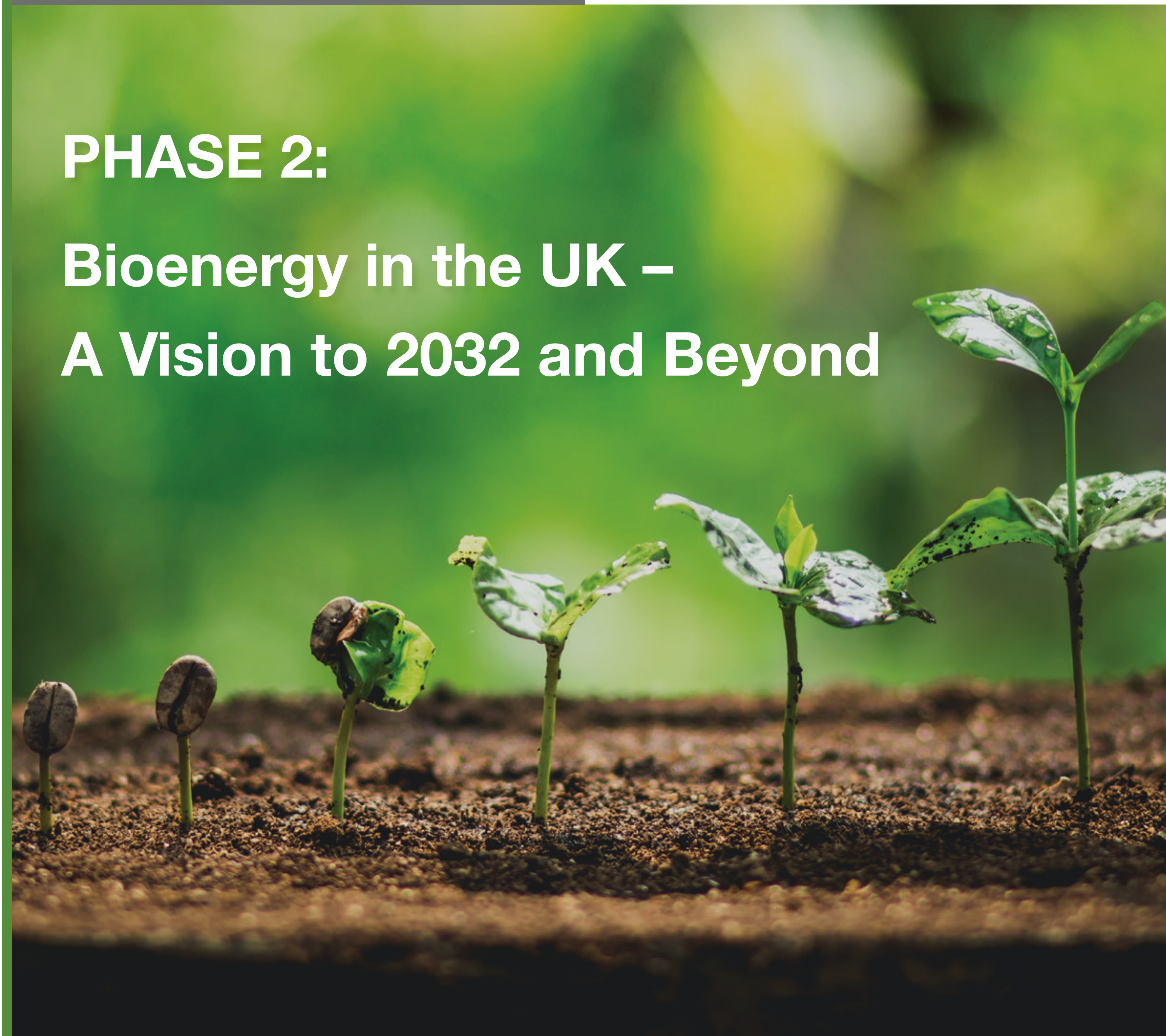
RENEWABLE ENERGY ASSOCIATION

| BIOENERGY STRATEGY

PHASE 2:

Bioenergy in the UK – A Vision to 2032 and Beyond



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Finally, also thank you to all the industry stakeholders who continue to participate in the numerous working group discussions, across power, heat and transport providing invaluable insight to inform the Strategy's development.

The REA Bioenergy Strategy Project

The REA is leading an industry wide strategy paper for bioenergy in the UK, which we believe is timely due to:

- The rapidly evolving UK and international perspective on bioenergy
- Its critical role in the UK renewable energy scene now and potentially in the future
- The absence of an up-to-date UK government strategy for bioenergy or plans to develop one.

Objective

The objective of this work is to provide an industry led perspective on:

- The current contribution of bioenergy to UK energy supply and demand, including looking at the benefits that this brings
- An appreciation of the strengths of the current UK bioenergy industry and its capabilities
- To identify the barriers, including those related to policy and regulation, which are holding back more rapid deployment
- To develop the vision of what the sector could provide (by 2032) and how this could help UK policy objectives relating to environment, energy security and to economic development
- The actions needed to deliver the vision, including what policy and regulatory framework would be needed to allow industry to deliver this future, along with the complementary actions by government, or other players, that would help deliver it. For example, investment in research, design and demonstration (R,D&D), removal of specific regulatory barriers and supporting finance, amongst further proposals.

