning process is underpinned by The UK Forestry Standard (UKFS) and is independently certified against the UK Woodland Assurance Standard (UKWAS) supporting Forest Stewardship Council (FSC) and Programme for Endorsement of Forest Certification (PEFC) endorsement.

Within upland northern Britain tree stability plays an important part of our management – harvesting trees before reaching a height at which the risk of windblow is high is economically and environmentally significant. Species choice (windfirm species), ground preparation (i.e., not ploughing as this reduces root spread impacting on tree stability), thinning regimes (delayed thinning reduces tree stability) and rotation lengths (not allowing trees to get too tall, which is when they start blowing over) are all strongly influenced by wind exposure. The forest is evolving every year through a 1000 ha annual clear fell and restocking programme.

This is the opportunity to plant more diverse species, create more open habitat and more native woodland.

We also make the felling and restocking coupes smaller than when originally planted which diversifies the age and height structure of the forest creating more windfirm edges. This evolution is making the forest more resilient to pests, diseases, storms and wider climate change impacts.

The forest sustainably produces over half a million tonnes of timber every year, providing a valuable resource of home-grown timber and supporting strongly the regional economy. The forest also provides home for wildlife including our iconic native red squirrel. Hundreds of thousands of visitors visit the forest every year to enjoy activities from mountain biking to dark sky star gazing.

Photo of storm damage in Kielder Forest following Storm Arwen in November 2021 © Steve Allen

Public engagement through the public dialogue project

The Biomass Public Dialogue Project,[38] explored the views of a diverse group of participants about biomass sustainability, biomass feedstock sourcing, and use. Participants heard a range of perspectives and remained sceptical about the concept of 'sustainable biomass' as well as the feasibility of implementing the current criteria. In particular, the emissions created in the sourcing and production of biomass were viewed as intuitively unsustainable.

Many participants were sceptical, given the complexity of international supply chains, that it is possible to ensure that all elements conform to the sustainability criteria. This was in part driven by people's pre-existing views about the difficulty of regulating supply chains. Participants generally viewed domestic biomass to be more sustainable, especially domestic waste. In this chapter, there is further information on the conditions under which biomass sourcing, use and production can be implemented as a sustainable energy source to address these concerns of sustainability.

Most participants felt the UK's land and GHG criteria covered the right areas. However, when discussing GHG criteria, participants perceived there were contradictions in the information provided by different specialists on the point of emissions accounting and reporting, with some highlighting specific emissions sources that are not included in the criteria that should be.

To ensure the sustainability of biomass, participants wanted a mix of organisations regulating private companies to ensure the focus remains on net zero.

Strengths of UK's sustainability criteria and opportunities for improvements

Alongside the review of the existing biomass sustainability landscape and stakeholder engagement, recommendations and insights from expert reviews, such as the Climate Change Committee's (CCC's) 2018 report on biomass,[39] and Supergen Bioenergy Hub's review of sustainability criteria,[40] among others, informed our assessment of the UK's biomass sustainability criteria.

The CCC's 2018 report recommended immediate and longer-term actions to strengthen sustainability governance at the domestic and international level. These recommendations included encouraging best practice while phasing out unsustainable feedstocks, including the impacts of carbon stocks in forests within principles and ruling out sourcing from areas with falling carbon stocks, and reviewing ILUC risks and social sustainability provisions. The CCC also recommended increased transparency in monitoring and reporting, and a need for strategic coordination in international governance.

The Supergen Bioenergy Hub's review of sustainability criteria highlighted inconsistencies in the sustainability

[38] https://www.gov.uk/government/publications/biomass-strategy
[39] https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy
[40] https://www.supergen-bioenergy.net/news/new-supergen-bioenergy-hub-report-assesses-sustainability-standards-for-sectors-utilising-bio-based-and-low-carbon-feedstocks

criteria between different biomass end use sectors. These inconsistencies were perceived to limit comparability and fair competition between sectors. The report highlighted the presence of well-developed sustainability policies within the energy and transport sectors, but a lack of similarly stringent requirements in the chemical, construction, and manufacturing sectors, where biomass use is growing in importance. The report noted the need for clear accounting frameworks for ecosystem services, land management and biodiversity. It also considered sustainability criteria beyond GHG emissions to be at a very limited level for sectors outside of transport and energy, with voluntary certification schemes filling in some of these sustainability accounting gaps.

Based on the comprehensive assessment of the UK's biomass sustainability criteria we identified strengths and areas for potential improvements within the existing criteria implemented within sector-specific subsidy schemes.

The strengths of the current sustainability criteria include:

- *Capturing sector-specific needs:* the UK's sector-specific criteria reflect the needs and reality of different sectors, allowing the criteria to be adapted to address and minimise risks specific to that sector, and to account for differing international best practice schemes.
- *Alignment to wider domestic environmental policies:* The current UK sustainability criteria align to and work with domestic environmental regulations and policies, such as those related to air quality, agriculture, forestry, waste, and planning, complimentarily (Annex B).
- *Alignment to international policies and schemes:* The existing criteria align to internationally recognised biomass sustainability criteria, such as the Forest Europe Sustainable Forest Management criteria, and work with internationally recognised best practices and certification schemes as part of the global biomass market.
- *Sustainability criteria for solid biomass (i.e., forest-derived biomass) employ requirements of sustainable management already in place in existing primary product market:* In the case of forest-derived biomass, it is a co-product of an existing industry, i.e., timber industry. Strict sustainability criteria have been in place for the forestry sector for a considerable time at a landscape level to ensure sustainable forest management and sustainable timber production. These forestry-specific criteria evolved over time through consultation to ensure they address stakeholder needs in line with the latest evidence base. Biomass sustainability criteria utilise the criteria of this primary industry from within which the biomass market was established. The criteria support the efficient use of the harvested material, maximising the value derived from the harvest and supporting the maintenance of the forest.

Areas where sustainability criteria can be strengthened include:

- *Lack of overarching criteria across the bioeconomy leading to some inconsistencies between sectors:* Although there are sector-specific requirements, these can mean that the same feedstock can be subject to different criteria depending on the sector of use, opening up the possibility of market distortion.

- *Reliance on local governance mechanisms:* For ecosystem services and social criteria, the benchmark for meeting the criteria is the existence of local governance mechanisms in the country of sourcing. Although the local mechanisms are risk assessed through the certification and auditing process, they may differ from one sourcing area to another for the same feedstock.
- *Developing criteria for new and emerging feedstocks and technologies:* New biomass technologies such as, power BECCS, and new feedstocks, such as algae, seaweed, and hemp are currently not eligible for existing subsidy schemes and therefore there is an opportunity to develop, revise and strengthen criteria that would have to be applied. These new technologies and feedstocks will have their own benefits, risks, and needs, which will need to be addressed through appropriate requirements.
- *Assessing the current evidence base on Indirect Land Use Change (ILUC) metrics, soil carbon accounting, and waste exemptions:* Scientific understanding continues to develop in these areas and should inform future iterations of the criteria. ILUC is further discussed in Box 4.1 and Box 4.2 in Chapter 4.

The themes encompassing the potential areas identified for strengthening sustainability criteria and addressing stakeholder areas of interest (identified through engagement) are summarised in Table 2.2.

The UK's strict biomass sustainability criteria already addresses some areas of stakeholder concerns in whole or partially, for example, protections for biodiverse habitats and protections for land use rights are included in current criteria. However, it is vital that biomass sustainability criteria continue to evolve and strengthen in line with the emerging needs of new technologies and feedstocks, and with new scientific evidence to ensure biomass feedstocks continue to deliver benefits for the climate, ecosystems, and society. Details on how the current criteria could be improved is provided in the following section.

2.4 Actions for strengthening the UK's biomass sustainability criteria

Key commitment: Development of a cross-sectoral sustainability framework for biomass

A cross-sectoral sustainability framework would deliver increased alignment of sustainability requirements across sectors of the bioeconomy by creating shared minimum criteria, which can also expand to cover emerging biomass feedstocks and uses. Such a framework would be applied to new future policies and schemes on biomass. It would not be applied to existing government schemes and contracts, save that it may be applied where an existing scheme updates its sustainability criteria, provided that it is deemed appropriate. This overarching sustainability framework would continue to allow flexibility for the variable sectoral and technical needs of different biomass feedstocks and end uses.

It is essential that biomass sustainability criteria are in place across the bioeconomy to ensure biomass continues to deliver towards net zero while providing environmental and economic benefits. This cross-sectoral sustainability framework will be the mechanism for the implementation of the actions detailed below to strengthen requirements based on up-to-date evidence and changing needs of the bioeconomy. It is our intention that this cross-sectoral framework would enable the management of sustainable biomass use across the economy in the future.

To enable the successful implementation of the cross-sectoral biomass sustainability framework, we intend to publish a consultation in 2024. The actions below detail the government's minded to position on the inclusion of various parameters and principles to be included in the sustainability framework, which will be subject to consultation. As part of this consultation, we will gather views on the details of the actions set out, including on implementation routes considered by government, as well as the necessary monitoring, reporting, and verification (MRV) requirements.

Actions for delivering a cross-sectoral sustainability framework

Overarching Actions

1 **Develop and implement a cross-sectoral sustainability framework for biomass:** Develop a sustainability framework that can be practically implemented across all biomass uses across the economy, which will increase alignment in approaches and provide market fairness. Details of a cross-sectoral sustainability framework, including detailed sustainability criteria, and the governance mechanisms involved will require development alongside continued engagement with stakeholders to ensure these are fit for purpose. Given the global and interacting nature of many biomass

supply chains, the development and implementation of a cross-sectoral sustainability framework will require consideration of the current international certification landscape, established voluntary certification schemes in use, and various government support schemes. Further work is also required to make best use of modern data collection methods for improving MRV, and to establish data reporting requirements of the biomass sustainability criteria. This will ensure suitable data granularity for transparency and assurance purposes, which can help build trust in the benefits biomass use can deliver. The sustainability criteria, and any associated governance mechanisms, including approved certification schemes should be kept under review, and updated regularly to ensure they remain aligned to the needs of a changing bioeconomy and retain confidence in the sustainability of the biomass supply chain.

2 **Encourage best practice alongside common minimum requirements in the cross-sectoral sustainability framework:** A cross-sectoral sustainability framework will look to include common minimum requirements, such as criteria for waste, crop cap, efficiency and GHG thresholds, but allow flexibility for sectors to set higher requirements and ambitions where achievable. To encourage different sectors of the economy to go beyond the minimum requirement and adopt best practices, we must identify the appropriate incentives and requirements for those sectors. International certification schemes and their requirements within different sectors also evolve at different paces, due to the unique conditions and needs of each sector. Any improvements in international voluntary certification schemes, and by extension, improvements in best practice within the global market will also need to be considered within the cross-sectoral sustainability framework alongside common requirements. For example, assessing whether the cascading use of biomass, which is now being adopted globally, can be implemented practically within sustainability criteria. In practice, industry and trade bodies are keen to highlight and implement best practice wherever possible, and adopting best practice into policy would support innovations and increase trust in biomass use overall.

Actions on Greenhouse gas criteria

3 **We are minded to implement a common GHG emissions calculation methodology for biomass supply chains with comparable units within the cross-sectoral sustainability framework:** We will look to implement a consistent and comparable calculation methodology for biomass uses that recognises and accounts for sector-specific needs (such as the existence of different supply chain steps). This would limit divergence of methodologies and potential perverse incentives across the bioeconomy. It would also allow comparisons between sectors to better understand the relative contribution of different biomass technologies to net zero. Any new feedstocks, technologies and ideas could be incorporated into the methodology as needed to address future stakeholder needs (e.g., BECCS).

We will set out the details of the common GHG emissions calculation methodology via the consultation.

4 **We will look to include Indirect Land Use Change (ILUC) in the cross-sectoral sustainability framework based on up-to-date scientific evidence on ILUC:** It is imperative that strict biomass sustainability criteria are in place to avoid food and feed crop-derived biomass causing indirect land use change, which could impact carbon-rich or biodiverse habitats. Biomass produced on existing agricultural land can lead to the production of food and feed crops elsewhere, potentially leading to the conversion of additional land to agricultural use. This can result in significant environmental impacts and in substantial amount of GHG emissions being released into the atmosphere if land with high carbon stocks and highly biodiverse habitats, such as forest land, grassland, peatlands, is converted to agricultural use. These ILUC effects cannot be easily observed or measured, or directly attributed to land use management decisions of individuals or groups and are complex to calculate (See Box 4.1).

Nevertheless, it is important to understand the potential ILUC impacts of our policies. The RTFO scheme already requires the reporting of ILUC effects where evidence-based default values are applied; however, these are not directly accounted for as part of the GHG emissions calculation methodology, but instead reported on as part of regular statistics. We commissioned a review of existing ILUC assessment methods (project is ongoing) and we will use outcomes from this report to review our approach to ILUC during the development of the detail of the cross-sectoral sustainability framework, which will be set out as part of the government consultation on biomass sustainability.

5 **Explore practicalities of accounting for soil carbon changes based upon up-to-date scientific evidence:** To support implementation of accounting for soil carbon changes based on up-to-date scientific evidence, we commissioned an assessment of the soil carbon accounting landscape and practicalities of reporting soil carbon. We intend to provide more information on this area as part of the biomass sustainability consultation.

Actions on Land Criteria

6 **Where not already mandatory, we are minded to require biomass users to ensure 100% of woody biomass feedstocks used in their operations to be proven sustainable, either via a certification scheme or national schemes that demonstrate compliance (e.g. felling licenses) or by collection of bespoke data by the supplier:** To maximise the contribution of biomass to decarbonisation, the government is minded to require all woody biomass to be from sustainable sources as part of the sustainability criteria. However, we recognise that certification may be beyond the means of some smaller landowners therefore placing a requirement on them may lead to unintended consequences. These could include having a negative impact on the

landowner, forester, and potentially the forests from which the woody biomass is sourced. Therefore, to implement this action, we are minded to require users of biomass to provide proof of certification, or align to a national scheme, or provide bespoke data to show 100% of woody biomass feedstocks are sustainable.

Demonstrating (by reporting relevant data to regulators) that woody biomass used in biomass operations is from sustainable sources can increase transparency and trust, which is vital for public acceptance of biomass technologies. Implementing such a requirement would address stakeholder concerns that unsustainable feedstocks may be used in operations as a result of the existing requirements in some schemes that sets a minimum 70% threshold for the portion of feedstocks that must be proven sustainable. This recommendation also aligns to the wider bioeconomy trends where retailers are increasingly using 100% sustainable certifications to meet their consumer's needs.

The existing 70% - 30% split for woody biomass sustainability derives from the existing government Timber Procurement Policy, recognising that forest-derived woody biomass is part of the wider forestry sector. Therefore, it is important to understand how the 100% requirement can be implemented without undesirable impacts on the wider forestry sector and forest landowners while also maximising the benefits of forest-derived, woody biomass for the environment. We intend to explore the implementation of this, including the monitoring and reporting requirements of this change, in the biomass sustainability consultation that will follow this strategy. The consultation will need to consider how implementation could avoid ruling out the using of legal and sustainable feedstocks that are not covered by the felling licence regime, including arboricultural arisings, material from power line clearance, and dead trees.

7 **We will look to implement the same definitions for sustainable feedstocks where possible to increase alignment across sectors:** Currently, definitions for different feedstock categories may differ across support schemes, including in how far a feedstock might classify as a waste or a residue. Aligned definitions within the cross-sectoral sustainability framework should be applied where possible while accounting for sector-specific definition needs such as around different feedstock uses. For example, Forest Research has suggested definition changes related to wood products.[41] We will review these definitions in line with current up-to-date forest management practices and evidence around cascading uses within a circular bioeconomy. Separately, biogenic waste feedstocks can be treated differently in GHG emission calculations and may receive a higher reward. Therefore, where a feedstock is deemed to be a waste, it is important to have certainty the waste is genuine and not purposefully created.

[41] https://europeanclimate.org/wp-content/uploads/2018/05/CIB-Summary-report-for-ECF-v10.5-May-20181.pdf

Research is ongoing to assess the sustainability of wastes to establish whether exemptions should remain in place for all biogenic waste feedstocks in a cross-sectoral sustainability framework. Further work and stakeholder engagement as part of the biomass sustainability consultation will be required to assess any requirements for changing definitions as appropriate based on scientific evidence, including considering verification processes and interactions with regulators.

8 **We will look to include requirements related to protecting, maintaining, and enhancing biodiversity within a cross-sectoral common sustainability framework, building on requirements within current support schemes and based upon scientific evidence:** Biomass production and use can be an important driver for sustainable use of land when robust sustainability criteria are followed and enforced. Sustainable land use can help achieve our biodiversity goals, leading to better outcomes for biodiversity. As part of existing sustainability criteria, biomass feedstocks cannot be sourced from protected lands and lands with high biodiversity, such as highly biodiverse grasslands, and there are requirements for maintaining biodiversity in biomass sourcing regions. However, there is potential to strengthen the existing criteria, by for example, stipulating adherence to internationally agreed or ratified agreements on biodiversity, and alignment to future domestic biodiversity policies and strategies. Impacts on biodiversity are of interest to some stakeholders, including the extent to which impacts are verifiable, how biodiversity is managed, and monitored on the ground. It is essential to ensure that the biomass sustainability criteria continue to strengthen its protections for biodiversity and continues to have appropriate processes in place to demonstrate how these requirements are achieved. Further engagement with stakeholders is required to understand the practicalities of measuring and benchmarking biodiversity, including through the consultation.

9 **We will look to include requirements explicitly around protecting ecosystem services within a cross-sectoral biomass sustainability framework:** Ecosystem services (e.g., air, water, soil quality) are intrinsically linked to both biodiversity and social criteria. Ecosystem services is a complex area, with location-specific needs which can be difficult to quantify. The complexity of measuring ecosystem services includes identifying the appropriate services to measure, the extent to which impacts are verifiable, and how they are managed and monitored on the ground. The interactions between biomass sourcing and ecosystem services are an area of interest for stakeholders. The current biomass sustainability criteria cover ecosystem services somewhat indirectly through the land criteria by stipulating requirements around land use change, land rights of local communities and health and vitality of forests. To strengthen this criterion, we are minded to include ecosystem services explicitly within the cross-

sectoral sustainability framework, considering the practicalities of appropriate measurable parameters and verification processes required. Further consideration is required on how to benchmark ecosystem services appropriately, such as stipulating requirements to adhere to local or national regulations in area of sourcing, or internationally agreed and ratified agreements on ecosystem services, whichever is deemed to be of a higher standard. Keeping these considerations in mind, further work and stakeholder engagement as part of the biomass sustainability consultation will be required to assess the appropriate mechanisms for including ecosystem services in the cross-sectoral sustainability framework.

10 **We will look to include Land and Labour rights, Health and Safety of workers, and Community welfare in a cross-sectoral sustainability framework and aligning with principles in internationally recognised agreements or conventions:** Social criteria are currently included as part of the land criteria, where they rely on local or national governance in areas of sourcing as the benchmark to which criteria must be met. The requirements in the existing criteria refer to health and safety, dispute solving mechanisms, and legal, customary and traditional rights of the local communities. Government is minded to strengthen this by benchmarking the social criteria requirements against principles in appropriate internationally agreed conventions (e.g., United Nations Declaration of Rights of Indigenous Peoples (UNDRIP), International Labour Organisation conventions (ILO 169)). Further work is required to understand which internationally agreed convention or agreement may be most suitable, and detail will be set out in the consultation.

Actions to develop New Criteria

11 **As biomass feedstocks and technologies evolve and new ones emerge, we are minded to introduce appropriate new criteria within the cross-sectoral sustainability framework and associated governance that ensure continued delivery towards climate and environment goals:** Ongoing monitoring and review of new feedstocks and technologies will be required, and an understanding of how they could scale up over time to allow timely implementation of improvements to the sustainability criteria. For example, further work is required to establish the requirements that would best help regulate new feedstocks such as algae and seaweed to ensure only sustainable feedstocks are produced. A process for implementation of new criteria will support adaptation of sustainability frameworks according to changes in the bioeconomy over time. This will allow us to address conflicts and gaps that may arise in future but cannot be accounted for in current criteria.

Future engagement on biomass across the global governance arena

The CCC's 2018 report on biomass[42] highlighted that the role of biomass in net zero depends on the quality and strength of international sustainability governance to mandate managing the risks related to sustainability of imported biomass feedstocks. The UK remains committed to engaging with international stakeholders and continues to support initiatives to embed strict biomass sustainability requirements for biomass use across the world, such as the work of GBEP and the Biofuture Initiative. We champion the need for biomass sustainability criteria for biomass use across the world to reduce sustainability risks for biomass production and use. Through ongoing bilateral and multilateral engagement, and as members of the main international biomass initiatives, we will continue to promote best practices in sustainability governance internationally.

Summary and next steps

We have set out our key commitment and related actions to develop a cross-sectoral sustainability framework, subject to consultation (Section 2.4). This commitment was developed through our own analyses and extensive stakeholder engagement outlined in the chapter. We will continue to refine details around the potential actions set out within this section as we develop the consultation which we intend to publish in 2024.

42 https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy

Table 2.2: Themes of interest within the current biomass sustainability landscape. These themes encompass areas for improvement identified through our assessment and stakeholder engagement.

Themes of interest within the current biomass sustainability landscape	Is this theme already addressed in current UK biomass sustainability criteria?	How will this theme be addressed through our commitments and actions
Consistency in sustainability across the bioeconomy: A need to ensure all biomass end uses adhere to the same minimum criteria across sectors and internationally, with alignment to the European and wider global market. Stakeholders wanted consistency, and unsustainable biomass use to be phased out while encouraging best practice.	Within government incentives, the UK only supports sustainable biomass which meets the sustainability criteria.	Our commitment to develop an overarching cross-sectoral sustainability framework, subject to consultation, will aim to address the identified lack of consistency across sectors. This framework would regulate all biomass uses across the economy in future.
Preference for domestic feedstocks: Domestic grown feedstock was preferred by some stakeholders.	Domestically produced feedstocks are not inherently more sustainable than imported feedstocks. The UK takes an agnostic approach to where biomass feedstocks are sourced from as long as they comply with the relevant sustainability criteria. Imported pellets form an important part of UK's energy supply and energy security, and currently domestic supply is unable to match demand. There are policies in place to support domestic biomass production, such as the Biomass Feedstocks Innovation Programme.	Any new feedstock types (produced in the UK or abroad) would need suitable criteria, as detailed in Action 11.

Themes of interest within the current biomass sustainability landscape	Is this theme already addressed in current UK biomass sustainability criteria?	How will this theme be addressed through our commitments and actions
Carbon emissions and accounting: Reducing emissions across the supply chain was important to stakeholders. More reliable evidence was deemed necessary by stakeholders on carbon emissions being accounted for in the right sectors, such as the LULUCF sector. A review of the most up-to-date evidence on ILUC accounting and soil carbon was deemed necessary to ensure landscape carbon stock changes are accurately calculated to ensure sourcing does not occur from areas of falling carbon stock.	The GHG criteria implemented in government support schemes requires the whole supply chain to be included, including growing, processing and transport of biomass. The UK reports and accounts for biomass use in accordance with internationally agreed rules that follow guidance from the IPCC that avoids double counting of emissions in both the forest and energy sectors. For example, the loss of carbon stock when a tree is felled is reported in the land use, land use change and forestry sector. For transparency, the UK reports internationally the emissions of carbon dioxide from bioenergy use as a memo item, outside of national totals.	Actions 3, 4, and 5 relate to GHG criteria. The actions highlight where further work is needed to understand how metrices can be included meaningfully in criteria, such as ILUC and soil carbon.

Themes of interest within the current biomass sustainability landscape	Is this theme already addressed in current UK biomass sustainability criteria?	How will this theme be addressed through our commitments and actions
Sustainable land management, Biodiversity and Ecosystem services: Stakeholders were keen that efficient and up-to-date land management practices were used, and verification of ecosystem services such as air quality match the clean air objectives. Some stakeholders had low confidence in the sustainability of imported feedstocks, particularly with regards to the impacts on highly biodiverse forests.	Current sustainability criteria already cover non-carbon criteria such as biodiversity and contain definitions for protected forests and ecosystems and provisions for protection of highly biodiverse areas, regardless of area of sourcing. While subject to a separate domestic legislative framework, biomass support schemes give due consideration to the air quality impacts of using biomass.	Actions on Land criteria set out further enhancements that could be made to strengthen criteria on biodiversity, ecosystem services and sustainable sourcing.
Social criteria: Stakeholders deemed the current criteria insufficient for social impacts. Engagement with experts identified corporate ethics and reporting should be verified. Current schemes do not feature high levels of local community ownership or focus enough on community welfare which may hinder a just net zero transition.	Land and labour rights to be upheld as per national or local law in country of harvest, and land rights respected as part of the existing sustainability criteria.	Action 10 set out how social criteria could be strengthened further by aligning to principles in internationally recognised criteria and standards explicitly.

Themes of interest within the current biomass sustainability landscape	Is this theme already addressed in current UK biomass sustainability criteria?	How will this theme be addressed through our commitments and actions
Scale and Adaptation: Criteria may work at smaller scales but may not translate to address societal concerns. Sustainability and governance framework may also need to adapt and change as the bioeconomy grows and new challenges emerge. Need to look beyond just improved/transparent sustainability frameworks, and consider other drivers such as finance, development activities, public procurement, trade agreements	The current criteria are periodically updated via consultation at different timescales, depending on sector-specific policies.	A cross-sectoral sustainability framework, subject to consultation, will aim to provide consistency within the bioeconomy and allow improved interactions with the wider policy landscape. Action 11 highlights the need to develop and accommodate novel feedstocks and technologies.
Monitoring, reporting and verification (MRV): Stakeholders were strongly in favour of an effective MRV system that follows a whole systems approach to sustainability. There was a lack of trust from some stakeholders in certification schemes. Some stakeholders highlighted that auditing should be prioritised over certification and the use of more transparent methodologies and modern technologies (e.g., satellite, public datasets)	Where biomass use is supported by the government, there are independent regulators in place to verify the use of sustainable biomass. All data submitted as part of this regulation process is already required to be independently verified and audited. Details of the compliance process is set out in Annex A. Certification schemes already use modern technologies for data collection wherever possible and practicable.	Further work will be required to understand appropriate governance mechanisms for a cross-sectoral sustainability framework, and how the governance system can address stakeholder needs around increased data transparency and accessibility.

Themes of interest within the current biomass sustainability landscape	Is this theme already addressed in current UK biomass sustainability criteria?	How will this theme be addressed through our commitments and actions
Industry stakeholders raised concerns that increased specificity in sustainability criteria would be cost prohibitive for small suppliers, stifle innovation, and prevent uptake of biomass within the market.	UK criteria are already aligned to internationally recognised best practice standards which industry follows.	The cross-sectoral sustainability framework would require regular updates in line with up-to-date evidence, and it is intended to keep pace with current industry led best practices and align to latest scientific evidence.

3

Biomass and Air Quality

Poor air quality is the biggest environmental risk to human health. The latest published figures[43] (2021) show that emissions of key pollutants have reduced significantly since 2010. However, government recognises that there is more to do to protect people and the environment from the effects of poor air quality and to meet emission ceilings.

The production and use of biomass can lower the quality of the air we breathe, increasing the risk of harm to human health. The pollutants emitted from biomass use can also affect the capacity of ecosystems to sequester greenhouse gas (GHG) emissions.

3.1 Impact of biomass use on air pollution

Making greater use of biomass can have a significant impact on air quality. For example, its combustion produces a variety of pollutants including fine particulate matter ($PM_{2.5}$). $PM_{2.5}$ has been identified as the most harmful air pollutant to human health, shortening lifespans and leading to respiratory and cardiovascular problems.

Another example comes from digestate, a by-product of the Anaerobic Digestate (AD) process, which can be used as a low-carbon fertiliser. It does, however, require careful management e.g., when it is stored and spread on agricultural land. Without this it can cause substantial emissions of ammonia and lead to harmful nitrogen deposition, which leads to loss of biodiversity and ecosystem function in sensitive habitats. To manage this, the Environment Agency's Quality Protocols require that quality Anaerobic Digestate products are supplied with documentation which specifies that they must be used, stored and handled in accordance with good practice guidelines to minimise ammonia emissions from spreading and soil management. In addition, EA Standard rules permits require the use of covered containers or covered lagoons to minimise ammonia emissions from digestate when stored.

As set out in the National Emission Ceilings Regulations 2018 (NECR),[44] the UK has statutory emission reduction commitments in place for emissions of five of the most damaging air pollutants, including ammonia and $PM_{2.5}$. The combustion of biomass already makes a substantial contribution to the national emission totals of several pollutants. For example, the stationary combustion of biomass and wood as a fuel within the manufacturing and construction industries accounted for 18% of $PM_{2.5}$ emissions in 2021. Likewise, the domestic combustion of wood accounted for 21% of $PM_{2.5}$ emissions in 2021. Emissions of $PM_{2.5}$ from both of these sources have increased significantly over the past 10 years.[45]

[43] https://www.gov.uk/government/statistics/emissions-of-air-pollutants
[44] https://www.legislation.gov.uk/uksi/2018/129/contents/made
[45] https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-particulate-matter-pm10-and-pm25

Combustion of biomass also contributes towards the population's exposure to PM2.5 concentrations. In order to protect human health and the environment, local concentrations of key pollutants are also subject to limits through the Air Quality Standards Regulations 2010.[46] We have also set two ambitious national targets for PM2.5 in The Environmental Targets (Fine Particulate Matter) (England) Regulation 2023.[47]

Consideration of the local impacts of biomass is therefore crucial, and these can vary according to several factors. Location is important, as air pollutants from domestic or district biomass boilers can have disproportionate impacts on people's health as they are often located closer to human populations. Technology type and size are also key, with domestic biomass boilers having less stringent emission limits than industrial-scale boilers, reflecting the greater ability and cost effectiveness of controlling emissions at larger scale.

These factors are already reflected in the regulatory framework for different end uses, for example through the consideration of local air quality impacts when setting emission limits for large biomass combustion plants through environmental permits. However, improvements could be made, particularly for smaller biomass combustion plants where regulation and permitting is currently less effective at ensuring local air quality is protected and population exposure minimised.

46 https://www.legislation.gov.uk/uksi/2010/1001/contents/made
47 https://www.legislation.gov.uk/uksi/2023/96/contents/made

3.2 Impact of biomass air pollutant emissions on greenhouse gas emissions

The use of biomass aims to decarbonise the economy and reduce GHG emissions. However, air pollution from the use of biomass can, in some cases, lead to secondary GHG emissions and lower carbon sequestration in habitats. For example, nitrogen oxides (resulting from the combustion of biomass) and ammonia can be deposited on soils. If this nitrogen is not taken up by plants, microbes can transform it to other forms of nitrogen, including nitrous oxide, a potent GHG.

Air pollution also impacts the sequestration of carbon in soils, plants, and trees. Nitrogen pollution (and its acidifying impacts) can reduce biological diversity by affecting plant growth and fungi in the soil which assist with nutrient uptake.[48,49] The habitats that are most sensitive to these changes, including peatlands, native woodlands, heathlands, and grasslands, are those that play a critical part in carbon sequestration in the UK.[50]

Nitrogen within the soil can also promote respiration of bacteria and decomposition of soil organic matter – both of which release carbon dioxide and reduce soil carbon sequestration.[51] As well as direct nitrogen pollution, the emissions from burning biomass can generate ozone. This can counteract any positive growth effects caused by nitrogen, and can affect photosynthesis, flowering and crop yield. Stressors such as drought and excess nitrogen deposition can exacerbate ozone injury.[52]

In order to achieve our net zero target and air quality goals in parallel, it is vital that biomass policies maximise co-benefits and mitigate negative impacts by being dynamic and promoting the latest and most effective abatement techniques.

48 https://data.jncc.gov.uk/data/9f1ab259-00f1-4080-9039-ec83e4031db1/JNCC-Report-447-FINAL-WEB.pdf

49 Lilleskov, E.A., Kuyper, T.W., Bidartondo, M.I. and Hobbie, E.A., 2019. Atmospheric nitrogen deposition impacts on the structure and function of forest mycorrhizal communities: a review. Environmental Pollution, 246, pp.148-162. (https://doi.org/10.1016/j.envpol.2018.11.074).

50 https://publications.naturalengland.org.uk/publication/5419124441481216

51 Jesmin, T., Mitchell, D.T. and Mulvaney, R.L., 2021. Short-Term Effect of Nitrogen Fertilization on Carbon Mineralization during Corn Residue Decomposition in Soil. Nitrogen, 2(4), pp.444-460. (https://doi.org/10.3390/nitrogen2040030).

52 Grulke, N.E. and Heath, R.L., 2020. Ozone effects on plants in natural ecosystems. Plant Biology, 22, pp.12-37. (https://doi.org/10.1111/plb.12971).

3.3 Regulatory requirements on biomass

Regulatory requirements develop over time as technologies improve, new evidence emerges, and markets change. Action will be needed in the future to ensure that, where biomass is used, regulatory requirements represent the best technically and economically achievable methods for controlling emissions. Main areas for policy development are:

Industrial and commercial biomass combustion plant

There is an existing regulatory framework, for instance, in England and Wales through the Environmental Permitting (England and Wales) Regulations 2016,[53] emissions controls on the smallest plant through the Ecodesign for Energy-Related Products and Energy Information Regulations 2021, and conditions within low carbon heat subsidy schemes.

However, there are gaps in this framework and the best available techniques (BAT) for reducing pollution are not required for all categories of plant. As set out in the Clean Air Strategy,[54] the government is considering the case for tighter emissions standards on Medium Combustion Plant (MCP) and Specified Generators (including biomass plant) and considering closing the regulatory gap between the current Ecodesign and MCP regulations.

In the Environmental Improvement Plan, we committed to consulting on a new system for updating standards for small industry. The BAT approach has been highly successful in reducing emissions from large industry and applying a similar approach to small industry will help to reduce and manage pollution from this source and increase regulatory certainty for industry.

Lastly, we will identify and manage the air quality impacts of bioenergy with carbon capture and storage (BECCS) technologies as they develop.

Domestic biomass combustion

New biomass boiler installations are supported where the building is located in a rural area and does not have an existing mains gas connection. The boiler must meet specific standards for emissions, to be eligible, to mitigate negative impact on air quality in line with the government's Clean Air Strategy. The scheme conditions for low carbon heating subsidy schemes such as the Boiler Upgrade Scheme (BUS) reflect this position. As new schemes are developed, we will review requirements to ensure they include adequate air quality protections.

Government has already taken steps to reduce emissions from domestic burning by introducing the Domestic Solid Fuels Standards Regulations.[55] These include restricting the moisture content of wood

53 The Environmental Permitting (England and Wales) (Amendment) Regulations (EPR) 2018 SI 110 were published in January 2018 to transpose the requirements of the Medium Combustion Plant Directive (MCPD) EU/2015/2193 of 25 November 2015.

54 https://www.gov.uk/government/publications/clean-air-strategy-2019

55 https://www.legislation.gov.uk/uksi/2020/1095/contents/made

sold for use in domestic burning and banning traditional house coal for domestic use. Government has also made it easier for local authorities to enforce smoke control area rules by providing powers to issue fines for smoke emissions, rather than prosecuting in court.

In the recently published Environmental Improvement Plan,[56] government committed to take forward further policy to restricted emissions from domestic solid fuel burning, including tightening limits that new stoves in Smoke Control Areas must meet, extending the solid fuels legislation, including to cover fuels burned outside, and designing and implementing measures to drive a shift towards newer appliances compliant with tough new emission standards.

We are not considering a ban on domestic burning in England. The UK government recognises that some households are reliant on solid fuel burning as a primary source for heating, hot water, and cooking. With this in mind government is not seeking to ban burning. This is particularly pertinent in light of the current focus on energy security and the global rise in energy prices.

Anaerobic digestion

Government is developing proposals on reducing ammonia emissions from organic manures. These will also relate to the storage and spreading of digestate, a by-product of biogas generation which is used as an agricultural fertiliser. These proposals will be consulted on later this year. For participants under the GGSS, plants are required to cover digestate stores and must spread digestate using low emission spreading techniques that reduce ammonia emissions. Government has published a techno-economic study into emerging ammonia abatement technologies and their associated environmental impacts.[57] We will continue to monitor the development of these technologies to understand their potential role in driving more sustainable biogas and biomethane production.

Transport

The government is continuing to take action to improve air quality and deliver cleaner transport through measures set out in the Environmental Improvement Plan. Regulation to reduce the impacts of biofuels from transport on UK air quality is already in place. This includes European Emission Standards which require vehicles operating on biofuels to meet the same standards as those running on fossil fuels. In addition, The Motor Fuel (Composition and Content) Regulations also outline the requirements that biofuels need to comply with in order to be sold and used in the UK.

When burned in internal combustion engines, biofuels typically do not deliver significant air quality benefits compared to their fossil equivalents. Within transport, biofuel use is therefore to be increasingly focused on transport applications with limited alternatives to liquid and gaseous fuels and our ultimate ambition is to support the development of vehicles with zero harmful tailpipe emissions.

[56] https://www.gov.uk/government/publications/environmental-improvement-plan
[57] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1145312/identifying-impacts-from-food-and-farm-digestates.pdf

Local action

Local Authorities (LAs) have a role to play in reducing emissions of harmful air pollutants, and the government will continue to support LAs to improve their air quality locally. We need to make sure that local authorities and regulators have powers that are fit for purpose to quickly address emissions that threaten health or habitats and make sure that the framework, including the planning regime, supports local action. This is particularly important in existing pollution hotspots, or where communities may be more vulnerable to health impacts of exposure. Siting of industry which emits air pollution must take local conditions into account, including whether new industry would exacerbate an existing air pollution hotspot, or disproportionately impact a group already severely affected by poor air. Government published a revised national Air Quality Strategy[58] in April 2023, with a focus on improving local authorities' delivery of measures to improve air quality across the country.

[58] https://www.gov.uk/government/publications/the-air-quality-strategy-for-england

3.4 Research, development, and innovation to support biomass sustainability requirements and air quality

Further research and innovation will also be required to ensure that the impacts of biomass on air quality are better understood and improvements in abatement technologies are developed.

Existing and planned work includes:

- The government has launched a funding competition of up to £1 million to help industry develop technologies to abate emissions from solid fuel burning.
- Ongoing domestic combustion survey work to track domestic burning activity and quantities and types of fuel burned.
- A research study to develop emission factors for domestic solid fuels, including wood, in order to better understand emissions from domestic combustion. These data will help develop future polices to reduce emissions from domestic burning.
- A process and impact evaluation of the Domestic Solid Fuels Standards Regulations 2020. The regulations were introduced in England and put in place a ban on the sale of wet wood in quantities under 2sqm and, from May 2023, a ban of the sale of traditional house coal, for use in domestic settings.
- A literature review and consultation with experts on the air quality impact of new and emerging low carbon technologies, including bioenergy.

4

Biomass Availability: sustainable resources from international and domestic sources

Our Key Messages

- The potential future availability of sustainable biomass is uncertain and challenging to determine with precision due to uncertainties over how economic factors will affect biomass availability in the future.
- We expect demand for biomass to increase in the medium to long term to support net zero through the delivery of negative emissions.
- Both domestic and imported supply of sustainable biomass are expected to continue to play an important role in supporting biomass use across the economy.
- Reducing barriers to increasing domestic production of biomass will be important to ensure the UK can secure the supply needed across the economy to support decarbonisation. This is supported by the £36 million Biomass Feedstocks Innovation Programme, which funded innovative ideas that address barriers to UK biomass production. However, we are determined that this will not compromise government's Food Strategy goal of maintaining food production or our ability to meet our Environment Act targets.
- We will soon publish the updated Global Bioenergy Resource Model that has supported the analyses in this Strategy.

The availability of sustainable and suitable biomass feedstocks at sufficient scale and at appropriate prices is one of the primary factors that will determine the overall contribution of biomass to net zero.

This chapter sets out government's latest assessment of biomass feedstock availability between now and 2050 from both domestic and international sources based on existing policies and the best available evidence for future projections.

The chapter also presents an overview of the existing policies and future policy plans to deliver sustainable biomass over time in support of biomass demand in the UK. We also highlight the opportunities to scale up domestic biomass production by increasing dedicated perennial energy crop production, and through delivery of novel feedstocks following research and innovation activities.

4.1 Biomass Feedstocks

Biomass feedstocks include purpose-grown feedstocks as well as organic wastes and residues. Biomass feedstocks under consideration in the strategy include conventional food and feed crops, perennial energy crops (Miscanthus and short-rotation coppice (SRC)), short-rotation forestry (SRF) and wastes, products (incl. forest derived products),[59] agricultural residues, forest residues, and residues from processing, as well as marine-based and novel feedstocks.

Sustainable biomass has multiple benefits for decarbonisation. Plants and trees absorb carbon dioxide (CO_2) as they grow, and the biomass harvested from them can be used to directly displace fossil fuels such as oil, coal, and natural gas, to produce energy or other products. Biomass can also provide a carbon sink by storing carbon in soil and plant material, and through long term storage in products (e.g., wood panels, construction) and in bioenergy production with carbon capture and storage (BECCS). However, permanent land use change, particularly for longer rotation biomass crops, can represent a very significant increase in the average carbon stock on the land.

Today, a significant portion of our biomass supply is composed of wastes and residues, with some purpose-grown arable crops being used for renewable gas or transport fuel production.[60] Solid biomass, including wood, waste wood, animal and plant biomass (excluding biodegradable waste), represented 33% of the total renewable energy demand in 2022, with nearly 66% being used in electricity generation and the remaining 34% to produce heat.[61] The electricity sector predominantly uses wood pellets from forest residues and low-grade roundwood. The heat sector utilises a combination of wood-based solid fuels and renewable biogas produced from animal-derived wastes (such as manures, poultry litter, and animal processing residues), food wastes, industrial organic wastes, and crops, such as maize. The biogas can be upgraded to biomethane and injected into the gas grid, where it directly displaces fossil natural gas. In the transport sector, renewable transport fuels are predominantly produced from wastes and residues, such as used cooking oil, starch slurry, food waste or tallow. Crops, such as corn, wheat and sugar cane, also play a role, in particular in bioethanol production.[62]

Given its key role for decarbonisation, it is important to understand the potential future availability of biomass. However, as the biomass feedstock supply is so diverse, understanding future availability is a complex task and one which is subject to significant uncertainties. Future feedstock availability will depend on a

59 Other biomass products, i.e., a product of economic value or use that could lead to indirect impacts if used for energy use (e.g., distillers' grain which could be used for animal feed) are not encouraged for bioenergy uses.

60 https://www.gov.uk/government/statistics/area-of-crops-grown-for-bioenergy-in-england-and-the-uk-2008-2020/summary

61 https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes

62 https://www.gov.uk/government/collections/renewable-fuel-statistics

range of factors, including government policies and market developments in the UK and in other countries, as well as the prices different end users are willing to pay.

To support our assessment of future biomass availability we have updated the UK and Global Bioenergy Resource Model, which will be published later this summer. This is a complex biophysical model that provides several future availability scenarios based on user inputs within a model framework. The model provides an estimate of potential sustainable biomass feedstock availability to the UK up to 2050 from domestic and international sources under various scenarios. Biomass feedstocks in scope of the model can be categorised into perennial energy crops, biogenic wastes and residues (including forestry residues), arable crops, and biofuels.[63] The full list of in-scope feedstocks and information on the supply assumptions can be found in the Technical Annex. There may be additional biomass feedstocks which may be in scope of the Strategy but have not been included in the model due to lack of available data or its relatively small scale, e.g., novel feedstocks, such as seaweed.