The project will examine bioenergy as a whole, and will consider the current and potential contributions from bioenergy to electricity, heat and transport, and in the context of the development of a sustainable bioeconomy.

Consultation

In order to ensure that the strategy is based on the active engagement of key stakeholders the following groups have been constituted:

- An advisory group made up of senior REA officials and industrial decision makers who can represent the main sectoral interests, along with experts/influencers from academia/consulting backgrounds and including key government officials as observers

- A number of small working groups of industry players to provide more detailed information and views for each of the main sectors.

As the strategy develops the work will also be discussed more widely with industry representatives via consultative workshops. The REA have also launched a call for evidence via their website to enable a broad range of stakeholders to contribute their views.[1]

Work Plan

In order to meet the objectives and scope above, the work project is organised into three main phases which are:

- **Phase 1** – a review of the current status and trends in bioenergy in the UK, covering;

    - Trends in the deployment of bioenergy;
    - The benefits of current bioenergy deployment in the UK in terms of impact on the environment, energy security and the economy (including jobs) and in developing industry strengths and capabilities that will be needed in the future
    - A review of the current policy and regulatory framework and the extent to which this is holding back further deployment.

- **Phase 2** – will develop a vision of bioenergy for the future with a focus on the contribution that can be made by 2032 the end of the 5th carbon budget accounting period. This will:

    - Consider current perceived role of bioenergy in future UK low carbon energy mix as described in government scenarios and plans
    - Review these to look at the implications for sector development in the medium to long term (2032 to 2050)
    - Identify other opportunities for greater bioenergy contribution in the medium term which can lead to immediate benefits or provide insurance against the non-delivery of other technologies
    - Identify potential, costs and benefits of additional options

- **Phase 3** – will develop an industry view of the key actions by the main actors to allow the vision to be achieved. This will include recommendations for:
    - Policy and regulatory measures
    - R,D&D priorities
    - Other actions relating to industry and to the finance sector, if appropriate

The aim is to complete the necessary work in order to allow publication of the report later this year.

For each of the three phases, a working paper will be produced, summarising the information and analysis provided by stakeholders. A summary of each paper will also be published via the REA website. These papers will form the basis for the final report from the project – a strategic document aimed at decision makers in government and industry.

Bioenergy Strategy Vision – Executive Summary

Key messages

- **Bioenergy is required to meet the UK's legally binding carbon budgets and realise Net-Zero by 2050**

  This report demonstrates that the role of bioenergy could be sustainably increased by a factor of 2.5 in the UK by 2032. Bioenergy deployment across power, heat and transport could address two-thirds of the Committee on Climate Changes (CCC) projected shortfall in carbon reductions required to meet the legally binding 5th Carbon Budget and is essential if the Government is to meet the CCC's recommended target for net zero emissions by 2050.

- **Bioenergy delivers energy security, mitigating future strain on the electricity system**

  Increasing levels of Biomass Power and using bioenergy to contribute to heating and transport, simultaneously decarbonises the electricity grid and reduces electricity demand allowing the UK to address the perceived 'nuclear gap' left by recently shelved nuclear power projects.

- **Bioenergy delivers most immediate and affordable route to carbon reductions in heat and transport sectors**

  In the heat and transport sectors, bioenergy is the cheapest and most technologically available route to immediate carbon reductions, while also providing a pathway to development and commercial deployment of future technologies, all of which will be needed to meet the levels of decarbonisation required.

Bioenergy and the UK's Low Carbon Strategy

The UK is committed to the development of a low carbon economy, with a target to reduce green-house gas (GHG) emissions by 80% by 2050. A recommendation by the Committee on Climate Change (CCC) to adopt a net-zero emission target for 2050 is currently under consideration. So far, the UK has met its interim carbon budgets, but the CCC warns that the targets embodied in the 4th and 5th carbon budgets are unlikely to be achieved.

The UK decarbonisation strategy, as set out in the Clean Growth Strategy, relies heavily on increased electrification of the energy system, including for heating and transport. A four-fold increase in low carbon electricity generation would be needed in the CCC's net-zero carbon scenario.There are some risks to this approach, particularly the practicality and cost of expanding the transmission and distribution system to meet increasingly seasonal loads associated with heating.

This concern is being exacerbated by the fact that the planned nuclear project pipeline looks unlikely to be delivered on time considering the cancellation of at least three projects, leaving a significant shortfall in the UK's low carbon generation portfolio.

Bioenergy is ready to help the UK meet its targets and mitigate these delivery risks.

Bioenergy can reduce the electricity generation and distribution infrastructure needs in a low carbon economy by providing a substantially larger contribution to heating needs for buildings and industry, both directly and via heat networks. It will play a particular role in providing heating in off-gas grid properties and those where heating via heat pumps is likely to be most challenging. While It can also provide low carbon supplies of gas into the gas network, allowing continued use of this infrastructure in a low carbon scenario.