The Biomass Public Dialogue Project,[64] which gathered public views on the role of biomass in achieving net zero, included views on the different sources of biomass. The report focusses on five main feedstocks: waste; food and feed crops; perennial energy crops; forestry and forestry residues; and marine feedstocks. Participants were not given criteria to assess sources but tended to rely on perceptions concerning the reliability of the source, its potential environmental impact, and land use. Participants expressed a clear preference for waste as a source of biomass compared to others because they saw it as a more reliable source, with a lower impact on the environment, and not detracting from other uses of land in the way that using crops for biomass would. Participants raised concerns over the sustainability of, for example, imported forestry residues, and whether sourcing biomass from forestry is the best use of land.

Participants also expressed hope that the domestic supply of biomass could potentially reduce the cost of energy and make energy supplies more reliable because it could exploit new or free resources, such as (domestic) waste. Participants were concerned about the impact that dedicating land to grow crops specifically for biomass would have on the availability of food. There were also doubts about the feasibility of sourcing biomass from both forestry residues and SRF, and whether there was enough land available in the UK to do this. When presented with information on perennial energy crops, and the ways they differ from food and feed crops, participants thought this allowed for a more consistent supply of biomass.

[63] Note that global biofuels included in the model are not ‘feedstocks’ but ‘finished fuels’. This is because it is likely that these will be processed overseas and imported to the UK as ‘finished fuels’ rather than raw feedstocks.

[64] https://www.gov.uk/government/publications/biomass-strategy

4.2 Future availability of biomass resources

Biomass Availability Scenarios

Several factors were considered in developing our assessment of potential future biomass availability to the UK. These include domestic policies relating to biomass production and availability (for example, waste reduction targets), domestic and global land availability under a range of socio-economic future scenarios, biomass crops yields, sustainability policies that stipulate supply chain greenhouse gas (GHG) emissions thresholds, and competition from non-energy uses. Here we set out ranges of future biomass availability that account for some of these factors and recognise the significant levels of uncertainty associated with estimating biomass resource availability, especially over the long term. The complex interactions across the biomass supply system make forecasting precise future availability unreliable.

Previous studies[65] show a number of models can assess the potential future availability of biomass for the bioenergy sectors, each with different constraints and assumptions, that provide a wide range of estimates (approximately 600 PJ to 3,200 PJ at the UK scale based on the energy content of the feedstocks).

To help inform policy development, it is important to differentiate between theoretical levels of potential future availability and what is referred to as 'sustainable implementation potential' (Figure 4.1). The former refers to the total amount of biomass that is theoretically available to a given region at a given time. The latter refers to the remaining portion of that biomass potential after considering technical, socio-economic and political developments (such as land use policies, population levels, agricultural productivity, and lifestyles) alongside biomass sustainability requirements.[66] Ultimately, the potential future biomass availability that reflects the 'sustainable implementation potential' is lower than the theoretical potential both on a global and a UK level.

We recognise that there are already significant pressures on global land use, food security and biodiversity. Climate-related policies and market initiatives which drive additional demands on land use amplify these pressures, as do the impacts of a changing climate. It is important that countries considering their approach to renewable energy consider the marginal impact of these policies on food security (both the level and volatility of agricultural prices), global emissions, factoring in both direct and indirect effects (in particular, indirect land use change), and biodiversity.

[65] Supergen Bioenergy Hub UK Biomass Availability Modelling Scoping Report, 2021: https://www.supergen-bioenergy.net/wp-content/uploads/2020/10/Supergen-Bioenergy-Hub-UK-Biomass-Availability-Modelling-Scoping-Report-Published-Final.pdf

[66] IEA Bioenergy Review, 2023: https://www.ieabioenergyreview.org

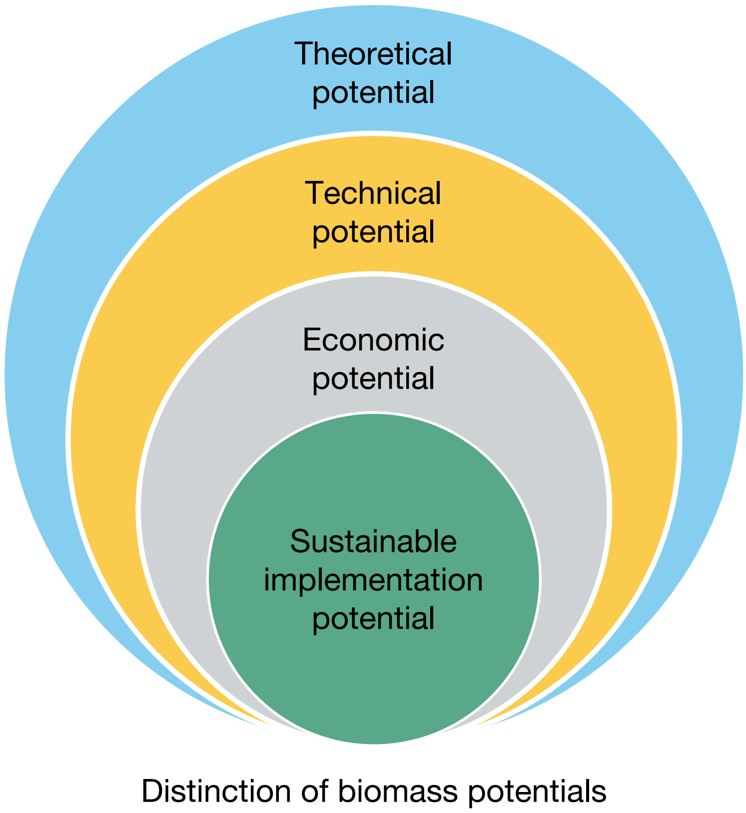


Figure 4.1: Different levels of future biomass potential. IEA Bioenergy Review 2023

The biomass supply scenarios presented in this strategy have been developed to minimise impacts on land use and food security. The scenarios limit the global land availability for biomass production by only allowing the expansion of bioenergy crops for import to the UK to be grown on abandoned arable land, as predicted by a global integrated assessment model (IMAGE). The global area of abandoned pastureland is assumed to be used to promote internationally agreed biodiversity goals. The land area available for biomass production is dependent on the scenarios' assumptions on socioeconomic pathways to 2050 which affect population, dietary habits and the outcome of efforts to improve food system efficiency and reduce food waste. Hence the demand for land for food can be impacted by a wide range of factors which will in turn influence the amount and production cost of biomass.

The approach taken aims to avoid the risk of causing indirect land use change (ILUC), which is caused when increasing demands for food and feed crops displaces production in ways that modify existing land use, or brings new land into cultivation, in ways that are associated with additional emissions (see Box 4.1), or by other measures that expand agricultural land at the expense of other land uses. The biomass supply estimates provided in this strategy are therefore considered to be conservative, as they assume no land use change from food production and hence a reduced risk of ILUC. The estimates also comply with current sustainability requirements by not including feedstocks produced from forestry regions that are harvested at a rate faster than their growth, or from deforested areas, so as to preserve forest area and carbon stocks. Further work is required to establish suitable ILUC metrics and emissions factors for land-derived biomass feedstocks in scope of the biomass availability model.

Potential future biomass availability scenarios

Modelling the future availability of sustainable biomass to the UK is complex and there are uncertainties over how various economic factors can affect biomass availability, e.g., future global competition and trade of biomass, the future cost of biomass and the price businesses will be willing to pay for biomass and secure long term supply chain contracts. Most potential biomass availability estimates are based on biophysical models that estimate maximum technical potential of biomass availability globally and do not include economic considerations that could limit or promote biomass availability in the future, for example due to the lag between establishing crops and harvesting them.

To illustrate this, we have set out two scenarios of biomass availability according to different constraints and assumptions concerning domestic and imported feedstocks. Due to the uncertainty described here, these are not intended to be upper or lower estimates of what we expect biomass availability to be, but rather to provide a broad frame of reference within which to analyse how biomass might be used in a world where there is greater or lower availability.

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The two illustrative scenarios include a restricted supply and an ambitious supply. The primary difference between these scenarios is how much feedstocks we can import. In both, we include a sustainability constraint to ensure we only build a picture of sustainable biomass potentials. In both, we use the same assumptions to determine the potential future availability from domestic sources, except for energy crop planting rates.

Assumptions of the future biomass availability scenarios:

Most domestic availability assumptions are kept consistent between the two scenarios. These include government's waste minimisation and increased recycling targets, the near elimination of biodegradable municipal waste to landfill, ambitious afforestation targets, and improved handling of sewage and slurries.

The main difference between the two scenarios relate to import levels and to domestic energy crop planting rates. These differences reflect the uncertainty about future UK land use change, the precise biomass species mix, policy choices around cultivation, and interaction between domestic biomass and other UK land-based targets. We assume no export of UK produced biomass or biofuels.

Box 4.1. Land Use Change

Land is a limited resource facing multiple increased demands, nationally and globally. A key rationale for incentivising the use of biomass in producing renewable energy is to reduce GHG emissions. Assessments of GHG savings take account of emissions directly associated with the production, transportation and use of biomass. However, beyond these direct effects, and in line with the sort of market processes outlined in Box 4.2, increasing biomass production can also result in emissions stemming from displacement effects known as indirect land use change (ILUC). Emissions associated with ILUC matter, because they can dilute or even outweigh direct emissions benefits.

Direct land use change occurs when an area of land is converted from one use to another, e.g., from forestry to the production of bioenergy crops, such as Miscanthus. Our existing biomass sustainability criteria include requirements to include GHG emissions or removals associated with direct land use change in the GHG emissions calculations and to prevent sourcing that adversely impacts areas with high biodiversity value or high carbon stocks, such as primary forest, protected areas, peatlands, and wetlands.

ILUC relates to unintended consequence of a land use decision taken elsewhere. For example, the use of biomass produced on existing agricultural land can lead to both the intensification of production on existing agricultural land (which may involve extra use of fertiliser, associated with additional GHG emissions) and the displacement of production of food and feed crops elsewhere, potentially leading to the cultivation of additional land. This cultivation can result in substantial amounts of GHG emissions being released into the atmosphere if land with high carbon stocks and highly biodiverse habitats, such as forest land, grassland, or peatlands, is converted to agricultural use. Similar effects might also apply to biomass other than their use as primary feedstocks. For example, if wastes have a range of potential uses, then it would be important to consider whether, and how far, their use might displace demand into the markets for alternative inputs produced on land.

GHG emissions associated with ILUC are inherently uncertain. ILUC effects are complex and cannot be easily observed, measured, or directly attributed to land use management decisions of individuals, groups, or a particular policy. The estimation of ILUC effects is dependent on modelling studies that seek to understand how changes in demand for agricultural commodities (e.g., via biofuel policies) and other products used for renewable energy production affect global land use. GHG emissions associated with ILUC are influenced by a variety of factors, such as what was produced on the land previously, the technology used for the bioenergy production, and the region of the world where ILUC occurred.

Not all feedstocks have the same ILUC impacts but when ILUC is considered, some biomass can have greater carbon impacts than fossil fuel alternatives.

A variety of modelling tools and approaches can be used to calculate ILUC. Any model-based ILUC factors used to calculate GHG emissions are not fixed values, but depend on market dynamics (see Box 4.2) and local circumstances. To account for the resulting lack of certainty in the impact of ILUC, while also accounting for the need to recognise the potential ILUC impacts of different biomass feedstocks we require the reporting of estimated ILUC emissions from land-based biofuels using ILUC values provided for suppliers under the RTFO and the LCHS. As detailed in Chapter 2.4, we commissioned a review of existing ILUC assessment methods (project is ongoing) and we will provide further detail in the forthcoming government consultation on biomass sustainability on next steps for ILUC in our biomass sustainability criteria.

- The restricted supply scenario:
  - Includes levels of domestic energy crop planting that reach 9 kha/yr from 2038 onwards.
  - The import levels in this scenario assume that most countries producing biomass prioritise their own domestic use, and so only one-fifth of overseas production is exported. Of this volume available for trade, it is assumed that the UK competes equally with all other nations and so is able to secure a fraction of this market equal to the UK's share of global GDP.
- The ambitious supply scenario:
  - Includes higher levels of domestic energy crop planting, reaching 17 kha/yr from 2038 onwards.
  - The import levels in this scenario assume the UK is able to import a fraction equal to its share of global GDP of all overseas-produced bioenergy that meets our sustainability criteria.

The full set of assumptions behind how the scenarios were constructed can be found in the Technical Annex and the model used will be published later this summer.

The illustrative scenarios presented in the Net Zero Strategy for how the UK could reach the net zero target showed that biomass use would scale up considerably from today's level, largely fuelling BECCS technologies. As negative emissions will play an important role, we expect biomass use in BECCS, and therefore overall demand, to increase in future as these new technologies deploy over time, which will require biomass supply to scale up.

The total potential sustainable biomass estimated to be available to the UK varies significantly across these scenarios (Figure 4.2), with 550-750 PJ in 2025, and 500-1,000 PJ in 2050.

Under both scenarios, the availability of biomass feedstocks from domestic sources remains relatively stable. In the ambitious supply scenario, total domestic resource supply varies only between 370 PJ in 2025 and 390 PJ in 2050, while in the restricted supply scenario, total UK resource supply remains around 370 PJ in 2025 and 2050 (Figure 4.3). The next section discusses the potential future domestic supply and policies influencing this.

Availability of biomass from international sources varies significantly between the two scenarios. Total supply from international sources in the ambitious scenario varies between 400 PJ in 2025 and 600 PJ in 2050 (Figure 4.3). The import availability increases out to 2030 under the assumption that we are able to increase our imports by clear signalling of demand policies until we are importing a share of overseas sustainable biomass production equal to the UK's fraction of global GDP. Then between 2030 and 2050 this scenario initially sees the UK's share of importable bioenergy slightly decreasing as the UK's share of global GDP decreases slightly due to the growth of developing countries, thereby increasing competition for the biomass resource. In later years this declining share is offset by increases in sustainable global production of biomass, which increases availability to the UK.

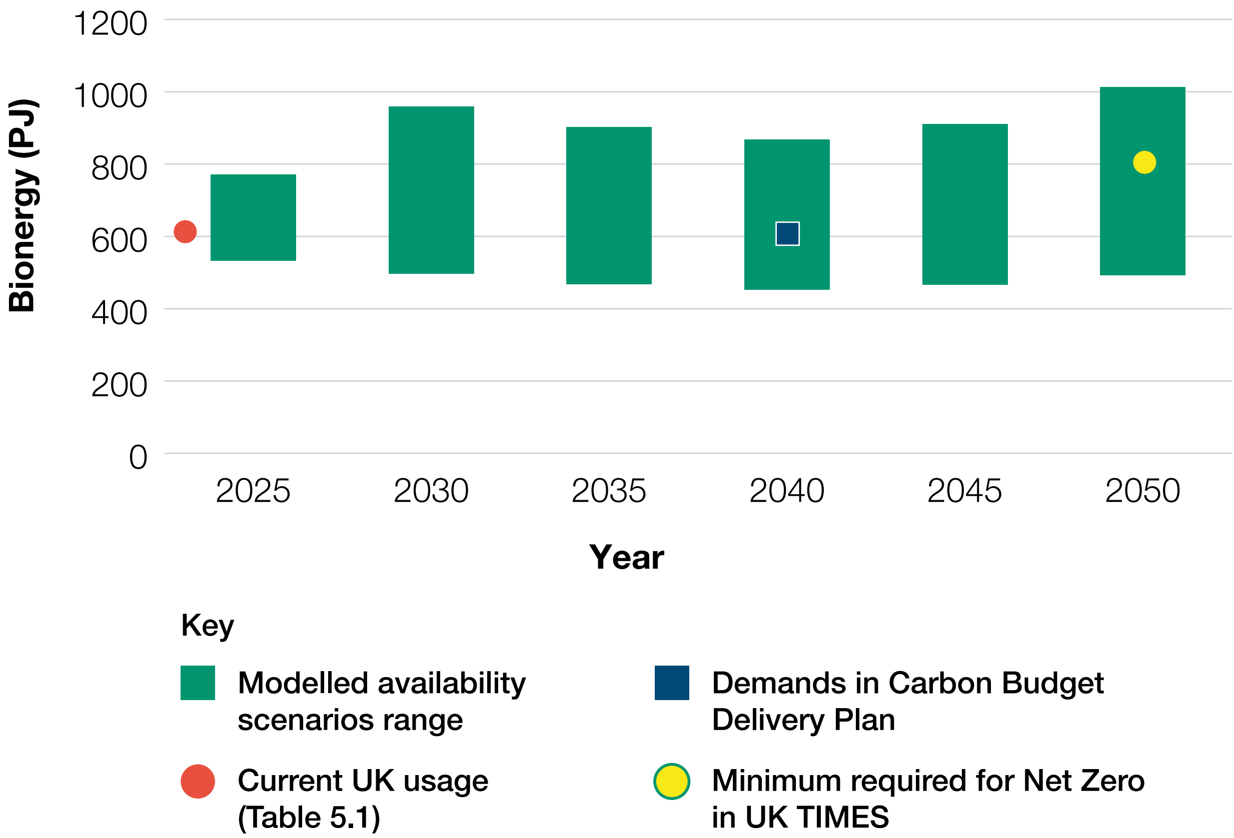

Figure 4.2: Sustainable biomass availability ranges (from domestic and international sources) potentially available to the UK between 2025 and 2050 based on availability estimates under two biomass availability scenarios, with comparisons to current and estimated future demand levels.

The breakdown of biomass by feedstock is included in Figure 4.5, based on the UK moving towards importing an equal share of each type of biomass which is available internationally - the actual future mix of imported biomass is uncertain, and the chart should not be read as a projection of future imports for each fuel.

In contrast, in the restricted supply scenario, total potential supply from international sources is 170 PJ in 2025 decreasing to 120 PJ in 2050 (Figure 4.3). This assumes that overseas producers of sustainable biomass only make one-fifth of their production available for export, and the UK must compete equally for this limited international supply and so is only able to accrue a share equal to its fraction of global GDP. Crucially, this restricted scenario sees the UK only have access to a total of around 500 PJ of sustainable biomass by 2050, which significantly reduces the amount of decarbonisation that is possible through deployment of biomass, with a particular reduction in the level of negative emissions achievable from BECCS. The impact of this is that our whole systems energy modelling (using UK TIMES, described in Chapter 5 and the Technical Annex) is no longer able to find a net zero solution for 2050, based on current demand and technology assumptions.

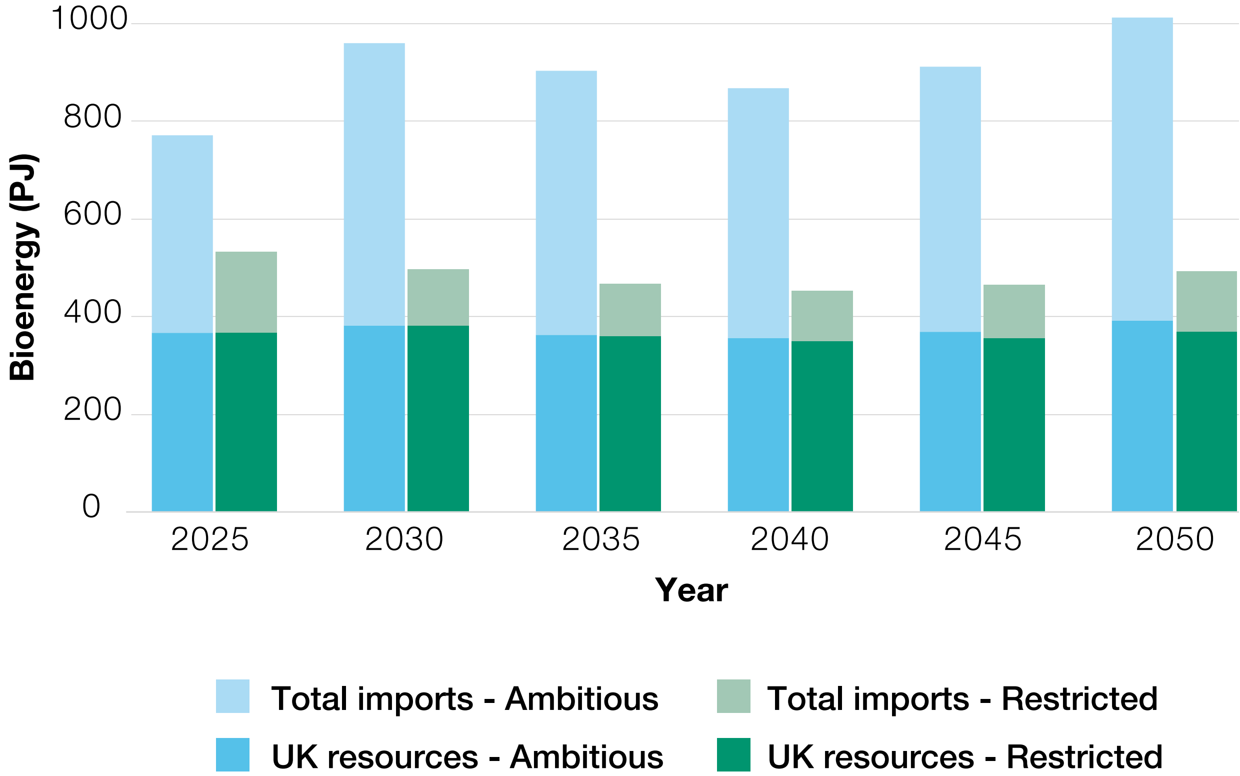

Figure 4.3: Total potential future availability of biomass feedstock to the UK from domestic and imported sources in restricted and ambitious supply scenarios.[67]

[67] The feedstocks (food and feed crops) from which the global first generation (1G) biofuels are made are not quantified in the model as these are assumed to be available to the UK as 'finished fuels', processed overseas and imported to the UK.

Therefore, we have modelled a further scenario by starting at the ambitious level of biomass imports and incrementally reducing the share of global production that the UK is able to access until the UK TIMES model is unable to find a pathway to net zero in 2050. This occurs at around two-thirds of the level of the ambitious scenario, or around 400 PJ per year of imports of sustainable biomass by 2050. This scenario uses the same level of domestic supply as assumed in the ambitious scenario, requiring in total around 800 PJ of sustainable biomass (Figure 4.2). This represents around 30% increase in bioenergy use between Carbon Budget 6 and 2050 to support net zero under current technical and demand assumptions.

Biomass supply is sensitive to the cost of biomass, therefore actions to reduce the cost of biomass will be needed to ensure the UK can secure the supply needed to support decarbonisation. Government, businesses, and biomass producers will all have a role in introducing interventions that increase the supply of biomass and develop sustainable supply chains while reducing supply costs, whilst at the same time safeguarding food production and the delivery of our nature goals.

We will continue to monitor the levels of biomass supply to ensure the UK can secure the biomass supply needed for any scale-up of biomass use across the economy. Should the 'restricted' supply scenario become likely, we would consider the interventions needed to remove barriers to increasing biomass supply from domestic or international sources. For example, innovation will also be needed to scale up domestic supply of sustainable feedstocks. The £36 million Biomass Feedstocks Innovation Programme is a government-funded innovation programme that aims to help scale up the domestic production of sustainable biomass by funding innovative ideas that address barriers to biomass feedstock production within the farm gate (Chapter 4.3).

The following sections provide a more detailed overview of the potential future supply of major domestic and international biomass feedstock to the UK, the use and availability of different feedstocks today, the policy landscape and what may be required in the future to support these feedstocks in the UK.

Domestic biomass sources

In 2022, 66% of biomass feedstocks used in renewable energy supply (heat, electricity, and transport) were from domestic sources.[68] The current makeup of domestic biomass resource is diverse. About 35% is composed of plant biomass, which includes straw, wood pellets, agricultural residues, and other plant-based biomass. Around 121,000 hectares of land are used to grow biomass crops for energy and the majority (92%) of this is used for biofuels or biogas.[69] Biogenic waste makes up about 18% of the domestic feedstock supply which includes materials such as waste wood, sewage gas, landfill gas and food waste. In the transport sector, renewable fuels from UK feedstocks made up 10% of total renewable fuels in 2021, with 77% of UK

68 https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes Table 6.1.

69 https://www.gov.uk/government/statistics/area-of-crops-grown-for-bioenergy-in-england-and-the-uk-2008-2020/summary

origin renewable fuel being produced from a waste feedstock, such as used cooking oil, food waste, and biogenic fraction of municipal solid waste.[70]

Domestically supplied biomass will continue to play an important role in providing the sustainable, stable, secure and cost-effective biomass supply that the UK will need for a variety of biomass uses across the economy. Our analysis suggests relatively stable levels of biomass availability from domestic sources in the future, varying between 370 PJ in 2025 and 370 PJ (restricted scenario) and 390 PJ (ambitious scenario) in 2050. Cattle slurry, residual biogenic waste, and waste wood are the three largest sources of domestic feedstocks in our analysis by primary energy content, with all three showing small variability between 2025 and 2050 (Figure 4.4). The largely stable future availability of these and other feedstocks (e.g., pig slurry, small roundwood, sawmill co-products, arboricultural arisings, sewage sludge, etc) is due to a mix of assumptions. For example, the quantities of straw surplus to agricultural requirements from cereal crops and production of other agricultural residues are stable in foreseen policy and market environments as are animal herd sizes. Some feedstocks such as sewage gas are a function of population and technology assumptions.

The availability of different waste and waste-related feedstocks, such as food waste, and residual biogenic waste, is dependent on our domestic waste policies and ambitions.

The total availability of biogenic waste resources is expected to decrease over time as environmental policies progress. For example, our waste minimisation ambitions in support of our Environment Act 2021 targets, and with greater use of a circular economy, will mean that the volume of waste going to residual waste treatment is expected to decrease. Concurrently, mandatory food waste collection policies will mean a greater volume of food waste will be available for recycling.

Future availability of purpose-grown biomass feedstocks is inherently more uncertain, while also having a greater potential for growth. In our feedstock availability assessment, the biomass supply from Miscanthus, short rotation coppice (SRC), and short-rotation forestry (SRF) sees a marked increase from 2030 onwards from today's low supply levels in both supply scenarios, but at different levels (Figure 4.4). The latest government assumptions on potential future planting rates assume that planting increases to c.17kha per year in England could be achieved by 2038. Higher prices for growers and removal of barriers to greater deployment of these feedstocks could facilitate development of stable supply chains and therefore, the greater production of these purpose-grown energy crops. Further work is needed to remove some of the technological barriers to using these feedstocks in a wider variety of applications and end uses, such as hydrogen production, to support the scale-up of domestic planting.

[70] https://www.gov.uk/government/statistics/renewable-fuel-statistics-2021-final-report/renewable-fuel-statistics-2021-final-report#renewable-fuel-trends

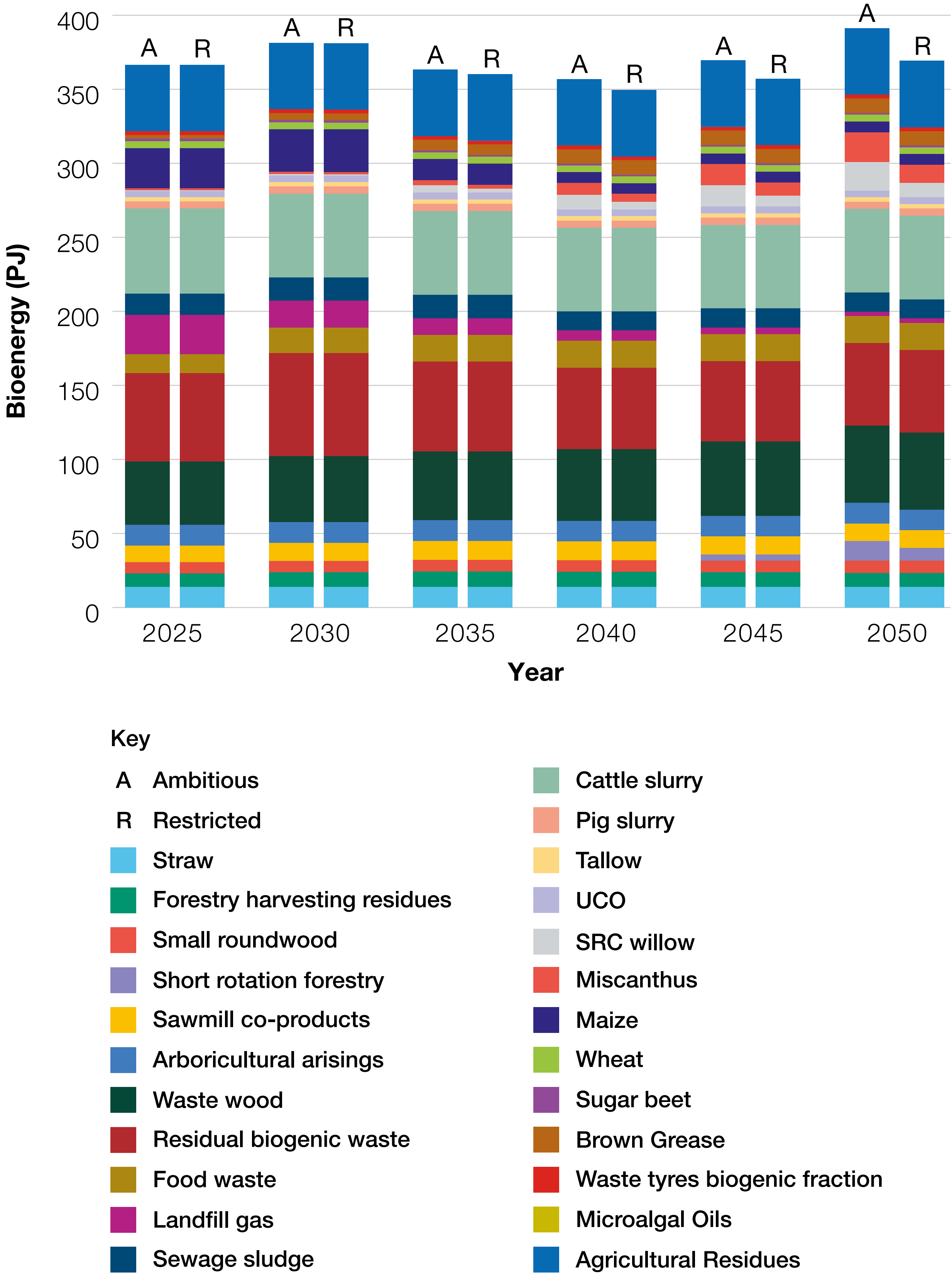

Figure 4.4: Potential future availability of biomass from domestic sources in the restricted and ambitious supply scenarios.

The following sections explore in greater detail the policies underpinning domestic biomass supply and the opportunities for increasing this.

Perennial energy crops and short-rotation forestry

A relatively small area of the UK (~10,000 hectares) is cultivated with perennial energy crops, and this is mainly used for heat and electricity generation. There is currently (2020) a negligible amount of dedicated SRF and around 2,000 hectares of SRC. There is an unknown area of SRF within UK Forestry Standard-compliant woodlands. Given the role that we expect biomass will play in the UK's journey to net zero, it is likely that the UK will grow more biomass here in the future, but domestic biomass cultivation and deployment should not compromise the government's commitment to broadly maintain current levels of food production, or ability to meet our legally binding Environment Act 2021 targets. The upcoming Land Use Framework for England will help support and balance the delivery of net zero, food production and Environment Act targets.

Government is considering the types of biomass that could be grown domestically as dedicated feedstocks for use in the generation of energy, or more broadly across the bioeconomy. Species covered are Miscanthus, SRC (e.g., Willow and Poplar) and SRF (including native and exotic species). Hemp is covered later in this chapter.

We are exploring these species types due to their potential to sequester carbon in both above and below ground stores, supporting the transition to net zero in the natural resources sector, as well as potentially providing low carbon feedstocks for energy generation that could be combined with carbon capture and storage, or processed as a material for manufacture.

Short-rotation forestry

Common forestry species such as Sitka spruce can be grown over shorter rotations (10-25 years), providing an SRF resource in the uplands. Some species such as Aspen, Sycamore, Birch and clonal Poplar hybrids have been grown as single stem short-ration biomass crops. They are often incorporated into agroforestry systems, although their planting is less common than elsewhere in Europe.

Fast-growing exotic species could make a rapid and major contribution to both biomass supply and carbon sequestration in growing biomass (increasing the long term average carbon stock of the land). However, such crops could have negative environmental impacts, including on water availability, plant health, and biodiversity, and more evidence on the scale of these impacts is needed for many novel species before adopting them at scale.

Short-rotation coppice

Clonal Willow hybrids, which have been grown extensively in SRC systems, are more familiar to landowners than SRF systems and can yield earlier (three to four years).

SRC crops such as Willow are attractive in that they are pioneer species and can grow in a wide variety of conditions and soils. Over a lifespan of at least 20 years, they can help rejuvenate soil, and can also offer excellent natural flood barrier protection as it can slow down the peak flow of water by increasing the hydraulic roughness. Native or naturalised species including sweet chestnut and hazel also offer potential for diversifying SRC.

A number of options are available for establishing new short-rotation crops with a view to expanding the availability of domestically produced feedstock. However, consideration must be given on how woodlands and or plantations comprising short-rotation crops are designed and managed.

The statutory tree canopy and woodland cover target for England excludes purpose-grown SRF and SRC plantations that are not UK Forestry Standard-compliant because they are unlikely to provide the range of woodland benefits set out in the Environmental Improvement Plan.

Woodland creation, including for species that have the potential to form woodland, is considered a permanent land use change under forestry regulations, acting as a barrier to the planting of SRC and SRF systems that have a short-rotation and are unlikely to develop the same natural capital benefits of 'conventional woodland'. We have recently consulted on developing a policy to no longer require that planting these systems represents a permanent land use change and will update on the results of this consultation in due course.

Perennial Grasses: Miscanthus

Miscanthus is usually propagated by planting sections of rhizomes and can be first harvested in the late winter spring two years after planting. Harvesting is then normally carried out every year with a lifespan of up to 20 years. The perennial nature of this crop is advantageous to farmers compared to the biomass types above in terms of providing an annual income once established.

Miscanthus is a relatively low-input crop and requires minimal fertilisers in its early production stages and limited inputs thereafter. Growers may therefore find this crop attractive due to its ease of establishment and maintenance and it can have comparative benefits for soil and water quality.

Miscanthus is a relatively versatile crop and can be grown in most soil types and tolerate a wide range of pH levels. It can survive being immersed in water for long periods of time and can support biodiversity depending on how and where it is cultivated. Miscanthus is considered a crop, and as such does not face the same permanency issues that SRF and SRC may do, providing greater flexibility of land use.

Existing Miscanthus and SRC is eligible for support under the Sustainable Farming Incentive (SFI), the first of the new environmental land management schemes introduced under the Agricultural Transition Plan. This support applies for actions taken to manage land in a way that improves crop production and is more environmentally sustainable, including one soil management action, three integrated pest management actions and one nutrient management action.

Interactions with Land Use

Domestic perennial energy crops and SRF would be developed in balance with other priorities on our limited supply of land. These priorities include growing food, planting trees, building homes and other infrastructure, creating natural habitats, and using land for leisure and recreation. Striking the right balance between different land uses is a challenging task which will involve trade-offs, and biomass is no exception. To help find the right balance between these priorities we will publish a Land Use Framework for England in 2023.

This will mean making sure that incentives and advice align to support food production and the delivery of environmental benefits from land according to what might be appropriate for a particular landscape, which will be dependent on the local context and needs. The Framework will support the delivery of multifunctional landscapes which will be dependent on the local context and needs and must be resilient to our changing climate.

Government has allocated £6.6m to a Net Zero Land Use Research & Development programme over the spending round (SR) period (2022-2025). The research programme's aim is to provide government with the capability and evidence to develop and deliver a strategic and operational approach to land use change for net zero and environmental recovery, whilst maintaining food security.

The research programme contributes to developing modelling capability and evidence on spatial land allocation, impacts of land-use change on ecosystem services and biodiversity and attitudes and behaviours towards land-use change. The Programme combines in-house and commissioned research. One of the land-use changes in scope of the programme is the development of woody biomass.

Outputs from this programme are supporting the development of the Land Use Framework. Longer term work will continue to underpin land use policy development.

Biomass Feedstocks and Waste Policies

The Environmental Protection Act 1990 (as amended by the Environment Act 2021) enable all local authorities in England to be required to arrange for the separate collection of food waste for recycling at least weekly from households.

The legal requirement for separate collections of food and garden waste will be enacted by secondary legislation and statutory guidance that will set out details, commencement dates and requirements.

Separately collected food waste must be recycled or composted. The government's preference is for food waste to be collected for treatment by anaerobic digestion (AD), which produces biogas (which can be upgraded to biomethane) and by-products, such as digestate. In addition to generating renewable energy, AD is recognised as a form of recycling activity where it recycles nutrients, and the resulting digestate can be spread to land creating a more circular economy. The use of food waste as a feedstock delivers significant carbon savings over sending food waste to landfill. Digestate produced from food waste and other wastes must comply with the Anaerobic Digestate Quality Protocol (QP), or it should be managed as a waste product. The QP establishes criteria for the production of quality outputs from AD and its use in the designated markets such as spreading on agricultural land – including limits on the size of plastic contamination within digestate as set out within the Publicly Available Specification (PAS) 110 standard.[71]

[71] https://www.gov.uk/government/publications/quality-protocol-anaerobic-digestate

Waste that cannot currently be prevented, reused, or recycled, including material that is too degraded or contaminated to recycle, is termed residual waste. Residual waste contains a mixture of biogenic matter (unrecycled food waste, wood, cardboard, paper etc.), as well as fossil carbon materials (plastics), and metals. It is dealt with in three main ways: recovery of energy to produce electricity and heat through domestic Energy from Waste (EfW) plants, production of refuse derived fuel (RDF) for export and energy recovery overseas, or disposal to landfill. According to our best estimates, EfW (even when producing electricity only) remains a better option for processing residual waste than landfill in terms of both GHG emissions and wider environmental impacts. If heat from the EfW process is utilised, it is an even more attractive option. Emerging technologies also seek to process residual waste into transport fuels or chemical streams that could be used to produce plastic products.

In England, as required under the Environment Act 2021, government has set a statutory target under The Environmental Targets (Residual Waste) (England) Regulations 2023 to ensure that the total mass of residual waste (excluding major mineral wastes) for 2042 does not exceed an average of 287kg per person in England. This is equivalent to a 50% reduction from 2019 levels. This reflects government's ambition to minimise waste and collectively means that the availability of residual waste for use as a feedstock will decline over the next 20 years. Additionally, much of this municipal material is tied into EfW treatment via established long term waste disposal contracts between waste operators and Local Authorities.

In 2022 there were 57 fully operational EfW plants in the UK.[72] The installed capacity associated with EfW was 1505 MW, and electricity generation (associated with biodegradable energy from waste) is 2,378 GWh.[73] A wide variety of wastes and residues can and are used in the production of biofuels. Examples include used cooking oil, which is typically collated from restaurants and converted into biodiesel, waste starch slurry which can be fermented to produce ethanol, and wastes such as sewage sludge and manure, which can be used as an AD feedstock to produce biomethane. Processing wastes into biofuels ensures effective energy recovery from wastes that cannot be prevented, reused, recycled. Under the Renewable Transport Fuel Obligation (RTFO), there is a feedstock assessment process which considers wider impacts on factors such as the environment and agriculture before awarding additional incentive. This helps to ensure that incentives are directed towards utilising the most difficult to process (e.g., contaminated) feedstocks.

Landfill Gas

The anaerobic breakdown of the biodegradable faction of residual waste in landfill produces methane. In modern engineered landfill sites, the gas containing the methane is captured. Power generation is currently the dominant use for landfill gas in the UK.

An estimated 6.1 Mt of biodegradable waste was sent to landfill in the UK in

[72] Tolvik – UK Energy from Waste Statistics 2022, based on Annual Performance Reports submitted to regulators for 2022.
[73] https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes Table 6.4.

2020.[74] In 2021, landfill gas from closed and operational landfills was estimated to emit 13.6 Mt CO_2e, which is ~72% of the total emissions from the Waste Sector.[75] In 2021 732 Kt of methane from landfills was captured (58%) of which the majority (662 Kt) was used for power generation and the rest (70 Kt) flared. Of the remainder an estimated 54 Kt of methane was oxidised (4%) and 486 Kt (38%) emitted.[76] In 2021 a reported 3,313 GWh of renewable electricity was produced from landfill gas.[77]

Government policy recognises that increased diversion of biodegradable waste, along with increased landfill gas capture from operating and recently closed, as well as legacy landfills, offers the best potential to reduce methane emissions from the waste sector.

Wastewater

Organic materials generated by the treatment of municipal sewage (sludge) at wastewater treatment works (WwTWs) contain nutrients that could potentially be recovered and recycled back to agricultural land. Sewage sludge can also be used as an AD feedstock for producing biomethane, and with the development of new technologies like hydrothermal liquefaction, could be converted into advanced fuels like sustainable aviation fuel.

Industry reports that around 53 million tonnes of raw sewage sludge are treated per annum by ~8500 WwTWs. Although most sludges are processed by AD in the UK (approximately 93% of sludge),[78] the resulting digestates are typically dewatered to produce a phosphorus-rich cake/biosolids. Nitrogen-rich liquors are either returned directly to WwTWs for processing or first processed via nitrogen removal systems that include nitrification and denitrification. This results in the production of approximately 4 million tonnes of biosolids. Approximately 87% (3.5 MT) of these are subsequently applied to agricultural land as a natural fertiliser with 6% used for land reclamation or restoration, 4% incinerated and 3% used in industrial processes.[79]

Although we expect to see some process changes in the wastewater treatment sector in future (for example, to accommodate chemical phosphorus sludges from final effluent polishing), we do not expect these to result in significant changes to sludge production. It is predicted that growth should correlate to population growth.

A reduction in riverine discharges of untreated domestic sewage (and rainwater) from storm overflows under the Storm Overflows Discharge Reduction Plan[80] is likely to increase the amount of sewage treated at WwTWs.

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74 UK statistics on waste: https://www.gov.uk/government/statistics/uk-waste-data/uk-statistics-on-waste

75 Emissions from Energy from Waste are not currently included in the Waste Sector for the purposes of reporting to the National Inventory.

76 UK Greenhouse Gas Inventory, 1990 to 2021 Annexes – Table A 3.5.4: https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2304171442_ukghgi-90-21_Annex_Issue1.pdf

77 UK Greenhouse Gas Inventory, 1990 to 2021 Section 7.2.3.2 Gas Utilisation: https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2304171441_ukghgi-90-21_Main_Issue1.pdf

78 Ofwat, 2021 Bioresources Market Review: https://www.ofwat.gov.uk/wp-content/uploads/2021/05/Jacobs-report-Bioresources-Market-Review.pdf

79 assuredbiosolids.co.uk

80 https://www.gov.uk/government/publications/storm-overflows-discharge-reduction-plan

Development of new WwTWs' processes with lower carbon footprints may also alter both the production and quality of treated sewage sludge, but these impacts cannot be quantified at this time.

The 'sludge strategy'[81] sets out recommendations for sludge to continue to be used as a beneficial resource. Application to farmland is the typical means of disposing of sewage sludge. However, in autumn and winter this is associated with biosolid application rates that may exceed soil and crop need and so can cause the farmer accepting the biosolid to be in breach of the Farming Rules for Water (FRfW).[82] There is the potential for an accumulation of sludge with both a risk to operation at the WwTWs and risk to human health, wildlife and the wider environment.

Biomass Feedstocks: Use of conventional arable food/feed crops

Food and feed crops are used for a range of bioenergy uses, and many conventional technologies for bioenergy conversion were developed with food and feed crops in mind. Wheat, maize and sugar beet are all used in UK bioethanol production and maize and forage grasses in AD for the production of biogas (and biomethane).

In terms of biofuel production, the main UK crops used include:

- Wheat – can be converted into bioethanol using enzymes and fermentation technology.
- Sugar beet and fodder beet – can be converted into bioethanol using similar techniques to those used for wheat.
- Oilseeds – the harvested crop is crushed and refined to produce biodiesel, although supply under the RTFO of biodiesel from food and feed crops is minimal as the RTFO focusses on biofuels derived from wastes and residues to minimise indirect land use change impacts.

Demand for food and feed crops as biomass feedstocks

The demand for UK produced food and feed crops as used for example in bioethanol production or AD are subject to global market prices and supply. Currently, no data is available for the UK-wide area of maize produced for AD; however, the government's June Survey of Agricultural and Horticulture asked farmers in England to specify the end purpose of their maize for the first time since 2014.

The demand for UK produced crops is subject to global market prices and supply. Strains of wheat grown in the UK are of a specification for food, feed and bioenergy standards, so that there is in-built flexibility for farmers to ensure an end-use market for their product. For farmers, the opportunity to sell into bioenergy offers a secondary market for their surplus or lower quality crops and associated agricultural residues. The production of biofuels also produces valuable by-products including protein rich animal feed which is used by livestock farmers.

[81] https://www.gov.uk/government/publications/environment-agency-strategy-for-safe-and-sustainable-sludge-use/environment-agency-strategy-for-safe-and-sustainable-sludge-use

[82] https://www.gov.uk/government/publications/applying-the-farming-rules-for-water/applying-the-farming-rules-for-water

The government's policy on the use of food and feed crops for energy is to proceed with caution taking advantage of the environmental opportunities they can offer, while safeguarding against its potential disadvantages. Whilst growing crops for the biofuel sector offers farmers flexibility and additional routes to market for their harvest, consideration must also be given to land biodiversity or carbon-store value. Therefore, the drive should not be on food and feed crops. The government supports the use of waste feedstocks in AD alleviating using maize as a purpose crop. Government will continue to monitor and evaluate agricultural land use change.

Low carbon transport fuels in the UK are predominately waste-based - in 2021, 76% of Renewable Transport Fuel Obligation (RTFO) fuel was produced from renewable wastes. The RTFO provides a double reward for the supply of waste-based fuels, incentivising their use over crop-based fuels. Furthermore, the RTFO has a tightening crop cap, which limits the amount of crop that can be used for low carbon fuel production.

As detailed in Chapter 2, policies are in place to limit the amount of food and feed crops used for renewable energy generation to minimise impacts on food security.

Opportunities to scale up domestic wood pellet production from existing woodlands and forests

Existing woodlands in the UK represent a potential material and feedstock resource, both from harvesting residues associated with commercial timber production and from bringing woodland into management, predominantly hardwood. The scaling up of domestic wood pellet and chip production could act as a catalyst. The UK Forestry Standard offers a robust framework for woodland creation and management which should guide the harvesting of biomass from our domestic woodland resource. However, increasing the level of harvesting in existing woodlands has the potential to increase land use, land use change and forestry (LULUCF) GHG emissions, which will be an important consideration of policy development.

The future availability of biomass feedstocks will be influenced by a number of the policies set out in the England Trees Action Plan, particularly those relating to future regulatory reform, timber in construction and the forthcoming revision to the Tree Health and Woodland Resilience Strategy. We are also considering biomass in the ongoing review of the UK Forestry Standard.

In conventional harvesting operations, about 20% of cut wood is left on-site as residue or branches and foliage. Some of these residues need to be left on-site for reasons of soil protection and soil sustainability, but some could be extracted for biomass without negative environmental impact. We are currently undertaking research into this and will provide more information publicly once it is available.

There is scope for increasing biomass feedstock from existing levels of timber processing, as long as the biomass sustainability criteria are met. Wood processing co-products (i.e., sawdust from timber mills) are already fully utilised as bioenergy. An increase in UK domestic timber production would also increase biomass available from wood processing co-products.

Unmanaged broadleaf woodland resource, particularly in England, where 70% is reported as unmanaged, offers potential as a significant feedstock (in England, potentially 1 million oven dried tonnes (ODT) per annum) for biomass, timber and other wood products. Bringing woodlands into management is a recognised policy for improving habitat condition by opening up the canopy allowing the ground flora to flourish.

To help bring more woodlands into management, we are already helping more owners manage more woodlands by providing Countryside Stewardship woodland management planning grants, infrastructure grants and woodland improvement grants. The Woods into Management Forestry Innovation Funds are part of government's Nature for Climate Fund, aim to encourage and broaden innovation in forestry. The second round closed in May 2022 and included Routes to Market for Ash Timber Innovation Fund, Temporary Infrastructure Innovation Fund, Regional Woodland Restoration Innovation Funds and the Timber in Construction Innovation Fund. These funds are aimed at forestry businesses and conservation organisations who are in a position to help owners better manage their existing woodlands.

International sources

In 2022, 34% of biomass feedstocks used in renewable energy production (heat, electricity, and transport) were from international sources (net imports). Biomass imports primarily composed of plant biomass (i.e., wood pellets, straw, and other plant-based biomass), waste wood, wood, and liquid biofuels. Plant biomass (mostly wood pellets) made up 61% of all biomass imports in 2022 and are used for renewable heat and electricity production in the form of wood pellets.[83] In 2021 the UK imported c. 9.1 million tonnes of wood pellets (a 1% increase on 2020) for renewable energy production, with the majority (c. 60%) coming from the USA, 18% from EU countries (Latvia, Portugal, and Estonia), and 16% from Canada, and the remaining pellets deriving from Brazil and Russia.[84]

In response to Russia's illegal invasion of Ukraine, we expect sourcing from Russia to have ceased in 2022 in line with policies requiring wood pellets to meet the 'Preferred by Nature' requirements,[85] and actions by businesses to end sourcing from the country.

In the transport sector, renewable fuels from imported feedstocks made up 90% of total renewable fuels in 2021. The largest single share of feedstock was used cooking oil (UCO) from China for biodiesel, which made up 23% of renewable fuel supplied. The most widely reported source for bioethanol supplied to the UK in 2021 was corn from Ukraine, which made up 7% of renewable fuel supplied. Overall, feedstocks from China, USA, UK, Ukraine and France accounted for 59% of the renewable fuel used in the transport sector in 2021.[86]

83 https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes Table 6.1.

84 https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/

85 https://www.ofgem.gov.uk/sites/default/files/docs/2021/04/sustainability_self-reporting_guidance_final_2021.pdf

86 https://www.gov.uk/government/statistics/renewable-fuel-statistics-2021-final-report/renewable-fuel-statistics-2021-final-report

Biomass used for renewable energy generation is incentivised in various government schemes, which all require compliance with biomass sustainability criteria. We intend the sustainability of biomass to continue to be a central pillar for biomass use in the UK in the future.

We expect biomass imports to continue to play an important role in providing sustainable and cost-effective biomass supply that the UK will need for a variety of biomass uses across the economy. However, we recognise that there will be increasing competition for biomass feedstocks from other countries as these countries implement decarbonisation policies. Well-established supply chains and where possible, long term supply contracts are important factors in ensuring stability, cost-effectiveness, and continuation of imports. The primary factors determining the volumes of biomass the UK will be able to import include global competition for biomass resources, developments in international biomass production and transport infrastructure, expansion of global markets, and the price at which these biomass feedstocks can be accessed. These factors become more uncertain the further we look into the future. Therefore, the future potential supply to the UK from imports is inherently uncertain and challenging to determine with accuracy.

It is important to recognise that not all biomass feedstocks are currently well suited to be imported. Wood pellets and liquid biofuels already have well-established international markets supported by long term, stable policies in the UK, Europe, and elsewhere, such as those incentivising renewable transport fuel use (e.g., RTFO), and renewable electricity production (e.g., RO in the UK, Renewable Energy Directive in the EU). International markets and trade may evolve over time for other feedstocks as well, as demand for biomass scales up around the globe. As global competition for biomass evolves and increases over time, we expect the UK's absolute share of global traded biomass to decrease.

Overall, the potential total availability of biomass from imports varies significantly between the two scenarios presented here. Total imported supply in the ambitious scenario varies between 405 PJ in 2025 and 622 PJ in 2050 (Figure 4.5), with some variability in the years in between due to variations in potential global production and demand (Box 4.2). In contrast, total potential imported supply varies between 166 PJ in 2025 and 124 PJ in 2050 in the restricted supply scenario (Figure 4.5) In 2025 agricultural residues make up the largest share of imports in the ambitious scenario, with sawmill residues and small roundwood contributing over half as much of supply than agricultural residues. In contrast sawmill residues, agricultural residues and small roundwood contribute similar levels of supply in the restricted scenario.

In 2050, availability of sawmill residues and small roundwood decreases significantly from the 2025 levels in both scenarios. Agricultural residues and energy crops dominate potential availability of imports in 2050 in both scenarios. In the ambitious scenario availability of global agricultural residues increased to 247 PJ in 2050 (from 171 PJ in 2025), while availability of global energy crops increases to 245 PJ in 2050 from 4 PJ in 2025, showing the importance of global energy crop production to potential future availability of international biomass supply to the UK. As noted, our scenarios assume that bioenergy crops are grown on abandoned arable land, and that there is sufficient land available to produce these crops on land not in direct competition with other activities, such as production of food and feed crops hence no indirect land use change occurs. Our assumption that production of bioenergy crops can only happen on abandoned arable land is important for ensuring that the increase in the production of these crops is achieved without adverse carbon, biodiversity, water, and other ecosystem service impacts. Other factors that will support the growth of bioenergy crop production will be increased yields achieved by advancements in crop species, and innovations in feedstock productions and processing.

In both scenarios, the availability of lignocellulosic feedstocks (plant-based biomass) (Figure 4.5) surpasses those of other feedstocks, including for example, food and feed crops or wastes and residues used in biofuel production. While availability of food and feed crops remains relatively stable in these scenarios, significant changes are expected in the lignocellulosic feedstocks. In both scenarios the potential future availability of biodiesel from UCO/tallow decreases significantly (from 36 PJ in 2025 to 14 PJ in 2050 in the ambitious supply scenario and from 32 to 3 PJ in the restricted scenario).

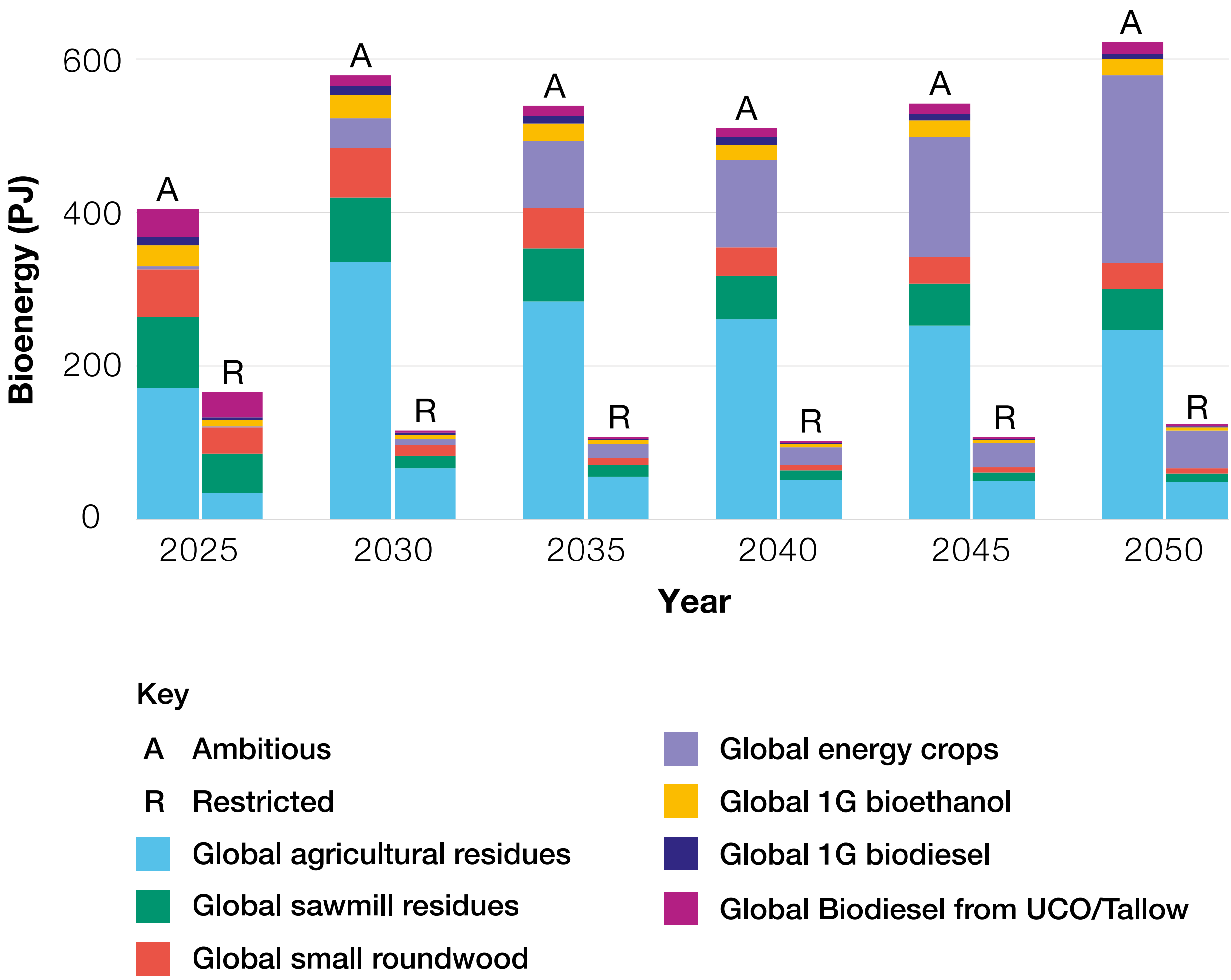


Figure 4.5: Potential future availability of different biomass feedstocks to the UK from international sources in the restricted and ambitious supply scenarios.

Box 4.2. International agricultural markets, and biomass for energy

An appreciation of the workings of international agricultural markets provides a framework for thinking about the likely impacts of using different forms of biomass for renewable energy, on global agricultural prices and food security. The world produces over 2.5 billion tonnes of grain every year. The most important grains and oilseeds are maize, wheat, rice and soybeans, and the biggest trade flows are typically from North and South America to Asia.

Key features of international grain and oilseeds markets include the following.

- Patterns of production and trade are constantly evolving. For example, over the last 40 years Brazil's share of global soybean exports has grown from under 10% to about 50% whilst the US's share of global wheat exports fell from around 40% to around 10%.
- Supply and demand are typically relatively insensitive to price changes in the short run.
- Prices are sensitive to changing expectations of supply and demand. This is most pronounced when projected end stocks are relatively tight, especially in major exporters.
- Prices can be volatile, and supply shocks can prompt significant price spikes.
- There are significant amounts of substitution between arable products (in consumption and production) so price movements in one can result in price movements in the others.
- International price transmission to national markets may be more or less than 100% and will vary over time and by country. It is typically affected by exchange rate movements, changes in regional supply and demand balances, movements in international freight rates and domestic trade policies.
- Internationally, growing shares of key crops are used to produce biofuels (currently around 15% of both global maize and vegetable oil production).

A sustained increase in global prices for arable crops will typically result in a combination of:

- Draw downs in global stocks, if there is scope;
- Reduced consumption internationally, concentrated in those parts of the market with most scope to contract, or the least scope to afford higher prices; and
- An international supply response in the next production season, partly from the intensification of production on existing arable land, and partly from expansion onto 'new' arable land.

This has important implications. For example, if there is an increase in the global demand, or expected future demand, for agricultural feedstocks for use in biofuels or other forms of renewable energy production, or if there is additional competition for arable land from the production of other forms of biomass, then key variables will be affected, by more than would otherwise have been the case:

- Internationally, prices for arable crops would be higher;
- Prices for agricultural products where arable crops are inputs, such as meat, eggs and dairy, would therefore be higher;
- International consumption of arable crops would contract across all potential uses; and
- In the subsequent year, there would be an international supply response (partly through intensification of production on existing land, and partly through bringing new land into production).

Furthermore, in times of tight markets, international prices may spike further than they otherwise would if biomass end-use demand remains insensitive to global prices, leading to important distributional issues. In the UK, policies are already in place to reduce impacts of biomass use on agricultural markets. For example, UK biofuels policy caps the contribution of biofuels from food and feed crops under the Renewable Transport Fuel Obligation (RTFO). In addition, the forthcoming Sustainable Aviation Fuel mandate excludes fuels produced from crops. Section 2.4 details how the government intends to explore options to incorporate ILUC reporting into other schemes.

Our analysis show that the source of imports is wide-ranging across the globe: the largest share of agricultural residues is derived from Brazil, with the USA, other countries in South and Central America, Europe, India and China, and other Southeast Asian countries also contributing considerable volumes of agricultural residues to the global market. Forest-derived biomass (e.g., small roundwood and sawmill residues) are supplied largely by African countries, India, Europe, Brazil and other South and Central American countries in the availability model. Meanwhile, energy crop production is widely dispersed across the world, as production increases in most countries and regions, with areas, such as Europe, North and South America, and Southeast Asia having a significant role in global supply. As detailed earlier, our assessment of future availability considers only the sustainable supply. Government is clear that regardless of where biomass is sourced from it needs to be sustainable for it to contribute towards our decarbonisation. As outlined in Chapter 2, we intend to consult on actions to strengthen the UK's biomass sustainability criteria to ensure biomass continues to deliver renewable and low carbon energy.

It is important to recognise that there is uncertainty over long term market developments of all biomass feedstocks, which will ultimately determine the origins of feedstock supply to the UK. Nevertheless, it is reasonable to expect global bioenergy production to scale up and diversify over time as countries increase production to support their move away from fossil fuel use. This will ultimately lead to a more resilient international biomass feedstock market with greater number of countries supplying feedstocks, which will help reduce future supply risks. This is in line with projections by other biomass demand and supply availability, such as the IEA.[87]

[87] IEA, 2021. Net Zero by 2050: https://www.iea.org/reports/net-zero-by-2050

4.3 Innovation opportunities for scaling biomass feedstocks in the UK

Biomass Feedstocks Innovation Programme

The Biomass Feedstocks Innovation Programme aims to increase the production of sustainable UK biomass feedstocks by funding innovative ideas that address barriers to their production. It supports projects seeking to improve productivity, through breeding, planting, cultivating and harvesting various feedstocks. The programme forms part of government's £1 billion Net Zero Innovation Portfolio (NZIP),88 which aims to accelerate the commercialisation of innovative clean energy technologies and processes through the 2020s and 2030s.

The Biomass Feedstocks Innovation Programme[89] has awarded £36 million across two phases. Phase 1 (design and feasibility) ran from July 2021 to March 2022 with £4 million of funding awarded across 25 contracts.[90] Phase 2 builds on Phase 1, providing £32 million in funding to take projects from the design stage through to innovation demonstration. As such, the Phase 2 competition was open to applications from projects supported under Phase 1.

The programme awarded 12 contracts,[91] with projects concluding in March 2025.

In Phase 1, projects received full funding to produce robust plans for innovations that, if implemented, would make a positive material contribution to UK feedstock supply. A diverse range of biomass feedstocks and technologies were covered, ranging from growing microalgae from whisky manufacturing, increasing production of hemp, improving the planting efficiency of trees with bio-based tree shelters, and exploring ways to harvest bracken with drone assisted technology.

In Phase 2, there are 11 innovation projects and 1 multi-site demonstrator project, 'Biomass Connect'.[92] The innovation projects cover a range of biomass feedstock types: Miscanthus, Willow, long- and short-rotation forestry, macroalgae, and heather; and for the different biomass feedstocks, a range of innovations focused on: breeding and propagation, cultivation and harvesting, on-farm processing, and decision support systems.

[88] The Net Zero Innovation Portfolio: a £1 billion fund aiming to accelerate the commercialisation of low-carbon technologies, systems and business models in power, buildings, and industry. https://www.gov.uk/government/collections/net-zero-innovation-portfolio

[89] https://www.gov.uk/government/publications/biomass-feedstocks-innovation-programme-successful-projects

[90] https://www.gov.uk/government/publications/biomass-feedstocks-innovation-programme-successful-projects/biomass-feedstocks-innovation-programme-phase-1-successful-projects

[91] https://www.gov.uk/government/publications/biomass-feedstocks-innovation-programme-successful-projects/biomass-feedstocks-innovation-programme-phase-2-successful-projects

[92] https://www.biomassconnect.org

Based on engagement with funded projects in Phase 2, a challenge and barrier faced by projects in this sector is the uncertainty around the end use; for most of the land-based biomass crops, planting is a long term (c. 20 year) commitment and so with many markets around different technologies and sectors still emerging (e.g., BECCS, gasification, biochar, verified carbon removal credits), policy is vital.

Case study on the multi-site demonstrator platform: Biomass Connect

The Biomass Connect project has created a demonstration and knowledge sharing platform to showcase best practice and innovations in land-based biomass feedstock production. Led by the UK Centre for Ecology & Hydrology, Biomass Connect has three aims: 1) to provide robust, independent information on biomass feedstock performance, agronomy, economics and environmental benefits to landowners and land managers; 2) to ensure that geographic variations in biomass feedstocks and relevant innovations are evaluated and demonstrated to a broad range of stakeholders across the UK; and 3) to enable the sharing of knowledge, experiences and case studies across the industry and contribute to relevant policy development.

During the first year, the project showcased harvesting a range of biomass feedstocks, and successfully planted eight Hub sites with the same ten biomass crops for comparisons of establishment and growth between different areas of the UK.

Case study on an innovation: Envirocrops

The Envirocrops[93] project has created a web-based app, which forms a decision support system for growers and end-users considering land-based biomass feedstocks. The project team is utilising a range of data from across industry, consultants, and academia, to create a series of linked calculators, decision trees, and digital mapping tools. Envirocrops, will therefore act as a digital consultant, providing users with the confidence to de-risk biomass crops as an investment choice.

Led by the Agri-food and Biosciences Institute in Northern Ireland, the innovation uses a wide evidence base to identify biomass crop types and varieties suited to different land areas; make estimates of land required for desired yields and overall economic potential; indicate production timescales and costs.

Envirocrops is looking to build up a directory of the main stakeholders, such as growers, local contractors, and end users, and act as an online trading platform with a local dimension. The team have also developed an engaging game called ‘Cropper’, which provides a useful way of educating the next generation of land use decision makers.

93 https://envirocrops.com

Case study on an innovation: New Energy Farms

New Energy Farms, based in Wiltshire, are leading an energy grass focused project, demonstrating new varieties appropriate for the UK and enhancing planting and establishment practices of the crops. The project is testing varieties from existing global breeding projects, reducing the time required to bring new, higher yielding variety options to the UK market. It has the added benefit of allowing consideration of varieties optimised for phytoremediation, producing biomass on metal contaminated land (spoil land) and degraded wetlands, which are a source of GHG emissions.

The project is also exploring agronomic improvements to energy grass crops, by evaluating cheaper and easier ways of multiplying and planting, utilising the company's patented artificial seed technology. New Energy Farms see the combination of higher yielding varieties and improved methods of establishing energy crops as encouraging more energy crop planting and increasing biomass production.

New Energy Farms

Hemp

Hemp is a long-standing crop in UK agriculture with a variety of uses. A strong resurgence of cultivation and use is now gathering momentum globally, driven by the need for spring cropping and greater diversity in the farmed environment.

Many forms of carbon sequestration, including enhanced soil organic matter content, use in many carbon-based, renewable alternatives to building materials, plastic and other synthetics is driving interest in this crop. New food and health products using extracts from the seeds, flowers and leaves are also emerging.

Hemp can provide good economic returns, with low agrochemical input requirements and great potential for reduced tillage and improved soil health. Hemp can produce around 8 tonnes of dry biomass per hectare and can be added into the normal annual farm rotation thereby not competing with food supplies.

Plant breeding to produce high biomass varieties for the UK climate is now a priority for those in the sector alongside the selection of the best existing cultivars. The recent Hemp-30 project conducted by the University of York and funded by the government's Biomass Feedstocks Innovation Programme, drew on their expertise in molecular plant breeding technology to fast-track improvement of hemp traits to meet the needs of developing markets. Researchers targeted traits such as biomass yield, fibre quality and drought resistance to produce varieties of hemp that are best suited to UK growing conditions.

Hemp offers potential to supply biomass pellets to the UK bioenergy sector, as a feedstock for second generation bioethanol production, and as insulation material. UK cultivation is estimated at 800 hectares annually, by around 20 farmers. However, there is growth potential.

Government is currently examining hemp cultivation from a grower and consumer standards perspective, alongside its environmental benefits and efficacy as an alternative break crop. Government will work to help farmers understand the agronomy of the crop and if it is suitable for their land and planting plans. The need to protect citizens from the potential harm from production of narcotics from high tetrahydrocannabinol (THC) varieties means that cropping requires a mandatory licence, obtained from the Home Office. This can be perceived as a barrier to growing hemp, in terms of cost and regulatory burden. Departments across government are working together to help farmers navigate the licencing system and make sure all related processes are fit for purpose; for example, there have been claims that delays in licencing paperwork can hinder the planting window and we are working across government to resolve this.

5

Priority use of biomass

Our Key Commitments

- **Government will continue to support policy for biomass use based on guiding principles that address sustainability, air quality, net zero and the circular economy & resource efficiency.** Government will be launching a series of sector-specific consultations in 2023 and 2024; these will support the implementation of these guiding principles, as relevant to different sectors in the economy.
- **Government's approach to achieving net zero is flexible and technology agnostic, acknowledging that pathways may change over time**, in response to new technologies and commercial opportunities that may emerge in the future. We will continue to promote and support innovation for development of biomass technologies.
- **In developing policy that directly or indirectly touches on biomass availability and use, government will take into account wider strategic issues** around energy security, electricity prices, land use and technology readiness and deliverability. Government will also take into account matters that are of concern to the public including impact on the environment and need for robust evidence base to support decision making.
- In the **short term** government will continue to facilitate biomass deployment through a range of incentives and requirements covering power, heat and transport.
- In the **medium term** government will look to further develop biomass uses in certain power, heat and transport sectors to support delivery of Carbon Budget 6, but with a view to transition away from unabated uses of biomass where possible to uses such as bioenergy with carbon capture and storage (BECCS), which are critical to meeting net zero.
- Biomass use in the **long term** is difficult to predict with precision owing to wide-ranging uncertainties and evidence gaps but current modelling implies that uses that are combined with BECCS will contribute the most towards net zero. Biomass could also have some role in hard-to-decarbonise sectors that cannot deploy BECCS.
- **Government will continue to build a robust evidence base** for biomass uses across different sectors and technologies in order to support optimal policy choices in achieving net zero and energy security targets.

5.1 Introduction

Biomass is a versatile low carbon resource with uses that span the economy, from energy generation to the synthesis of bioproducts and materials, as well as the delivery of negative emissions. The versatility of biomass means that it is a highly complex and interconnected resource with competing and complementary uses across the economy. As highlighted in Chapter 3 and 4, there are interactions with wider environmental services which need to be carefully considered when utilising biomass.

This chapter sets out a priority use assessment that informs the best use of biomass in the short (2020s), medium (2035) and long term (2050) to meet our net zero target, based on our existing evidence base. The assessment is centred around a series of guiding principles as set out in Section 5.2. This assessment is supported by analysis of the current biomass use landscape (short term view), analysis of the role of biomass to meet Carbon Budget 6 (medium term view) and a series of illustrative scenarios (using whole energy system modelling) to outline the potential role of biomass to meet net zero (long term view). The assessment also takes into consideration wider strategic context around energy security and economic growth to inform this assessment (Section 5.3).

The analysis presented within this chapter is centred around the biomass availability scenarios presented in Chapter 4. It presents a range of illustrative scenarios for biomass use across the UK economy to provide a view on the scale and impact of biomass, in meeting UK's net zero target.

We also recognise that this is an area undergoing significant evolution with new technologies and data emerging and acknowledge the need for ongoing review of the government's evidence base supporting this assessment, especially with regards to prioritisation of biomass use in the longer term.

5.2 Principles of best use of biomass

The Biomass Policy Statement[94] set out a series of guiding principles that are used here to support the priority use assessment for biomass, recognising it is a limited resource that will require targeted uses to achieve the best outcomes. These principles should be considered when developing sector specific policies related to biomass use, along with other relevant factors relating to the wider strategic context for biomass use, such as on energy security.

The biomass priority use principles address four main areas: **sustainability, air quality, net zero and the circular economy & resource efficiency**. These principles were developed through consultation with stakeholders (including through the responses to the Biomass Strategy Call for Evidence).[95]

[94] https://www.gov.uk/government/publications/biomass-policy-statement-a-strategic-view-on-the-role-of-sustainable-biomass-for-net-zero

[95] https://www.gov.uk/government/consultations/role-of-biomass-in-achieving-net-zero-call-for-evidence

	Short term (2020s)	Medium term (2035)	Long term (2050)
Sustainability	Be compatible with current and emerging sustainability criteria based on latest evidence considering a range of economic, social, and environmental impacts.*	Be compatible with the future cross-sectoral sustainability framework and associated sector specific criteria and legislation*	
Air quality	Be compatible with regulatory requirements on air quality and compliance with statutory air quality targets and ceilings. Wherever practicable, biomass use should be carried out away from populations and at a scale where mitigation techniques can be applied economically, to minimise public health impacts.		
Net Zero	Utilise existing infrastructure and planned investments to provide through carbon abatement existing and emerging policy frameworks.	Contribute to carbon budgets and net zero by providing greatest life cycle GHG emissions savings**, considering biomass feedstock availability and cost-benefits.	
	Support the achievement of our longer term (over CB6 and net zero timelines) objectives for biomass end use, e.g., avoiding technology lock-in or not diverting investments in long-term solutions.	Integrate Carbon Capture, Usage, and Storage (CCUS) where feasible to produce genuine negative emissions. Where CCUS is not feasible biomass is only used in harder to decarbonise sectors with limited or no low carbon alternatives.	
Circular economy and resource efficiency	Be compliant with waste hierarchy principles.	Be compliant with waste hierarchy principles and provide additional co-benefits and/or circular economy benefits.	

*A consultation to support the development of a common sustainability framework for biomass use across the economy is being planned for 2024.

**Compared to GHG emissions of appropriate counterfactual.

Figure 5.1: **Guiding principles for prioritising the uses of biomass in the short, medium and long term (updated).**

Following further policy development and stakeholder engagement, some minor amendments have been made to the priority use principles to strengthen them (Figure 5.1). The changes relate to the sustainability principle which now reflect the commitments made in this Strategy to develop a cross-sectoral sustainability framework, which we intend to consult on in 2024. As part of this consultation, we will gather views on the details of the actions set out in Chapter 2, including on implementation routes considered by government, as well as the necessary monitoring, reporting, and verification (MRV) requirements. We recognise that the priority use principles will need to be updated as evidence evolves.

Sustainability

Biomass use should be compatible with strict sustainability criteria.

The priority use principles shown in Figure 5.1 have been revised to make clear the need for biomass uses across the economy to meet existing sustainability criteria applicable to the relevant sector in the short term. (Table 5.1, Section 5.5.1). As the new cross-sectoral sustainability framework is developed (subject to consultation), any new government support for biomass use will be expected to meet the requirements under the common sustainability framework. We anticipate that, over the medium to long term, biomass use across the economy should be compatible with the cross-sectoral sustainability framework and any additional associated sector-specific criteria and legislation.

Air quality

Prioritising biomass use should consider compatibility with relevant UK air quality requirements to minimise any public health impacts.

The use of biomass, and particularly its combustion, releases pollutants that can damage health. These will be more damaging in more densely populated areas, and therefore biomass combustion should, wherever practicable, be carried out away from populations and at a scale where mitigation techniques can be applied economically.

We will continue to work across government on the implications of the priority use principles and framework on air quality. The regulatory framework for environmental permitting will continue to reduce harm to health and the environment from the combustion of biomass, as well as anaerobic digestion (AD) and other biomass technologies. New regulatory standards will also reflect detailed engagement between regulators and industry. (Further details on the existing air quality regulations can be found in Chapter 3).

Net zero

The determination of the priority use for biomass in the short, medium, and long term hinges on the scale and impact of its contribution towards the UK's net zero target.

The priority use principles (Figure 5.1) set out guidelines for assessing whether a particular biomass end use should be a priority.

In the short term, uses should avoid technology lock-in to avoid impacting our ability to meet carbon budgets and net zero in later timescales. This may require assessing whether a biomass use involves utilising existing infrastructure and planned investments. For example, in the electricity sector this may involve requiring new and refurbished biomass plants to meet Decarbonisation Readiness requirements (Chapter 7), meaning they are fit to deploy carbon capture in the future.

Considerations of the scale and impact of the contribution towards carbon budgets and net zero should become more prominent when supporting medium to long term policies for biomass use. Here, outcomes that provide the greatest greenhouse gas (GHG) emissions savings, compared to alternatives, should be prioritised. This will require a whole system analysis that considers cost and benefits, biomass feedstock availability and the wider energy-system impacts of biomass use. The following sections capture this principle by considering the carbon abatement potential and GHG emissions associated with each of the biomass pathways in scope of this strategy. The ability of the technology or pathway to produce negative emissions (including the scale and costs of those negative emissions) is considered in the assessment. This is because negative emissions are needed to meet net zero to balance the residual emissions from hard-to-decarbonise sectors, as set out in the Net Zero Strategy.

The net zero principle also allows for the biomass to be prioritised where there are no other available alternatives for decarbonisation. This recognises the fact that there are areas of the economy that are hard to decarbonise e.g., transport modes such as aviation and maritime, and off gas grid properties.

Circular Economy

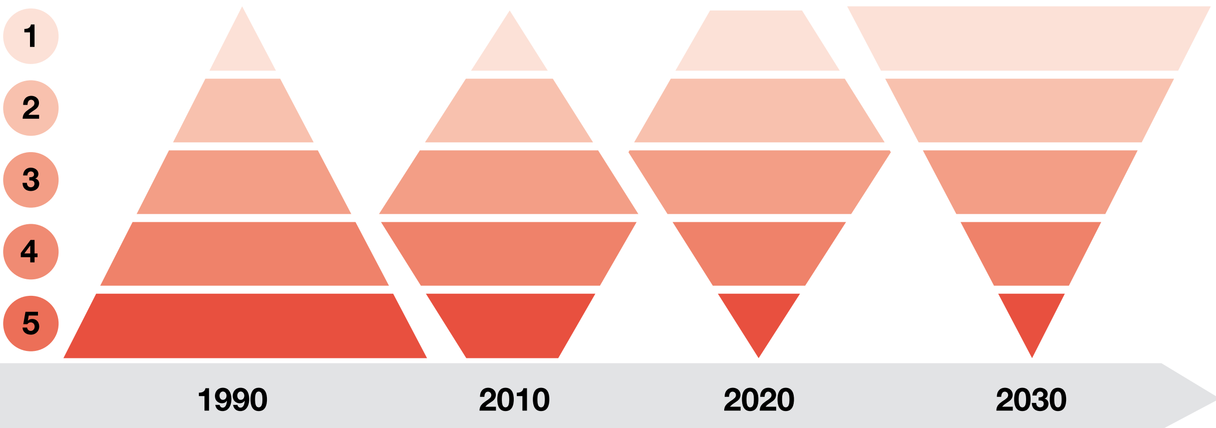
Prioritising biomass use should consider circular economy benefits and resource efficiency.

For pathways that use biogenic waste resources (a major feedstock group within the scope of this strategy), this principle is already being followed through the implementation of the Waste Hierarchy,[96] which should continue to be followed in line with current government (England only) and devolved administration policies and guidance. The UK government's Resources and Waste Strategy for England[97] sets out how we will preserve material resources by minimising waste, promoting resource efficiency and moving towards a circular economy in England (Figure 5.2). An addendum to the Resources and Waste Strategy which will focus on net zero, will be published this summer.

The waste hierarchy ranks waste management options according to their environmental impact. It informs wider government priorities and policies, including the biomass priority use principles. The waste hierarchy supports the circular economy and resource efficiency by ensuring that waste is prevented where possible and that valuable resources remain in circulation for as long as possible, preventing resource depletion and reducing the environmental costs of waste. Any public body or business that handles waste has a legal obligation to take all such measures as are reasonable, on the transfer of waste to apply the waste hierarchy as a priority order to avoid waste in the first instance, or during the transfer of waste to another owner.

96 https://www.gov.uk/government/publications/waste-management-plan-for-england-2021
97 https://www.gov.uk/government/publications/resources-and-waste-strategy-for-england

Evolution of waste management practices
In the past, most waste was dealt with by disposal, but over that will shift increasingly to recycling, reuse and ultimately prevention.



1 Prevention

Using less material in design and manufacture. Keeping products for longer; reuse. Using less hazardous materials.

2 Preparing for reuse

Checking, cleaning, repairing, refurbishing, whole items or spare parts.

3 Recycling

Turning waste into a new substance or product. Includes anaerobic digestion and composting.

4 Other recovery

Includes materials
form waste and some landfilling; also co-incineration plants, and incineration plants (including gasification and pyrolysis) that have R1 status.

5 Disposal

Includes landfill, and incineration plants (including gasification and pyrolysis) that don't have R1 status.

(See **gov.uk** for more information on how energy-from-waste plants can obtain R1 status).

Figure 5.2 : Waste Hierarchy and the Evolution of Waste Management Practices[98]

[98] https://www.gov.uk/government/publications/waste-management-plan-for-england-2021

A number of policies are also in development that will seek to minimise waste from arising in the first place and increase the proportion of waste that is recovered for recycling. As announced in the Environmental Improvement Plan,[99] government published the Maximising Resources and Minimising Waste programme in England in July 2023.[100] The programme will set out our priorities for action across seven main sectors – construction, textiles, furniture, electronics, vehicles, food, and plastics, packaging and single-use items – to manage resources and waste in accordance with the waste hierarchy.

There are similar strategies currently in place across the devolved administrations. The Scottish Government has set out priorities for moving towards a more circular economy and a pathway to deliver its world leading climate change targets in its recent Circular Economy and Waste Route Map consultation (2022),[101] and in the update to the Scottish Government's Climate Change Plan (2020).[102]

These include proposed priorities and actions to accelerate progress against its waste, recycling and emissions reduction targets, including ending the landfilling of biodegradable municipal waste by 2025, and recycling 70% of all waste. In Northern Ireland, the Climate Change Act[103] has set a 70% recycling by 2030 target. To support this, NI has developed a number of strategies – the Energy Strategy,[104] the draft Circular Economy Strategy,[105] the draft Green Growth Strategy[106] and the draft Environmental Improvement Plan.[107] The Welsh Government in 2021 published its Beyond Recycling strategy.[108] Wales has already increased recycling rates so that over 65% of municipal waste is recycled and is on track to meet its target of zero waste going to landfill by 2025. The Welsh Government has set a 70% recycling target for 2025, alongside a 26% reduction in waste and a 50% reduction in avoidable food waste (against a 2006-07 baseline). It has additional targets of a 33% reduction in waste and 60% reduction in avoidable food waste by 2030, with an overarching aim of achieving one planet resource use and zero waste by 2050.

For the longer term, this principle also involves looking at the cascading use principle identified in Chapter 2; that resources should be first prioritised for use and re-use sequentially in the order of appropriate resource quality at each stage of the cascade chain – such as the refurbishment of furniture for reuse and at a later stage the use of waste timber to make panel board. Only when materials are unsuitable for material use should they be used for energy recovery.

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99 https://www.gov.uk/government/publications/environmental-improvement-plan
100 https://www.gov.uk/government/publications/waste-prevention-programme-for-england-maximising-resources-minimising-waste
101 https://www.gov.scot/publications/consultation-delivering-scotlands-circular-economy-route-map-2025-beyond/
102 https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/
103 https://www.legislation.gov.uk/nia/2022/31/contents/enacted
104 https://www.economy-ni.gov.uk/publications/energy-strategy-path-net-zero-energy
105 https://www.economy-ni.gov.uk/consultations/circular-economy-strategy-northern-ireland
106 https://www.daera-ni.gov.uk/consultations/consultation-draft-green-growth-strategy-northern-ireland
107 https://www.daera-ni.gov.uk/consultations/environmental-plans-principles-and-governance
108 https://www.gov.wales/beyond-recycling

This is to ensure biomass stays in circulation for the longest time possible before becoming waste or is used for energy production. Additional resource efficiency can be achieved from certain biomass pathways by ensuring that the by-products from production stages of either materials or energy vectors are used to make other products and materials which can be used elsewhere in the economy, preventing them from being discarded. To support a move towards a more circular economy, we will make a further assessment on how best to adopt the cascading use of biomass in the UK as part of the sustainability criteria. To support this, work is underway to better understand biomass uses in non-energy sectors such as chemicals and materials, which will help to clarify the broader circular economy benefits from biomass use.

The UK is also supportive of international collaboration and coordination of action on biomass use and sustainability, including that of the G20 Energy Transition Working Group on the circular bioeconomy as highlighted in Chapter 2 (Section 2.2).

5.3 Wider Strategic context for Biomass Use

The implementation of the principles described above requires consideration of the wider strategic context for biomass use across the UK economy. In meeting our primary objective to maximise the decarbonisation benefits from biomass, which is a limited resource, we also need to consider the impact this might have on wider government priorities and ambitions. Ensuring that the UK is on track to meet its legally binding net zero target while also supporting economic growth by significantly speeding up delivery of network infrastructure and domestic energy production is a priority for government. Any future policy on biomass use across all sectors should take into consideration:

- **Energy security:** In March 2023 the government published the Energy Security Plan[109] which set out a vision to power the UK through affordable, home-grown, clean energy. This follows the publication of the British Energy Security Strategy in April 2022.[110] For the UK, this means a future in which we are more energy secure, which will support our objectives to bring down energy bills and reduce inflation. Therefore, where the UK still needs to import biomass or biomass fuels, those imports should be built on strong relationships with trusted partners and allies that can ensure a sustainable, stable and lowest cost source of supply. This highlights the importance of ensuring the UK biomass sectors remain competitive on the global market for a range of biomass feedstocks, which is currently being achieved by having a stable biomass policy landscape.

[109] https://www.gov.uk/government/publications/powering-up-britain
[110] https://www.gov.uk/government/publications/british-energy-security-strategy

- **Land Use:** Future policy development to support biomass use in the UK needs to consider the impact of increased demand for domestic biomass feedstocks on domestic and global land use. As discussed in Chapter 4, the government will publish a Land Use Framework for England later this year. The Framework will take a systems approach to set out how we can deliver multifunctional landscapes that are resilient to our changing climate whilst meeting our needs for net zero, food production and environmental recovery. Our existing biomass sustainability criteria already consider land use, as direct land use change is already regulated, while reporting requirements exist for indirect land use change (ILUC) within the Renewable Transport Fuel Obligation (RTFO). We have commissioned an assessment of how ILUC could be reported under all biomass support schemes (See Section 2.4).

- **Sector-specific objectives** relevant to biomass use in the short, medium and long term needs to be considered as part of any assessment on best use of biomass across the UK economy. These relate to hydrogen production, greenhouse gas removals (GGRs), low carbon fuels, including aviation, industrial low carbon fuel switching and biomethane production. The relevant Strategies' specific objectives are introduced in Chapter 1, and in further detail in Chapter 7.