In the transport sector biofuels can provide immediate GHG savings in road transport using existing vehicles and infrastructure, without in any way impeding the development of electric vehicles as the technologies and infrastructure develops. They can also offer a long-term low carbon solution for commercial vehicles, compatible with local clean air requirements using biomethane and a low carbon alternative for the aviation and shipping sectors, which are hard to decarbonise in other ways.

Bioenergy for power generation can provide an alternative to nuclear as a low carbon, dispatchable source of electricity, with lower costs of power generation than nuclear. Capacity can be built more quickly (with potentially 3 GW online by 2032) and be funded by the private sector while avoiding the long-term sustainability issues associated with nuclear waste storage. Bioelectricity generation can also be linked to carbon capture and use or storage (CCUS), thereby providing a "negative emission" technology likely to be needed in very low carbon scenarios.

The effective deployment of Bioenergy in heat, power and transport also provides a market pull that stimulate GHG savings in non-energy sectors through improved waste management practices including the move away from landfill, better agricultural waste management and the stimulation of improved forestry practices.

What's more, looking further ahead, if the Government follows the CCC's recommendation that the UK should set a Net Zero Emissions target by 2050, bioenergy will play a key role in its attainment, especially through the deployment of bioenergy systems linked to CCUS. This will pave the way for large-scale deployment of these technologies after 2032, linked to the production of biomethane, advanced biofuels (e.g. aviation fuels), and hydrogen.

Bioenergy – Vision to 2032

This report constitutes phase two of the REA Bioenergy Strategy, within it a quantitative vision of the role that bioenergy could play in the UK by 2032 has been developed. The approach adopted takes account of factors such as the volume of biomass resources available while respecting sustainability criteria and the rate at which markets could realistically be developed. It uses a mix of established and commercially available technologies and some technologies still at an earlier development stage, including some that are likely to be significantly deployed only after 2032 (notably those associated with bioenergy with CCUS).

The vision recognises that the on-site use of residues or wastes at the point of production is preferable when possible as the most economic, energy and carbon efficient. This is because associated transport costs and emissions are avoided. The vision also recognises that the most efficient use of biomass from a GHG perspective is in the direct production of heat with a conversion efficiency equivalent to fossil fuels (approaching 90%).

The ways in which bioenergy are used may change over time, as new bioenergy technologies mature and as the overall energy system becomes less GHG intensive. However, the technologies that will enable some of the low carbon bioenergy options are not as yet technically proven and commercialised, including the large-scale thermal gasification of biomass to produce biomethane and the production of biofuels for aviation. There are very few examples of bioenergy production with CCS globally, even at a pilot scale, although a handful are using – rather than storing-captured CO_2. Rather than do nothing until these solutions are available, the approach proposed here is to deploy bioenergy as soon as practicable using technologies that are available now so long as they are low cost and provide GHG and other co-benefits.

This approach will:

- Lead to immediate GHG, economic and other benefits
- Develop national and international supply chains that will be needed to support any large-scale use of bioenergy in the future (and which will take some time to evolve) and maintain and develop UK expertise in bioenergy
- Provide opportunities to develop projects which serve as stepping-stones along the roadmap towards the longer-term options (e.g by providing initial market opportunities for biomass gasification or for projects associated with carbon capture and use)
- Provide insurance against delays or longer-term problems in deploying the new technical options

Increased Contribution to UK Energy Supply

The vision identifies opportunities to expand the role of bioenergy for heating, transport and electricity generation based both in technologies available now and those which can play a significant role by 2032. The vision for the contribution of bioenergy is summarised in **Table 1**

Table 1 • Bioenergy vision to 2032 – summary of contributions

Contribution to UK Energy Supply PJ

	2020	2026	2032
Heat	159	219	376
Transport	42	167	261
Electricity	121	144	205
Total	**323**	**530**	**843**

Overall, the role of bioenergy is increased by more than 60% between 2020 and 2026 and by a factor of over 2.5 by 2032. Growth is targeted particularly at the heat and transport sectors, where bioenergy can play a unique role in decarbonisation efforts.

The overall share of bioenergy in final energy demand rises from 5.5% in 2020 to 9.5% in 2026 and nearly 15% in 2032. The role of bioenergy rises in each of the main sectors:

- In providing heat for homes businesses and industry energy, the share rises from 6.6% in 2020 to nearly 10% by 2026 and 16.3% in 2032
- In transport bio energy grows from below 2% in 2020 to over 7% in 2026 and nearly 12% in 2032
- Bioelectricity rises from 11% in 2020, to 13.5% in 2026 and over 17% by 2032

The vision also includes the demonstration of carbon capture and use or storage at a significant scale, laying the basis for expansion of these technologies post 2032

Biomass Resources

Meeting these levels would make full use of the potential feedstocks from residues and wastes that are available or that could be developed within the UK. In addition the strategy relies on the deployment of markets for energy crops – "dry" cellulosic crops such as miscanthus and short rotation coppice, and crops suitable for digestion. An active programme will be required to develop the necessary supplies and infrastructure.