5.4 Principles and conditions for biomass in achieving net zero: The Public Dialogue Project

The principles and conditions for biomass use in achieving net zero, developed during the Biomass Public Dialogue Project,[111] have been considered as part of the priority use assessment set out in this chapter:

- **On cost and financing:** The priority use assessment includes careful consideration of system-wide costs of biomass use and comparison with alternative solutions to biomass in each sector. See Section 5.5.3.
- **On feasibility and evidence base:** The analysis for the priority use assessment is built on robust evidence base on biomass feedstock availability and end uses including biomass technology readiness and feasibility collected from a broad range of sources. The priority use assessment also includes a consideration of potential supply and demand side risks of biomass in the achievement of decarbonisation goals set out in this Strategy (see further detail in Technical Annex).
- **On impact on the environment:** The priority use framework takes into account wider environmental impacts of biomass use through the sustainability principle which means that biomass uses should align with the UK's current and future sustainability criteria (Chapter 2.4).
- **On prioritising natural resources:** The priority use principles include circular economy and maximising resource efficiency aims which is designed to ensure biomass uses continue to align with the waste hierarchy and can provide additional circular economy benefits via the products or co-products resulting from biomass pathways.
- **On impact on society:** The priority use assessment includes domestic and global land use considerations within the future sustainable biomass availability estimates used in the analysis (see Technical Annex). In addition, the sustainability and air quality principles were developed to ensure impact on society is minimised.

[111] https://www.gov.uk/government/publications/biomass-strategy

5.5 Prioritising biomass usage in the short, medium and long term

Given the complexity and scope of the priority use principles, a range of analytical approaches have been used to present a current government view on the priority uses of biomass in the short, medium and long term. For the **short term** view, the current policy landscape, investment, and infrastructure across the different end-use sectors are analysed to establish where biomass has a continued role to play. For the **medium term**, our Carbon Budgets 6 analysis is used to understand the supply and demand constraints for biomass into the mid-2030s. For the **long term**, a whole systems energy model (UK TIMES) is used to understand the role of biomass under the existing net zero strategy pathways. Additional sector-specific context is also presented and incorporated into the longer term view where there was insufficient evidence to feed into our main modelling.

5.5.1 Current Biomass end-use policy landscape (Short term view)

This section provides an overview of how biomass is currently used and incentivised across the different sectors, including a view of existing and planned support in the short term (up to and including Carbon Budget 5 and beyond in some instances). Biomass already plays an important role as a low carbon resource across the UK economy (Table 5.1).

In 2022 it was estimated that bioenergy provided 8.6% of the UK's energy supply,[112] most of which was supported by government. Table 5.2 shows the existing and planned government support for biomass use across different sectors in the UK over the short term.

[112] https://www.gov.uk/government/statistics/energy-chapter-1-digest-of-united-kingdom-energy-statistics-dukes

Table 5.1: 2022 Biomass use across the UK[113]

Usage	Source	Terawatt-hours (TWh)
Used to generate electricity	Solid biomass (plant and animal)	62.2
	Biogas (landfill, sewage and anaerobic digestion)	21
	Biodegradable wastes	19
	Bioliquids	0.3
Used to generate heat	Solid biomass (wood, waste wood, plant and animal biomass)	32.7
	Biogas (landfill, sewage and anaerobic digestion)	2.1
	Biodegradable wastes	1.4
	Bioliquids	0.5
Used as transport fuels[114]	Biodiesel	13.7
	Bioethanol	7.2
	Other fuels (e.g., biomethane, hydrogenated vegetable oil (HVO), sustainable aviation fuel (SAF), drop-in fuels)	6.4
Biogas (biomethane) injected into the grid	Anaerobic Digestion	6.2
	Sewage gas	0.6
Total		**173.5**

[113] https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes
[114] RTFO publications 2022: https://www.gov.uk/government/collections/renewable-fuel-statistics

Table 5.2: **Summary of existing policy measures that support biomass across different UK sectors**

Area	Policy measures that support biomass use	Timeline
Renewable Electricity	Renewable Obligations	2002-2017, with support for last entrants lasting until 2037.
	Feed in Tariff (FIT)	2010 – 2019 (with some exceptions due to COVID-19). Existing accreditations run for between 10 and 25 years.
	Contract for Difference (CfD)	2017 – ongoing.
	Smart Export Guarantee (SEG)	2020 – ongoing (no end date)[115]
Biomethane injection to the gas grid – Renewable Heat	Non-Domestic Renewable Heat Incentive (NDRHI)	2018-2021. Closed to new applicants. Existing contracts run until 2041[116] supporting biomethane injection into the grid.
	Green Gas Support Scheme (GGSS)	2021-2025.[117] Expected to support biomethane injection until early 2040s. Participants are also eligible to submit claims for the RTFO, subject to eligibility criteria.
Renewable Heat – domestic heating and non-domestic heating	Domestic Renewable Heat Incentive (RHI)	2018-2021. Closed to new applicants. Existing contracts run until 2029.[118]
	NDRHI	As above on NDRHI
	GGSS	As above, using biomethane injected into the gas grid
Renewable Heat – Industry	NDRHI	As above on NDRHI
	GGSS	2021-2025. As above, using biomethane injected into the gad grid.
Renewable Transport Fuels	RTFO	Since 2008. No end date, rising targets set to 2032 and will continue at that level.
	Upcoming Mandate for SAF	Separate SAF mandate is to apply from 2025 onwards

[115] There is no current end date for the SEG policy. Individual contracts agreed by biomass plants and SEG licensees may have end dates.
[116] The number of participants will gradually start reducing from 2031, given the typical contract length of 20 years.
[117] Proposal to extend the application window to March 2026 currently being consulted on through the scheme's mid-scheme review.
[118] The number of participants has gradually started to reduce given the typical contract length of 7 years.

5.5.2 Carbon Budget 6 Analysis (Medium term view)

Biomass is expected to continue to be important for many sectors to deliver emissions savings up to the end of the Carbon Budget 6 (CB6) period, as set out in the Carbon Budget Delivery Plan (CBDP),[119] published in March 2023.

The CB6 period can be viewed as a mid-way point between now and our 2050 net zero target. The expected demands for biomass during this period (Figure 5.3) reflect the medium term priority use principles in an ambitious biomass supply scenario. Here biomass uses in harder to decarbonise sectors, and in uses that can support delivery of negative emissions in the longer term, are expected to increase.

For example, in the transport sector, biomass demand for aviation is expected to rise, while its use in surface transport is expected to fall as electric vehicle (EV) numbers continue to increase. By CB6, biomass will also have a role in hydrogen production through hydrogen BECCS. This is a critical technology to support longer term decarbonisation through its potential for significant negative emissions, and which could also support hydrogen production ambitions.

[119] https://www.gov.uk/government/publications/carbon-budget-delivery-plan

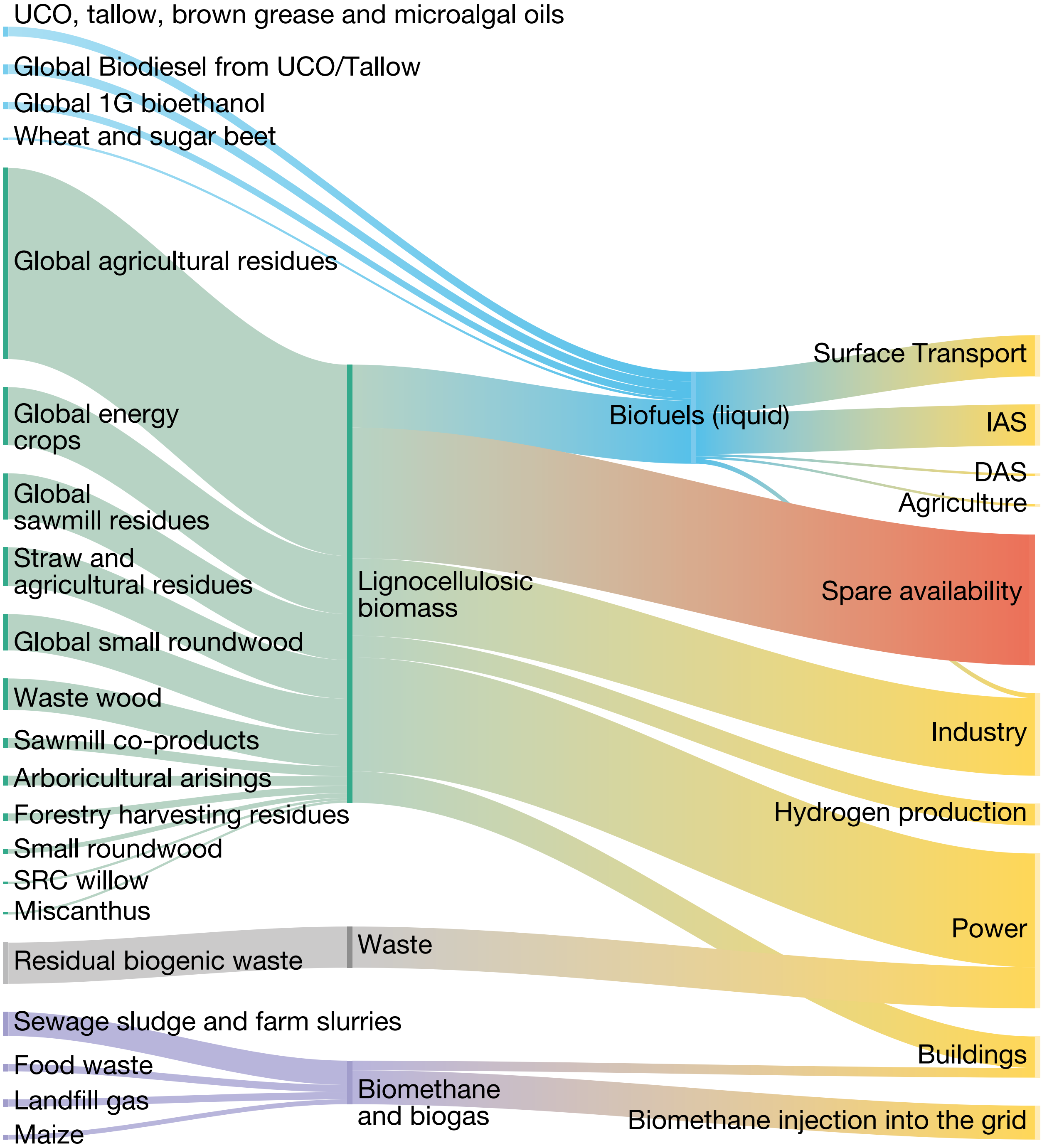


Figure 5.3: Sankey diagram representing biomass feedstocks and end-use sectors in 2035, in an ambitious biomass supply scenario. 'Global' feedstocks imply those which the UK has access to, and the 'Spare availability' node denotes excess availability that the UK would not need to import. Sector demands are averages across the CB6 period. Presented uses for feedstocks are indicative and may vary based on policy development and changes in end-use demand.

The level of biomass demand during CB6 is subject to uncertainty as we develop our Carbon Budget plans, recognising the need to retain flexibility to adapt as circumstances change. However, based on the policies and proposals set out in the CBDP in the CB6 period, the average annual biomass demand is expected to be 176TWh per year between 2033 and 2037. This represents little overall change from biomass demand in 2022, though the makeup and use of that biomass is expected to be significantly different.

The future biomass supply estimates developed using the availability model suggest a total potential biomass availability of between 130TWh and 251TWh in 2035 across the restricted and ambitious supply scenarios, which after processing yields between 113TWh and 234TWh of delivered energy. As such CB6 demand is estimated to be within the range of overall biomass availability.

The biomass routes represented in Figure 5.3 provide an indication of where we expect biomass supply to be directed to meet the expected demand, however this is illustrative and subject to uncertainty. It represents potential biomass pathways in line with existing and planned policies. For example, depending on feedstock availability and technological readiness, it is possible that lignocellulosic biomass could be processed through gasification to generate biomethane. Additionally, residual biogenic waste, biomethane and hydrogen could be used in transport fuel applications. On food and feed crops for first generation biofuels, the Renewable Transport Fuel Obligation (RTFO) already has a gradually reducing crop cap in place to limit the amount of such crops being used in biofuels used in transport to minimise impacts on food security.

The Sankey diagram also makes no indication of how sustainable aviation fuels (SAF) will be produced, as this is subject to the government's ongoing work on the SAF mandate consultation, although sector demands for SAF are considered in line with the CBDP. Under the SAF mandate, food and feed crops, as well as perennial energy crops (Miscanthus and short rotation coppice (SRC)), and short rotation forestry (SRF) will not be eligible. Further details around SAF production routes will be provided on this as part of the government's response to the recent SAF mandate consultation. The Low Carbon Fuels Strategy will also outline how low carbon fuels, including biofuels, could be deployed across transport modes in the period to 2050, with the aim to provide more investment certainty, including for biofuel production.

To succeed in delivering our biomass Carbon Budget 6 targets we will need to manage the supply and demand side risks associated:

- **Supply side:** As highlighted in Chapter 4, the potential future sustainable biomass supply from domestic and international sources is uncertain. As indicated by our feedstock availability analysis, we recognise that sustainable imports will continue to play a role to support our Carbon Budget 6 biomass demands. In the medium term, this means that action to deliver the quantities of sustainable biomass that will be needed. To support this, we are also working with industry, academia and other partners to support UK domestic biomass production.
- **Demand side:** Technology readiness and attracting investment to the UK also create additional risks to delivery where expected demand for

biomass may not come through. To minimise these risks, the government is actively developing various policies to support the deployment of emerging biomass technologies such as the power BECCS and GGR business models, and potentially the Net Zero Hydrogen Fund (NZHF) and hydrogen business model.

We must acknowledge that the package of proposal and policies contained in the CBDP represents one of many routes to full decarbonisation of the UK economy by 2050. We expect the world to change between now and the end of Carbon Budget 6, so we expect that the plan will evolve to adapt to changing circumstances, new evidence, to use technological developments and to address emerging challenges.

5.5.3 Biomass use towards 2050 (Long term view)

Whole energy system analysis

The UK TIMES Model[120] is a model of the UK energy system that identifies the most cost-effective way of achieving net zero while meeting the UK's energy demands. The model minimises the total energy system costs, subject to constraints such as the requirement to meet future carbon budgets and net zero by 2050. It was previously used[121] in agreeing the level of Carbon Budgets 5 & 6 and the Net Zero Strategy, among other projects. While UK TIMES is unable to capture the detail or precision of more granular sector models, its system-wide perspective can reveal interactions between sectors that cannot be covered by individual sectoral models. It is used here to understand the potential roles, and associated costs, of biomass technologies compared to low carbon alternatives, across the whole UK energy system.

In addition to costs and carbon emissions, UK TIMES includes additional constraints on wider environmental impacts. These include ensuring that bioenergy feedstocks comply with existing UK biomass sustainability criteria and GHG emission thresholds and include damage costs of air quality pollutants arising from the energy system.[122,123] UK TIMES can present illustrative optimal paths of using resources towards net zero but may not represent the distributions of resources across many options or account for delivery risks across policies and technologies.

We use three illustrative scenarios to explore a range of potential uses for biomass in 2050, noting that different outcomes within and beyond this range are also possible. This is due to various risks and uncertainties relating to the biomass system which are difficult to predict, especially in the longer term.

[120] UK TIMES uses the TIMES methodology which emerged from the Energy Technology Systems Analysis Program (ETSAP); one of the longest running Technology Collaboration Programmes of the International Energy Agency (IEA).

[121] https://www.legislation.gov.uk/uksi/2016/785/impacts; https://www.legislation.gov.uk/uksi/2021/750/impacts; https://www.gov.uk/government/publications/net-zero-strategy

[122] https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-damage-cost-guidance

[123] Lott et al., 'Quantifying the co-impacts of energy sector decarbonisation on outdoor air pollution in the United Kingdom', Energy Policy, Volume 101, 2017 (https://doi.org/10.1016/j.enpol.2016.11.028).

This highlights the need to remain flexible to ongoing developments. These risks and uncertainties relate to:

- **Scale of demand:** The detail of how existing and planned biomass policies to meet wider UK priorities on decarbonisation are implemented will have an impact on the optimal use of biomass.
- **Scale of resource supply:** As discussed in Chapter 4, the potential future availability of sustainable biomass to the UK is uncertain. The scenarios presented here assume the ambitious supply profile. The amount of biomass available will determine the scale of decarbonisation possible from bioenergy technologies and of the role biomass in the UK can play in achieving net zero.
- **Technology readiness and deployment:** The scale of negative emissions achievable through technologies such as BECCS will depend on how quickly such technology and the supporting infrastructure becomes available and can be deployed.

Illustrative UK TIMES 2050 scenarios

Modelling different illustrative net zero scenarios enables us to contrast different potential energy and technology solutions in 2050, gain a deeper understanding of crucial system-wide interactions, and, in particular for this Strategy, explore the role that biomass can play in these scenarios. The three scenarios presented below demonstrate a range of practical ways in which net zero could feasibly be delivered with the technology and resources we are aware of today. It is important to note that these scenarios do not represent 'most likely' or 'preferred' solutions, and the actual state in 2050 is likely to differ from these. Given the uncertainties associated with modelling distant futures such as 2050, these outcomes are highly sensitive to economic, societal, and technological developments. See the Technical Annex for details of the modelling.

The three scenarios, constructed in UK TIMES, are based on the illustrative scenarios used for the Net Zero Strategy, but updated to include the ambitious biomass feedstock availability supply profile as set out in Chapter 4.2, where the risks and uncertainties are discussed in more detail. The other major change to the model since the publication of the Net Zero Strategy is the addition of a number of technologies to produce SAF as well as the central-level SAF mandate from DfT's recent consultation.[124] The table below sets out the illustrative scenarios explored.

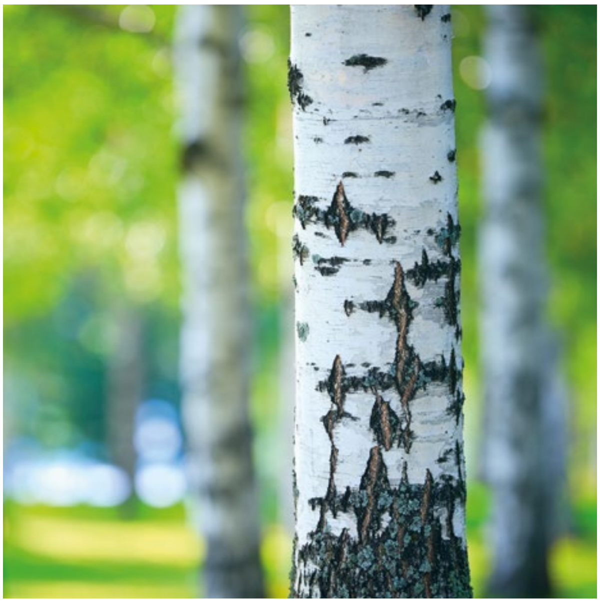
[124] https://www.gov.uk/government/consultations/pathway-to-net-zero-aviation-developing-the-uk-sustainable-aviation-fuel-mandate

Table 5.3: Illustrative scenarios and associated assumptions

Illustrative scenario	Assumptions
High Electrification	Transport, heating and industry predominantly electrified. No hydrogen used for power or heating buildings.
High Resource	Greater use of hydrogen including heat and power. Increased ambition in afforestation.
High Innovation	Significant technological advances, including increased carbon capture rates, deployment of direct air carbon capture & initial roll-out of hydrogen-powered aeroplanes.
All scenarios	Meet all Carbon Budgets and Net Zero by 2050 and assume ambitious biomass supply profile.

Common themes across all illustrative scenarios

Under current technological and demand assumptions, not all sectors are able to fully decarbonise by 2050. Therefore, as set out in the Net Zero Strategy, GGRs are important for achieving net zero. BECCS technologies are a major source of these GGRs.



The common theme across the three scenarios is that biomass is most cost-effectively used in BECCS technologies that can achieve the highest negative emissions, whilst producing additional low-carbon energy vectors. However, the exact mix of these different BECCS technologies depends on the relative conversion efficiencies, capture rates and costs as well as wider system considerations. This means that all lignocellulosic feedstocks (plant-based biomass) are allocated to BECCS technologies, whether producing hydrogen, electricity, biomethane or biokerosene in all scenarios.[125] Furthermore, biomethane is most often used in the power and industry sectors, where it can be combined with CCUS technologies at the point of generation, providing further negative emissions.

Other BECCS technologies such as industrial routes of BECCS and anaerobic digestion with BECCS, have not been included in UK TIMES modelling at this stage due to an incomplete evidence base around transport and storage of CO_2.

[125] Under the proposed SAF mandate, food and feed crops, as well as perennial energy crops (Miscanthus and short rotation coppice (SRC)), and short rotation forestry (SRF) will not be eligible.

The other main theme in the modelling results relates to the role of biomass in the production of biofuels such as biokerosene and biodiesel, particularly where carbon capture and storage (CCS) can be part of the production process. These are primarily allocated to hard-to-decarbonise modes of transport, e.g., aviation, which require fuels with high energy densities (See Section 7.5 for more on transport). A small proportion however could also be used in heating buildings that are not connected to the gas grid and are unsuitable for heat pumps or further electrification - this use is not fully captured in UK TIMES modelling but is discussed further in Section 7.3.

We will continue to update the UK TIMES whole energy systems model as the evidence develops and attempt to reduce the uncertainty around supply and demand, and technological readiness.

Due to existing evidence gaps, we are aware of potential biomass pathways that are not currently represented here but could play an important role in achieving net zero, including non-energy uses that fall outside the scope of UK TIMES (see Chapter 7.8 which covers bio-chemicals and materials, and the use of biomass in construction).

Work is also required to understand the impact of biomass use on the deployment of other non-biomass technologies within the energy system as part of the government's ongoing carbon budget and net zero delivery plan work.

2050 Illustrative Scenario 1: High Electrification

In a scenario where widespread and deeply decarbonised electrification is deployed to decarbonise transport, heating and industry, biomass is cost-effectively used to provide crucial negative emissions and low carbon energy vectors such as hydrogen, biomethane and biofuels.

Under this scenario, as much lignocellulosic biomass feedstock as possible is allocated to BECCS technologies, achieving large amounts of GGRs whilst producing zero-carbon energy vectors such as hydrogen, electricity and biokerosene (SAF) (Figure 5.4).

In this High Electrification scenario, a greater proportion of surface transport (road & rail) is decarbonised using low or zero-carbon electricity and so there is less production of biofuels than in other scenarios. Sustainable aviation fuels still play a role in decarbonising air travel.

Biomethane is produced from wet feedstocks by anaerobic digestion, which could also deploy BECCS technology in future. The biomethane is primarily used in carbon-capture technologies in the power and industry sectors by 2050.

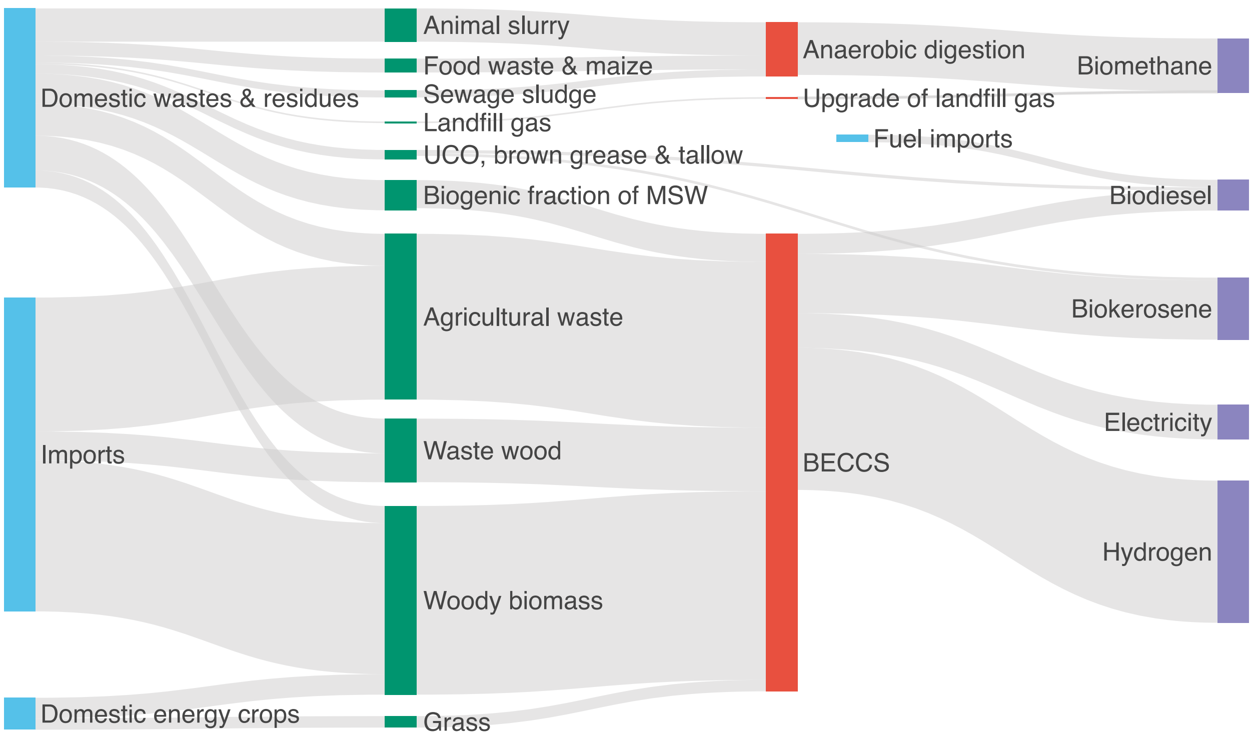


Figure 5.4: Sankey diagram representing the allocation of biomass to the different processing technologies and end uses in illustrative Scenario 1, High Electrification.

2050 Illustrative Scenario 2: High Resource

Within an energy system scenario that uses low carbon hydrogen extensively (particularly for decarbonising buildings, power and heavy vehicles), biomass plays less of a role as a source of hydrogen, instead producing more biomethane and biofuels. This scenario also assumes higher levels of non-energy-use forest planting are achievable, increasing the 'negative emissions' possible from land-use sinks.

The High Resource illustrative scenario features less electrification across the energy system, instead relying on hydrogen for decarbonisation, particularly for heating buildings. However, the broad role of biomass remains unchanged, with all lignocellulosic feedstocks allocated to BECCS technologies (Figure 5.5). The mix of BECCS technologies used changes somewhat; with less hydrogen BECCS and an increase in biokerosene (SAF) BECCS, and also the production of additional biomethane, through the use of gasification to biomethane with BECCS. This reflects lower reliance on overall removals from BECCS (due in part to higher assumed levels of nature-based removals) which allows for a lower cost mix of technologies.

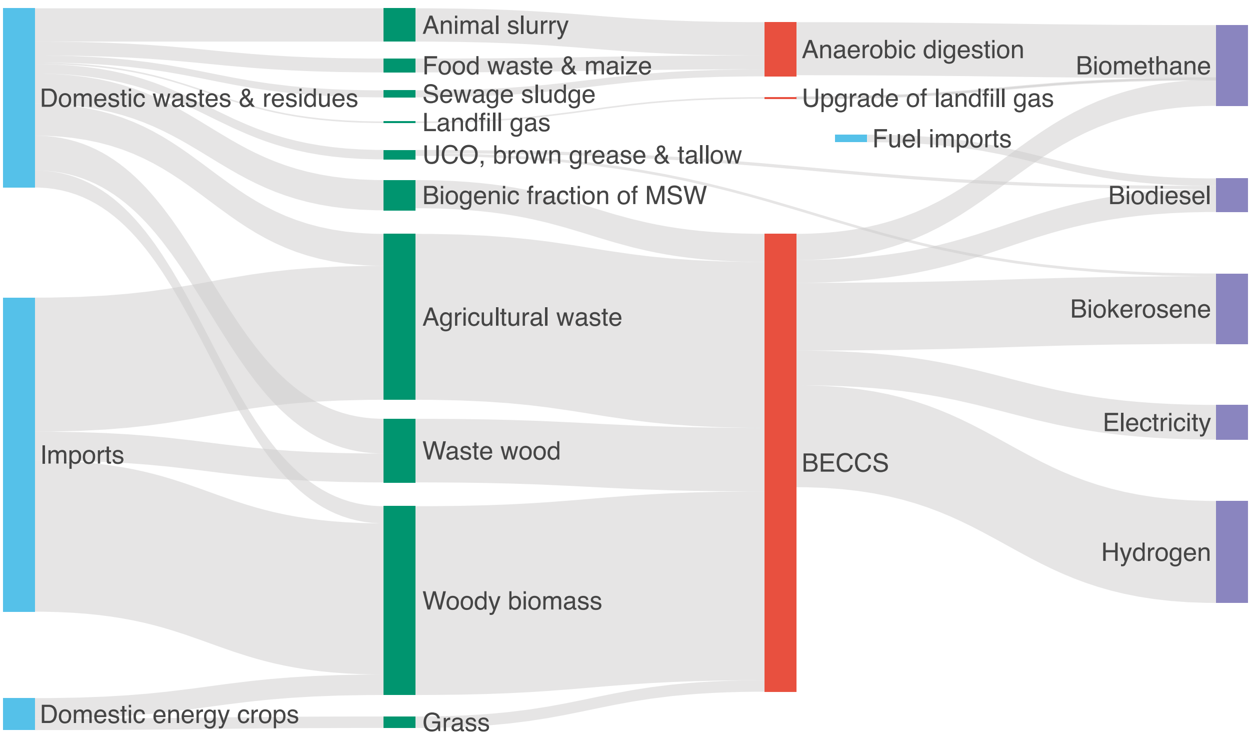


Figure 5.5: **Sankey diagram illustrating the uses of biomass and derived energy forms in 2050 in illustrative Scenario 2, High Resource.**

2050 Illustrative Scenario 3: High innovation

In a world where successful innovations enable higher carbon capture efficacy, greater deployment of Direct Air Carbon Capture and Storage (DACCS) through the 2040s accompanies improvements in aviation, such as efficiency gains and the introduction of hydrogen-powered aircraft. The overall energy system is therefore less reliant on BECCS to provide greenhouse gas removals, and biomass is used more extensively to provide biofuels instead.

The third illustrative scenario features significant technological advancements which reduce the residual emissions from many sectors across the economy and also permit additional negative emissions from greater deployment of DACCS.[126] This means lower levels of negative emissions from BECCS are required to meet net zero, which enables a mix of BECCS technologies that produces more biofuels[127] to abate other sectors (Figure 5.6). There is therefore less hydrogen produced by BECCS technologies than in the other scenarios, but an increase in biokerosene (SAF) and biomethane.

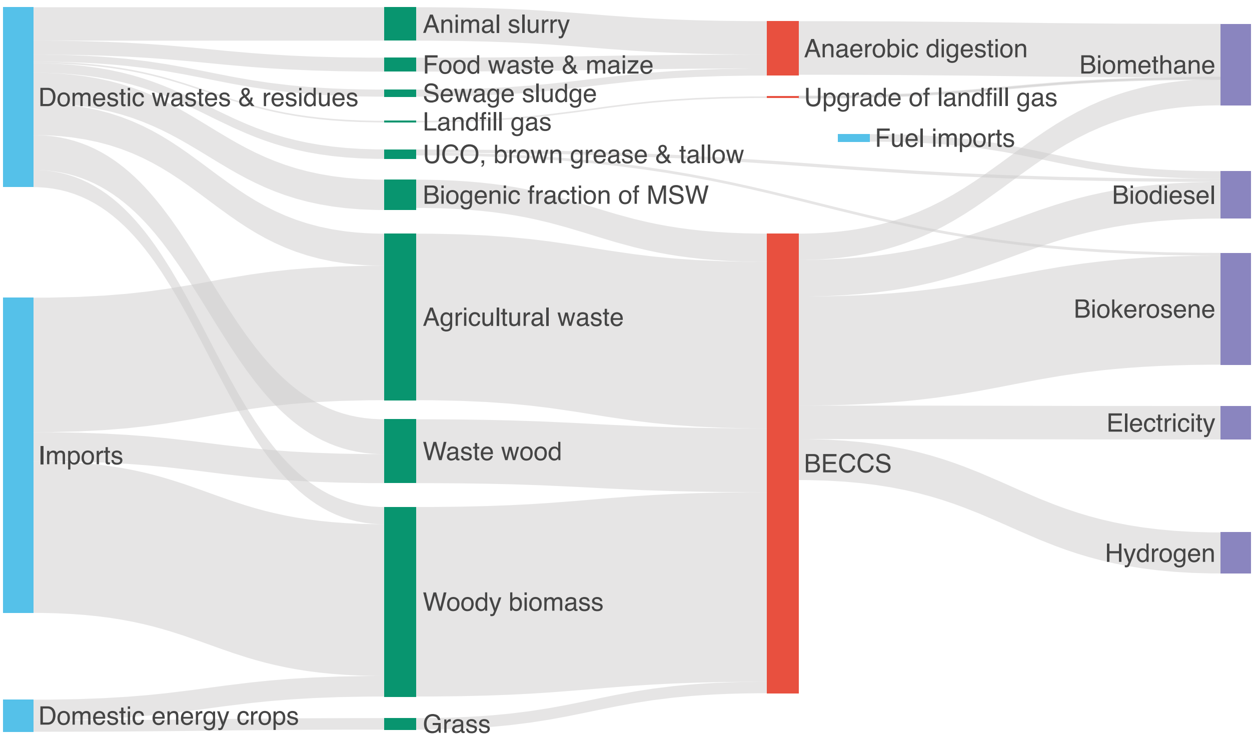


Figure 5.6: Sankey diagram depicting the various uses of biomass across the energy system in illustrative scenario 3, High Innovation.

[126] DACCS refers to a suite of greenhouse gas removal (GGR) technologies that capture carbon dioxide directly from the atmosphere and sequester it in permanent storage.

[127] Biomass-to-Liquid BECCS technologies that produce biofuels like kerosene and diesel cannot capture as much of the carbon contained in the biomass feedstocks as the hydrocarbon fuel outputs must still contain carbon, in contrast to technologies that produce hydrogen or electricity.

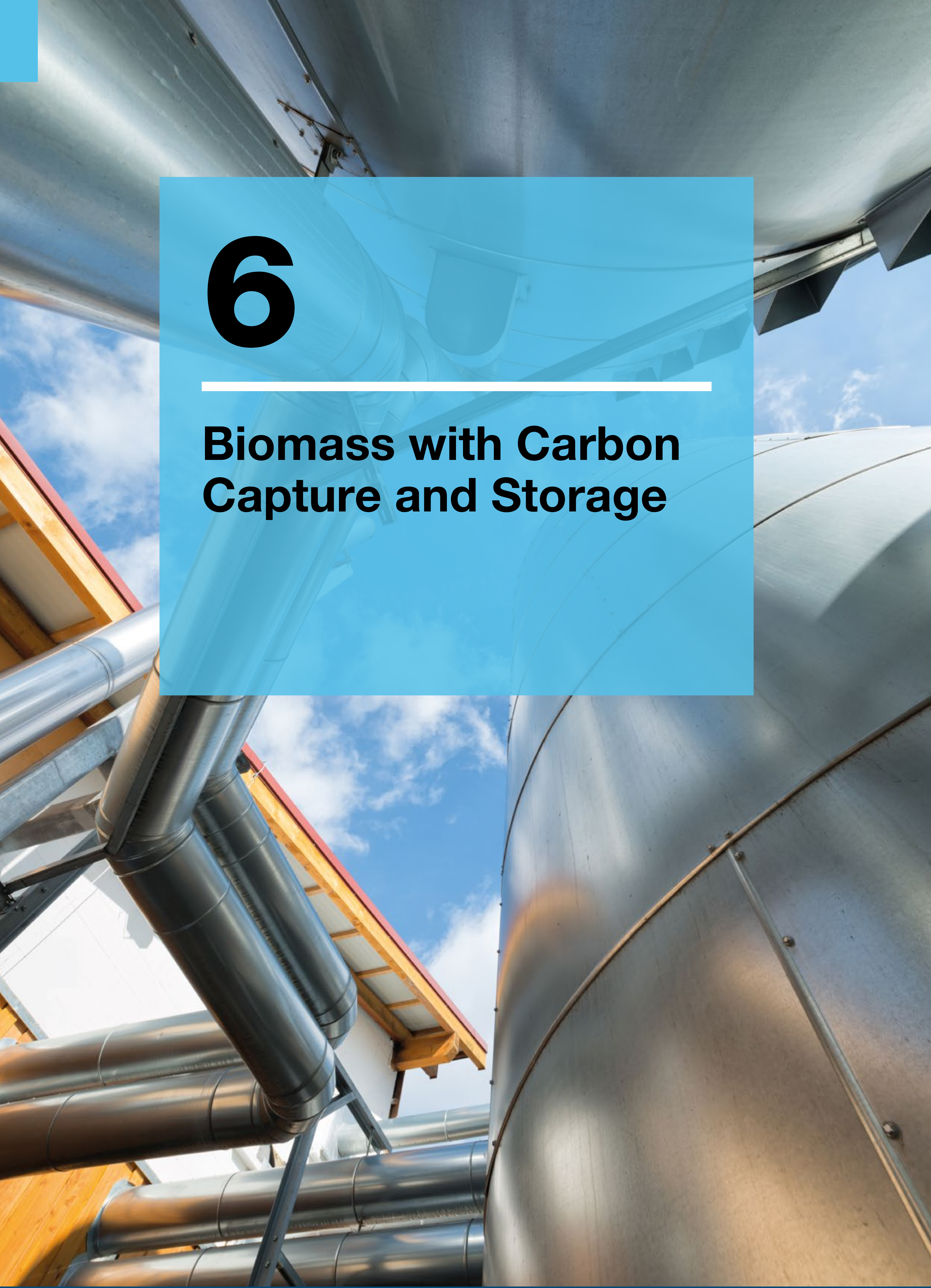
5.5.4 Insights from the biomass priority use assessment

Despite the evolving picture on biomass and the uncertainties around supply and demand, we can draw some broad conclusions from the priority use assessment set out in this chapter to help shape our approach:

- In the short term, biomass will continue to make important contributions across the UK economy to support decarbonisation through existing support schemes.
- For the medium term, biomass is expected to play an important role in meeting Carbon Budget 6, with an increasing role in hard-to-decarbonise sectors.
- In the long term, the illustrative 2050 scenarios prioritise biomass uses that produce negative emissions through BECCS. The precise mix of BECCS technologies should be determined over time as cost- and carbon-effective solutions develop. As many technologies are at an early development stage, it is inappropriate to favour specific options at this point.
- Power BECCS will likely provide an important contribution to deliver negative emissions and low carbon electricity in upcoming Carbon Budget periods and the run-up to 2050s, while hydrogen BECCS is expected to have a greater role in the longer term.
- Biokerosene (SAF) BECCS has potential to deliver negative emissions in the UK, with three projects currently in development, supported through the DfT Advanced Fuels Fund.
- Access to carbon transport and storage infrastructure is needed for the delivery of negative emissions from BECCS technologies.
- Biomass use to support industrial decarbonisation will also be an area of priority for the government, though currently outside this modelling work. This will require coupling industrial uses with carbon capture where feasible.
- While delivery of negative emissions is essential for net zero and should be prioritised, biomass could also have a complementary role to play in producing biomethane (which by 2050 is likely to be predominately used in carbon-capture technologies in the power and industry sectors) and providing other low carbon fuels for those transport modes and rural off-gas grid properties with limited alternatives (particularly where CCUS can be integrated with the production process).
- Sustainable biomass will be increasingly important for manufacturing materials and chemicals, drawing on infrastructure such as bio-refineries. However, the relative future demands of these applications are uncertain at present and are outside the scope of energy system modelling using UK TIMES. Further research and development are needed to bring such technologies to the market. Policy frameworks will play an important role in facilitating the deployment of new technologies in a sustainable manner.

6

Biomass with Carbon Capture and Storage



Our Key Messages

- Greenhouse Gas Removal (GGR) technologies are essential to the UK's Net Zero Strategy – balancing residual emissions from hard-to-decarbonise sectors while providing new economic opportunities.
- Bioenergy with Carbon Capture and Storage (BECCS) is an engineered GGR technology that captures and stores CO_2 from biomass while producing low carbon energy.
- Well-regulated BECCS can provide both genuine GGRs and low carbon energy or products.
- There is active work ongoing in government to support BECCS, including the development of new business models, underpinned by clear guidance and principles for GGRs and BECCS.
- In 2023 we will set out a vision for the UK carbon capture, usage and storage (CCUS) sector, setting out how CCUS will support our net zero ambitions to raise confidence and improve visibility for investors.

Greenhouse Gas Removal (GGR) technologies are essential to the UK's net zero strategy – balancing residual emissions from hard-to-decarbonise sectors while providing new economic opportunities.

The importance of GGRs as part of the UK's efforts to tackle climate change has been widely recognised by a range of independent institutions, including the Climate Change Committee (CCC), the Royal Society, the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change (IPCC). These institutions make it clear that removing carbon dioxide from the atmosphere is imperative for achieving net zero and limiting global warming.

GGRs are defined as measures that result in net removal of greenhouse gases (GHGs) from the atmosphere and storage in organic material or geological stores.[128] The range of GGR approaches fall broadly into two categories: engineered GGRs and nature based GGRs. Nature-based approaches include techniques such as afforestation, and soil sequestration.[129] The Biomass Strategy focuses on the engineered-based BECCS technologies.

Below we have outlined the role that **BECCS** can play in reducing carbon emissions across the economy and set out how the technology could be deployed. Section 6.7 provides an overview on the potential for **biochar** to deliver GGRs.

[128] https://www.ipcc.ch/report/ar6/wg3
[129] https://www.gov.uk/government/publications/net-zero-strategy

6.1 Bioenergy with Carbon Capture and Storage (BECCS)

BECCS is an engineered GGR technology that captures and stores CO_2 from biomass while producing low carbon energy.

There are several potential routes to BECCS recognised, such as:

- Post-combustion CO_2 capture (wood, agricultural residues, wastes, etc.).
- Capturing CO_2 streams arising from advanced conversion processes such as gasification or steam reformation to produce fuels such as sustainable aviation fuels and hydrogen;
- CO_2 emitted and captured via biological processes such as fermentation or anaerobic digestion (AD).

As outlined in the Net Zero Strategy: Build Back Greener,[130] engineered removals could be deployed at a scale of between 75 and 81 $MtCO_2$/yr by 2050 to help compensate for residual emissions. The Strategy set an ambition of at least 5 $MtCO_2$/yr of engineered removals by 2030, potentially rising to 23 $MtCO_2$/yr by 2035. BECCS is expected to make the bulk of this, potentially delivering 52-58 $MtCO_2$/yr by 2050.

Chapter 5 of this strategy indicated that biomass uses with carbon capture and storage (CCS) will contribute the most to meeting net zero. This way, BECCS has the potential to not only deliver negative emissions, but also deliver co-benefits through providing low carbon energy products and providing a use for low value products. Therefore, either new or existing biomass applications should consider options to and routes to deploy CCS in the short to medium term, in order to plan a transition to BECCS.

6.2 Public perceptions of BECCS

Public perceptions of BECCS tend to focus on the validity of BECCS as a negative emission technology and are sceptical of the ability to deploy BECCS at scale.

We recognise that biomass GHG emission accounting is highly complex and there is some public concern over the large-scale use of biomass, and scepticism in the use of biomass for delivering negative emissions via BECCS. These concerns are understood by policy makers and are one of the reasons we have focused on the robustness of our sustainability criteria.

Responses to the 2021 Call for Evidence highlighted the need for more funding and investment and support for BECCS, particularly at low carbon innovation clusters where high-quality skilled labour and economic growth can be stimulated. Respondents highlighted the various routes that BECCS could be deployed,

[130] https://www.gov.uk/government/publications/net-zero-strategy

highlighting the need for innovation and investment required to reduce the costs of BECCS across a range of scales. Many of the points raised focused on the sustainability of the biomass used in BECCS, stressing the need for a full life cycle emissions assessment of BECCS and improved sustainability of biomass sources.

The Public Dialogue Project presented participants with a detailed explanation of BECCS. Although some respondents were ambivalent about BECCS, after the discussions there was some agreement that it has a role to play in achieving net zero. Participants raised concerns that BECCS is, as yet, unproven at scale and emphasised that some scaled implementation should be assessed first until the evidence becomes more certain. As with sustainability, participants wanted regulation of the sustainability of biomass sources used for BECCS and the carbon captured when it is deployed, to occur through a coalition of independent stakeholders to ensure that the focus of BECCS remained on net zero.

The following section provides a review of BECCS technologies, and an overview of the research government has done to assess how BECCS can deliver negative emissions.

6.3 BECCS Technologies

Bioenergy for power generation and carbon capture and storage are not new technologies.

Carbon capture and storage (CCS) refers to the process that:

- Captures CO_2 from power stations, processing plants or other industrial sources;
- Handles and transports CO_2; and
- Stores the CO_2 for example by injection in deep geological formations; or
- Stores carbon in a non-CO_2 form such as solid carbon/biochar (see Section 6.7)

Although BECCS is not currently operating at scale in the UK, the technology is operating elsewhere globally in demonstration plants and at commercial scale. The 2022 Global CCS Institute Status Report shows there are 30 commercial CCS facilities in operation,[131] with 11 under construction and more than 150 in various stages of development. The commercial CCS facilities in operation today are capturing CO_2 from a wide range of emission sources inducing gas processing, ethanol, fertiliser, steel, hydrogen production as well as power generation.[132]

[131] https://status22.globalccsinstitute.com/2022-status-report/global-status-of-ccs
[132] https://www.globalccsinstitute.com/wp-content/uploads/2022/06/MythBusters-Flyer_FINAL-5.pdf

Norway has used CCS technology in its North Sea oil fields for more than two decades,[133] and the USA has operated CCS since the 1970s.[134] The current total of CO_2 captured and stored is over 42 Mt per annum which would rise to 244 Mt when current projects are completed. At a single plant, post combustion carbon capture has been demonstrated up to a scale of capturing 1 Mt CO_2/yr.[135] Properly permitted and operated CCS is a safe and mature technology and there is a strong regulatory framework in place to mitigate any associated risks.

The deployment of BECCS will come via several possible routes, each of which are at various stages of technology readiness (Table 6.1). While some BECCS routes may be more technologically advanced, their potential may be limited by the scale of the parent technology, or the size and location of existing or future plants.

Examples of more mature BECCS technologies include those that could be deployed with low carbon fuel production, such as in bioethanol production in the United States. Low carbon fuel production coupled with BECCS is yet to be deployed in the UK but has potential to deliver negative emissions. The upcoming sustainable aviation fuel (SAF) mandate proposes to reward SAF on the basis of GHG savings to ensure the future integration of CCS in SAF production and encourage the best use of biomass.

Chapter 5 identified many biomass pathways that will rely on gasification-based routes for BECCS (hydrogen and SAF BECCS), therefore gasification is a priority area for innovation. For this reason, as part of the Net Zero Innovation Portfolio (NZIP), the **Hydrogen BECCS Innovation Programme** supports technologies which can produce hydrogen from biogenic feedstocks and be combined with carbon capture (Box 6.1). The NZIP Direct Air Capture (DAC) and GGR Innovation Programme has directed funding to deliver a portfolio of First-of-a-Kind (FOAK) GGR projects, including BECCS and biochar. The programme aims to identify the most promising technologies for deployment in the UK, verify the quantity and cost of removing CO_2, and through successful piloting, catalyse further investment into the UK (Box 6.2).

There may be more innovative, next generation routes of CO_2 capture that are on a longer deployment timescale and are at the lower Technology Readiness Level (TRL) stages than shown in Table 6.1, to which innovation funding has been targeted (Box 6.3). Such innovations can accelerate deployment at scale, and some may not require direct access to the CO_2 transport and storage network connected to the CCUS clusters. Therefore, in the medium- and longer-term future, BECCS deployment may develop at various scales.

[133] https://www.ccsassociation.org/discover-ccus/explore-ccus
[134] https://www.iea.org/reports/about-ccus
[135] https://www.globalccsinstitute.com/wp-content/uploads/2021/10/2021-Global-Status-of-CCS-Report_Global_CCS_Institute.pdf

Box 6.1. Innovation: Hydrogen BECCS Innovation Programme

In Phase 1, launched in early 2022, the programme awarded £5m to 22 projects to scope and develop a demonstration project to be run in Phase 2.[136] In June 2023, £21.2 million of funding was awarded for Phase 2 of the programme, enabling five organisations to build and test their innovative hydrogen BECCS technologies by March 2025. The aim of the programme is to support the development of technologies which will enable the commercialisation and deployment of hydrogen BECCS at scale to achieve negative emission and hydrogen production ambitions. Technologies being supported in Phase 2 of the programme including syngas upgrading after gasification, pyrolysis to generate hydrogen and biochar, and conversion of biogas from wastewater treatment into hydrogen and, a novel means of carbon capture and storage, graphene.

Hydrogen BECCS case study: Compact Syngas Solutions Ltd

Compact Syngas Solutions (CSS) is an SME based in North Wales that creates synthesis gas from biomass, waste biomass and prepared solid recovered fuels (SRFs). Synthesis gas, or 'syngas', largely comprises hydrogen (H_2), carbon dioxide (CO_2) carbon monoxide (CO) and methane (CH_4), with hydrogen being a critical net zero fuel and carbon capture being essential for the net zero negative emissions.

CCS has been awarded almost £4 million in Phase 2 of the NZIP Hydrogen BECCS programme to demonstrate their novel advanced gasification and syngas separation process. As part of their Phase 1 feasibility study, CSS designed and constructed a water-based carbon capture prototype capable of processing 100 Nm3/h of syngas to extract more than 75% of the CO_2 from the gas stream. This unit was tested in conjunction with their gasification system to produce hydrogen. The study proved that it is feasible to integrate both systems and viable to use water as a CO_2 capture solvent, rather than using the higher cost, traditional solvents such as amines. The trials also allowed CCS to improve their hydrogen production.

The carbon life cycle assessment suggests that the system will provide significant emissions reductions when compared to competitor technologies, due to (1) the sequestration of the carbon in the biochar generated in the gasifier and (2) the additional capture of CO_2 in the scrubbing column.

[136] Further details of the projects funded in Phase 1: https://www.gov.uk/government/publications/hydrogen-beccs-innovation-programme-successful-projects

Box 6.2. Direct Air Capture (DAC) and GGR Innovation Programme

Phase 1 (design and feasibility) ran from March 2021 to April 2022 with a total value of £7.5 million. Each project was awarded up to £250,000. Phase 2 (construction and operation of a pilot) has a total value of around £55million will continue until March 2025, with projects awarded up to £5 million. Only projects from Phase 1 were able to apply for Phase 2 and the 14 successful projects are split between 4 technologies namely, DAC, BECCS, biochar and Direct Ocean Capture.

Phase 2 case study: Kew Projects Ltd – CCH_2: Carbon Capture and Hydrogen

This project focuses on carbon capture and hydrogen production from biomass (CCH_2) and plan to demonstrate a modular, cost-effective system capable of delivering 50ktCO_2/yr of GGR during 2025-2030 and scaling to a potential 24 MtCO_2/yr in the subsequent decade. The CCH_2 demonstration will combine two individual units (TRL6) into an innovative and fully integrated BECCS hydrogen system.

The technology using an advanced gasification process (a form of Advanced Conversion Technology, or ACT) can convert a wide range of sustainable feedstocks to produce a hydrogen-rich syngas as a replacement for natural gas. By coupling this process with additional carbon capture and hydrogen purification steps, KEW can capture CO_2 while simultaneously producing a carbon negative hydrogen stream which can help decarbonise other energy-intensive industries.

©KewTech

Box 6.3. Innovation: CCUS Innovation

Between 2004-2021 the UK has provided over £346 million in public funding for CCUS research, development and demonstration projects.[137] This has been crucial in understanding the fundamental science, developing improved capture processes and equipment, as well as training the next generation of subject matter experts in CCUS.[138]

More recently, as part of the £1 billion Net Zero Innovation (NZIP), 2021 - 2025, the £25 million has been allocated for CCUS innovation.

The £5 million **Accelerating Carbon Capture and Storage Technologies 3 (ACT-3)** led by academia and industry has provided research grant funding for eight projects.[139]

The £20 million **CCUS Innovation 2.0** competition aims to reduce the cost of capture and help UK industry to understand the opportunity for developing and deploying next generation carbon capture technologies from 2025.

Eight projects were awarded over £12 million in Call 1[140] with £7.3 million available during Call 2.[141] In addition to the grant funding, a technology review and techno-economic analysis of next generation carbon capture technologies for industrial, waste and power sectors was published in May 2022.[142]

137 https://www.iea.org/data-and-statistics/data-tools/energy-technology-rdd-budgets-data-explorer
138 CCUS Supply Chains: a roadmap to maximise the UK's potential: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/984308/ccus-supply-chains-roadmap.pdf
139 https://www.gov.uk/government/publications/accelerating-carbon-capture-and-storage-technologies-act-3-grant-funding-winners/grant-funding-winners-accelerating-carbon-capture-and-storage-technologies-3#the-winners
140 Further details of the successful Call 1 projects: https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-innovation-20-competition-call-1-successful-projects
141 Further details on Call 2: https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-innovation-20-competition-call-2
142 Review of next generation carbon capture technology for industrial, waste and power sectors: https://www.gov.uk/government/publications/review-of-next-generation-carbon-capture-technology-for-industrial-waste-and-power-sectors

Table 6.1: BECCS TRL produced in support from the IEA Clean Energy Technology Guide – IEA(2022), ETPClean Energy Technology Guide, IEA, Paris
https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide

Routes to BECCS	Type	Technologies	CO_2 Capture method	CO_2 Transport	TRL Assessment
Fuel-BECCS	Biological	Fermentation	Separation	Pipeline	Mature
Biomethane-BECCS	Biological	Anaerobic digestion	Separation	Pipeline	Early adoption
Hydrogen BECCS	Biological	Anaerobic digestion	Biomethane with steam methane reforming with CO_2 capture*	Pipeline	Early adoption
Power BECCS	Post-Combustion	Combustion	Chemical absorption	Pipeline	Precommercial
Industrial BECCS	Post-Combustion	Combustion	Chemical absorption	Pipeline	Precommercial
SNG or Biomethane -BECCS	Thermochemical	Gasification to SNG	Pre-combustion	Pipeline	Demonstration
Fuel-BECCS	Thermochemical	Gasification to fuel	Pre-combustion	Pipeline	Demonstration
Hydrogen BECCS	Thermochemical	Gasification to fuel	Pre-combustion	Pipeline	Demonstration

Key

Mature	Above TRL9
Early adoption	Early adoption – solution is commercially available, but needs improvement to stay competitive
Precommercial TRL8-9	Proven to work
Demonstration (TRL 6-7)	Prototype complete, planned operation

[143] https://www.globalccsinstitute.com/wp-content/uploads/2019/03/BECCS-Perspective_FINAL_18-March.pdf
[144] https://co2re.co/FacilityData

	Regarded as the most mature and relatively cost effective of BECCS- where the CO_2 emitted from the fermentation stage is captured and either used or stored. There are five operational BECCS projects in North America that have combined bioethanol production with CCS. The largest, the Illinois Industrial CCS facility, which has been operational since 2017, captures up to 1 Mt CO_2/yr from corn-based bioethanol and stores the CO_2 in a dedicated geological storage site deep underneath the facility.[143, 144]
	Anaerobic digestion plants routinely separate CO_2 during the process of biogas upgrading prior to grid injection. The AD-route of CO_2 capture has been demonstrated to be cost effective for the utilisation market, and the role for AD as a source of low carbon CO_2 may expand. There is, however, no current demonstration of geological carbon storage and AD combined- although the Audi-E plant in Germany utilises CO_2 captured from a biogas plant to produce synthetic methane.
	Although not yet demonstrated in the UK, hydrogen production via natural gas SMR with CCS is already operational in North America at two plants. It could therefore be possible in the UK for biomethane could be used to generate hydrogen-BECCS with relatively little innovation required. This route is currently eligible for support under the Renewable Transport Fuel Obligation (RTFO).
	The Mikawa plant in Japan that captures and temporarily stores biogenic CO_2 at a rate of 500t/ CO_2 day (ref). Other demonstration plants (e.g., Drax in conjunction with C-Capture (from 2018) and then Mitsubishi Heavy Industry (2020) have captured and vented at a small-scale UK pilot programme since 2018. BECCS in industrial applications has been demonstrated at two plants under development in Norway, combining CCS with biomass use in cement manufacture, and with energy from waste, so far demonstrating successful capture at a few thousand tonnes of CO_2, and aim to save 0.8 Mt CO_2/yr by 2024.
	Some of these gasification processes have been proven, but not with integrated carbon capture and utilisation or storage, though there are some emerging projects that will be developing this soon.

6.4 How BECCS can deliver negative emissions

Well-regulated BECCS can deliver genuine GHG removals, providing biomass is sourced sustainably, if supply chain emissions are regulated, and if the BECCS value chain is robustly and independently verified.

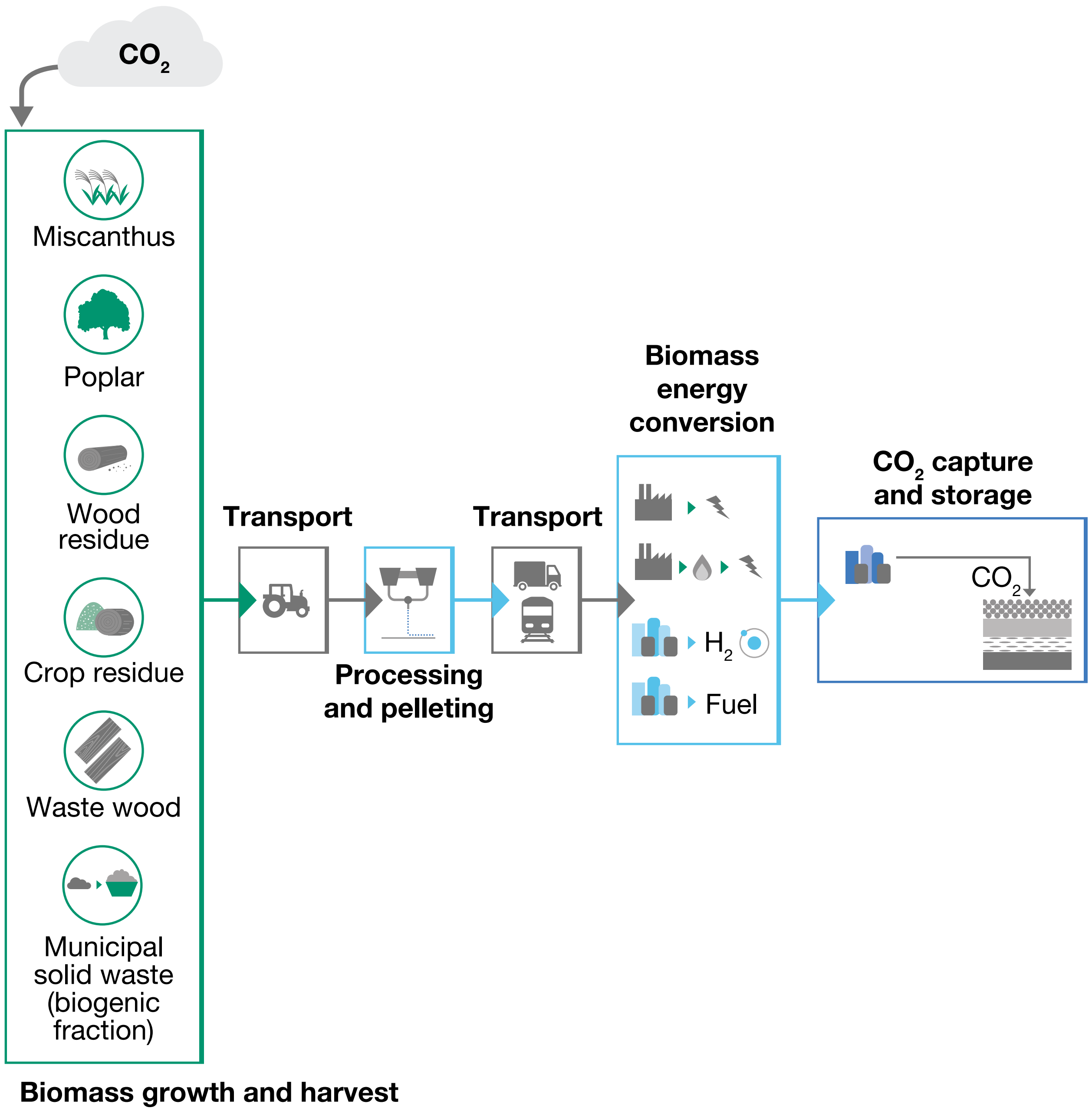


Figure 6.1: Illustrative flow diagram of an archetypical bioenergy with carbon capture and storage (BECCS) value chain.

The biosphere is estimated to remove 3.5 ±0.9 Gt CO_2 from the atmosphere each year through plant growth.[145] Therefore, combining biomass use, whatever the source, with carbon capture is a route to create a flow of 'negative CO_2 emissions' where CO_2 leaves the atmosphere, enters the biosphere, is captured and then moved into long term storage.

The additional benefit of BECCS is that the process involves the conversion of biomass into valuable energy products, such as electricity, heat or renewable fuels. This enables BECCS to provide an additional decarbonisation benefit from the energy use in the relevant sectors of the economy.

Task and Finish Group Report: The ability for BECCS to generate negative emissions

Alongside this Strategy, government has published a report led by the Department for Energy Security and Net Zero Chief Scientific Adviser's Task and Finish Group which sought to establish an evidenced based position on the validity of BECCS as a GGR option to deliver negative emissions.[146] While the group recognised there are some challenges, it did not identify any insurmountable scientific barriers to the net removal of CO_2 from the atmosphere and subsequent permanent geological storage via BECCS when carried out in accordance with appropriately designed biomass sustainability criteria and via sustainable supply chains.

The report noted there is a substantial opportunity for the UK to develop a leadership position in the range of technical, commercial, legal, financial, and policy "know-how" associated with the delivery of sustainable BECCS/GGR. If the UK chooses not to pursue GGR and BECCS, it could miss out these innovation and associated export opportunities, in addition to increasing the costs of delivering net zero.

The BECCS Task and Finish Group report set out suggested approaches whereby BECCS could achieve its objective to deliver negative emissions and ensure positive outcomes for people, the environment, and the climate. This can be possible if the biomass is "well regulated" meaning if it is sourced, sustainably with appropriate certification, if significant negative impacts on forest carbon stocks are avoided, and if carbon and supply chain GHG emissions are minimised and regulated, and if the BECCS value chain is robustly and independently verified. These areas are all being addressed in government policy development currently. Any biomass used in BECCS will be required to meet the updated sustainability requirements, as per commitments set out in this Strategy (See Chapter 2), which will be refined via consultation.

It is recognised that negative impacts on forest carbon stocks and the supply chain emissions would reduce the net carbon removal efficiency of BECCS. Supply chain emission are already regulated in unabated biomass policies in government, where reward or subsidy are conditional on meeting strict GHG criteria. Literature suggests that in practice, the carbon removal efficiency of power BECCS could be between 65-85% after accounting for the supply chain and losses of non-

[145] Friedlingstein, P. et al, Global Carbon Budget 2022, Earth Syst. Sci. Data, 14, 4811–4900, 2022 (https://doi.org/10.5194/essd-14-4811-2022).
[146] https://www.gov.uk/government/publications/biomass-strategy

captured biogenic carbon. So far, emerging policy work in government has recognised the need to regulate supply chain emissions from BECCS so that it achieves at least a minimum approved level of negative emissions.[147] Further investigation is needed to understand the potential to supply biomass from forests, whilst ensuring positive impacts on of forest carbon stocks are encouraged, whilst negative impacts are avoided or minimised. Also, government is examining how to encourage BECCS from utilising biogenic wastes in low carbon fuel production to ensure GHG savings are maximised and is assessing how best to treat negative emissions under the upcoming SAF mandate.

Biomass supply for BECCS

It is recognised that a portfolio of GGR methods will be required for net zero, with BECCS being just one of them. For this reason, the GGR business model is designed to be applicable to a range of GGR technologies (See Section 6.5). Government has also been clear that GGRs are not a substitute for taking decisive action across the economy to cut emissions.

The deployment of BECCS in the UK will be limited by the biomass supply and the deployment of CCUS infrastructure. Chapter 4 provides the full assessment of the UK and Global Bioenergy Resource Model, where it is fully recognised that there is a limit to the quantity of sustainable biomass that can be produced globally, and then potentially be available to the UK. This is why this Strategy has identified that prioritising biomass use in BECCS will maximise the contribution that biomass can make to the net zero target.

In terms of land use, the modelling to inform the Strategy took a precautionary approach to reduce the risk of Indirect Land Use Change (ILUC), limiting the expansion of bioenergy crops to abandoned agricultural land, which will ultimately place a limitation on the extent that BECCS will be delivered via purpose-grown crops. Such crops would need to be grown in suitable locations and an appropriate scale, or innovations will be required to gain access to other novel feedstocks that are either complementary to other land uses, or go beyond land (e.g., marine feedstocks).

The carbon dynamics of BECCS: Forestry Focus

The Task and Finish Group report noted significant stakeholder interest in forest-derived biomass, and therefore focussed on this aspect. It outlined the ideal carbon dynamics of conventionally managed forests as they cycle between establishment, active growth and felling on a landscape level to provide a continuous supply of harvested wood products and biomass.[148] The report stated that in principle, forests can be managed to supply carbon neutral biomass at scale, and the ability of the Carbon Capture and Storage element of the value chain to deliver was not contested.

After the Report concluded, the outputs of the Forest Research CARBINE Forest Sector Carbon Accounting Model were elaborated to allow for the impact of

147 https://www.gov.uk/government/consultations/business-model-for-power-bioenergy-with-carbon-capture-and-storage-power-beccs

148 Matthews, R., 2020, ERAMMP Report-36, Annex-4: Climate Change Mitigation: https://erammp.wales/sites/default/files/2022-11/36%20ERAMMP%20Rpt-36%20NF%20Annex-4%20Climate%20Change%20v1.0_en.pdf

integrating BECCS into the scenarios presented in the report. This assumes a proportion of forest residues are used in a power BECCS plants and a proportion of post-consumer waste products are used in an energy from waste (EfW) BECCS plant (Figure 6.2). It shows, in this scenario, that the permanent removal of CO_2 via BECCS can significantly increase the overall long term carbon removal potential from the forest landscape. It shows that the use of harvested wood products can provide additional decarbonisation benefits by displacing the production of other building materials (such as cement and steel). Additional CO_2 removal can be achieved by placing harvested wood products in EfW BECCS facilities at the end of their useful life.

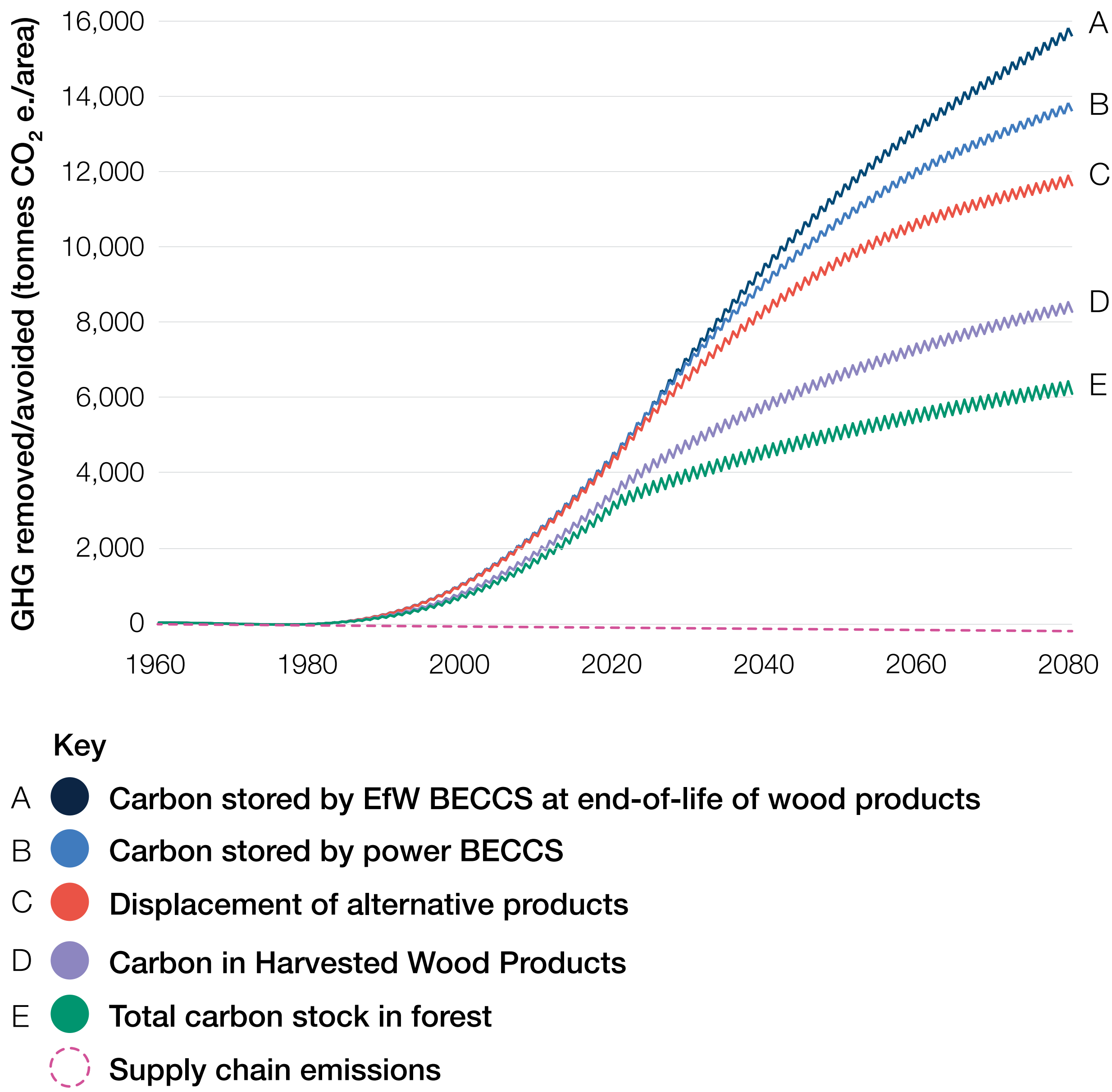


Figure 6.2: Results from the Forest Research CARBINE Forest Sector Carbon Accounting Model after allowing for the impact of integrating BECCS into the scenarios presented in the Task & Finish report.

The scenario includes the additional CO_2 removal that BECCS could contribute, in addition to that provided from an area of recently created commercially managed forest in the UK, where any recovered biomass was used in BECCS, and end of life wood products entered energy recovery with CCS. As the UK imports the majority of its wood pellet supply, it is necessary to develop this work to assess the impact of sourcing, processing and importing biomass to the UK from overseas. Research is also needed to assess the carbon removal potential of energy crops as a BECCS feedstock, including any impacts of land use change.

The drivers of forest management can be diverse, and can include economic, biodiversity, fire reduction, or other management objectives. While biomass from managed forests (including low value thinnings and low grade roundwood) and residues from sawmills can make a sustainable and economically significant contribution to existing forestry operations and local economies,[149] the evidence on whether the market for biomass influences decisions in forest management are less clear cut, as biomass is part of a system of products from the forestry sector and management decisions are influenced by multiple parameters. Nevertheless, this will continue to be an area for research.

6.5 Principles of deploying BECCS

The government is actively working on developing clear guidance and principles for GGRs and BECCS.

The government recently published a response[150] to the GGR consultation held in 2022, which focussed on developments of the GGR Business Model. The response also set out the ongoing work to develop clear guidance and principles for defining negative emissions and to strengthen our understanding of the current landscape of standards for all GGRs, including BECCS.

Alongside the business model, we recognise the need to develop a monitoring, reporting and verification (MRV) framework which provides confidence that GGR projects deliver verifiable climate benefits based on a full life cycle assessment.

A robust evidence base on existing standards for GGRs will provide a sound basis for future policymaking, and we are mindful that there are various standards already operating or in development across the marketplace. Building on responses to the consultation, our MRV proposals will be informed by an independent review of the existing landscape of standards being conducted by E4Tech and Element Energy, which we intend to publish.

Until those standards are developed, the recently published response to the GGR Business Model consultation laid out some ‘guiding parameters’ for our overall strategic priorities for deploying GGRs in the UK. These principles relate to revenue certainty, value for money, climate integrity, amongst others.

[149] https://www.forumforthefuture.org/beccs-done-well-conditions-for-success-for-bioenergy-with-carbon-capture-and-storage
[150] https://www.gov.uk/government/consultations/greenhouse-gas-removals-ggr-business-models

The government response also set out criteria for robust negative emissions that drew on the previous GGR MRV Task and Finish Group's report for government[151] (Table 6.2).

Table 6.2: The government's criteria for a robust negative emission.

CO_2 source	CO_2 must be directly captured from the atmosphere or seawater (via biological, chemical or geochemical means).
Net Negativity	End-to-end CO_2 emissions must be lower than the total amount of stored carbon. For some technologies we propose that we would set requirements to limit the level of supply chain emissions, to ensure that GGR technologies achieve a minimum level of net negative emissions.
Permanence	Once captured by a project, carbon must be sequestered in a highly durable store. The assessment of permanence should consider durability and 'risk of reversal' (likelihood of captured carbon being re-emitted into the atmosphere) associated with a carbon store. Utilisation of carbon in short-lived products, such as fuels and plastics, does not constitute a negative emission.

The Biomass Strategy sets out principles specifically for BECCS deployment. They are designed to reflect both the government's wider approach to engineered removal technologies and the need to maintain strict sustainability standards for BECCS as are used in existing bioenergy support schemes.

The Biomass Strategy has identified complementary principles, or detail to the GGR principles, that are specific to BECCS. They are designed to reflect the need to maintain strict sustainability standards for BECCS as are used in existing bioenergy support schemes.

In summary, the BECCS principles state that:

- Government should only support the capture and storage of biogenic CO_2 emissions generated from sustainable biomass which meets clear, enforceable, and transparent sustainability criteria.
- Support should only be for BECCS systems that deliver net GGRs based on a full life cycle assessment irrespective of where in the supply chain emissions occur.
- BECCS should provide valuable, low carbon co-products or services alongside GGRs to maximise the use of sustainable biomass.
- A BECCS project must achieve long term and safe carbon storage to guarantee atmospheric carbon removal.

Unlike targets and rules, this principles-based system is flexible enough to remain valid in the face of evolving evidence and technological development and innovation.

[151] https://www.gov.uk/government/publications/monitoring-reporting-and-verification-of-ggrs-task-and-finish-group-report

Principle 1: Government should only support the use of sustainable biomass.

It is vital that biomass used in BECCS is sustainably sourced. All biomass supported under government support schemes must meet sustainability criteria covering land and GHG criteria, and this will apply to BECCS. It is expected that biomass used in BECCS will meet the wider land criteria and air quality requirements covered in Chapter 2.

As applies under both the existing land and GHG sustainability criteria, no government support will be available unless the consignment of sustainable biomass is evidenced and verified by third-party sustainability auditors, including on the basis of UK-domestic category B evidence.[152] This is consistent with the UK's existing MRV processes for renewable electricity, heat generation or renewable transport fuel production.

Principle 2: Support of BECCS should only be for BECCS projects that deliver net-negative emissions.

Following on from the GGR consultation response[153] it is the intention that the supply chain emissions from BECCS will be monitored, reported and verified in order to ensure that the BECCS process results in net negative emissions. The government's overarching ambition is to ensure that removals deployed in the UK can meet an agreed definition of legitimacy and therefore be confidently attributed to our carbon budgets.

BECCS will therefore be required to meet GHG criteria, and GHG supply chain thresholds that ensure that the full biomass supply chain GHG emissions, from growing, processing, transporting and storing, are taken into account in the assessment of the final capture of CO_2. These GHG emissions should be accounted for irrespective of the international boundaries where the emissions are taking place.

It is important that these BECCS principles apply when attempting to calculate the CO_2 removal potential of BECCS, i.e., the calculation must be based on GHG emissions that have been emitted, versus the volume of biogenic carbon or CO_2 captured during the process that is stored in safe, long term storage.

In the power BECCS Business Model Consultation, government asked for views about whether power BECCS projects should run during periods of Transport & Storage (T&S) unavailability, such as temporary outages. In the response, we recognised that there are both benefits and risks of incentivising projects to run during these periods. We set out that we are continuing to develop a position on power BECCS projects running during periods of T&S unavailability.

Where BECCS is integrated into an existing biomass scheme, there may be some circumstances where it is necessary to use CCS to reduce the carbon intensity of a bioenergy co-product (e.g., sustainable aviation fuel). In instances where captured CO_2 is used to meet a defined GHG threshold, such as the Low Carbon Hydrogen Standard, these units of captured carbon cannot qualify for

[152] https://www.gov.uk/guidance/timber-procurement-policy-tpp-prove-legality-and-sustainablity
[153] https://www.gov.uk/government/consultations/greenhouse-gas-removals-ggr-business-models

additional government support or be sold on a negative emissions market. They will also not be double claimed under national carbon inventories.

Principle 3: BECCS should provide valuable, low carbon co-products alongside a greenhouse gas removal

By combining GGRs and low carbon energy outputs, BECCS will help maximise the contribution to the UK's net zero commitment. BECCS could be delivered alongside energy vectors that can provide additional decarbonisation across the sectors, including delivering electricity, heat, hydrogen, biomethane and sustainable transport fuels.

In the biomass sphere, there is a growing international focus on alternative storage methods such as mineralisation and biochar, which could potentially deliver highly durable carbon storage outside of the CCUS clusters. As highlighted in the government response to the GGR Business Model consultation, further work is needed to understand the feasibility of deploying large-scale non-CCUS GGR approaches in the UK (see Section 6.7 on biochar).

Principle 4: A BECCS project must achieve long term and safe carbon storage to guarantee atmospheric carbon removal.

As with the government's criteria for a robust negative emission (Table 6.1), once captured by a project, carbon must be sequestered in a highly durable store. The assessment of permanence should consider durability and 'risk of reversal' (likelihood of captured carbon being re-emitted into the atmosphere) associated with a carbon store. Utilisation of carbon in short-lived products, such as fuels and plastics, does not constitute a negative emission.

6.6 Supporting BECCS

There is active work ongoing in government to support BECCS.

In 2023 we will set out a vision for the UK CCUS sector, setting out how CCUS will support our net zero ambitions to raise confidence and improve visibility for investors.

Initially, BECCS deployment will be dependent on there being access to carbon transport and storage infrastructure. Powering Up Britain includes a commitment to deploy CCUS in two industrial clusters by the mid-2020s (Track-1), and a further two clusters by 2030 (Track-2). The Net Zero Strategy confirmed government's ambition to capture and store 20-30 $MtCO_2$/yr by 2030, with at least 10Mt of this capacity to be delivered by 'Track-2' clusters.

Government maintains the ambition to deploy 5Mtpa of engineered GGR by 2030. In March 2022 the government confirmed the Track-1 project negotiation list, which included some projects with the potential to deliver negative emissions (see industrial carbon capture (ICC) Business Model).

Delivering BECCS is likely to require government support initially. A number of business models are being developed to support BECCS or facilitate the generation of negative emissions. There will be similarities across other business models and the government will ensure alignment where possible. The following section provides a summary of the main business models being developed to support or deliver negative emissions.

Power BECCS Business Model

As set out in the Biomass Policy Statement, published in November 2021, the government has commenced work to develop a business model for FOAK Power BECCS. The model will incentivise the delivery of both low-carbon electricity generation and negative emissions. The business model is being designed to enable the deployment of power BECCS at scale, through addressing prevailing market failures, deployment barriers and risk to investment. A priority for the power BECCS business model is to provide projects with sufficient support to give investor confidence, whilst ensuring that these projects are affordable and represent value for money for consumers and/or taxpayers alike.

Government recently published a response to a consultation on potential power BECCS business models.[154] The response confirmed the Dual contract for difference (CfD) as the preferred model and set out several early design features. The model will include a payment mechanism of three parts, a difference payment for the low carbon electricity generated (referred to as a CfDe); a difference payment for carbon captured (referred to as a CfDc); and, to support the use of a transport and storage (T&S) network, a T&S charges payment. The two difference payments are broadly based on the difference payment mechanism in the existing CfD scheme and all parts of the payment mechanism will be within one contract.

[154] https://www.gov.uk/government/consultations/business-model-for-power-bioenergy-with-carbon-capture-and-storage-power-beccs

The contract will include a requirement to comply with robust sustainability criteria. Work to determine how the business model will ensure compliance with the sustainability criteria is ongoing, and the Biomass Strategy will inform that work as it develops.

As confirmed in the consultation response, government is keen to gather evidence and develop the design of the business model through a series of regular engagement sessions with industry, NGOs and other interested parties.

GGR Business Model

In the Net Zero Strategy we committed to developing markets and incentives for investment in GGRs by consulting on our preferred business models to incentivise early investment in GGRs. Modelling by the government and CCC shows that a mix of GGR technologies will play an important role in meeting Carbon Budget 6 and net zero. A diverse portfolio of GGRs will be strategically important to reduce reliance on any single technology and create a resilient negative emissions market that can support net zero at the lowest cost to business, while maximising the benefits of this sector to the UK economy.

A consultation on the design of a GGR business model was published in July 2022. It outlined the government's intention to introduce a contract-based business model to incentivise investment in a portfolio of GGR projects by providing revenue support for negative emissions.

The government response to the consultation, published in June 2023,[155] confirms our intention to proceed with the development of a GGR business model based on a contract for difference structure, where the subsidy is determined by the difference between a 'strike price' reflecting the cost of producing negative emissions and a 'reference price' reflecting the market value.

Building on our initial analysis of the consultation responses, we will continue to develop the business model design with input from stakeholders, including through the GGR Business Model Expert Group, with a view to setting out our preferred positions on the detailed design features later this year.

The consultation invited views on the potential role of the GGR business model in supporting BECCS projects that are not eligible for the FOAK Power BECCS, ICC or Waste ICC business models. The evidence we received will inform future decisions on eligibility criteria for the GGR business model. More details will be announced in due course.

Industrial Carbon Capture (ICC) and Waste ICC Business Models

There is a role for BECCS in the industrial sector, including the cement and glass industries, where the use of sustainable biomass and biodegradable waste derived combined with CCS could deliver negative emissions alongside the decarbonisation of these industries.

[155] https://www.gov.uk/government/consultations/greenhouse-gas-removals-ggr-business-models

The 2021 GGR methods and their potential UK deployment study[156] assessed the maximum technical potential for industry BECCS deployment at 10Mt CO_2 year. Analysis carried out for the Net Zero Strategy and the Net Zero Growth Plan suggests, within that technical potential, the socially cost-effective potential deployment of industry BECCS could be between 2-4Mt CO_2 per annum by 2050 depending on T&S availability. This range includes relatively significant 'low regret options' in industrial clusters. For example, biogenic content used in the cement sector can generate BECCS and can deliver significant co-benefits by mitigating process emissions that can otherwise not be abated, alongside any fossil fuel emissions, via CCS.

The technological barrier to industrial BECCS deployment is not deemed to be larger than power or hydrogen, however a number of factors complicate the robust assessment of the costs and the cost-effectiveness of these technologies. For one, BECCS can be applied to a range of industrial sectors and combustion technologies, from autogeneration to cement kilns, leading to a wide range of parameters on fuel gas compositions and other characteristics. Secondly, the amount of CO_2 that can be removed from one site can vary significantly, leading to radically different economies of scale. Thirdly, many sites currently using biogenic fuels are dispersed sites and not located in industrial clusters, which means future access to CO_2 T&S networks introduces further uncertainty on costs. Reflecting this variation, latest estimates suggest a wide range for capture cost of between £50-270/t by 2030 and £40-300/t by 2050 for industrial BECCS applications.

The residual waste management sector disposes of mixed wastes, which currently have a range of fossil:biogenic content split (usually around 50%:50%). Residual waste is expected to continue to need to be processed through to 2050 and, at present, CCS is the only net zero compliant technology for the residual waste management sector. This will help deliver potential engineered removals requirements set out in the Net Zero Strategy through the capture of biogenic emissions.

It is anticipated that some BECCS could be delivered through support provided via the Industrial Carbon Capture ICC) and Waste ICC business models, which aim to support deployment of CCUS in UK industrial and residual waste management sectors. The ICC and Waste ICC business models will cover the capital and operational costs of deploying CCUS, including Transport and Storage (T&S) fees. Initial projects will be eligible to receive a grant for up to 50% of the capital costs through the CCUS Infrastructure Fund. The ICC and Waste ICC business models will support the costs and fees associated with the capturing of both fossil and biogenic emissions. The sale of negative emissions will initially be restricted, but subject to a review, this may be lifted in future. The subsidy payments will then be adjusted proportional to the value of the negative emissions credits.

In Track-1 of the Cluster Sequencing Programme, three ICC and two EfW facilities were selected to proceed to negotiations. In the short term, these two EfW facilities could be some of the first projects in the UK to deliver BECCS.

[156] https://www.gov.uk/government/publications/greenhouse-gas-removal-methods-technology-assessment-report

Biomethane BECCS

Biomethane is a renewable gas produced most commonly via anaerobic digestion (AD), a process whereby organic materials are broken down by microbes in the absence of oxygen to produce biogas, which is in turn upgraded by removing CO_2 and other gases prior to grid injection. This upgrading process generates a high purity stream of CO_2 as a by-product, in comparison to other CO_2 sources, that can be efficiently captured, resulting in additional carbon savings.

Anaerobic digestion is a mature industry (Table 6.1), with carbon capture technologies already in use across the sector. At present, it remains a commercial decision for producers to use CCUS technologies, however CO_2 capture represents a significant opportunity for the AD industry.

The shortage of CO_2 from UK fertiliser production has offered opportunities for AD plants to sell their CO_2 to the general usage market, including the food and drinks industry. Other markets for CO_2 usage may develop in time such as low carbon cement and refrigerated transportation. CO_2 used in food production must meet a specific standard, which the majority of CO_2 from the AD process in the UK meets.

As more AD plants invest in capture equipment to profit from the utilisation market, by either designing new plants with CO_2 capture or retrofitting, the usage market will eventually become saturated. Therefore, AD plants will need to consider longer-term opportunities to provide a form of BECCS.

We will consult on introducing a policy framework for biomethane to follow the closure of the Green Gas Support Scheme (GGSS) and as set out in the GGSS Mid-Scheme Review, we are taking a holistic approach to identify the barriers to the growth of the biomethane market and understanding how best to address these. This includes understanding the economic and carbon abatement opportunities from CO_2 from biomethane production in both the usage and storage markets, and how we can seek to maximise these opportunities, and identifying and considering how to address potential barriers to AD Biomethane BECCS deployment, including transport and storage of CO_2.

In addition to the potential for AD biomethane BECCS described above, any future gasification plants producing biomethane could also capture carbon for storage, though these technologies are not yet deployed commercially at scale (Table 6.1). The UK TIMES modelling of High Resource and High Innovation scenarios suggests that deployment biomethane BECCS (via gasification) could be cost-optimal in 2050.

Hydrogen BECCS

Hydrogen BECCS is expected to play an important role in supporting the UK's decarbonisation objectives. The government is supporting new low carbon hydrogen projects through the development of a Hydrogen Production Business Model, to provide ongoing revenue support, and the Net Zero Hydrogen Fund (NZHF), to support development and construction costs of new low carbon hydrogen production facilities. These will help to stimulate private investment in new low carbon hydrogen projects and to achieve our ambition of up to 10 GW of low carbon hydrogen capacity by 2030, subject to affordability and value for money. Both the Hydrogen Production Business Model and NZHF are designed to be applicable to a broad range of hydrogen production technologies and operating patterns.