Additional imported resouces would be required, notably solid biomass pellets for large scale power generation where the volumes imported would need to double to around 400 PJ. Additional liquid biofuels for transport would need to come from international markets (between 100 and 150 PJ, depending on the volumes available from the UK) but in industry's view, the necessary materials could be procured whilst still respecting stringent sustainability criteria.

Benefits

Developing the use of bioenergy in this way would significantly increase its environmental and economic benefits.

- The implementation of the proposed vision and strategy could play a major role in reducing the CCC's predicted emissions overshoot of 10-65 MTCO2e for the end of the 4th and 5th carbon accounting period, with total reduction in GHG emissions due to fossil fuel replacement amounts to some 41 MTCO2e in 2026 and to 65 MTCO2e in 2032. A further 23 MTCO2e, could be saved by 2032, due to CCUS of CO2 separated from bioenergy processes (existing processes and newly installed capacity with purposed designed capture systems)
- The deployment would contribute an additional 215 PJ (60 TWh) to the supply of heat in the UK without calling on the electricity supply and distribution system. The additional bioelectricity generated would amount to some 57 TWh. Taken together these two contributions reduce the need for other low carbon generation needed to supply the growing demands for heat, transport and other uses by 117 TWh – more than enough to close the predicted "nuclear gap" of 72 TWh
- The increase in deployment is likely to increase the number of jobs associated with bioenergy in the UK to over 80,000 by 2026 and over 100,000 by 2032

Next Steps

Such a vision will only be realised with a supportive policy and regulatory framework, which provides long-term confidence to investors while setting strict standards for sustainability management. The CCC point out that such a policy and regulatory framework is required for the whole of the UK low carbon strategy, and is particularly the case for bioenergy.

Progress in bioenergy in the UK over the last ten years has been stimulated by a number of supportive policy measures, but they have now either been progressively removed or are now coming to an end. This is creating a growing policy gap which is inhibiting further development and investment.

A new policy framework is urgently needed which reflects the increased maturity and improved cost effectiveness of a number of bioenergy sectors, while also recognising the need to support the emergence of a further range of technology solutions which can play a role in increasingly challenging carbon targets. In the third and final phase of this project a set of proposals for such an appropriate policy and regulatory framework will be developed in discussion with industry and Government, along with a set of further actions which will be required to deliver the vision set out here.

CONTENTS

1. Introduction

The important role of bioenergy today and in future sustainable low carbon scenarios is well recognised. Bioenergy makes the largest contribution to global final energy demand of any renewable energy technology (more than five times that of wind and solar combined) and is the only renewable technology so far making an important contribution in the heating and transport sectors (IEA 2018a).

Bioenergy can deliver low carbon energy using technologies and fuels which are well established and fully commercialised, and which are compatible with current energy infrastructure and the devices that use this energy to produce heat, electricity and transport fuels. It also provides some of the lowest-cost low carbon solutions for each sector. A range of other conversion technologies are still at the development, demonstration and commercialisation stages, along with a number of ways in which the supplies of bioenergy feedstocks can be boosted, while respecting sustainability concerns (IEA 2017).

However, bioenergy is a complicated subject, with many possible combinations of feedstocks, conversion technologies and energy products. It involves many interactions with other parts of the bioeconomy – for example with agriculture, forestry and the waste management sectors. It can also be a controversial topic, particularly as far as ensuring the sustainability of the production and use of bioenergy. Over the last ten years the understanding of these issues has much improved, internationally and in the UK, and industry and government have worked together to develop comprehensive approaches to sustainability management.

Given the importance of bioenergy, now and in the future, it is crucial that there is a clear strategy for its future deployment. The last comprehensive UK bioenergy strategy was published by DECC in 2012 (DECC 2012). Much has changed since then; bioenergy has been deployed more extensively, costs have reduced, and the issues around sustainability are better understood and managed. Increased deployment has been helped by a supportive policy and regulatory framework. However, many of the policy instruments, which have helped stimulate progress, are now coming to an end, and the future regulatory context is unclear (REA 2019).

There is the potential for bioenergy to grow further and to continue to deliver environmental and economic benefits, while at the same time laying the foundations for the important role that bioenergy will have to play over the longer-term in a low carbon UK. This includes the key role of bioenergy with carbon capture and storage (CCS), a technology likely to be essential in achieving zero emissions in the UK.

Action is needed now to build on the successes of recent years and to maintain the expertise that has been developed. However, there is no clear roadmap for how the UK can build on the progress made, making it difficult for the industry to invest with confidence. To address this, the REA has decided to facilitate the development of an industry-led strategy for bioenergy, as described in the foreword. (page iii)

The first phase took stock of the current state of play and at how the contribution of bioenergy to the UK's energy economy has grown in the last ten years, as well as the benefits that this has delivered. It also reviewed the current policy and regulatory framework (REA 2019).

This document is a summary of the work carried out under the second phase. It develops a vision for what bioenergy could provide to the UK by 2032 (the end of the UK's 5th carbon accounting period).

The third phase of the project will identify the key actions that stakeholders, including government, industry and the research community will need to take to deliver this vision.

2. The Role for Bioenergy in Low Carbon Futures

International Perspective

The important role of bioenergy in future sustainable low carbon scenarios is well recognised. In the IEA's low carbon scenario (2DS), sustainable bioenergy expands four-fold by 2050. This complements a huge improvement in energy efficiency, a widespread uptake of other renewable technologies (especially in the power sector) and other measures, including carbon capture and storage (CCS) (IEA 2017).

The International Renewable Energy Agency (IRENA) gives bioenergy a similar role in its global REMap scenario for 2030, with bioenergy providing 22% of total global energy needs for transport, 14% of energy for buildings, 19% of energy needs for industry, and 4% of electricity generation (IRENA 2019).

The use of bioenergy becomes particularly important in scenarios which target very deep cuts in carbon emissions such as those associated with global temperature rises below 1.5^{o}C or with net-zero emissions, such as those recently advocated by the UK Committee on Climate Change (CCC). (CCC 2019) Bioenergy can play a vital role in decarbonising otherwise hard to reach sectors such as aviation, and bioenergy with carbon capture and storage (BECCS) offers the promise of “negative emissions” to offset any remaining net emissions (IPCC 2018).

UK Perspective – UK Low Carbon Strategy

Climate Change Act and Carbon Budgets

The UK government is committed to reducing emissions, with a target to reduce greenhouse gas (GHG) emissions by 80%, against 1990 levels, by 2050 embodied in the UK Climate Change Act (Climate Change At 2008). To meet these targets, the government has set five-yearly carbon budgets which currently run until 2032, based on advice from the Committee on Climate Change (CCC). The targets restrict the amount of GHG the UK can legally emit in a five-year period. The UK is currently in the third carbon budget period (2018 to 2022), which requires a 37% reduction below 1990 levels by 2020. Budgets have also been set for the fourth and fifth carbon accounting periods for 2023 – 2027 and 2028 – 2032, with targets of 51% and 57% reductions below 1990 levels by 2025 and 2030 respectively.

So far, the UK has made good progress in reducing emissions, which were 43% below 1990 levels in 2017. The first carbon budget (2008 to 2012) was met and the UK is currently on track to outperform on the second (2013 to 2017) and third (2018 to 2022).

(CCC 2018 a) Progress has been particularly good in decarbonising the power sector, with major reductions in coal use, and growing use of renewable sources of electricity including bioenergy. There has been less success in the harder to decarbonise heating and transport sectors. (CCC 2018a)

However, the UK is not on track to meet its fourth carbon budget, and the fifth looks increasingly challenging. Even if the policies proposed under the Clean Growth Strategy (CGS) are fully implemented the CCC estimate that there will be overshoots of between 10 and 65 million tonnes of CO2e, and there are additional risks that the policies will not be put in place on time or deliver the expected savings.(CCC 2018a). The CCC says that efforts to reduce emissions will need to accelerate so that emissions reduce by at least 3% a year from now on and that this will require the government to apply more challenging measures. They encourages Government to:

- Support simple, low-cost options
- Commit to effective regulation and strict enforcement
- End the chopping and changing of policy
- Act now to keep long-term options open

The likely outcome of the current strategy is embodied in BEIS's current Energy and Emissions Projections 2018 (BEIS 2019). The reference scenario is based on central estimates of economic growth and fossil fuel prices and contains all agreed policies where decisions on policy design are sufficiently advanced to allow robust estimates of impact, including "planned" policies.

In this scenario the role of renewables as a whole in final energy consumption rises by only 35% between 2017 and 2026 (outside of the electricity sector), and remains at that level in 2032. Bioenergy, which is likely to be the most significant renewable technology in non-electricity sectors, therefore only grows slowly.

The vision set out in Section 3 of this report suggests that bioenergy can play a much more significant role between now and 2032, and that the associated GHG reductions could more than make up for the projected underperformance, allowing the UK to meet its 4th and 5th carbon budgets.

The Clean Growth Strategy

The last comprehensive strategy on how the UK can make progress towards its low carbon goals to 2050 was published in 2011 and has not been updated.(UK Government 2011) In 2017 the Government produced a Clean Growth Strategy (CGS), which has a focus on achieving the 5th Carbon budget by 2032 (UK Government 2017). The strategy is designed to meet GHG reduction commitments at the lowest possible net cost to UK taxpayers, consumers and businesses, while maximising the social and economic benefits for the UK from this transition. The strategy emphasises the important role of innovation in developing low carbon energy solutions, committing the Government to provide £2.5 billion to support low carbon innovation from 2015 to 2021, with an additional £4.7 billion from the National Productivity Investment Fund.