Whilst the Hydrogen Production Business Model does not explicitly value negative emissions, it will support both the capture plant and hydrogen production plants for CCUS-enabled hydrogen producers. Therefore, it is possible that the model may provide sufficient policy support to deliver negative emissions through hydrogen BECCS, without the need for additional support. In 2022 the GGR business models consultation sought views on the most appropriate route to incentivising this technology, which will inform future decisions on the relationship between the Hydrogen and GGR business models with respect to hydrogen BECCS.

The Low Carbon Hydrogen Standard[157] sets a maximum threshold for GHG emissions allowed in the production process for hydrogen to be considered 'low carbon' and therefore potentially eligible for the Hydrogen Production Business Model and the NZHF. Hydrogen producers are permitted to account for negative emissions directly related to CCS in their process when calculating the carbon intensity of hydrogen production. However, the Low Carbon Hydrogen Standard does not provide an incentive in and of itself to deliver additional negative emissions beyond the threshold being met.

Low carbon fuels BECCS

Although production of low carbon fuels with BECCS is yet to be deployed in the UK, there are five operational BECCS projects in North America that have combined bioethanol production with CCS. The largest, operational since 2017, captures up to 1 Mt CO_2/yr from corn-based bioethanol and stores the CO_2 in a dedicated geological storage site deep underneath the facility.[158] It is likely that the future deployment of this route of BECCS will be minor, due to the capped nature of crop-based routes for renewable fuel supply, although advanced fermentation processes may develop.

As with hydrogen BECCS, there are more advanced and developing technologies, such as gasification with Fischer-Tropsch, that will be vital for delivering low carbon fuels, that could also provide a stream of CO_2 for capture and sequestration.

[157] https://www.gov.uk/government/publications/uk-low-carbon-hydrogen-standard-emissions-reporting-and-sustainability-criteria

[158] https://www.globalccsinstitute.com/wp-content/uploads/2019/03/BECCS-Perspective_FINAL_18-March.pdf

This will be deployed at a larger scale, but on a longer timeframe than other BECCS routes.

Encouraging the integration of BECCS in the SAF production process will maximise GHG savings from SAF. The upcoming SAF mandate, due to start in 2025, is viewed as a key mechanism to increase the adoption of SAF BECCS. It has been confirmed that the mandate will reward the supply of SAF proportionate to the life cycle GHG savings, thereby incentivising technologies that can maximise decarbonisation.

The recent SAF consultation sought views on how negative emissions should be treated under the mandate and how this can complement existing and future DESNZ policy. When finalising the policy design, we will ensure that it is appropriately aligned with wider government policy on negative emissions markets and incentives to avoid perverse impacts; for example, by creating market distortions or a competitive advantage for SAF projects over other negative emissions production technologies.

6.7 Biochar

Biochar is a carbon-rich solid material obtained from the thermochemical conversion of biomass, that has removed CO_2 from the atmosphere during plant growth, via pyrolysis or gasification. It can be produced from a range of biomass, though biochar properties are highly affected by the biomass feedstock and production conditions.

There is growing interest in the application of biochar to suitable land to deliver a range of environmental co-benefits – including reduced GHG emissions, improved soil functions, and carbon sequestration. In addition to agricultural and land use benefits, biochar may offer a GGR route by providing stable carbon storage over long timescales – potentially hundreds or thousands of years under the right conditions.[159] If realised, these dual benefits of environmental improvement and carbon storage would mean that biochar could play a valuable role in achieving the UK's climate objectives and providing ecosystem services whilst leaving our natural environment in a better state than we found it. We have committed to continue exploring the potential to deploy biochar for carbon sequestration through application to land in the Carbon Budget Delivery Plan.

However, these benefits are still not assured and further research is required before biochar could be deployed at scale. For example, there remain uncertainties on the precise timescales of carbon storage as well as the potential risks associated with applying biochar to soils

[159] Estimates of the carbon sequestration potential of biochar in the UK is limited. According to a 2021 study conducted by Element Energy and the UK Centre for Ecology and Hydrology, commissioned by Department of Energy Security and Net Zero, biochar could deliver 3.8 $MtCO_2$/yr engineered removals by 2050 under the Balanced-Central scenario. However, these estimates assume the use of dedicated biomass crops and do not account for variable durability of biochar in soils, which may vary as a function of biomass feedstock, pyrolysis, and the properties of the soil in which it is stored.

in the UK. To date, much of the evidence on biochar stability is based on laboratory data and localised short term studies in tropical regions. Additional complexity arises from the fact that biochar's physical properties, carbon sequestration potential, and co-benefits when applied to the soil are highly affected by variables such as biomass feedstock type, pyrolysis conditions, application rate, soil conditions, climate, and agricultural or management practices. As a result, biochar represents a challenge to regulators, because different varieties of biochar can have so many different properties, and these can in turn influence its effects.

There are existing regulations which landowners who want to apply biochar produced from waste feedstocks to land must adhere to, as well as guidance and a permitting system for using this biochar for land spreading that they can consult. The Environment Agency has published advice covering the small scale and low risk production of biochar and is continuing to explore appropriate regulation for biochar.[160]

Land use implications will be important when considering most suitable biomass feedstocks for biochar production. Demand for dedicated biomass crops for biochar will need to be balanced with other priorities such as food security and delivering environmental targets.

The government is taking active steps to address critical evidence gaps through its GGR research and innovation programmes. As part of a £30 million project, UK Research and Innovation (UKRI) is funding a biochar demonstrator that will investigate the stability of biochar with respect to carbon sequestration as well as impacts on environmental health and soil ecosystems (e.g., Box 6.4).

The project includes field trials of biochar application across different farming and land management scenarios in England and Wales, allowing the effects of 'real-world' management practices on the behaviour of biochar to be evaluated to provide a sound basis for future policy development. Additionally, the Environment Agency is currently undertaking its own research to collate evidence on the wider environmental impacts of biochar, as well as undertaking long term biochar trials to assess their impact on soil health as well as agricultural quality and quantity. Phase 2 of the DAC and GGR Innovation Competition was announced in July 2022, which included £18 million of government funding awarded across five promising biochar demonstration projects.[161]

Along with the government's regular engagement with academics and research institutes, the findings of these research programmes will help to inform the development of policy and regulatory frameworks to enable the safe and sustainable utilisation of biochar for climate mitigation and other environmental services.

[160] Storing and treating waste to make biochar: LRWP 60 – GOV.UK (https://www.gov.uk/government/publications/low-risk-waste-positions-miscellaneous/storing-and-treating-waste-to-make-biochar-lrwp-60), Storing and spreading biochar to benefit land: LRWP 61 – GOV.UK (https://www.gov.uk/government/publications/low-risk-waste-positions-landspreading/storing-and-spreading-biochar-to-benefit-land-lrwp-61), SR2010 No 4 mobile plant for land spreading (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/790263/SR2010_No_4_mobile_plant_for_landspreading.pdf)

[161] https://www.gov.uk/government/publications/direct-air-capture-and-other-greenhouse-gas-removal-technologies-competition

Box 6.4 Case Study: Severn Wye Energy Agency – Mersey Biochar

The Mersey Biochar project is part of the GGR Innovation Programme. It is led by Severn Wye and Pure Leapfrog, two charities with a drive to deliver community scale zero carbon energy solutions. The project combines innovative and existing technologies to create a carbon negative, community scale, flexible power and heat process. The vision is for small scale biochar processing facilities to be connected onto communal and district heat networks, decarbonising heat and providing flexible dispatchable power into the grid from the projects innovative energy storage system. The process not only removes carbon from atmosphere, but critically it tackles the two of the biggest challenges in the energy transition, the decarbonisation of heat and the provision of zero carbon peak demand energy. This is achieved by using biochar pyrolysis technology designed by Pyrocore, to turn underutilised biomass feedstocks from local and sustainable sources into biochar, capturing carbon in a stable structure which is then sequestered for generations. The pilot site location will be in Warrington.

7

Biomass uses across the economy

Our Key Messages

Electricity

- The use of biomass in the UK's power sector has helped to reduce the use of fossil fuels.
- Biomass electricity and Power Bioenergy with Carbon Capture and Storage (Power BECCS) could play an important role in providing either dispatchable or baseload power, complementing the variability of other renewables.
- The priority for biomass in the electricity sector is BECCS. Government recently consulted on all new and refurbishing biomass plants needing to be carbon capture ready.

Biomethane and greening the gas grid

- Biomethane can directly displace fossil methane across a range of end uses, and the government recognises that it will continue to play an important role in optimising the path to net zero and increasing energy security.
- Government is considering options for a future policy framework for biomethane following closure of the Green Gas Support Scheme (GGSS) and will consider the strategic and value-for money case of including other technologies and business models within scope.

Heating

- Biomass has a role in decarbonising the heating of certain properties such as off-gas grid homes that are not readily suitable for heat pumps, and where appropriate mitigations can be set in place to minimise air quality impacts.

Combined heat and power

- The Combined Heat and Power Quality Assurance Programme (CHPQA) will be setting out a Net Zero aligned policy trajectory for to help incentivise current combined heat and power (CHP) sites to decarbonise whether that be transitioning to electrification or low carbon CHP option.

Transport

- Biofuels are liquid and gaseous fuels produced from biomass that play an important role in the decarbonisation of the transport sector, replacing the use of fossil fuels.
- While we see the use of biofuels today in light road vehicles, their role in transport will increasingly shifting to transport modes with limited alternatives to the use of liquid and gaseous fuels, such as aviation and maritime.[162]

[162] Maritime is another transport mode that will be difficult to decarbonise in the period to 2050. More work is still needed to understand the demand for the different low carbon fuels needed to decarbonise the sector.

Industry

- Government aims is to facilitate industry's switch from fossil fuels to low carbon renewable alternatives such as biomass. The challenge is to support this change by creating a robust strategy that enables industry to meet its objective of replacing 50TWh of fossil fuels with renewable energy sources by the year 2035.
- Our focus is on effectively utilising biomass to achieve this target using greenhouse gas removal (GGR) technologies, such as BECCS. In the absence of viable BECCS infrastructure, we will continue to support biomass use in industry where limited low carbon alternatives are available.

Hydrogen

- In the British Energy Security Strategy (2022) we doubled the UK ambition to 10GW of low carbon hydrogen production capacity by 2030, subject to affordability and value for money. The hydrogen economy is still a nascent sector, and the UK is committed to supporting multiple production routes, including those that use biomass feedstocks, provided they meet the Low Carbon Hydrogen Standard and relevant funding criteria.

Non-energy uses

- Biomass is a flexible resource with potential to contribute towards decarbonisation activities not just as an energy source but also as material to displace fossil fuel use.
- There is an increasing focus globally on the concept of the bioeconomy, which can be defined as including all sectors of the economy that use biomass to make materials and products.

The following Chapter outlines details on sector-specific policy plans and action to support biomass use in the short, medium and longer-terms. It is split to cover the main policy areas in government, and includes electricity, biomethane and greening the gas grid, biomass with combined heat and power, transport, industry and low carbon hydrogen production. Each section identifies the role of biomass within the sector and upcoming policies, plans and milestones.

Government is clear that wherever practicable, biomass use should be carried out away from dense populations and at a scale where mitigation techniques can be applied economically, to minimise impacts to public health from air pollution (Chapter 3).

Biomass use across the economy: Public views

Biomass use across the economy was explored in the Biomass Public Dialogue Project.[163] Participants evaluated the various uses of biomass through a prioritisation exercise before explaining their underlying

[163] https://www.gov.uk/government/publications/biomass-strategy

thinking. Participants tended to discuss biomass in the context of the current energy crises, and so focused on the potential impact on fuel costs and the capacity of biomass to meet the nation's energy needs.

The majority thought that using biomass for electricity generation should be prioritised over other uses because it has multiple applications, such as heating homes and powering electric cars. In discussion, electricity and heating were considered to always be in demand, rather than linking directly back to their potential contribution to achieving net zero.

There were some concerns over the cost of transitioning to biomass alternatives to heat, power and transport fuels (biofuels), though for the latter it was expected that biofuels could be cheaper in future.

Participants tended to connect biofuels more directly to net zero. Participants were in favour of using biomass for the modes of transport they perceived as the highest emitting, such as aviation and diesel-fuelled vehicles. Participants were also in favour of using biomass to replace other sources of electricity generation that were perceived as less sustainable, such as gas.

7.1 Biomass for renewable electricity generation

Summary

The use of biomass in energy generation in the UK's power sector has helped to reduce the use of fossil fuels dramatically. Biomass electricity generation (and power BECCS) can operate at a baseload or dispatchable level, which can help make the electricity system reliable as well as net zero consistent. Post combustion carbon capture and storage (CCS) is technologically ready to deploy, and therefore government recently consulted on all new and refurbishing biomass plants needing to be carbon capture ready.

Government is reviewing the role of biomass electricity in the power sector (unabated and with BECCS) in the Review of Electricity Market Arrangements (REMA) and will consult later this year.

Key benefits and opportunities

The use of biomass in energy generation in the UK's power sector has helped to reduce the use of fossil fuels dramatically. In 2022, renewable electricity represented 41.5% of total generation (135 TWh), and biomass provided 11%[164] of this, making it the second largest renewable electricity provider that year.[165]

Biomass electricity generation (and power biomass with carbon capture and storage: power BECCS) can operate at a baseload or dispatchable level, which can help make the electricity system reliable as well as net zero consistent. Biomass and BECCS therefore can contribute to our energy system by ensuring a resilient and reliable

[164] https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes Table 6.2.
[165] Second to wind which is combined onshore and offshore wind.

supply, a priority outlined in the Powering Up Britain – Energy Security Plan.[166]

Most biomass-based electricity generation, and some biomass with CHP has been incentivised in the UK since 2002 under the Renewables Obligations (RO), and since 2010 in Great Britain at small scale under the Feed in Tariff (FIT), which in total have accredited 6.6 GW of installed capacity. These schemes are now closed.

The Contracts for Difference (CfD) scheme is now the government's main mechanism for supporting new low carbon electricity generation in Great Britain – which supports 1.4GW of biomass generation.[167] This provides income stabilisation, generally for 15 years, making projects with high up-front costs but long lifetimes attractive to investors and lenders. It also protects consumers when electricity prices are high.

The role of biomass for net zero in supporting the decarbonisation of electricity generation

In 'The Role of Biomass in Achieving Net Zero Call for Evidence' (2021) a number of respondents indicated that biomass could be valuable in supporting the decarbonisation of electricity, and the opportunity for biomass in delivering negative emissions alongside electricity was important. For unabated power, there was a general view that biomass should be moved to where more valuable contributions to decarbonisation could be made. These views are supported in the main by the priority use principles and analysis underpinning this Biomass Strategy.

We have no plans to remove support for biomass generating stations that are already supported under a current government scheme. The existing support schemes have enabled the investment and construction of plants, the establishment of biomass supply chains, and local distribution grid investment that have been instrumental in reducing greenhouse gas (GHG) emissions from the power sector so far.

Moving forward, it is anticipated that support for new plants will be directed towards those priority use areas that may best enable biomass to be used to decarbonise hard to abate sectors and provide the services and products that will be vital for meeting net zero.

Ensuring a resilient and reliable electricity supply

The REMA programme is a major review into Britain's electricity market design. REMA considers options for reform to all electricity (non-retail) markets and policies that can provide signals for the investment and operation of assets that generate, store, and use electricity. This includes biomass and BECCS to the extent that it currently does, or potentially could, participate in electricity markets.

One of REMA's core objectives is to increase the renewables deployment rate to meet our commitment to decarbonise our electricity grid by 2035. The REMA consultation[168] in

[166] https://www.gov.uk/government/publications/powering-up-britain
[167] Includes 299MW plant MGT Teesside which is commissioning.
[168] https://www.gov.uk/government/consultations/review-of-electricity-market-arrangements

Summer 2022 identified that biomass and BECCS could play an important role in providing either dispatchable or baseload power, complementing the variability of other renewables. REMA will build on the successes of the CfD scheme and will consider the role of biomass and BECCS within this to ensure our market arrangements are fit for the future, and that they deliver for current and future consumers, and maintain security of supply.

Power bioenergy with carbon capture and storage

Although there are various routes for deploying BECCS across different industries, deploying BECCS in the power sector meets the priority framework in that there are opportunities to deploy BECCS on existing plants which have already established biomass supply chains. Also, the carbon capture technology, with the ability to capture around 90% of the CO_2 emitted during combustion, is available and already being deployed at some scale on non-biomass plants[169] (Chapter 6).

Biomass electricity and CHP without carbon capture is recognised as an important contributor to the electricity system, but we do not anticipate government support for deployment of any new, large scale biomass plants without CCS.

Policy plans, proposals, milestones

The transition to a fully decarbonised power system by 2035, subject to security of supply, poses challenges to the continued smooth running of the electricity system. It will be critical that we have a range of firm and flexible assets (including biomass and BECCS) which can generate electricity when variable renewable output is low, for example during periods of low wind.

Balancing services that are used to ensure grid operability, such as reserve and system restoration are currently highly dependent on fossil fuel generation. Biomass already supplies ancillary services, including frequency response and system restoration services. REMA is considering options for raising the participation of low carbon providers in balancing services, including through possible reforms to the Electricity System Operator's (ESO) procurement processes and modifications to the CfD and the Capacity Market to provide an incentive for low carbon generators to provide these services. **Government intends to publish a second REMA consultation in Autumn 2023.**

We will continue to allow new eligible[170] biomass projects to participate in the CfD scheme. The government keeps CfD eligibility under review, and any proposals to change the technology scope of the scheme for future CfD awards would be consulted on, with any reforms to the CfD being wholly considered within the context of the proposed REMA reforms.

[169] Wang et al. A Review of Post-combustion CO_2 Capture Technologies from Coal-fired Power Plants. Energy Procedia 114 (2017) 650-665.

[170] Eligible new projects include those that can meet the 2018 CfD sustainability criteria, and include technologies such as advanced conversion technologies, biomass with CHP, sewage gas, landfill gas and anaerobic digestion (above 5MW).

Power generation with Carbon Capture and Storage

BECCS has been identified as a priority use of biomass, and plants should consider the various business models being developed by government at present directly or indirectly supporting biomass with carbon capture, as well as other practical considerations for deploying BECCS from a particular location and scale. For this reason, the Decarbonisation Readiness Consultation,[171] proposed all new and substantially refurbishing biomass generation plants will need to meet the Carbon Capture Readiness requirements[172] on their plant to provide a feasible future route to BECCS. The government response to this consultation will be published this year.

While there were no power BECCS projects on the Track 1 project negotiation list announced in March 2023, the government indicated that Track 1 was not the extent of our ambition and announced future development of carbon capture, usage and storage (CCUS) through Track 2 and expansion of the Track 1 clusters. Government is committed to facilitating the transition to power BECCS and has committed to develop a power BECCS business model, subject to affordability and value-for-money. Government is currently considering the energy security landscape and the future ability to deploy power BECCS given the CCUS timelines and is in discussions on power BECCS deployment with Track 1 applicants.

Unabated generation: Repowering or repurposing?

Several respondents to the 2021 Biomass Strategy Call for Evidence highlighted that consideration needed to be given to the future of current electricity plants that are not possible to retrofit to BECCS after they reach the end of their subsidies.

It is recognised that many biomass plants provide an environmental service as well as provide low carbon electricity and CHP generation. Examples include landfill gas, poultry litter, waste wood and straw that would have to otherwise find alternative disposal routes. It is expected that the support schemes should have delivered the necessary investment to deliver the plant and necessary infrastructure, however it is a priority that these feedstocks are used now and in the future.

This government acknowledges that the full repowering of renewable electricity generation sites could play an important role in our future electricity system and meeting HMG's net zero and energy security objectives. HMG published its consultation response to the future considerations for the CfD in July,[173] within which we note there is merit in further exploring the most appropriate revenue support mechanism for repowering of existing renewable sites. This includes the role the CfD specifically could deliver from CfD allocation round 7 onwards, however further work is required before specific decisions can be made.

[171] https://www.gov.uk/government/consultations/decarbonisation-readiness-updates-to-the-2009-carbon-capture-readiness-requirements

[172] https://www.gov.uk/government/publications/carbon-capture-readiness-ccr-a-guide-on-consent-applications

[173] https://www.gov.uk/government/consultations/considerations-for-future-contracts-for-difference-cfd-rounds

This does not apply to unabated coal-to-biomass conversions, as government is working towards a power BECCS business model that will look to support these types of technologies in the future.

Whilst we are committed to considering the case for repowering within the CfD, it may be beneficial to divert biomass to priority uses. In some instances, it could be possible to repurpose existing sites to provide more strategic outcomes. For example, Anaerobic Digestion (AD) technologies could be diverted to grid injection, as is currently supported by the GGSS (AD biomethane production was supported under the Non-Domestic Renewable Heat Incentive (NDRHI)), however eligibility is restricted to new biomethane plants. In the recent Green Gas Support Scheme Mid-Scheme Review consultation,[174] government set out proposals to maintain the eligibility criteria of the GGSS to exclude CHP plant conversions to biomethane injection, due to value for money and operational considerations. Responses to that consultation are currently being analysed.

The Energy Security plan committed to consulting on a policy framework for biomethane following the GGSS. As part of considering options for future biomethane policy, government will consider the strategic and value-for-money case of including other technologies and business models within the framework's scope, including conversion of existing infrastructure (e.g., biogas CHPs) to biomethane production.

There may be alternative options to repurpose or to otherwise support plants, for example, government is undertaking research to consider the options for landfill sites, including the co-location of linked electricity generation or other low carbon businesses.

[174] https://www.gov.uk/government/consultations/green-gas-support-scheme-mid-scheme-review

7.2 Biomethane production and greening the gas grid

Biomethane is a renewable gas produced most commonly via anaerobic digestion (AD), a process whereby organic materials are broken down by microbes in the absence of oxygen to produce biogas, which is in turn upgraded by removing CO_2 and other gases. This biomethane can be injected into our existing gas grid to directly displace fossil methane across a range of end uses. Biomethane also contributes to increasing energy security, by virtue of being produced domestically, sustainably, and delivering steady production volumes, provided feedstock supply is stable; plants can also be deployed relatively quickly, compared to other energy infrastructure.

Though AD plants are presently the chief source of biomethane, it could also be produced through the gasification of biomass, or the upgrading of landfill gas produced when organic waste decomposes in landfill sites. Whilst biomethane will be the predominant focus here, raw biogas from AD can also play a role in decarbonising off-grid heating and power through direct use of biogas in CHP engines.

Government recognises that biomethane injection into the gas grid is a cost-effective way of contributing to near term legally binding carbon budgets and decarbonising our gas supplies. Biomethane production via AD and injection into the gas grid is currently supported by two schemes in Great Britain: the Non-Domestic Renewable Heat Incentive (NDRHI, which closed to new applicants on 31st March 2021, subject to certain exceptions), and the GGSS, which launched on 30th November 2021. Both schemes will support biomethane injection into the early 2040s. In the Powering Up Britain: Energy Security Plan, the government recognised the role that increasing domestic biomethane production can play to reduce carbon emissions, decrease reliance on fossil methane, and provide diversity in gas supply. Biomethane is also eligible for support under the Renewable Transport Fuel Obligation (RTFO), reflecting its potential to support the decarbonisation of heavy transport. Biomethane also has an important role to play in improving the circularity of our food systems, as resulting digestate could reduce the need for fossil fuel-based fertilisers, and increased treatment of slurries in AD could reduce the carbon emissions associated with agriculture.

The analysis underpinning the priority use assessment in Chapter 5 illustrates the important role that biomethane production and usage can play in optimally reaching net zero by 2050. The prioritisation and sustainable deployment of biomass will be critical to enable this role. Feedstocks suitable for the AD process represent only a subset of the whole of biomass considered through this Strategy, and this Strategy analysis indicates which elements of the whole could be prioritised for biomethane production in 2035 and 2050. Across the three modelled 2050 pathways and the Carbon Budget Delivery Plan scenario for 2035, feedstocks such as food waste, slurries and manures, sewage sludge, and the upgrade of landfill gas, are prioritised for biomethane production via AD. As biomethane can be used flexibly across many different end-uses, it has the potential to help decarbonise multiple distinct sectors. This flexibility is valuable as it enables us to adapt to the hard to predict cost curves and deployment trajectories of existing and emerging technologies in each sector, without having to make expensive decisions on which solutions to focus on too soon.

This section sets out how sustainable biomethane production and usage is consistent with principles underpinning the priority use of biomass across the economy, and how it can make an important contribution to the delivery of net zero and increasing energy security.

Key benefits and opportunities

Key benefits and emissions savings from biomethane production and usage can be split into upstream and downstream elements. Upstream refers to benefits associated with waste management and the feedstocks used, whereas downstream incorporates displacement of fossil fuels with biomethane, and benefits from CCUS and use of digestate.

Beginning with the downstream component, biomethane has a range of end-uses, which contribute to decarbonising various sectors of the economy. This includes decarbonising heat, transport and power, and it can also be used as a feedstock for a variety of industrial processes, as well as hydrogen production, through steam methane reformation (SMR). Its flexibility as a fuel provides valuable optionality across end uses, which could be adapted based on a context that will inevitably change and evolve between now and 2050.

Increasing the proportion of biomethane in the grid is a practical, established, and cost-effective way of reducing carbon emissions associated with gas usage for heating. The Climate Change Committee has been recommending increasing the proportion of green gas in the grid since 2016, which government has supported through the NDRHI, and now the GGSS.

Biomethane can also be used as a renewable fuel to decarbonise transport (either compressed into bio-CNG or liquefied into bio-LNG). Its use is particularly attractive for heavy goods vehicles (HGVs) and agricultural machinery, and other harder to decarbonise fleets, which may be more challenging to electrify. Biomethane (or raw biogas) from AD can also be used as part of a CHP system to power and heat industrial processes or a small off-grid area, as well as generate renewable electricity to export to the national grid. Alongside production of digestate and its use as a natural fertiliser, this can contribute to decarbonising the agricultural sector.

Capturing the biogenic CO_2 removed from biogas as part of the upgrading process to biomethane can result in even greater carbon savings. This upgrading process generates a relatively pure stream of CO_2, in comparison to other sources, that can be efficiently captured, and the technology to do so is currently being deployed on AD biomethane plants. In the future, this CO_2 could either be geologically stored, with the potential to deliver negative emissions as a form of BECCS (Chapter 6) or treated for CO_2 usage markets across a variety of sectors including agri-food and construction. Given the dispersed location of AD plants across the country and the need to diversify and secure sources of food-grade CO_2 supply, much of the focus on AD CO_2 capture has been to potentially service the agri-food utilisation market. However, as shown in Chapters 5 and 6, we will need an increasing volume of negative emissions to remain on track for net zero up to 2050, in which biomass has a critical role to play. As part of work on a future biomethane policy framework to follow current support, government intends to identify, and consider how to address, potential barriers to AD Biomethane BECCS deployment, including transport and storage of the CO_2.

As well as biomethane and biogenic CO_2, the AD process produces digestate. This organic material is what remains of the biomass after the digestion process and can be used in place of fossil-derived fertiliser, due to its nutrient rich content. This further cements AD's position in local circular economies and diversifies fertiliser supply with a low carbon alternative. In this way, waste streams produced directly from agriculture, such as slurries and crop residues, food waste, sewage sludge, and sustainably grown energy crops, can be processed to deliver renewable energy before being returned to the soil as a high-quality fertiliser, beginning the cycle anew.

In addition to these downstream emission reductions, biomethane from AD delivers upstream emissions savings and wider environmental benefits through its role as a waste management technology. When left to decompose either in the open or in a landfill, organic matter such as food waste, municipal biowaste, sewage sludge, or agricultural waste (manures, slurries), release potent GHG emissions such as methane and nitrous oxide.

As recognised in the United Kingdom methane memorandum,[175] processing wastes via anaerobic digestion reduces these methane emissions, contributing towards the UK's commitments in line with the Global Methane Pledge. To ensure we have capacity to optimally treat these wastes and deliver the associated emissions savings, it is necessary for the AD biomethane sector to continue growing and developing.

Biomethane production also contributes towards the development of renewable energy supply chains. Our analysis suggests that over two thirds of existing biomethane plants are located in rural areas, with 80% of all GB plants located in areas with a lower-than-average Gross Value Added.[176] Supporting the development of this industry therefore benefits the wider economy by creating jobs, developing net zero skills in the workforce, and helping to diversify and grow the rural economy.

The role of biomass for biomethane production and its contribution to net zero

The continued growth of the biogas and biomethane sector and maximising the role it plays in the pathway to net zero, is dependent on a sustainable supply of biomass. Likewise, ensuring the optimal treatment of wastes, such as food waste, sewage sludge and slurries, depends on this continued growth in AD capacity (and consequent biogas or biomethane production).

[175] https://www.gov.uk/government/publications/united-kingdom-methane-memorandum
[176] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1018133/green-gas-impact-assessment.pdf

Waste and residue feedstocks are a crucial element of the feedstock mix for AD, as their use cements AD's place in the circular economy and leads to higher carbon savings overall. As part of the food and drink waste hierarchy, AD is the preferred destination for unavoidable food waste that cannot be redistributed, used as animal feed or processed into biomaterials. This delivers significant carbon savings over sending food waste to landfill and digestate that recycles nutrients to land and supports a more circular economy. AD contributes toward several objectives; exploring options for the near elimination of biodegradable waste to landfill from 2028 (England), meeting an ambition to work towards eliminating food waste to landfill by 2030 (England) and meeting the target to recycle 65% of municipal waste by 2035. Through using minimum waste thresholds of 50% of biomethane by energy content on support schemes such as the NDRHI and GGSS, we encourage the use of wastes and residues in biomethane production over bioenergy crops.

The use of perennial and non-perennial crops can also be incorporated in a sustainable feedstock mix for AD biomethane production, provided they are grown sustainably, for example as part of an integrated crop rotation regime and in accordance with good practice and high environmental standards and with minimal risk of indirect land use change emissions. When incorporated in this way, we recognise the useful role that crops can play for managing feedstock mix when waste supplies fluctuate. However, the use of these feedstocks should be balanced with other priority uses across the economy and managed appropriately to minimise any potential impacts on food security, biodiversity and other sustainable land management practices.

Biomethane production from AD is consistent with each of the principles that underpin the biomass priority use assessment (sustainability, air quality, net zero, circular economy), when produced and managed sustainably and in line with sustainability criteria and environmental protections. It contributes to net zero and near-term carbon and has the potential to deliver biogenic CO_2 for usage markets or sequestration through the deployment of proven carbon capture technology. The upstream and downstream emissions abatement means a biomethane plant supports maximising the value of residual biomass, in line with waste hierarchy principles. Government support for AD biomethane through the NDRHI and GGSS is already contingent on compliance with stringent sustainability criteria, and we will explore opportunities to further build on this for any future policy framework through the sustainability work described in Chapter 2.

The analysis underpinning Chapter 5's priority use assessment confirms the important role that biomethane production and usage can play in optimally reaching net zero by 2050. Across the three illustrative scenarios reaching net zero by 2050, and the CB6 projection to 2035, feedstocks such as food waste, slurries and manures, sewage sludge, and the upgrade of landfill gas, are prioritised for biomethane production via AD.

When biomethane is injected into the grid, it can play a role in decarbonising all end-users of the gas grid, such as heat for buildings, industry, and power generation. As we transition to net zero, we will continue to rely on the gas grid for energy and biomethane will play a role in decarbonising the grid and various end-uses, alongside other renewable technologies. As seen in the Carbon Budget Delivery Plan scenario for 2035 in Chapter 5, biomethane can help decarbonise users of the gas grid, including heating buildings. Beyond 2035 and towards 2050, the role of biomethane for heating buildings will be contingent on future decisions on the role of the gas grid and will likely decrease as other renewable heat technologies play a much larger role. The UK TIMES model (Chapter 5) suggests that by 2050, in certain pathways, biomethane could largely be used to deliver peaking power requirements with CCS technology as part of a cost-optimised pathway to net zero. In this way, biomethane in the gas grid could become in effect a flexible “green gas battery”, that could support both inter-seasonal and short term power requirements, complementing the variability of other renewables. However, it is important to note that these scenarios just set out what is possible, rather than represent the ‘most likely’ or ‘preferred’ solutions, and the UKTM does not model the optimal future role and scale of the gas grid.

In 2022, 6.2 TWh of biomethane was injected into the GB gas grid through AD.[177] Most of this injection was supported financially by the NDRHI or the RTFO. Continued support from these schemes and the current GGSS is expected to support a peak of around 8TWh of biomethane injection per annum by 2030.[178]

UK TIMES modelling suggests around 30-40 TWh of biomethane production across the illustrative scenarios in 2050 would help the UK achieve net zero cost-effectively. 30 TWh of AD and landfill gas production is consistently included across each pathway, with additional production coming from gasification BECCS in certain pathways. This significantly exceeds projected peak generation from current policy support for AD biomethane.

Biomethane can also play a role in decarbonising transport in the transition to net zero and prior to other technologies such as electrification becoming widely available. This is reflected in the fact that biomethane is currently helping to decarbonise transport through the RTFO.

In addition to increasing AD deployment to make best use of the biomass feedstocks referenced above, there is the potential to increase biomethane production from other sources, including slurry lagoon gas capture, landfill gas upgrading and advanced gasification of biomass. As the technology matures, gasification could facilitate increased biomethane production beyond the upper potential derived from waste AD-suitable feedstocks, in line with the priority use assessment and UK TIMES analysis in Chapter 5. Gasification plants could be designed to allow the production of biomethane, hydrogen or other biofuels, providing adaptability through the transition to net zero. We will consider the strategic and value-for-money case of including further technologies and business models within the scope of a future post-GGSS biomethane policy framework. Likewise, as existing AD CHP sites approach the end of their subsidies for producing combined power and heat under existing schemes such as the Renewables Obligation, Feed-in-Tariffs and the NDRHI, we will continue

[177] https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes

[178] Based on internal DESNZ modelling of projected NDRHI and GGSS AD deployment and biomethane injections.

to review evidence of the value for money case associated with converting AD biogas CHP sites to AD biomethane injection plants or expanding those plants with biomethane injection capacity.

Biomethane production from AD can be, and is being, deployed at scale now to deliver carbon savings without requiring end-user behaviour change or infrastructure investment. Where there is demand for gas across the economy, biomethane has a role to play in decarbonising this fuel supply. As mentioned above, the technology also has the potential in the future to deliver negative emissions as a form of BECCS.

Policy plans, proposals, milestones

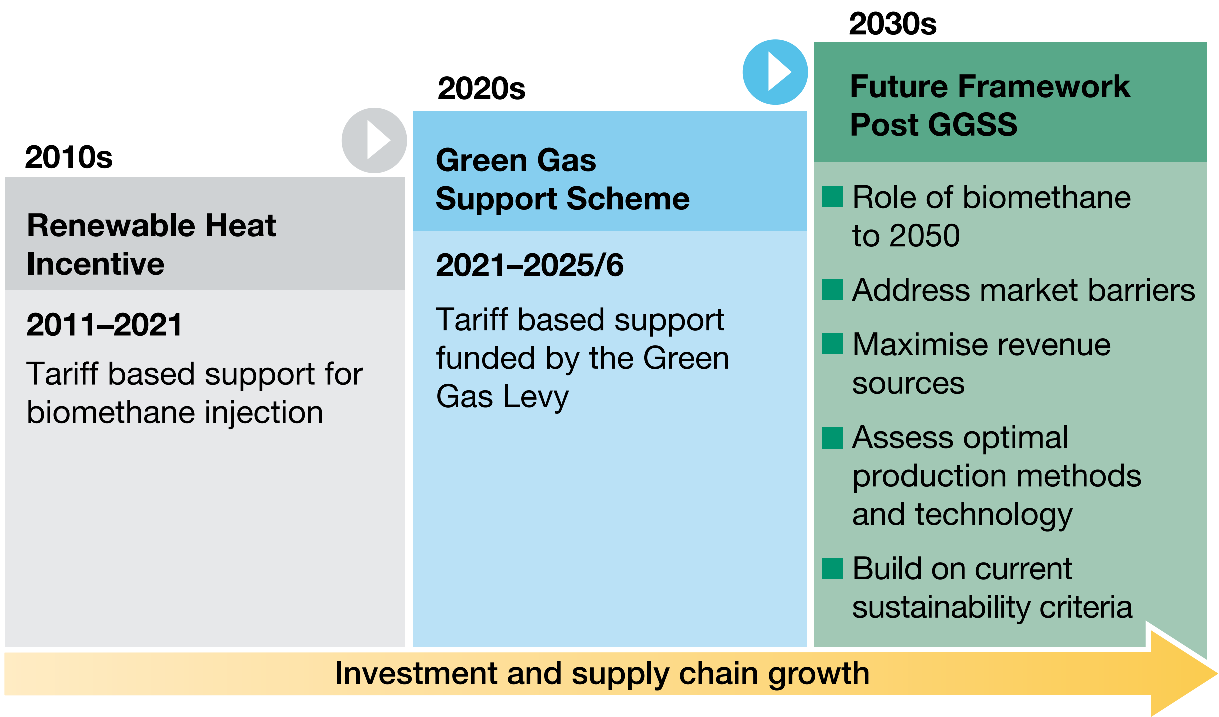


Figure 7.1: Policy plans, proposal and milestones to support biomethane production.

Current support – GGSS and NDRHI

The Non-Domestic RHI launched in 2011 and closed to new applications on 31 March 2021 (subject to certain exceptions).

The GGSS provides tariff-support for biomethane produced via AD and injected into the gas grid. Producers will receive tariff payments for a 15-year lifetime. The GGSS launched on 30 November 2021 and is currently open to applicants for four years. The GGSS only supports new AD plants and does not support conversions of existing plants to biomethane injection.

In March 2023, we published the GGSS mid-scheme review consultation[179] to consider the effectiveness of the scheme

[179] https://www.gov.uk/government/consultations/green-gas-support-scheme-mid-scheme-review

and review several areas for potential amendments, with the aim of implementing any amendments during the 2023-2024 financial year.

If it meets eligibility criteria, biomethane use as a fuel can be supported under the RTFO. Under GGSS regulations, quarterly production can be split between both the GGSS and the RTFO to enable different consignments of biomethane to receive payments from either the GGSS or the RTFO within the same quarter. Allowing interaction between the GGSS and RTFO provides a strengthened incentive for investment in biomethane and encourages maximum utilisation of plant capacity and provides greater flexibility for plants.

Future biomethane policy framework

Chapter 5 illustrates the additional volume of biomethane that could be required for an optimal pathway to net zero by 2050, above the level projected from current policy support. In line with commitments in the Net Zero Strategy, Heat and Buildings Strategy and Repowering Britain: Energy Security Plan, we are considering options for a consultation on a future policy framework for biomethane to follow the closure of the GGSS. As set out in the GGSS Mid-Scheme Review, we are taking a holistic approach to identify the barriers to the growth of the biomethane market and understand how best to address these. This includes, among others, the following areas: work to understand the right mix of soft levers and regulations required to support growth of the biomethane market, and assessing whether a market-based mechanism is required and what form this could take; how future policy could mitigate long term challenges affecting the availability of waste and non-waste feedstocks for AD; the potential for greater diversion of livestock wastes to AD as a possible enabler of a more circular economy for nutrients and agricultural decarbonisation; and barriers to maximising the value of revenue streams that form part of the biomethane business model, including CO_2 capture and digestate valorisation. This will consider how to unlock the benefits from the growth in AD capacity and biomethane production, as well as how to ensure any environmental impacts are appropriately managed.

Government will continue to work towards ensuring that the potential negative environmental impacts of AD deployment are mitigated, and practices which maximise the environmental benefits of AD and biomethane are incentivised. Government recognises that digestate contributes to ammonia emissions if handled improperly when stored or spread onto land. Therefore, government is bringing forward a range of actions to reduce ammonia emissions, as set out in the Clean Air Strategy. Industry standards such as the Environment Agency's (EA) Quality Protocols[180] and the British Standard Institution's Publicly Available Specification (BSI PAS 110: Specification for whole digestate, separated liquor and separated fibre derived from the anaerobic digestion of source-segregated biodegradable materials)[181] ensure that digestate is managed and used appropriately to mitigate these environmental impacts.

Government has set out plans to reform fertilisers regulations and consult on

[180] https://www.gov.uk/government/publications/quality-protocol-anaerobic-digestate
[181] https://wrap.org.uk/resources/guide/bsi-pas-110-producing-quality-anaerobic-digestate

measures to reduce ammonia from the storage and spreading of digestate. Similarly, as part of a broader review of waste quality protocols, the Environment Agency is currently reviewing the quality protocols for digestate. We will also continue to monitor best practices in ammonia mitigation from digestate and work with partners, including in industry, to consider future policy decisions. This will include work to further our understanding of the market for digestate and consider ways to stimulate demand and facilitate end uses so that it can become a substantial revenue stream for AD plants.

In order to avoid erosion of the benefits set out above, it is vital that methane leakage from AD biomethane plants is minimised. Government commissioned a study into fugitive methane emissions from the AD industry, which concluded in April 2023, and we have also sought to gather evidence on current and potential methane leakage prevention, monitoring, and mitigation practices through the GGSS Mid-Scheme Review consultation, which closed in May 2023. Government is keen to continue working with industry to minimise the risk of fugitive methane emissions reversing the assumed climate benefits of policy and so undermining the multitude of benefits deriving from biomethane AD production. Government is also committed to ensuring the planning and environmental processes continues to support efficient and sustainable biomethane deployment.

Research & Innovation

To support existing and future biomethane policy, we are commissioning research to create a methodology for conducting a life cycle assessment (LCA) of biomethane produced from AD in the UK. This work will result in an updated tool for calculating whole-life GHG emissions, including the impacts of end-of-life use of feedstock, embodied carbon in the infrastructure used to process the feedstock, fugitive emissions or indirect land use change due to feedstock expansion. The project will also provide an evidence review of AD LCAs and develop a methodology to assess different types of AD plants. This will inform analysis of the carbon saving benefits from AD biomethane, and how it may be supported in the future.

7.3 The use of biomass in heating

Summary

The use of biomass in heat generation has increased in recent years. Renewable heat generation across all technologies (e.g., bioenergy technologies, active solar heating, heat pumps, etc) has increased by 14.6% between 2019 and 2022 with most of the increase generated from use of biomass resources. In 2022, biomass for heat (including biodegradable waste) totalled 3.2 Mtoe representing 72% of the 4.4 Mtoe of heat from renewable sources, whilst heat pumps provided most of the remainder (27% or 1.2 Mtoe). Of the heat from biomass resources 2.8 Mtoe or 89%, was provided by wood, waste wood, and plant biomass, with the remainder provided by biogas and biodegradable waste.[182]

The Heat and Buildings Strategy[183] outlined the strategic approach government is taking to the decarbonisation of the heat and buildings sectors. The Scottish Government published its Heat in Buildings Strategy[184] on 7th October 2021, setting out a vision and actions for the decarbonisation of heat in homes and buildings in line with Scotland's statutory climate targets.

Electrification of heat is currently one of the few proved scalable options for decarbonising heat. The 'Ten Point Plan for a Green Industrial Revolution', the government announced an aim to install 600,000 heat pumps a year by 2028, up from approximately 70,000 per year currently. Heat pumps will have a role to play in all future heating scenarios, therefore this is a 'no-regrets' target as it will be necessary even if hydrogen were to become the primary fuel source for heating buildings.