Key policies and proposals in the Clean Growth Strategy include:

- Improving business and industry efficiency by:
    - Developing a package of measures to support businesses to improve their energy productivity, by at least 20% by 2030
    - Phasing out the installation of high carbon forms of fossil fuel heating in new and existing businesses off the gas grid during the 2020s.
- Improving the energy efficiency in homes by a number of measures including:
    - Building and extending heat networks across the country
    - Phasing out the installation of high carbon fossil fuel heating in new and existing homes currently off the gas grid during the 2020s, starting with new homes
    - Investing in low carbon heating by reforming the Renewable Heat Incentive, spending £4.5 billion to support innovative low carbon heat technologies in homes and businesses between 2016 and 2021

- Accelerating the shift to low carbon transport by:
    - Ending the sale of new petrol and diesel cars and vans by 2040
    - Spending £1 billion supporting the take-up of ultra-low emission vehicles and investing an additional £80 million to support charging infrastructure delpoyment

- Delivering low carbon electricity by:
    - Phasing out the use of unabated coal to produce electricity by 2025
    - Delivering new nuclear power through Hinkley Point C and other projects
    - Improving the route to market for renewable technologies and extending the budget for Contracts for Difference (CfD) auctions by £557 million
    - Targeting a total carbon price in the power sector which will give businesses greater clarity on the total price they will pay for each tonne of emissions

- Demonstrating carbon capture usage and storage (CCUS) technologies and investing up to £100 million in innovation to reduce costs

- Enhancing the benefits and value of UK natural resources by:
    - Establishing a new network of forests in England including new woodland on farmland, and fund larger-scale woodland and forest creation
    - Working towards an ambition for zero avoidable waste by 2050, and minimising the negative environmental and carbon impacts associated with their extraction, use and disposal

Low Carbon Heating

Since the publication of the CGS, further documents providing more detail on some of its provisions have been published. In particular, BEIS has published discussion papers relating to the development of a strategy for low carbon heating. These include "Transforming Heating", published in December 2018. (BEIS 2018a) This document reviews the low carbon options for heating in advance of developing an appropriate long-term policy approach. It accepts that there are number of potential approaches and discusses benefits and challenges of each.

It focusses on:

- Using electricity, either directly or via heat pumps. The report acknowledges that this approach will be challenging for a number of older, poorly insulated buildings, where meeting the required heat demand in winter by using heat pumps will be challenging, and that the costs of improving insulation levels to allow effective heat pump use may be prohibitive
- Hydrogen
- Bioenergy including biomethane from bio and thermal processes
- It does not consider in detail the option for heat networks in urban situations despite their potential to play a role in facilitating heat recovery from buildings and industry, as well as the use of bio-energy heat (e.g. energy production from MSW, CHP etc.) and other uses of biomass
- Neither does it give much consideration to the direct use of solid biomass for heating, even though this is the most efficient way to use biomass and can play a particularly important role in rural properties including for those most difficult to heat using electricity via heat pumps

Low Carbon Transport

DfT has published its "Road to Zero Strategy". (DfT 2018)This outlines how Government will support the transition to zero emissions road transport and reduce emissions from conventional vehicles during the transition. The strategy is long term in scope and ambition, considering the drivers of change, opportunities and risks and looks out to 2050 and beyond, while also looking at the measures needed to lay the foundations for the transition in the shorter-term.

CCC Bioenergy Reports

The CCC published two reports relevant to the role of bioenergy in the UK in 2018 – Biomass in a Low-Carbon Economy (CCC 2018b) and Land Use - Reducing Emissions and preparing for Climate Change (CCC 2018c).

The reports:

- Highlight the importance of managing biomass stocks as a component of climate change mitigation as part of a sustainable land use strategy
- Note that there is scope to increase carbon stocks while, at the same time, increasing the amount of biomass used sustainably as a feedstock for bioenergy, globally and in the UK, when there is good sustainability governance in place
- Recognise that biomass can play an important role in meeting long term climate targets provided it is used appropriately, prioritising uses that lead to carbon sequestration either in products or via CCS
- Indicate that bioenergy could provide up to 15% of UK energy needs by 2050 and highlighted the important role of bioenergy associated with carbon capture and storage and in hard to decarbonise sectors, such as aviation

A Net-Zero Carbon UK?

The CCC has recently published its advice, which recommends that the Government should adopt a more ambitious long- term GHG target of net zero emissions by 2050 (CCC 2019). They argue that this is needed to match the government's international commitments to combating climate change. They suggest that meeting such a target is both possible and affordable, despite the UK is falling behind the trajectory needed to meet its current commitments. It also notes that Government will have to adopt a clear, stable and well-designed set of policies across the economy without delay.

The Challenges of Electrification

Like most national low carbon strategies, the plan being developed in the UK relies heavily on electrifying a wide range of energy services, notably for heating (directly or via the use of heat pumps) and for transport. This is understandable given there are now a well-developed set of renewable technologies which can be used to produce low carbon electricity, and whose costs have been falling rapidly. In addition, the use of electricity for heating and transport can be inherently more efficient, thereby using less primary energy to deliver the same services.

However, this approach does have some important challenges that will need to be overcome, notably associated with the costs of extending the electricity generation portfolio and the necessary delivery infrastructure. The CCC estimates that the amount of low-carbon electricity generated and used in the UK will have to rise by a factor of four in a scenario compatible with net zero emissions, even when significant improvements in energy efficiency are taken into account (CCC 2019).

This challenge is exacerbated because some of the “new uses” for the electricity – notably heat for buildings – have extreme seasonal variations. Energy demand in buildings in winter is typically seven times higher than in the summer months (BEIS 2018a). This means that the necessary production and delivery infrastructure designed to meet this use will have a low utilisation rate.

The UK has very significant potential to increase generation from on- and off-shore wind and solar PV. These are all “variable renewable resources” (VRE) – meaning that the power output varies according to the wind and solar conditions. With a large proportion of power coming from such sources, balancing electricity supply and demand becomes more challenging. Much progress has been made in understanding how to manage electricity systems with high shares of variable renewables.

This can involve improving the overall system flexibility by making dispatchable generation more able to respond to changing loads, enhancing the grid capacity, managing consumer demand and using electricity storage (IEA 2018b). However, challenges remain for systems with very high VRE shares, notably associated with longer periods when the wind or solar resource is limited (e.g. “quiet” winter periods when wind speeds are low but demand for heating is high). In the absence of economic long-term storage systems, some dispatchable electricity capacity will be essential to cope with this issue, but in a very low carbon economy this capacity cannot be supplied by unabated fossil fuels.

The UK’s plans include a substantial expansion of nuclear capacity to provide this dispatchable capacity. Nuclear is not ideally suited as a complement to high shares of VRE as nuclear plants are not able to ramp up and down to meet changing demand, and the economics depend on achieving high load factors. (Energy Transition 2018) Additional nuclear capacity is due to come online in 2026 at the 3.3 GW Hinkley Point C plant currently under construction. However, the costs of nuclear generation are high and plants can only be built with very long-term contracts are in place – £92.50/MWh (2012 prices), and a contract length of 35 years in the case of Hinkley Point C (BEIS 2018b). Constructing and commissioning nuclear plant on schedule and on budget has proved difficult. The problems of long-term nuclear waste storage are so far unresolved, raising questions about the sustainability of such plant.

A number of the existing nuclear plants are coming to the end of their lifetime between now and 2030. There is a pipeline of project proposals for additional plants due to come online in the late 2020's, 30's and 40's which aim to replace this lost capacity and increase the overall nuclear contribution (Carbon Brief 2019).

However, the developers of three of these plants (Hitachi and Toshiba) have now stopped development work on the projects at Wylfa, Oldbury and Moorside, as they do not believe that they will be able to reach contractual agreements covering the outputs from the plants, given the high generation costs. This reduces the capacity in the pipeline by some 9.1 GW and will lead to the loss of around 72 TWh/year of low carbon electricity. If that capacity had to be filled with gas generation, then emissions would rise by 29 MTCO2e/year (Carbon Brief 2019).

Government has been discussing alternative ways of facilitating the construction of nuclear plants, for example by providing some of the capital from public funds, but replacing this capacity with new nuclear plant on schedule will be challenging, given the long project development, construction cycles and high up-front generation costs.

There are therefore some serious risks to delivery of the low carbon strategy based on electrification associated with:

- Developing, building and operating the necessary transmission and distribution infrastructure to meet much expanded but highly seasonal demand
- Expanding generation capacity to meet increased demand with constraints on new nuclear capacity and without pushing up carbon emissions

An expanded role for bioenergy could help mitigate these risks by:

- Providing alternative low carbon solutions that will reduce the need to enhance the electricity transmission and distribution systems, by providing heat directly where it is needed or through heat networks and the gas grid
- Provide a low carbon alternative to nuclear through the generation of electricity from biomass linked to CCUS

The Role of Bioenergy in Low Carbon Futures

The significant expansion of bioenergy discussed in the following sections of this report can help to enable the delivery of the low carbon strategy, especially one compatible with the Net-Zero Carbon ambition proposed by the CCC, in the following ways.

- Bioenergy can reduce the emissions associated with providing heat by:
  - Providing substantially larger contributiuon to meeting heating needs for buildings and industry through very efficient use of biomass feedstocks for heating in buildings, directly and via heat networks
  - Playing an important role in providing low carbon supplies of gas into the gas network, allowing continued use of current infrastructure in a low carbon scenario
  - Provide heating in off gas-grid properties and those where heating via heat pumps is likely to be most challenging
- In the tranpsort sector biofuels can provide:
  - Immediate GHG savings in the road transport sector using existing vehicles and infrastructure, without impeding the development of electric vehicles as the technologies and infrastructure develops
  - A long-term low carbon solution for commercial vehicles, compatible with local clean air requirements through the use of biomethane
  - A low carbon alternative for the aviation and shipping sectors, hard to decarbonise in other ways
  - Further options to link bioenergy production to CCS and CCU technologies
- Bioenergy for power generation can provide an alternative to nuclear as a low carbon, dispatchable source of electricity, which:
  - Has lower costs of power generation than nuclear
  - Can be built more quickly (with potentially 3 GW online by 2032)
  - Can be funded by the private sector
  - Avoids the long-term sustainability issues associated with nuclear waste storage