Biomass has a role in decarbonising certain properties, such as off gas grid homes that are not readily suitable for heat pumps, and where appropriate mitigations can be set in place to minimise air quality impacts. Biomass is also used to generate biomethane for injection into the gas grid, or to use directly for heat (Section 7.2).

Biomass for use in domestic and non-domestic heating has until recently been supported through the Domestic Renewable Heat Incentive (DRHI) and NDRHI and more recently by the Boiler Upgrade Scheme.

The role of biomass for net zero in heating decarbonisation

Domestic Renewable Heat Incentive (DRHI) Scheme

The DRHI launched in April 2014 and closed to new applications in March 2022. It operated in England, Scotland, and Wales (there was a separate Northern Ireland Renewable Heat Incentive which is also closed to new applications). The DRHI supported ground and air source heat pumps, and solar thermal

[182] https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2022 Table 6.4.
[183] https://www.gov.uk/government/publications/heat-and-buildings-strategy
[184] https://www.gov.scot/publications/heat-buildings-strategy-achieving-net-zero-emissions-scotlands-buildings

panels, in addition to biomass boilers and pellet stoves. The scheme was targeted largely, but not exclusively at single domestic retrofit properties that are off gas grid. Although the scheme has closed to new applications, DRHI payments are made in arrears over 7 years, so final payments will be made, and the scheme will finally shut down, in 2029. DRHI payments for biomass installations are calculated by multiplying the biomass tariff by the heat demand for the property, taken either from the property's Energy Performance Certificate or the actual heat generated by the installation if metering for payment has been installed.

At the end of December 2022, 114,766 installations had been accredited to the DRHI, generating 7,865 GWh of heat, and installing 1,355 MW of renewable capacity. Of these installations, 12,477 were biomass boilers or pellet stoves, generating 3,242 GWh of renewable heat, and installing 323.5 MW of renewable capacity. The majority of these installations took place in 2014 (4,054 installations), and 2015 (4,816 installations). This reflected that 'legacy' installations (installations with a commissioning date on or after 15 July 2009 that were otherwise eligible for the DRHI) could apply to be accredited to the DRHI in the first year of scheme operation, and that the biomass tariff at scheme launch made biomass installations particularly attractive.

As part of the DRHI's budget control measures, the biomass tariff 'degressed' (reduced) several times throughout 2014 and 2015, and deployment levels after 2015 were much lower, averaging just over six hundred installations per year for the remaining 6 years that the DRHI was open for applications.

Non-domestic Renewable Heat Incentive (NDRHI) Scheme

In November 2011 the NDRHI scheme was launched offering financial support for the installation of eligible renewable heating systems. It was applicable in Great Britain (there was a separate NDRHI Scheme for Northern Ireland). It was open to renewable heat installations that provide heat to buildings and for purposes other than heating a single domestic property.

A range of technologies were eligible for support under the NDRHI, include biomass boilers; air source, water source and ground source heat pumps; solar thermal systems; deep-geothermal; biogas-combustion systems; combined heat and power CHP) systems using a range of renewable fuels and sources, and the production of biomethane for injection into the gas-grid.

As per the Clean Air Strategy, the government changed the regulations in 2021 to manage the trade-offs between energy and public health when developing strategies to meet air quality and carbon targets. These changes included mandating fuel quality standards and the introduction of annual maintenance checks (See Chapter 3 for more on air quality).

In March 2022 both the DRHI and NDRHI schemes introduced air quality standards, with the requirement that all wood pellets must meet the ENplus A1 standard or an equivalent standard, and that all other wood fuel must also meet fuel quality standards. However, the Russian illegal invasion of Ukraine in February 2022 led to the UK and European Union suspending imports of Russian and Belarussian pellets. This caused a shortage of biomass pellets and significant price increases across Europe. As a result, these air quality requirements for pellets were suspended for 12 months to allow alternative grades of pellet to be used in installations accredited to the NDRHI, and to reduce pellet prices. The government is keeping biomass pellet prices under review and has powers to extend the suspension, if necessary.

The Scheme was closed to new applicants on 31 March 2021, subject to certain exceptions.

Biomass saw a strong deployment under the NDRHI and continue to provide strong contributions towards the UK's decarbonisation targets. Support for biomass under the NDRHI aimed to foster a strong market and supply chain, by bridging the gap between the cost of biomass systems, their feedstocks and fossil fuel alternatives.

NDRHI installations are required to comply with strict sustainability criteria for the feedstocks used and this properly managed use of biomass can deliver the additional benefit of encouraging sustainable forestry practices.

Solid biomass is eligible for the NDRHI only where that heat is generated using boilers specifically designed and installed to burn biomass. The 2018 reforms to the NDRHI delivered improved value for money to the taxpayer by altering the tariff structure to focus support on larger installations and biomass for process and district heating.

At scheme closure, there have been 16,890 biomass installations accredited to the NDRHI, with a combined total capacity of 4,252MW. As per the Clean Air Strategy, the government changed the regulations in 2021 to manage the trade-offs between energy and public health when developing strategies to meet air quality and carbon targets. These changes included mandating fuel quality standards and the introduction of annual maintenance checks.

The NDRHI scheme is now closed and there are no policy changes planned. We however will continue to monitor with a view to ensuring that policies are compatible with net zero plans. This will ensure the sustainability of the fuel is compatible with UK laws and could help stabilise prices during periods of scarcity.

Boiler Upgrade Scheme

The Boiler Upgrade Scheme opened for applications on 23 May 2022 and aims to incentivise and increase the deployment of low carbon heating by providing targeted support to the supply chain. It is focused on building the heat pump supply chain but will offer grants of £5,000 to support the installation of biomass boilers up to 45 kW capacity in domestic and non-domestic buildings in rural areas off the gas grid. Biomass boiler owners should use fuel from a supplier listed on the Biomass Suppliers List.

Decarbonising Properties Off the Gas Grid

There are around 1.1 million homes in England not connected to the gas grid, which are using some of the most carbon intensive fuels still in use for heating purposes across the UK, including heating oil, liquefied petroleum gas, and coal. Transitioning these properties onto clean heat is a priority as it will keep us on track for net zero, build our energy independence, and help protect households from the impact of high and volatile energy costs.

We expect most of these properties will ultimately transition to a heat pump. Heat pumps are a proven, highly efficient technology. They are consistent with net zero as the electricity grid decarbonises, and households switching to them from oil systems will be much less exposed to the impact of price spikes in global energy markets due to the greater use of secure, renewable forms of energy. Government modelling estimates that around 80% of off-gas-grid homes are already sufficiently well insulated for a low temperature heat pump to work effectively.

We recognise that heat pumps will not work everywhere, a small number of off-gas-grid properties are simply too poorly insulated or have certain characteristics that would make installing this technology unfeasible. Consistent with the principles of best use of biomass (set out in Chapter 5) we expect any use of biomass to decarbonise heat off the gas grid would be focussed on those properties which are not readily suitable for electrification.

The government is considering a range of options to decarbonise off-grid properties that are not readily suitable for electrification, including pairing energy efficiency measures and a low temperature heat pump, installing high temperature heat pumps, hybrid heat pump systems, solid biomass systems, and renewable liquid fuels. The government will assess the suitability of these options, considering the extent to which they are consistent with the priority use principles and also the extent to which they offer a positive experience for households.

The use of biomass to decarbonise heat off the gas grid is one of the areas that have not been included in the UK TIMES illustrative scenarios set out in Chapter 5. This is because the renewable liquid fuels which have been proposed for use in heat – including Hydrotreated Vegetable Oil (HVO) and bio-liquified petroleum gas (bioLPG) – are not currently available for heat on a commercial basis. It is not currently clear what volume of sustainable feedstocks would be available to produce these fuels, but we expect them to be limited in supply and in high demand from other sectors like transport.

However, we have been working with representatives of the heating oil industry, and liquified petroleum gas (LPG) industry, to start building the evidence on the potential to scale up production of renewable liquid fuels such as HVO and bioLPG, respectively, consistent with very low levels of carbon emissions for use in heat.

Use of HVO in heating

Hydrotreated Vegetable Oil (HVO) could prove a convenient route to decarbonising some off-grid properties – oil heated households would only need to make minor modifications to their existing oil boilers to use this fuel. However, HVO is not currently offered to heat customers on a commercial basis, and the government understands that the current cost of heating a property with HVO would be significantly more expensive than the cost of heating a property with kerosene.

When derived from waste feedstocks like used cooking oil, HVO can have considerably lower carbon emissions than the traditional fossil fuels currently used for heating off the gas grid. However, HVO derived from used cooking oil is likely to be in short supply and in high demand from other sectors such as transport due to its suitability as an aviation fuel. HVO derived from other feedstocks can be associated with much higher carbon emissions than fossil fuels. Moreover, over-committing these scarce sustainable feedstocks risks shortages in sectors that need it most, or driving up the use of virgin feedstocks like palm oil, which can have much higher emissions, and which are associated with deforestation in other countries, to supply global HVO demand that cannot be met from wastes.

Use of bioLPG in heating

Renewable liquid petroleum gas (BioLPG) and renewable dimethyl ether (rDME) could also prove useful measures for decarbonisation of off-grid properties. BioLPG is a drop in fuel that could be used in existing LPG boilers without modifications being made. We understand from the LPG industry that rDME could be used in an existing LPG system with certain modifications or blended with LPG up to a certain point with no need for system modification.

As with HVO, these fuels are not yet commercially available for home heating, may be subject to limited availability of sustainable feedstocks, and the costs of using these fuels in heat may be much higher than current cost of heating a property with regular (fossil) LPG.

Policy plans, proposals, milestones

The use of sustainable biomass must be prioritised in sectors that offer the greatest opportunity to reduce emissions and where there are fewest options to decarbonise through alternative low carbon technologies For heat, this will mean focussing the use of renewable liquid fuels such as HVO or bioLPG towards those properties off the gas grid that cannot be readily decarbonised through electrification, subject to further work to establish confidence in the likely available supply of the sustainable feedstocks used to produce these fuels, and considerations around best use across other sectors, incorporating the priority use principles.

Following the publication of the Biomass Strategy, the government will continue to work with stakeholders to build the evidence base that will inform decisions later this decade on what role renewable liquid fuels could play in the future heating mix, especially where heat pumps cannot be used, and the policy framework which would support such a role. This work will consider the overall amount of sustainable feedstock, available to the UK, that could be used to produce renewable liquid fuels for heat, how this could be best used across the economy to achieve our net zero target.

Domestic heat policy, including domestic biomass, is a devolved competence in Scotland. Therefore, any future support for biomass and other domestic heat decarbonisation measures in Scotland will now be provided by the Scottish Government as part of their Heat in Buildings Strategy.[185]

[185] The Scottish Government's Heat in Buildings Strategy: https://www.gov.scot/publications/heat-buildings-strategy-achieving-net-zero-emissions-scotlands-buildings

7.4 Biomass with combined heat and power

Summary

Combined heat and power (CHP) is an efficient process that captures and uses the heat that is produced in power generation, this is usually electrical but can in some instances be mechanical. By generating heat and power simultaneously from the same fuel, CHP can achieve high efficiencies and reduce emissions. Where a demand for both heat and electricity exists in the same location, CHP can reduce energy costs.

CHP plants can encompass a range of different generation technologies and be fuelled by fossil fuels or renewable sources such as biomass. CHP generators may export power not used on site and when acting as dispatchable generation, CHP can adjust its exported power output to provide flexibility services to the electricity network. CHP has been identified as having an important role in contributing to decarbonising heating and cooling, achieving energy efficiency savings across multiple sectors and the transition to low carbon fuels.

The Combined Heat and Power Quality Assurance Programme (CHPQA) certification acts as a 'passport' to enable certified CHP plants to access government support through several incentives. The current incentives are predominantly operational tax exemption-based incentives which require the CHP plants to maintain CHPQA Certified Good Quality status to continue to access the support.

Following the closure of the Renewable Obligation scheme and the Non-Domestic Renewable Heat Incentive, a Contracts for Difference scheme has provided funding to some renewable CHP sites.

Renewable fuels used in CHP are reported to have generated a total of 16.0 TWh of electricity and heat in 2022.[186] CHPQA certified CHP plants are able to provide an audit compliant high efficiency use for strategically important biomass feedstocks. Such applications of CHP technology are well suited to hard-to-decarbonise situations such as providing low carbon heat and power to dispersed locations distal from the industrial clusters.

The role of biomass for net zero in CHP

CHP is a proven and versatile technology that can provide a low carbon fuel option for existing unabated natural gas CHP. A benefit of the technology is that it can maximise the efficiency of biomass conversion by producing heat and power simultaneously. It is also flexible in that it is suitable for dispersed locations and off grid applications and can operate from small to large capacities (10 KW to 1.3 GW). It can therefore provide flexibility and security of supply for sites, with an 8-15-year life cycle of main engine component allowing for long term investment decisions to be made. CHPQA will be setting out a Net Zero aligned policy trajectory to help incentivise current

[186] https://www.gov.uk/government/statistics/combined-heat-and-power-chapter-7-digest-of-united-kingdom-energy-statistics-dukes

CHP sites to decarbonise whether that be transitioning to electrification or low carbon CHP options.

CHP can also offer flexible dispatchable capacity to the electricity grid to help offset renewable generation intermittency and can provide surplus heat to district heating projects and heat networks. The widespread use of CHP across different sectors results in many complex cross cutting policy interactions. There are interdependencies with fiscal matters and legislative links to various other government policies where CHP is represented.

Use of BECCS alongside CHP must be carefully considered and strategically deployed to maximise the potential benefits. There are potential applications to combine BECCS with highly efficient CHP technology in dispersed hard to decarbonise sectors such as cement production that are geographically suitable for the onward transportation of the captured carbon.

Policies, proposals, and milestones

CHPQA does not administer or control any direct funding mechanisms to support biomass CHP. The scheme has historically provided a passport via certification to a range of fiscal measures. As new business models are developed to encourage the use of biomass to aid decarbonisation, CHPQA certification could provide a valuable means of verifying fuel inputs, primary efficiency savings and heat and power outputs thus acting as an eligibility gateway to new funding opportunities for potential biomass users.

Some major CHP equipment manufacturers are producing engines which are able to operate on natural gas initially but be converted with minimal modification to be able to burn alternative fuels.

7.5 Biomass use in transport

Summary

Biomass plays a role in decarbonising transport as set out in the Transport Decarbonisation Plan. Biofuels, including bioethanol, biodiesel and biomethane, account for around a third of the carbon savings in the domestic transport sector required under current carbon budget. Currently, biofuel use in transport is mainly incentivised by the UK's Renewable Transport Fuel Obligation RTFO), which obligates all fuel suppliers to blend a proportion of low carbon fuel into fossil fuels used in transport. The RTFO sets rising low carbon fuel targets to 2032 after which they will continue at that level. In 2021, 2,558 million litres of low carbon fuels, mainly biofuels, were supplied under the RTFO, which contributed 5.4% of total fuels supplied to the road and non-road transport sectors.[187]

As set out in Chapter 6, BECCS can be deployed in the production of biofuels and has the potential to deliver negative emissions. Some biofuel plants already regularly capture and produce stored CO_2 for use in the beverage and nuclear industry. The RTFO already accounts for CCS in its methodology, and the upcoming sustainable aviation fuel (SAF) mandate will reward SAF on the basis of GHG savings to ensure the future integration of CCS in SAF production. However, further work is still needed to establish how BECCS can be best incorporated in the biofuel production processes and incentivised accordingly.

Biofuels can be made from a variety of biomass feedstocks. 2021 RTFO statistics list 45 different biogenic feedstocks from 89 countries.[188] As biofuels and their feedstocks are often traded internationally, feedstocks and country of origin can vary year-on-year, depending on market drivers. UK policy for low carbon fuels,[189] including biofuels, is driven by our commitments to reduce our climate impacts, enhance energy security and support green growth. We are focused on promoting waste-derived rather than crop-derived biofuels, to deliver the highest possible GHG savings and address risks of indirect land use change. All RTFO eligible biofuels need to comply with strict sustainability criteria and minimum GHG thresholds.

The dominant feedstock for biofuels has been used cooking oil (accounting for 55% of all renewable fuels in 2021), predominately used in the production of biodiesel. Other waste feedstocks include food waste, waste starch, slurry, tallow and waste pressings. The contribution of crop-derived biofuels to RTFO targets is capped, with the cap decreasing from 4% of total fossil and renewable fuel supplied in 2020, to 2% in 2032. In 2021, less than a quarter (24%) of biofuels supplied under the RTFO were made from crops

[187] In 2021, only 1,878litres of renewable fuels were derived from non-biomass origins, mainly hydrogen (a non-biological origin renewable fuel).

[188] https://www.gov.uk/government/statistics/renewable-fuel-statistics-2021-final-report

[189] The term low carbon fuels refers to fuels which deliver greenhouse gas savings compared to fossil fuels on a life-cycle basis. This includes biofuels but also renewable fuels of non-biological origin, for example renewable hydrogen, or recycled carbon fuels produced from unrecyclable plastics or waste gases.

such as wheat, corn, barley, sugar beet and sugarcane. Use of vegetable oils, such as rapeseed oil, palm or soy, tends to be minimal given incentives for waste-derived fuels.

Currently, most biofuels deployed in the transport sector are used to reduce emissions from road vehicles. As the transport sector decarbonises and the uptake of vehicles that are zero emission at the exhaust accelerates, the demand for liquid and gaseous fuels from the road sector will decline across all forms of road transport. However, low carbon fuels, including biofuels, will remain important in replacing fossil fuels in transport modes with more limited alternatives to use of liquid and gaseous fuels, such as parts of industrial Non-Road Mobile Machinery (NRMM) and in aviation, where they will likely be required in the period to 2050 and beyond.

Separate to the RTFO, in support of the Jet Zero Strategy, DfT is developing a mandate for SAF to be operational from 2025, which includes waste-derived biofuels amongst other low carbon transport fuels. Crop based biofuels will not be eligible. The government response to the 2021 SAF mandate consultation confirmed a target of at least 10% of UK aviation fuel to be made from sustainable sources from 2030 and high-level principles for the supply of SAF. The SAF mandate second consultation was published in March 2023, building upon these commitments, outlining the mandate's detailed design. The long term trajectory for the mandate will be confirmed in the government response to the second consultation.

In view of the transition of the use of low carbon fuels within the transport sector, DfT will also publish a Low Carbon Fuels Strategy which will set out how the deployment of low carbon fuels, including biofuels, may evolve in the period to 2050 across the different transport modes.

Key benefits and opportunities

At present, biofuels offer an available and flexible resource to achieve immediate carbon savings in the road and NRMM sector. In 2021, fuels supported under the RTFO saved 5,068 kt CO_2. On average, fuels supported under the RTFO achieved a GHG saving of 83% compared to fossil fuels on a life-cycle basis (almost 80% when accounting for indirect land use change impacts) in 2021. This reflects the fact that 76% of the fuels under the RTFO were produced from waste and residues. By diversifying supply of feedstocks, biofuels could also make a contribution to enhancing fuel security.

Most biofuels are currently blended into standard petrol and diesel, using existing infrastructure for fossil fuels. As we move to zero emission cars and vans, demand for liquid and gaseous fuels from road transport will decline. This may offer further opportunities to deploy fuels with a higher biocontent, such as higher blends of biodiesel, drop-in fuels[190] or biomethane, to maximise GHG savings from existing vehicles with internal combustion engines in the short and medium term. However, as use of some of these fuels will require some adaptations to infrastructure and engines, their use will need to be focussed on compatible heavy-duty vehicles.

[190] 'Drop-in fuels' are fuels that are sufficiently similar to the fossil fuels they replace (e.g., petrol, diesel or kerosene) that they can be blended with no particular limits or 'blend wall'.

As part of the Transport Decarbonisation Plan, DfT committed to work with stakeholders to identify potential measures to address existing barriers to the deployment of higher biocontent fuels.

Heavier vehicles and vessels covering long distances will continue to require liquid and gaseous fuels for some time to come. In these cases, biofuels can play a vital role in providing an alternative to fossil fuels and reduce carbon emissions.

According to industry figures, more than 10,000 people are currently employed in the UK biofuels sector.[191] The government's ambition to establish a UK SAF industry could support around 60,000 jobs by 2050 and £10bn of Gross Value Added per annum including upstream benefits, though not all these fuels would be produced from biomass.[192]

The production of biofuels can also result in valuable by-products, with biofuels just one outcome of the refining process. Bioethanol production in the UK, for example, results in protein-rich animal feed and stored CO_2 which is used in the agriculture and nuclear industries. Additionally, emerging biofuel production technologies such as gasification and pyrolysis tend to result in a suite of hydrocarbon products, some of which can be used as precursors for the materials and chemicals sectors, supporting the circular bioeconomy. Adopting a biorefineries approach could enable a suite of different products to be produced which could process different feedstocks depending on availability, with the products being flexibly directed towards the sectors where they are most needed.

The role of biomass for net zero in the transport sector

Biofuels are currently one of the major measures to reduce carbon emissions in the transport sector, in particular from road vehicles. As set out above, their role within the transport sector is expected to evolve. As we move to net zero, their use in the transport sector will need to be increasingly focused in areas and transport modes with limited alternatives to the use of liquid and gaseous fuels. This includes aviation and maritime, which are likely to require low carbon fuels beyond 2050. To further reduce emissions, carbon capture and storage technologies will increasingly need to be applied to biofuel production processes, particularly in SAF production.

Policy plans and milestones

- Later in 2023: Publish Low Carbon Fuels Strategy, followed by further implementation actions.
- Summer 2023: Launch UK Clearing House for Sustainable Aviation Fuels and announce winners of the second round of the £165m Advanced Fuels Fund.
- By end of 2023: Government response to second SAF mandate consultation and successful operation of the world's first transatlantic flight on 100% SAF.
- By end of 2023: Publication of a refreshed Clean Maritime Plan 2, setting out UK's vision for the decarbonisation of maritime, including the role of low carbon fuels.
- 2025: SAF mandate to come into force.

[191] https://www.r-e-a.net/wp-content/uploads/2021/07/REview-2021-.pdf, p.34.
[192] https://www.sustainableaviation.co.uk/wp-content/uploads/2023/04/Sustainable-Aviation-SAF-Roadmap-Final.pdf. The jobs and GVA figures are based on direct, construction and upstream jobs benefits. Analysis assumes UK SAF production costs are equivalent to wider global SAF production costs.

Research & Innovation

The government is supporting research and innovation on diversifying feedstocks for biofuels, new and improved processing technologies as well as carbon capture and storage through various means. As such the RTFO contains a sub-target for “development fuels”, which are strategic fuels not yet fully commercialised. These are novel, waste-derived biofuels and renewable fuels of non-biological origin of strategic importance. They include for example drop-in fuels, hydrogen and fuels for aviation. As new feedstocks and processing technologies become available, we will also make sure that these fuels are sustainable and provide maximum GHG savings, for example through updates to our sustainability criteria.

DfT has also run successive grant funding competitions targeted to develop innovative low carbon transport fuel production: the Advanced Biofuel Demonstration Competition, the Future Fuels for Freight and Flight Competition and the Green Fuels Green Skies competition providing capital funding to UK projects. A total of £62m was previously made available through these competitions.

With demand for biofuels in particular from aviation expected to increase, government want to capitalise on the environmental and economic opportunities that developing a strong UK SAF industry can bring and we are exploring how to accelerate the commercialisation of UK SAF facilities. Through the Advanced Fuels Fund, DfT has made an additional £165m available to support the development of sustainable aviation fuel (SAF) plants in the UK. In December 2022, five winning projects were awarded a share of £82.5 million and the remaining funds will be allocated in the second application round. This funding drives the ambition to see at least five commercial scale SAF plants under construction in the UK by 2025. To accelerate novel SAF production pathways to market, DfT is also setting up a UK SAF Clearing House to support testing and certification of advanced fuels. The Clearing House is expected to launch in Summer 2023.

7.6 The use of biomass to support the decarbonisation of industry

Summary

Biomass is a widely used, renewable source of energy and input material for industrial processes. However, it comes in many forms and is used in a variety of industrial processes, the relative sustainability of these materials and uses varies. We recognise the role of biomass use in industry to meet net zero, particularly where there are limited alternatives to biomass to decarbonise specific processes (including those where solid fuel is currently used). This includes long term uses in combination with BECCS to generate negative emissions, and in the short and medium as a transition fuel. Additionally, as set out in Chapter 7.8, we recognise the need to further understand non-energy uses of biomass across the economy including within industry.

Biomass usage as a fuel in industry had a steady increase in growth over the last ten years. Industry biomass use for final energy has increased steadily from 2 TWh in 2005 to 20 TWh in 2022. Alongside this, biomass has made up an increasing share of total industry final energy use over time, reaching 6.8% from a low of 0.5% in the early 2000s.[193] Biomass, predominantly plant based followed by waste wood derived fuels, are used in a range of industrial sectors, including paper, mineral products, chemicals, food and drink, and other industries.

Stakeholder engagement

The Biomass Strategy Call for Evidence and several bilateral engagement sessions explored stakeholder views on the use of biomass in the industrial sector. The engagement outlined the challenges the sector had encountered in finding a secure supply of waste biomass. Industries with feedstock uses and waste opportunities, for example sugar and paper industries, noted concerns about market distortion by intervention. Trade-offs also include the use of biomass for bioenergy where, for example, it may be more beneficial to continue to sell feedstock for other uses, such as animal feed.

Stakeholders suggested that biomass use should be prioritised to sectors that have limited options for decarbonisation, which could include decarbonising heat use and raw materials in the manufacturing industry. Responses also reflected that the costs of switching to biofuels should be supported, as there was competition for biomass in other sectors.

The engagement outlined the varying views on the potential for biomass to support decarbonisation across different industrial sectors, which ranged between biomass being seen as transitional rather than long term, to biomass being the only current technological alternative to fossil fuels. They did however emphasise that where biomass was used, it was in CHP

[193] Digest of UK Energy Statistics Table 1.1: Aggregate energy balances and Table 6.1: Renewables and waste commodity balances 2023 (https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes#2023)

plants, which helped maximise the net energy output. In contrast, the minerals sector viewed the use of waste biomass as central to a zero fossil carbon fuel mix for cement manufacture. In the glass sector, biofuels are viewed as transitional as they can be used in existing furnaces.

Industry noted that the security of supply and sourcing of biomass in the future is a challenge. Trade-offs also include the use of biomass for bioenergy where, for example, it may be more beneficial to continue to sell feedstock for other uses, such as animal feed. Government is considering what, if any, intervention is required.

The sectors that utilise biomass are mostly outside of the main industrial clusters which affects which technologies are accessible for decarbonisation. Any use of BECCS, for example, will be expected to occur in areas within or close to the industrial clusters in the short term.

Key benefits and opportunities

The UK's industrial sector (manufacturing and refining) plays an important role in society, contributing £180 billion to the overall UK economy in 2019 (£160 billion in 2020).[194] It is a high value area of employment, directly accounting for 9% of the UK's GDP in 2019 (8% in 2020)[195] and providing 2.5 million direct jobs[196] across the country, rising to around 5 million jobs[197] if including indirect jobs across the value chain.

However, industry is also a major source of CO_2 emissions, producing 17% (76 $MtCO_2e$) of UK's total in 2021.

Biomass will continue to play a key part in the transition to net zero for the industrial sector, allowing industry to transition away from fossil fuels, reducing their emissions while infrastructure is developed or replacing fossil fuels in processes where other alternatives aren't feasible, such as off gas-grid sites, or in industries, such as cement production, where biomass is the only current technological alternative to fossil fuels in some stages of the process. Biomass, in the form of biofuels, can also act as a fuel replacement for industrial NRMM, which currently accounts for 6 $MtCO_2e$/yr, with some industrial NRMM users already switching to biofuels, such as HVO. Biofuels may play an important role as a transition fuel for industrial NRMM (and potentially longer term for certain machine types), in particular where these can be substituted for fossil fuels without the need for machine modifications.

Fuel switching from fossil fuels to low carbon alternatives in industry is crucial for the sector to meet its net zero target, and biomass will play a role in this in the short and medium term as well as in the long term in combination with BECCS. Additionally, as referenced previously in this Strategy, non-energy uses of biomass could play a role in decarbonising industrial processes by replacing fossil fuels.

194 https://www.ons.gov.uk/businessindustryandtrade/business/businessservices/datasets/uknonfinancialbusinesseconomyannualbusinesssurveysectionsas
195 https://www.ons.gov.uk/economy/grossvalueaddedgva/timeseries/abml/qna
196 https://www.ons.gov.uk/businessindustryandtrade/business/businessservices/datasets/uknonfinancialbusinesseconomyannualbusinesssurveysectionsas
197 https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/adhocs/009747ftemultipliersandeffectsreferenceyear2015bespokeindustrygroups

The role of biomass for net zero within the sector

As laid out in the Industrial Decarbonisation Strategy (IDS) (2021) and the Biomass Policy Statement, it is the government's position that biomass use in industry should be prioritised in combination with CCUS. Bioenergy is a part of the IDS and, along with other technologies, will help to transform the UK's industrial regions, attracting inward investment, future proofing businesses and securing the long term viability of jobs. Additionally, biomass also has potential as a transitional fuel for sectors where decarbonisation networks cannot be accessed or in processes where other decarbonisation technologies are not readily available.

The government's ambition, as set out in the Net Zero Strategy (2021), is to achieve 50TWh of industrial fuel switching to low carbon fuels by 2035. We expect this primarily to be reached via switching from fossil fuels to electricity and hydrogen, though bioenergy could enable further carbon savings. We recognise that UK industrial electricity prices are higher than those of other countries and have committed to address this to ensure UK industry remains competitive. A call for evidence on industrial electrification will be published later this year.

Additionally, as described in Chapter 7.2, biomethane can be used either in CHP systems or separately to power industrial processes, the high innovation and high resource scenarios set out in Chapter 5 see increased roles for biomethane in industry.

Analysis for the IDS found that between 51 to 57% of industrial energy will be decarbonised from fuel switching by 2035, increasing to 71-84% by 2050.

The Industrial Pathway modelling carried out for the 2023 Net Zero Growth Plan indicates that bioenergy demand could be in the range between 25TWh to 35TWh between 2035-2050 depending on scenario.

Policy plans, proposals, milestones

Government support for biomass will continue to align with the principles for best use. We will continue to support biomass use across industry as a short term transitionary fuel for some of the sectors within the scope of current schemes. In the long term (out to 2050), biomass use will be supported when combined with CCS technologies, or when there are limited alternative options to decarbonise.

Current government support includes the Non-Domestic Renewable Heat Incentive (NDRHI) (See Section 7.3). Government outlined a series of reforms in 2018 which included tariff guarantees to provide investment certainty to larger renewable installations, changes to feedstock requirements to ensure the utilisation of waste feedstock for anaerobic digestion and amendments to eligible heat uses. The scheme subsequently closed in March 2021 and was replaced by the Green Gas Support Scheme (GGSS), which supports biomethane production via anaerobic injection into the gas grid.

The Industrial Energy Transformation Fund (IETF) supports biomass projects principally as part of fuel switching technology solutions. This includes switching from fossil fuels to biomass if the stakeholder can justify the reason for switching to biomass over other fuel switching options within scope of the IETF. Other criteria specific to biomass apply such as compliance with relevant air quality regulations, intention to secure appropriate permits, sustainable sourcing of the biomass feedstock and operational temperature of the industrial process ≥240°C. Subject to business case approval, IETF Phase 3 will open for applications in early 2024, increasing the total funding available to over £500 million.

As described above, modelling carried out for the Net Zero Growth Plan gives an indication of the demand for bioenergy, however further work is needed to fully understand how to manage use within industry to maximise carbon abatement and drive us towards our decarbonisation goals.

Where other technologies are not yet mature enough for widespread deployment and biomass can play a crucial role in driving abatement as a `transitional' fuel, we will work to see if further support is needed to incentivise biomass use for this purpose and ensure equal access to biomass for industry to use as both a feedstock and a decarbonisation option.

Additionally support for industrial BECCS will incentive industry to both decarbonise its processes and deliver negative emissions in the long term.

As made clear in the previous sections of this strategy, biomass is a limited resource and as such its use needs to be targeted, additionally we recognise that, biomass represents one of the limited options to decarbonise certain industrial processes, and that work is needed to ensure access to these feedstocks is maintained. What follows from this is that biomass should be used where switching to other low carbon alternatives is not feasible and prioritised where carbon capture is possible, thus generating negative emissions.

Biomass does have potential to act as a transition fuel in industry and it is important to strike a balance between taking advantage of these short term emission reductions and the longer term `deep decarbonisation' emission reductions that can be generated by other forms of fuel switching and BECCS.

In line with the priorities for biomass use laid out in Chapter 5, we will continue to review the need for further intervention to direct the use of biomass within industry.

7.7 Biomass for low carbon hydrogen production

Summary

To deliver the future energy system we need to meet our legally binding carbon budgets and achieve net zero, we need a rapid increase in new low carbon hydrogen production in the UK. In the British Energy Security Strategy (2022) we doubled the UK ambition to 10GW of low carbon production capacity by 2030, subject to affordability and value for money.

The hydrogen economy is still a nascent sector, and majority of hydrogen production this decade is expected to come from water electrolysis powered by low carbon electricity ('green hydrogen') and CCUS-enabled methane reformation ('blue hydrogen'). The UK is however committed to supporting multiple production routes, including those that use biomass feedstocks, provided they meet the Low Carbon Hydrogen Standard and relevant funding criteria. This will help bring forward the broad range of projects needed to ensure a rapid and cost-effective build out of the hydrogen economy.

Biomass can be used directly as a feedstock to produce low carbon hydrogen, through reformation, gasification, or pyrolysis technologies, and if carbon capture and storage is added this can provide negative emissions.

Key benefits and opportunities

The most prominent hydrogen production pathways using biomass as a feedstock are expected to involve gasification technologies, were high levels of heat is used to break down organic material in the presence of little to no oxygen. It can also be produced via the AD of organic material, can be reformed using steam methane or autothermal reformers. Other methods of producing hydrogen from biomass are in development, but not yet proven in an operational environment at commercial scale.

Delivering on our hydrogen production ambition could mobilise over £11 billion of private investment and support over 12,000 jobs by 2030,[198] ensuring that we have reliable, secure energy while maintaining progress towards our legally binding targets under the Climate Change Act. The CCC have estimated that by 2050, low carbon hydrogen could be comparable in scale to existing electricity use in the UK, As set out in the Net Zero Strategy, up to 20% of hydrogen supply in 2050 could come from hydrogen BECCS, providing not only a valuable route to decarbonising multiple end-use sectors, but also delivering negative emissions in support of our carbon budgets and net zero.

[198] https://www.gov.uk/government/publications/hydrogen-net-zero-investment-roadmap

The role of biomass for net zero in supporting low carbon hydrogen production

The deployment of hydrogen BECCS over the coming decades will be contingent on the availability of appropriate biomass feedstocks, the availability of CCUS infrastructure, including storage capacity, and technological innovation.

Evidence from the CCC's Sixth Carbon Budget[199] advice suggests that the extent of deployment of hydrogen BECCS is more dependent on the demand for negative emissions, more so than the need for additional hydrogen production. However, we recognise that hydrogen BECCS projects may help to meet localised demand for hydrogen, or potentially make use of otherwise underutilised feedstocks.

Policies, proposals, and regulation

Support for commercial-scale low carbon hydrogen production is available through the Net Zero Hydrogen Fund (NZHF)[200] (development and capital support), the Hydrogen Production Business Model[201] (revenue support) and the Renewable Transport Fuel Obligation. We are taking forward actions to support development of biomass to hydrogen and welcome further input from stakeholders on how best to enable this. Strands 1 and 2 of the Net Zero Hydrogen Fund (NZHF) have the potential to support near-term hydrogen from biomass projects. The first allocation round for access to Hydrogen Production Business Model support was limited to electrolytic hydrogen production, but this does not preclude the inclusion of other technologies (including hydrogen BECCS) in future allocation rounds (See Chapter 6 for more on hydrogen BECCS).

All hydrogen production routes seeking funding through these routes must first meet the UK Low Carbon Hydrogen Standard.[202] This standard ensures that the hydrogen production supported is sufficiently low carbon across its supply chain and conversion process and sets sustainability criteria for biomass feedstocks in line with wider government policy.

In addition to meeting a GHG emissions intensity of no more than 20 gCO_2e/MJ_{LHV} of produced hydrogen, bio-hydrogen producers wishing to prove compliance with the standard must meet additional requirements for the use of biogenic inputs, where relevant and as appropriate for the feedstock source and classification, This includes demonstrating compliance with the land, soil carbon and forest criteria, satisfying the minimum waste and residue requirement, and reporting on estimated indirect land-use change (ILUC) GHG emissions.

It is likely that the ability to use hydrogen BECCS to produce both hydrogen and negative emissions will constitute the most valuable use of biomass in hydrogen production in the long term, although innovation and the availability of CCUS infrastructure will be important to enabling this. However, we are aware of nearer-term production projects

199 https://www.theccc.org.uk/publication/sixth-carbon-budget/
200 https://www.gov.uk/government/publications/net-zero-hydrogen-fund-strand-1-and-strand-2
201 https://www.gov.uk/government/publications/hydrogen-production-business-model
202 https://www.gov.uk/government/publications/uk-low-carbon-hydrogen-standard-emissions-reporting-and-sustainability-criteria

looking to produce low carbon hydrogen from biomass, particularly involving the reforming of biomethane from AD. While these may have value in helping develop local hydrogen use, direct use of this biomethane in the gas grid is likely to deliver greater energy efficiency and carbon reduction benefits. Other policies across government already incentivise use of biomethane in the energy system, such as the GGSS and the RTFO.

In response to the recommendations from Mission Zero: Independent Review of Net Zero,[203] we have committed to publishing a hydrogen production delivery roadmap by the end of 2023. This will set out details on the mix of technologies needed to meet our 2030 production ambition, as well as meet expected demand in 2035 for our sixth carbon budget. This will include detail regarding our position on hydrogen from biomass, including hydrogen BECCS.

Research & Innovation

To help facilitate the development of hydrogen BECCS, government launched the Hydrogen BECCS Innovation Programme in 2022. During Phase 1 £5 million of funding was awarded to develop 22 project proposals aiming to deliver commercially viable, innovative hydrogen BECCS technology solutions. Technologies being supported by the programme include gasification feedstock pre-processing, syngas treatment and upgrading, and novel biohydrogen technologies such as dark fermentation.

Phase 2 was launched in January 2023 with total budget of £25 million, and it intends to take projects from innovation design through to innovation demonstration.

Innovation funding has been provided to a range of different hydrogen production technologies through the Low Carbon Hydrogen Supply Competition.[204] While this and other programmes in the £1.3 billion Net Zero Innovation Portfolio are now closed, a progress report[205] was published in May 2023 and the findings will be integral to the design of future government net zero innovation portfolios.

[203] https://www.gov.uk/government/publications/review-of-net-zero
[204] https://www.gov.uk/government/publications/hydrogen-supply-competition
[205] https://www.gov.uk/government/publications/net-zero-innovation-portfolio-and-the-advanced-nuclear-fund-progress-report-2021-to-2022

7.8 Non-energy uses of biomass

Summary

Biomass is a flexible resource with potential to contribute towards decarbonisation activities not just as an energy source but also as material to displace fossil fuel use. There is an increasing focus globally on the concept of the bioeconomy, which can be defined as including all sectors of the economy that use biomass to make materials and products. This includes both energy uses, and non-energy uses, such as wood-based products (e.g., timber, wood panels, etc), and bio-chemicals and bio-materials (bio-plastics).

Responses to the 2021 Biomass Strategy Call for Evidence, alongside reports by the IEA Bioenergy, CCC, and others, have highlighted that there is a clear opportunity for biomass to be used in non-energy sectors for the production of high value renewable chemicals and materials and in construction applications. Here biomass can displace fossil fuel-heavy materials in the chemicals, materials, and manufacturing sectors, supporting sustainable production and the decarbonisation of these sectors. The use of biomass in higher value, higher employment markets, such as fine and speciality chemicals and materials (etc.) can enable the extraction of maximum value from the finite biomass feedstocks and can help maximise end-of-life energy recovery from biomass waste arisings. An important enabling technology for this is industrial biotechnology (IB).

While these non-energy uses of biomass present real economic and job opportunities, there is significant uncertainty on the potential demand these end uses generate for biomass, the size of these markets, and the GHG emissions reductions some of these uses will offer in the future.

Timber and woody biomass as low carbon materials

Timber and woody biomass are low carbon materials that can displace the use of carbon intensive materials. The UK consumed 53.1 million m3 Wood Raw Material Equivalent (WRME) underbark[206] of wood in 2021, with UK production accounting for 31% of the UK sawnwood market, 50% of the UK wood-based panel market and 54% of the UK paper market in 2021.[207]

We have committed in the Environmental Improvement Plan to maintain and grow a sustainable and long term UK timber supply. This includes measures to encourage both supply and demand for UK grown timber, including a new £1.5 million Forestry Innovation Fund which will provide financial support to develop innovative timber products, and increasing public demand for sustainably sourced timber through procurement policies.

We have identified that increasing the safe use of timber in construction can encourage greater demand for wood

[206] Volumes are expressed in wood raw material equivalent (WRME) underbark. WRME volumes represent the amount of wood that would have been required to make the product.
[207] https://cdn.forestresearch.gov.uk/2022/09/Ch3_Trade_2022.pdf

products, displacing more carbon intensive building materials such as concrete and steel. We have committed in the England Trees Action Plan (ETAP) and Net Zero Strategy to work with industry and across government to develop a timber in construction policy roadmap setting out how we will achieve this.

The ETAP is supported through the Nature for Climate Fund, enabling a new tree planting programme. Additional funding of £124 million for the Nature for Climate Fund was announced in the Net Zero Strategy. We aim to at least treble tree planting rates in England by the end of this Parliament, reflecting England's contribution to meeting the UK's overall target of planting 30,000 hectares per year by the end of this Parliament. We have also legislated a statutory tree and woodland target to increase tree canopy and woodland cover in England to 16.5% by 2050.

There are similar strategies and policies in place across the devolved administrations. The Scottish Government has committed to an ambitious target of increasing woodland cover from around 19% of the total area of Scotland, to 21% by 2032 by increasing annual woodland creation from the current level of 8,000 hectares per year in 2022/23 up to 18,000 hectares per year by 2024/25 of which 4,000 hectares would be native woodland.[208] The Welsh Government has committed to tree planting targets of 43,000 hectares by 2030 and a total of 180,000 hectares by 2050.[209]

The resulting increase in tree planting and managed woodland cover by 2050 could provide a source of domestic biomass supply in the form of harvesting residues generated through sustainable forest management practice.

Engineering Biology

Engineering biology is the design, scaling and commercialisation of biologically derived products and services that can transform sectors or produce existing products more sustainably. It draws on the tools of synthetic biology to create the next wave of innovation in the bioeconomy. Engineering biology has a wide range of applications, from growing climate resistant crops and creating new sources of proteins, to sustainably producing chemicals and materials like dyes, to more effective medicines like the COVID-19 vaccine. In the government's Science and Technology Framework engineering biology was identified as a critical technology.[210]

Engineering biology's applications will create a greater demand for sustainable feedstocks. Carbon in the form of sustainable sugars is the primary raw material for producing products from biology, and this is largely derived from biomass.[211] For example, Colorifix is a UK firm that uses engineering biology to dye fabrics, powering their microbes with feedstocks such as sugar, yeast, and plant byproducts. The UK's strategy for engineering biology and the business

[208] https://www.gov.scot/publications/scotlands-forestry-strategy-20192029/pages/2
[209] https://gov.wales/written-statement-trees-and-timber
[210] https://www.gov.uk/government/publications/uk-science-and-technology-framework/the-uk-science-and-technology-framework
[211] National Research Council. 2015. Industrialization of Biology: A Roadmap to Accelerate the Advanced Manufacturing of Chemicals. Washington, DC: The National Academies Press.

models of UK engineering biology firms will need to account for biomass feedstock distribution and seasonal availability.[212]

Engineering biology is also increasing the range of what biomass can be used for because it could enable efficient resource recovery from waste.[213] For example, C_3 Biotechnology is an innovative UK firm working on creating a range of products not derived from fossil fuels using waste biomass, including synthetic kerosene and acrylics. The ability to repurpose this waste can be an important resource for the UK's bioeconomy.[214]

Engineering biology is a critical technology with potential to be essential for the UK's health, wealth, and security. It is also a field where the UK can become a leading nation. Government is establishing a strategic approach to engineering biology and its applications across the economy to maximise its opportunities. This will involve building on the biomass availability mapped in this Strategy and its principles of best use and prioritisation.

Biomass in chemicals and materials production

The carbon-based chemical and materials sectors cannot be fully decarbonised, since most chemical products that can be displaced by biogenic alternatives are carbon-based. Instead, the use of fossil fuels can be reduced through a shift to biogenic carbon. Therefore, sustainable biomass will be increasingly important for manufacturing of materials and chemicals using engineering biology, drawing on infrastructure such as biorefineries. It is theoretically possible to use biomass as a feedstock for many different chemicals.

The UK chemical industry directly employs around 104,000 highly skilled workers.[215] It is also the UK's largest manufacturing export sector and the second largest domestic manufacturing industry, with £28 billion value added to the UK economy in 2020. It is also the national leader in research and development spending at £8bn per annum, providing significant economic scope for investment into the bioeconomy.[216] However, the emissions are difficult to evaluate, with voluntary reporting on Scope 3 emissions which make up an estimated 77% of the chemical industry's emissions.[217] Further work is needed to understand the applications and conditions necessary for the bio-based chemicals and materials sectors to form part of the long term priority use of biomass. As a first step, government commissioned a project to understand the economic and climate benefits to the UK of an increased use of bio-based chemicals (see below). This will help shape the UK's future ambition in this area and how this sector can best contribute to growing innovation and the economy, while also

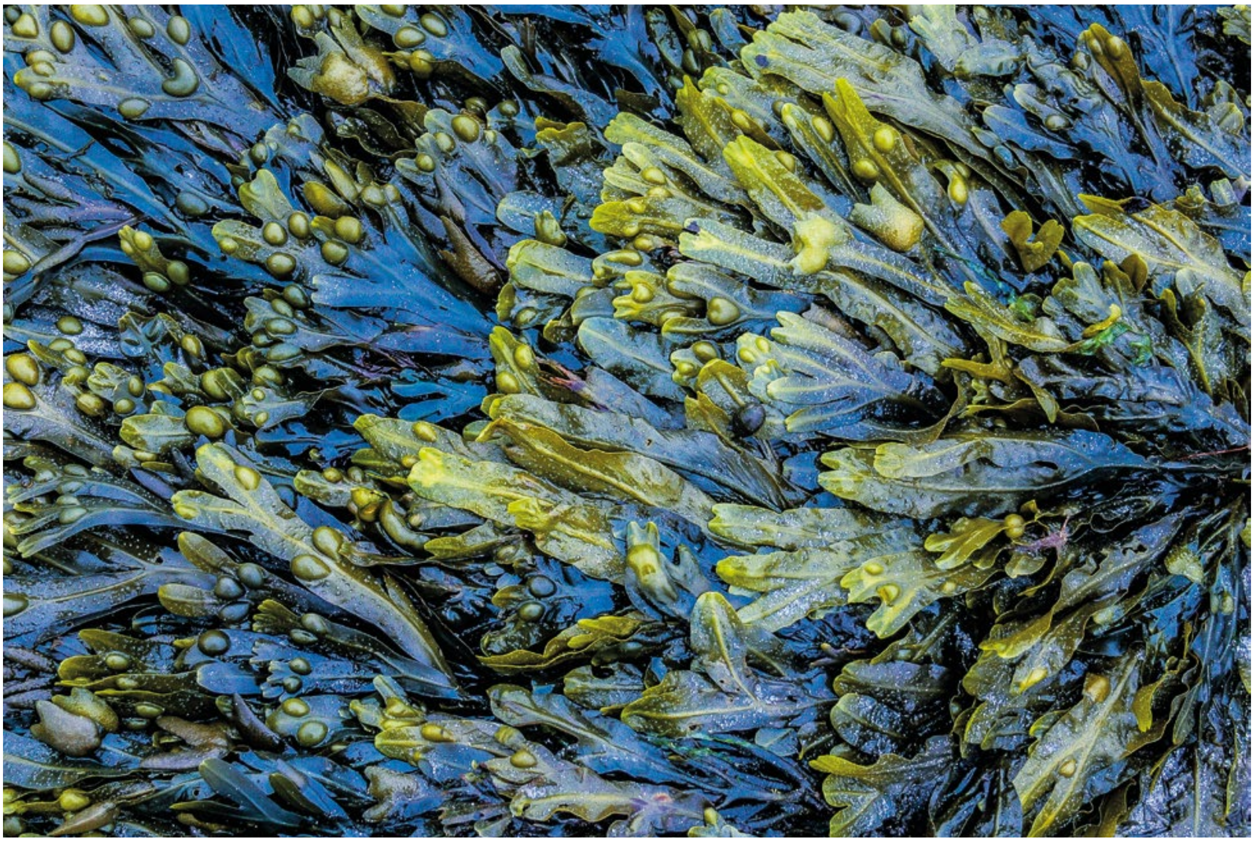
[212] Cambridge Industrial Innovation Policy (2022). Life Sciences beyond human health: modern industrial biotechnology in the UK. IfM Engage. Institute for Manufacturing, University of Cambridge.
[213] Dietz, T.; Börner, J.; Förster, J.J.; Von Braun, J. Governance of the Bioeconomy: A Global Comparative Study of National Bioeconomy Strategies. Sustainability 2018, 10, 3190.
[214] House of Lords (2014). Waste or resource? Stimulating a bioeconomy. Science and Technology Select Committee.
[215] https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/datasets/employeejobsbyindustryjobs03
[216] https://cefic.org/a-pillar-of-the-european-economy/landscape-of-the-european-chemical-industry/united-kindgom/#h-chemical-industry-snapshot
[217] CDP Europe (2020). Running Hot: Accelerating Europe's Path to Paris.

helping to meet UK's net zero ambitions.

The project aims to gain a deeper insight into the role of these sectors in the context of net zero. The project will answer three main questions which will fill evidence gaps and support future policymaking:

1. Which bio-based chemicals offer the largest potential for GHG emission savings relative to the fossil incumbents?
2. How can the UK's sustainable biomass resource be effectively and efficiently processed to bio-based chemicals?
3. What economic benefits could result from the increased production of bio-based chemicals, including the value-add compared to bioenergy applications and the opportunity for the UK to develop a competitive advantage in export markets?

Results and conclusions are expected to be published in 2024. These results will improve government's understanding of how biomass can help decarbonise the chemicals and materials industries, providing a more holistic view of the overall demand for biomass and serving as a platform for future policy decisions.



Case study on an innovation: SeaGrown

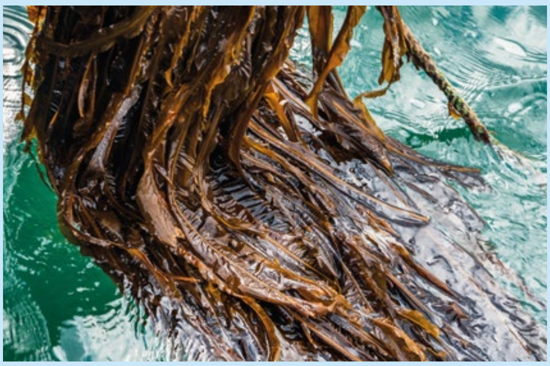
Wild harvested seaweed accounts for the majority of seaweed utilised in the UK. However, any increasing demand will likely be met by seaweed aquaculture production. While the seaweed farming industry is still very much in its infancy a shift in production has already been observed with the number of applications for seaweed farms steadily increasing throughout the early 2020s.

To enable sustainable growth in the seaweed aquaculture sector, government, the Marine Management Organisation, Natural England and the Centre for Environment, Fisheries and Aquaculture Science (Cefas) have compiled guidance aimed at applicants and regulators, that will provide clarity around the application process for seaweed aquaculture in the marine area within England.

Scarborough-based SeaGrown operate a 25-hectare offshore seaweed farm in the North Sea off the Yorkshire Coast. Their project, 'Transforming UK offshore marine algae biomass production', is developing and demonstrating an innovative, automated end-to-end seaweed farming system, which will enable year-round production in open-water sites.

The project is creating a system that can provide a source of sustainable bulk biomass from the ocean, positioning the UK to lead the way in European seaweed farming and develop a national Blue Carbon capability. SeaGrown see huge potential in Seaweed biomass as a low carbon alternative, for use in a wide range of industries, including packaging, foods, animal feed and biofuels.

SeaGrown are using their expertise in the offshore environment – both technical and scientific to innovate equipment and processes used in seaweed farming that are currently expensive, time consuming, labour-intensive and failure-prone, especially in offshore waters. A year into the project, their new in-water system is already showing great improvements in cost and labour efficiencies over previous methods, and the team will now continue trialling equipment and optimising the system for commercialisation.



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Annexes

Annex A: Compliance requirements of government biomass subsidy schemes

The compliance requirements vary slightly across schemes, as summarised below:

- **Renewables Obligation (RO):** For projects supported through the RO, Ofgem requires monthly reporting for all generators at capacity greater than 1MW. Alongside this, the generator is required to report annual profiling data which contains information on characteristics of the fuel, such as type of biomass, country of origin, derived from wood or wood, and form of biomass. An annual sustainability audit report is required from an independent party commissioned by generators, to verify the sustainability information submitted by the generator.
- **Contracts for Difference scheme (CfD):** Similarly, generators supported through the CfD with a minimum Commissioned Installed Capacity of 1MW or above are required to submit monthly and annual reports to LCCC demonstrating compliance with the Sustainability Criteria under the CfD Scheme. Reports by generators must include information on the sustainability characteristics of all consignments of fuel, such as the biomass feedstock type, country of origin, the form of biomass and fuel classification. Data from monthly and annual submissions are cross-checked by LCCC. LCCC employ additional auditing mechanisms to verify data collected by generators through the sustainability criteria audit report, which provides an independent third-party view, commissioned by generators, to verify that generators have provided sufficient evidence of compliance with the criteria. Failure to comply with an exercised sustainability criteria audit may lead to the suspension of payment to generators of any Net Payable Amounts. LCCC has appointed Ofgem as a contractor to support and advise LCCC on sustainability aspects related to the CfD scheme.
- **Renewable Heat Incentive (RHI):** The scheme is administered by Ofgem. Once accredited onto the RHI there are on-going obligations to comply with, these include measures to meet air quality requirements such as operating and maintaining the installation in line with the manufacturer's instructions and meeting fuel sustainability requirements by providing evidence of only using fuels on the Biomass Suppliers List (BSL) or an equivalent. Participants must complete and submit an annual declaration confirming they meet their obligations. Additionally, Ofgem have a robust annual audit programme to mitigate non-compliance, this includes randomly selected and targeted audits. The audit checks the installation is eligible to receive RHI payments and that the scheme rules are being properly followed.
- **Green Gas Support Scheme (GGSS):** Under the GGSS scheme participants must demonstrate to Ofgem that they meet the scheme's

sustainability requirements through quarterly declarations and independent annual sustainability audit reports commissioned by the generator. These reports must demonstrate compliance with the scheme's Greenhouse Gas (GHG) limits, including information about the total life cycle emissions associated with the injected biomethane, as well as evidence that their biomass has been sustainably sourced in line with the Land Criteria including requirements ensuring it does not come from protected land. Failure to comply with these sustainability requirements may result in compliance action, including reducing or withholding support payments, which would be determined on a case-by-case basis.

- **Renewable Transport Fuel Obligation (RTFO):** Under the RTFO, all applications for renewable transport fuel certificates (RTFCs) must be independently verified and the vast majority of fuel supplied is certified by voluntary schemes (98% in 2021).[218] To provide an additional check on compliance, the RTFO Administrator also performs a series of random and risk-based checks on applications including in-depth investigations where necessary. Collectively, this provides assurance over the sustainability and traceability of fuels supplied under the RTFO. Non-compliance is rare, but where identified can result in the revocation of certificates and/or the issuing of civil penalties. Any suspected fraud identified is reported to the police.
- **Low Carbon Hydrogen Standard (LCHS):** The individual schemes which apply the LCHS set the exact requirements for evidencing compliance with the emissions threshold, audit frequency and coverage, and consequences of non-compliance. This includes the Net Zero Hydrogen Fund (NZHF) and Hydrogen Production Business Model. For demonstrating compliance with the additional sustainability criteria which apply to biomass feedstocks, the use of a voluntary scheme listed in the LCHS is strongly recommended. Otherwise, an independent third-party audit may be used.
- **UK Emissions Trading Scheme (UK ETS):** Under the UK ETS, sustainability criteria are agreed by the UK ETS Authority and must be met for specific exemptions under the scheme and a zero-emissions factor rating associated with emissions. If an operator is using bioliquids to generate energy; the land use criteria exemption for waste; the specific qualifying category for tallow; or a recognised certified voluntary scheme for the RTFO, they must provide evidence and demonstrate to their independent verifier that they meet the specified sustainability criteria associated with that exemption. If it is determined an operator has reported emissions as being sustainable and it is later determined that this was incorrect, the regulator will re-determine their emissions to ensure they are reported correctly. This may result in enforcement action after the fact. Government recently consulted on the UK ETS biomass sustainability criteria. Further information about the development of criteria is available in the government response.[219]

[218] https://www.gov.uk/government/statistics/renewable-fuel-statistics-2021-final-report
[219] https://www.gov.uk/government/consultations/developing-the-uk-emissions-trading-scheme-uk-ets

Annex B: Domestic policies which interact with domestic biomass sourcing and use

Biomass policies interact with domestic policy landscape through the following domestic regulations:

1 **Forestry policies (felling licences, forestry regulations and timber regulations):** Forestry in England is regulated by the Forestry Act 1967. Other relevant legislation on afforestation and deforestation includes the Environmental Impact Assessment (Forestry) Regulations 1999, the Forestry (Felling of Trees) Regulations 1979, the Forestry (Exceptions from Restriction of Felling) Regulations 1979 and the Forestry (Modification of Felling Restrictions) Regulations 1985. The UK Forestry Standard is the reference standard for sustainable forest management. The UK Woodland Assurance Standard (UKWAS) is an independent certification standard for verifying sustainable woodland management in the UK that is used for certification by the Forest Stewardship. The Timber and Timber Products (Placing on the Market) Regulations 2013 regulate the placing on the market of imports of some forms of biomass, for example wood pellets. This is based on their legality of harvest in the country of harvest. The Forest Law Enforcement Governance and Trade (FLEGT) Regulations 2012 aim to prevent illegal logging through Voluntary Partnership Agreements (VPAs) with producer countries who opt to provide national level assurance of legal harvest.

2 **Waste regulation:** Waste is a devolved area and some provisions for waste regulation vary across the devolved administrations, such as the definition of food waste. All parts of the UK have policies in place to reduce waste. In England the resources and waste sector is regulated by the Environment Agency and in Wales by Natural Resources Wales under The Environmental Permitting (England and Wales) Regulations 2016. In Scotland the sector is regulated by the Scottish Environment Protection Agency (SEPA). In Northern Ireland to operate an Anaerobic Digester (AD) for food waste an authorisation (licence or permit) is required from Northern Ireland Environment Agency (NIEA). If the food waste includes animal by-products there must also be approval for the AD from a Divisional Veterinary Office in Northern Ireland. There are exceptions for an on-farm facility that only handles waste from the farm. The spreading of digestate from an AD that takes in waste and is not PAS110 is also regulated by NIEA in the form of a Paragraph 9 Exemption.

3 **Air Quality:** The UK has statutory ceilings in place for emissions of five of the most damaging air pollutants (including ammonia and $PM_{2.5}$), as well as local concentrations limits of key pollutants. In addition, England has two ambitious national concentration targets for $PM_{2.5}$. To ensure that these targets can be met, regulatory requirements that apply to the use of biomass (primarily through environmental permitting and Best Available Techniques) will need to develop over time as the use of biomass expands, and as our knowledge and understanding grows. Further detail on Air Quality regulations is found in Chapter 3.

4 **Other regulation:**

a. The UK Emissions Trading Scheme (UK ETS), a 'cap and trade' scheme, is a market-based pricing mechanism to incentivise and control the reduction of emissions in a cost-effective way. A cap is set on the total amount of certain greenhouse gases that can be emitted by the sectors covered by the scheme over a given period. The cap is divided into allowances, and participants receive or purchase allowances which they can sell and buy with one another as needed. The UK ETS will reduce over time, providing a long term market signal so companies can plan and invest in abatement accordingly. The UK ETS acts as a cross-cutting policy lever to drive market-based abatement, incentivising industries to find the most cost-effective solutions to decarbonise. The UK ETS currently applies to energy intensive industries, the power generation sector and aviation.

b. Biomass operations are also regulated through the planning system. Planning applications are determined in accordance with the development plan, (including the adopted local plan and any made neighbourhood plans) unless material considerations indicate otherwise. The National Planning Policy Framework[220] sets out the government's planning policies for England and how these should be applied, and the National Policy Statements for energy,[221] currently being updated, detail government's policy for the delivery of Nationally Significant Infrastructure Projects (NSIPs) for energy and provide the legal framework for planning decisions. The National Planning Policy for Waste will also be relevant particularly if the biomass operations are utilising waste as a feedstock.

[220] https://www.gov.uk/government/publications/national-planning-policy-framework--2
[221] https://www.gov.uk/government/publications/national-policy-statements-for-energy-infrastructure

Technical Annex

The analysis that underpins the Biomass Strategy is taken from three main sources:

- modelling of biomass availability
- Carbon Budget 6 analysis (CB6)
- UK TIMES modelling of the UK energy system

The sources and models used have been subject to rigorous quality assurance.

Biomass feedstock availability scenarios

The UK and Global Bioenergy Resource Model was originally developed in 2011 and used to support the 2012 Bioenergy Strategy. The model was updated substantially in 2015/2016 with a new module on sustainability, and an expansion in the range of feedstocks modelled to reflect developments in the market. Finally, estimates of land available for the cultivation of biofuels and energy crops globally were updated to be consistent with the Shared Socioeconomic Pathways developed for use in international climate modelling. This version of the model, and its supporting spreadsheets, were published in 2017.[222] In support of the Strategy, the model was updated again in 2022-2023 with an aim to:

- review and determine whether methodological developments are necessary to improve the representation of key sensitivities.
- include the most up to date evidence base and improved methodologies.
- overhaul the representation of domestic feedstock supply, in particular making it more spatially granular at an ITL1 level of detail.
- future-proof it so that it is able to incorporate new evidence that emerges.

The spreadsheet-based model provides estimates of the quantity of both domestically produced and imported biomass feedstocks that the UK could access out to 2050, if the technical potential availability of a range of feedstocks were realised.

Imports of bioethanol and biodiesel are considered as availability of finished fuels as the UK is unlikely to access the raw feedstocks. For the first-generation (1G) biofuels, production of a representative feedstock is modelled for each region, such as maize, sugar cane or wheat for 1G bioethanol; or soybeans, rapeseed or oil palm fruit for 1G biodiesel.

The model does not directly address timber or other high-value biological materials such as food. Use of potential feedstocks for higher value purposes are subtracted from the theoretical supply available for energy. However, any substantial increase in the use of biomass for higher value uses such as materials, food or the chemical sector to substitute for fossil fuel derived carbon may make these projections higher than the outturn, as these sectors are likely to have a higher willingness to pay than the energy sector.

[222] https://www.gov.uk/government/publications/uk-and-global-bioenergy-resource-model

The final published 2023 version of the model will include a further major restructure to provide a break-down of the domestic feedstock supply by regions of the UK, and a more flexible treatment of the share of imports and of sustainability criteria. These changes were implemented internally by DESNZ analysts to an interim model for the purposes of the Biomass Strategy and so minor differences may exist between the final model outputs and those used here.

Key sources of estimates used in modelling:

- Global non-forestry feedstock production is estimated based on land area information from the IMAGE Integrated Assessment Model, shared by PBL of the Netherlands incorporating scenarios that span a range of future climate outcomes using assumptions derived from the IPCC's Shared Socioeconomic Pathways.
- The production of biomass crops requires land availability estimated by IMAGE where land availability is a function of pressures such as population growth, dietary change, food productivity, food waste and system efficiency. The model takes a precautionary approach in only allowing the planting of energy crops on abandoned arable land to avoid biomass displacing food crops.
- The global forestry model (from Forest Research) contains data on areas of coniferous and non-coniferous primary, regenerated and plantation forest on a country-by-country basis. These areas are combined with estimates of the mean yield class of each type of forest in each country, to estimate the annual potential harvest of forestry biomass wood in that country.

  The global forestry model includes several mechanisms to allow the user to represent the implementation of sustainability criteria, including the ability to specify the proportions of each of the forest types represented in the model, and allowing the user to select a threshold yield class below which harvesting is assumed to be avoided or partially restricted. In line with the UK's current sustainability criteria the model has been set to exclude harvest from primary forests and to not take material from countries in which the forest harvest rates are greater than gross forest growth.
- The domestic feedstock availability assumptions were circulated to a range of government stakeholders taking into account current policy objectives. Feedstock numbers are constrained by views on the likely outcomes of policy in England rather than representing technical potential. The SRC/SRF areas, while significantly greater than currently planted areas, are much lower than other estimates and represent Defra views on the constraints on land from food security and biodiversity and other land use pressures arising from Environment Act requirements.
- All feedstocks are required to meet current UK sustainability requirements.

There remain major uncertainties about the UK's share of internationally produced biomass and of the uptake of bioenergy crops domestically, particularly in the Devolved Administrations which are poorly represented in the model due to policy frameworks being under development. The model was used to support the Biomass Strategy by generating scenarios which illustrate ranges of feedstock availability.

The Biomass Strategy presents two availability scenarios to explore how much sustainable biomass the UK could access.

The ambitious supply scenario:

- Includes higher levels of domestic energy crop planting, reaching 17 kha/yr from 2038 onwards.
- Assumes the UK can import a fraction equal to its share of global GDP of all overseas-produced bioenergy that meets our sustainability criteria.
- Includes the underlying assumption that the future may see a well-established global market for biomass supported by the required increase in infrastructure, with producers of biomass willing to export it rather than retain it for domestic use. This would likely be supported by strong price signals from importing countries, possibly with demand ensured by firm decarbonisation policies.

The restricted supply scenario:

- Includes levels of domestic energy crop planting that reach 9 kha/yr from 2038 onwards.
- Assumes that most countries producing biomass prioritise their own domestic use, and so only one-fifth of overseas production is exported; of this volume available for trade, it is assumed that the UK competes equally with all other nations and so can secure a fraction of this market equal to the UK's share of global GDP.
  - This factor of one-fifth (20%) is based on values found through interrogating other modelling, specifically the 2017 version of the 'UK and Global Bioenergy Resource Model', the TIAM-UCL global energy model[223] and the Global Energy and Climate Outlook 2022 of the EU's JRC.[224, 225]
- Could be characterised as each country prioritising their own decarbonisation goals ahead of considering potential market opportunities.
- In these scenarios, GDP is used as a proxy to reflect the UK's potential purchasing power and therefore ability to import and compete for biomass from other regions. The UK's GDP as a proportion of global GDP is taken from Shared Socio-economic Pathways modelling using IMAGE,[226] assuming the 'SSP1: Sustainability – Taking the Green Road' scenario:

[223] https://www.ucl.ac.uk/energy-models/models/tiam-ucl

[224] Keramidas et al., 'Global Energy and Climate Outlook 2022: Energy trade in a decarbonised world', Publications Office of the European Union (https://publications.jrc.ec.europa.eu/repository/handle/JRC131864).

[225] It is not a strict average of the export proportion seen across different time periods in these models but instead an indicative, 'order of magnitude' assumption to illustrate a potential range. The 2017 bioenergy resource model, described above, was a biophysical model that assumed each region met its own demand and only exported surplus production. The TIAM-UCL and JRC models are, in general, least-cost optimising models of the global energy system while meeting decarbonisation or climate targets, and so while profits from trade are considered, this would be secondary to ensuring, for example, that global warming stays below 1.5°C.

[226] https://www.pbl.nl/en/publications/the-2021-ssp-scenarios-of-the-image-32-model

Year	UK fraction of global GDP
2020	2.62%
2025	2.56%
2030	2.29%
2035	2.09%
2040	1.95%
2045	1.85%
2050	1.77%

The UK's fraction falls over time as, generally, the GDP of developing countries grows faster than that of developed countries.

- In both scenarios, we assume that the UK retains its biomass and biofuel production for domestic use, with no exports. We make this assumption because we anticipate domestic demand to be underpinned by robust decarbonisation policies (e.g., the SAF mandate) and so domestic use will be an attractive market for UK producers, particularly as it will keep their transport costs low. In the ambitious scenario, this equates to the UK consuming around 3% of global (overseas plus UK) sustainably produced biomass, so not excessively beyond our fraction of global GDP.

The economic interactions between import levels, demand, price, market share and overseas production are not modelled here, as this is only a biophysical model looking at sustainable technical potential. Many of the feedstocks in question are bulky and relatively low value and so transport costs may be prohibitive to the development of a global market at scale.[227]

In reality, the future level of imports is likely to fall somewhere in between the two scenarios, as many, but not all, countries may keep their biomass production primarily for domestic use, while not all countries will be competing equally for imports – for example, those that have high domestic production and exports of biomass are unlikely to also be importing significant quantities. Decarbonisation goals and delivery plans around the world are still at a nascent stage and so it is difficult to predict individual countries' approaches. Nevertheless, the profiles used give an indicative range, though the eventual outturn levels may still fall outside of these profiles.

Carbon Budget 6 demand analysis

The methods used to model energy demand projections up to the end of CB6 in 2037 are the same as those used to model emissions projections at a policy and sector level, as published in the Carbon Budgets Delivery Plan (CBDP, March 2023).[228] For each policy within the CBDP, sector teams model the energy demand impacts of the policy for each year – for example the policy 'Biomethane – future support' projects a net increase in demand of biomethane and a net reduction in demand for fossil natural gas, as biomethane is injected into the grid. For biomass-related energy demands,

[227] Economic trade modelling is complex and many factors could affect future trade potential such as distance between countries and regional policies affecting demands and availabilities over time. Furthermore, individual commodities will have characteristics that make them more or less suited to trading, e.g., wet feedstocks will be less stable and more expensive to transport.

[228] https://www.gov.uk/government/publications/carbon-budget-delivery-plan

four categories of biomass are included in sectoral energy demand modelling: liquid biofuels, lignocellulosic biomass, biomethane/biogas, and biogenic waste.

Energy demand impacts for all policies within each sector are cumulated and added to a baseline based on the 2021-2040 Energy Emission Projections (EEP 2021-2040) publication.[229] The EEP 2021-2040 reference scenario sets out the government's central projections of how the energy and emissions system will evolve under EEP-ready policies. This projection assumes no further government policy action beyond policies that are in very late stages of development or have already been implemented.

Together, the EEP 2021-2040 baseline and sectoral modelling of energy demand impacts provide us an energy demands pathway to 2037. Full methodology of sector modelling can be found within the Powering Up Britain Technical Annex.[230]

In order to analyse biomass feedstock availability to meet demand projections, feedstocks were manually assigned to one of the four biomass fuel types tracked in sectoral energy demands modelling. This assignment was based on expert assessment and by reference to the feedstock processing pathways in the UK TIMES model (see following section), in order to maintain consistency with modelling for the 2050 scenarios.

We expect that, between now and 2050, the package of proposals and policies will evolve to adapt to changing circumstances, new evidence, technological developments and emerging challenges. In addition, for the purposes of Figure 5.3, each feedstock has only been assigned as contributing to a single fuel type, whereas in reality it is likely some feedstocks may contribute to more than one fuel category. It is possible that the preferred use of biomass feedstocks may change between now and the end of CB6, as demand, feedstock availability, and technological readiness vary and change. As such, the precise energy demand pathway should be considered illustrative and subject to change.

Illustrative 2050 scenarios – UK TIMES analysis

The Biomass Strategy presents three illustrative scenarios to help explore the potential role of biomass in 2050. All three scenarios are set in the context of an energy system that meets net zero but using different approaches. These are based on the Net Zero Strategy scenarios, which themselves built on the pathways developed for the Sixth Carbon Budget Impact Assessment. These have been deliberately selected to illustrate a wide range of outcomes for the economy that are possible by 2050. However, different outcomes within or beyond this range are also possible.

This section explains the methodology that was used for this analysis and summarises the differences between the three scenarios. For the approach used to build these scenarios, please see the Net Zero Strategy.[231]

[229] https://www.gov.uk/government/publications/energy-and-emissions-projections-2021-to-2040
[230] https://www.gov.uk/government/publications/powering-up-britain
[231] https://www.gov.uk/government/publications/net-zero-strategy

The modelling uses the UK TIMES Model; a least-cost, optimisation model covering all UK emissions (including land use) and the UK energy system over the period 2010 to 2060.[232] The model includes assumptions about technology costs, availability, performance, and build rates.[233] It also includes assumptions for future fossil fuel prices and energy services demand by end-use sector. These inputs are pre-determined for each model run and do not vary with deployment. Based on the input assumptions, the model identifies the least-cost way of meeting a given GHG reduction trajectory while also meeting assumed end-use demand for energy services. Further information on the methodology and assumptions used in the UK TIMES model can be found in Annex A.2 of the sixth carbon budget impact assessment.[234]

A particular advantage of UK TIMES is that it identifies the least-cost technology pathway for a given set of assumptions, taking account of interactions across energy supply and end-use sectors over time. The model is therefore useful for identifying which technologies could be essential or important in the long run for achieving a low cost, net zero consistent energy system. It also helps identify the appropriate sequencing of abatement opportunities.

However, there are several limitations to the modelling:

- The model does not directly take account of uncertainty of any kind over future technology costs and availability. Uncertainty is only displayed through the range of inputs used and outputs given across the different scenarios. Furthermore, assumptions are based on current evidence that is subject to change and new technologies or assumptions could develop that change pathways to net zero.
- Technology cost reductions over time in the model are based on fixed assumptions and do not vary with deployment levels. In reality, costs per unit would likely be higher when deployed at small scale but could decrease as the scale of technology expands.
- No additional barriers beside cost and technical build rates nor the potential industrial benefits from developing and deploying new low-carbon technologies are considered. Modelling does not consider any upside or downside risks to the economy arising from the energy transition, such as job creation or retention.
- Delivery risk is not considered which, when combined with the cost-optimising nature of the algorithm, means that if presented with two similar technologies, the model will exclusively choose the cheaper option. Sector analysis can help protect against this by identifying other plausible choices that could be used to diversify the delivery portfolio and protect against technology-specific risks.

[232] UCL, 'UK TIMES', https://www.ucl.ac.uk/energy-models/models/uk-times
[233] The model takes account of the direct cost of purchasing, installing, running and maintaining the abatement technologies. The cost of purchasing and installing includes assumed capital costs and the cost of borrowing to pay for the capital. Running costs include the cost of energy supplies, both domestic and any imports.
[234] UK Legislation (2021), 'Carbon Budget Order 2021 impact assessment': https://www.legislation.gov.uk/ukia/2021/18/pdfs/ukia_20210018_en.pdf

- Behavioural or other practical considerations that might make certain pathways more or less expensive to achieve are not accounted for (other than where they are reflected in costs or build rates).
- The model varies in detail by sector. In some areas only high-level representations are provided and so results may vary from detailed sector-specific modelling.
- UK TIMES does not currently include spatial or geographical aspects and so cannot model all the costs and practicalities of building, maintaining or decommissioning transmission and distribution networks (such as for electricity, gas, hydrogen or captured carbon).
- The model also has limited temporal resolution, which may miss important details in the power sector.

As such, our analysis within the Strategy using the UK TIMES model is largely qualitative in nature, exploring the broad potential uses of biomass in different scenarios, and drawing broad conclusions that are robust to the limitations outlined.

The three illustrative 2050 scenarios presented in the Biomass Strategy are summarised below:

- **High electrification:** explores the impact of using widespread electrification to support transport, heating, and industry decarbonisation coupled with deep decarbonisation of electricity supply.
- **High resource:** explores the impact of using low-carbon hydrogen more extensively, particularly for decarbonising buildings and heavy vehicles. It assumes higher levels of tree-planting are achievable, increasing the 'negative emissions' available from land-use sinks.
- **High innovation:** explores a world in which successful innovations, such as synthetic fuels and zero emission aircraft, enable lower residual emissions to be reached sooner in aviation. Higher capture rates – above baseline assumptions – increase the impact of carbon capture technologies, particularly higher deployment of direct air capture.

The scenarios were constructed in UK TIMES by varying input assumptions for:

- The extent to which technologies can be rolled out. For example, in the high electrification scenario, 100% of buildings are set to be heated by electricity in 2050, whereas in the high resource scenario heat pump deployment is constrained and this figure drops to 40%.
- The availability of resources and technologies. For example, in the high resource scenario, we assume 50 kha afforestation per annum by 2050 (compared to 30 kha in the other scenarios). Higher efficiency capture technologies are only available in the high innovation scenario (for example CCUS capture rates of 99% compared to 95% in most cases in the other scenarios).
- Sectors such as industry and aviation, where the model does not represent the full range of known abatement options, supplementary adjustments to emissions, energy demand, and key deployment requirements have been made. These have been taken into account in the optimisation of other sectors via the specification of the emission targets.

Other assumptions were kept the same across the scenarios. For instance, projections of final demand for end-use sectors are consistent with those used in the central 2037 delivery pathway and are the same for each of the modelled 2050 scenarios. Technology and resource cost assumptions, including fossil fuel prices, are also the same across each scenario. As mentioned above, these scenarios could change over time with new evidence.

Sensitivity analysis conducted as part of the Sixth Carbon Budget Impact Assessment showed that the impact of economic growth and fossil fuel prices on the technology mix in 2050 is relatively small, therefore these effects were not considered further.[235]

The UK TIMES model is under continual development and since the publication of the Net Zero Strategy, there have been three key updates relevant to this Biomass Strategy:

- **Biomass availability:** the availability of biomass feedstocks and biofuels, both domestically including energy crop planting rates and for imports, has been aligned with the ambitious supply profile of the availability model as described here and in the Biomass Strategy.
  - There are significant uncertainties around future biomass availability which makes estimating future supply to the UK very challenging, particularly with respect to imported biomass, as discussed above.
  - In the biomass availability chapter, we have presented two supply profiles to provide a broad frame of reference within which to analyse the role of biomass in meeting net zero. These are not intended to be upper or lower estimates of future expected biomass availability.
  - The ambitious supply scenario has been used in UK TIMES modelling, based on the assumption that the UK will continue to be a leading importer of biomass, to illustrate how biomass could be used to support net zero under the various energy system scenarios. However, we are working with departments across government to understand the impacts of the UK having less access to biomass supply, including what policy action may be required to mitigate this risk.
- **Sustainable aviation fuel technologies and mandate:** A range of technologies have been added to the model such as:
  - Biomass-to-Liquid and Waste-to-Liquid processing based on Fischer-Tropsch gasification with and without carbon capture;
  - Alcohol-to-Jet processing including fermentation technologies with and without carbon capture;
  - HEFA production; and
  - Power-to-Liquid technologies.

  A mandate requiring the use of sustainable aviation fuel is currently under consultation and includes a central option that reaches 22% by 2040. This central mandate level has been added into UK TIMES, remaining at the same level for future years, until further decisions are made.

[235] UK Legislation (2021), 'Carbon Budget Order 2021 impact assessment': https://www.legislation.gov.uk/ukia/2021/18/pdfs/ukia_20210018_en.pdf

The distribution of fuel types is as yet undetermined and is to be set out further in the government response to the SAF mandate consultation.[236]

- **Hydrogen BECCS technological assumptions:** the costs and efficiencies of the hydrogen BECCS technology has been updated to align with the latest evidence published in 'Hydrogen production costs 2021'.[237]

These updates have been used in all three illustrative scenarios presented in the Biomass Strategy.

Data collection exercise

The impact of growing and using biomass on water quality, land use and air quality emissions, among others, are important factors that should be considered as government policies are developed. However, the UK TIMES model is a technology-focused model that seeks only to minimise the costs of reaching net zero and so provides limited treatment of these factors.[238]

Therefore, in developing the Biomass Strategy, DESNZ engaged with other government departments to identify those factors extraneous to the UK TIMES model that might influence the future balance of biomass usage, including uses for non-energy purposes.

One output of this exercise is a dataset describing the impact of a variety of different biomass feedstocks, technologies, and end-uses on a wide range of environmental criteria. This will be useful in future policy development and assessment by providing additional insight into how biomass should be prioritised up to 2050.

There are many ways to convert biomass feedstocks (e.g., forestry residues, cooking oils, manures and slurries) into forms suitable for many end-uses. Further work would be required to use the data we have collected to provide further insight into how biomass use could be best prioritised. This would complement the insights and findings from the UK TIMES model.

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236 DfT (2023), 'Pathway to net zero aviation: developing the UK sustainable aviation fuel mandate': https://www.gov.uk/government/consultations/pathway-to-net-zero-aviation-developing-the-uk-sustainable-aviation-fuel-mandate

237 BEIS (2021), 'Hydrogen production costs 2021': https://www.gov.uk/government/publications/hydrogen-production-costs-2021

238 UK TIMES does have limits imposed on land available for energy crops but is not otherwise incentivised to reduce land take. Similarly, the generation of airborne pollutants is tracked within the model, and damage costs (https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-damage-cost-guidance) are applied which encourage the model to avoid these emissions as part of the cost-minimising algorithm, but the location of these emissions and the resulting ground level concentrations are not considered.

Glossary

ACT	Advanced Conversion Technologies
ACT-3	Accelerating Carbon Capture and Storage Technologies 3
AD	Anaerobic Digestion
BAT	Best Available Technology
BECCS	Bioenergy with Carbon Capture and Storage
Bio-CNG	Bio-Compressed Natural Gas
Bio-LNG	Bio-Liquified Natural Gas
Bioeconomy	Economic activity involving the use of biotechnology and biomass in the production of goods, services, or energy.
Bioenergy	A form of renewable energy that is derived from recently living organic materials known as biomass
Biofuel	Fuels produced over a short time span from biomass
Biomass	Refers to any material of biological origin (including wastes) which is used as a fuel for bioenergy (conventional combustion, gasification, energy from waste and low-carbon fuels like biofuels and hydrogen) or in products (such as chemicals, bioplastics and timber for construction).
Biomass feedstock	Refers to any material of biological origin which is used to supply or fuel a machine or industrial process, including construction.
BUS	Boiler Upgrade Scheme
BSI	British Standards Institution
BSL	Biomass Suppliers List
CB	Carbon Budget
CBDP	Carbon Budget Delivery Plan
CCC	Climate Change Committee
CCUS	Carbon Capture Usage and Storage
CCS	Carbon capture and storage
CCH_2	Carbon Capture and Hydrogen
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CEM	Clean Energy Ministerial
CfD	Contracts for Difference
CH_4	Methane
CHP	Combined Heat and Power
CHPQA	Combined Heat and Power Quality Assurance Programme

CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide equivalent
CSS	Compact Syngas Solutions
DAC	Direct Air Capture
DACCS	Direct Air Carbon Capture and Storage
DAERA	Department of Agriculture, Environment and Rural Affairs for Northern Ireland
DESNZ	Department for Energy Security and Net Zero
DEFRA	Department for Environment, Food and Rural Affairs
DFT	Department for Transport
DLUC	Direct Land Use Change
DRHI	Domestic Renewable Heat Incentive
ECSWG	Environment and Climate Sustainability Working Group
EfW	Energy from Waste
Energy crops	Refers to crops that are grown for energy or material uses only and would not normally be used for consumption as food or feed.
ETAP	England Trees Action Plan
ETWG	Energy Transition Working Group
ESO	Electricity System Operator
EV	Electric Vehicles
FIT	Feed In Tariff
FLEGT	Forest Law Enforcement Governance and Trade
FOAK	First Of a Kind
FRfW	Farming Rules for Water
FSC	Forest Stewardship Council
GGR	Greenhouse Gas Removal
GGSS	Green Gas Support Scheme
GHG	Greenhouse gas
GBEP	Global Bioenergy Partnership
H_2	Hydrogen
HGV	Heavy Goods Vehicle
HVO	Hydrogenated Vegetable Oil
IB	Industrial Biotechnology
ICAO	International Civil Aviation Organization

IDS	Industrial Decarbonisation Strategy
IEA	International Energy Agency
IETF	Industrial Energy Transformation Fund
ILO	International Labour Organisation
ILUC	Indirect land use change
IMAGE	'Integrated Model to Assess the Global Environment' developed by PBL Netherlands Environment Assessment Agency
IMO	International Maritime Organization
ICC	Industrial Carbon Capture
IPCC	Intergovernmental Panel on Climate Change
ISCC	International Sustainability and Carbon Certification
ISO	International Standards Organisation
LA	Local Authority
LCA	Life cycle assessment
LCCC	Low Carbon Contract Company
LCHS	Low Carbon Hydrogen Standard
LPG	Liquified Petroleum Gas
LULUCF	Land Use, Land Use Change and Forestry
MCP	Medium Combustion Plant
MRV	Monitoring, Reporting, and Verification
NDRHI	Non-Domestic Renewable Heat Incentive
NECR	National Emission Ceilings Regulations
NIEA	Northern Ireland Environment Agency
NRMM	Non-Road Mobile Machinery
NZHF	Net Zero Hydrogen Fund
NZIP	Net Zero Innovation Portfolio
ODT	Oven Dried Tonne
Ofgem	Office of Gas and Electricity Markets
PAS	Publicly Available Specification
PEFC	Programme for Endorsement of Forest Certification
PJ	Petajoule
Power-BECCS	Power Bioenergy with Carbon Capture and Storage
QP	Quality Protocol
RDF	Refuse Derived Fuels

rDME	renewable dimethylether
RED	Renewable Energy Directive
REDD+	Reducing Emissions from Deforestation and Forest Degradation
REMA	Review of Electricity Market Arrangements
RHI	Renewable Heat Incentive
RO	Renewables Obligation
RPS	Regulatory Position Statement
RSPO	Roundtable on Sustainable Palm Oil
RTFC	Renewable Transport Fuel Certificates
RTFO	Renewable Transport Fuel Obligation
SAF	Sustainable aviation fuel
SBP	Sustainable Biomass Programme
SDG	Sustainable Development Goals
SEG	Smart Export Guarantee
SEPA	Scottish Environment Protection Agency
SFI	Sustainable Farming Incentive
SME	Small to Medium Enterprise
SMR	Steam Methane Reformation
SNG-BECCS	Substitute Natural Gas Bioenergy with Carbon Capture and Storage
SR	Spending Round
SRC	Short-Rotation Coppice
SRF	Short-Rotation Forestry
SUiAR	Sewage Use in Agriculture Regulations
THC	Tetrahydrocannabinol
TPP	Timber Procurement Policy
TRL	Technology Readiness Level
T&S	Transport and Storage
UCO	Used Cooking Oil
UKETS	UK Emissions Trading Scheme
UK TIMES	UK The Integrated MARKAL-EFOM System model
UKRI	UK Research and Innovation
UNDRIP	United Nations Declaration of Rights of Indigenous Peoples
WRME	Wood Raw Material Equivalent
WwTW	Wastewater Treatment Works