- Can be linked to carbon capture and use or storage so providing a “negative emission” technology likely to be needed in very low carbon scenarios

- Bionenergy can also provide market pull that stimulate GHG savings in non-energy sectors through:

  - Improved waste management practices including the move away from landfill and better management of agricultural residues, manures, etc

  - Stimulation of improved forestry management practices and afforestation

3. Vision for 2032

Approach

In this section, a quantitative vision of the role that bioenergy could play in the UK by 2032 is developed. The approach adopted is to look at the contribution that the various biomass sources can make to the UK energy system, given a supportive policy and regulatory environment, in the short, medium and long term. The estimates are based on discussions with UK industry players on what could be possible on this time scale.

The estimates of contribution below take account of:

- The availability of biomass resources that can be made available while respecting sustainability criteria

- The rate at which markets could realistically be developed.

- A mix of well-developed and commercially available technologies and some technologies still at an earlier development and commercial stages, including some (notably those associated with bioenergy along with carbon capture and storage) that are likely to be significantly deployed only after 2032.

There are many ways in which biomass may be used to provide energy, and the "best use" of bioenergy is very situation dependent, depending on the whole energy system and, in a low carbon context, the other opportunities to decarbonise. However, the specific characteristics of biomass as an energy feedstock imposes a number of principles that need to be respected.

These include:

- Production of residues or wastes on-site is to be preferred when possible as the most economic, energy and carbon efficient as transport costs and related emissions are avoided

- The most efficient use of biomass with best GHG balance is used for the direct production of heat with a conversion efficiency matching those of fossil fuels and approaching 90%. Heat production efficiency and capital cost not strongly dependent on scale.

- Transformation to other products or vectors always means a loss efficiency – for example efficiencies for conversion to electricity are usually between 20 and 40%, and thermal conversion to methane has an efficiency of around 50%.

- When biomass needs to be converted to other products or vectors rather than used directly there is an advantage in moving to larger scale projects in order to gain improved efficiencies and lower unit capital costs e.g. change in efficiency of power generation with scale, scaling factor for power or thermal processes

In developing the vision these principles have been respected, privileging local use of biomass for heat where possible. The vision also acknowledges that the ways in which bioenergy is used may change over time, as new bioenergy technologies mature and as the overall energy system becomes less GHG intensive. In the long-term there will be opportunities for bioenergy linked to carbon capture usage and storage, and in applications for which other low carbon options are limited or very expensive, such as for aviation, as proposed by the CCC. But not all biomass feedstocks are necessarily suited to these uses and the local use of biomass to meet energy needs will always offer some advantages in terms of efficiency and cost. The technologies that will enable some of the low carbon bioenergy options are not as yet technically proven and commercialised.

For example:

- Large-scale thermal gasification of biomass to enable production of biomethane (bioSNG) is not yet commercialised

- Biofuels for aviation are at an early stage of development and so far provide some 0.01% of aviation fuel

- There are very few examples of bioenergy production with CCS even at a pilot scale

Rather than do nothing until these solutions are available, the approach proposed here is to deploy bioenergy as soon as practicable using technologies as they are available so long as they provide GHG reductions and provide low cost, low carbon options, along with other benefits. This approach will:

- Lead to immediate GHG, economic and other benefits
- Develop national and international supply chains that will be needed to support any large-scale use of bioenergy in the future, and which will take some time to evolve
- Maintain and develop UK expertise in bioenergy
- Provide opportunities to develop projects which serve as a stepping stone towards the longer-term options (e.g. by providing initial market opportunities for biomass gasification or for projects associated with carbon capture and use)
- Provide insurance against delays or longer-term problems in deploying the new technical options

Having a large scale and active UK bioenergy sector will also make it easier to deploy new technologies when the time is right, as it will be easier to develop and finance such projects when there is a mature biomass supply chain in place.

Developing solutions based on conventional technology will not stand in the way of new technologies and applications in the longer term. Rather this approach will provide a solid basis for the introduction of these technologies as market opportunities develop.

For example:

- Flexibility is already evident in the biogas sector, were an initial market for electricity production was stimulated by the Renewable Obligation (RO) and Feed in Tariff (FiT) mechanisms, but with priority then shifting to the to the production of biomethane for heating and now to transport applications. As discussed below this trend is likely to continue
- The immediate opportunity to increase the penetration of biofuel in the road transport sector does nothing to discourage the take up of electric vehicles. If this constrains the market for liquid transport fuels, then the biofuel infrastructure developed can be adapted to supply other transport sectors. For example producing HVO (hydrotreated vegetable oils) or biojet from biodiesel feedstocks, or by using bioethanol as a feedstock for jet fuel or for biochemical production
- Proposals to produce additional low carbon electricity from biomass provide a basis to demonstrate carbon capture and use at a large scale, as a precursor to BECCS when the necessary infrastructure becomes available

Aims and Objectives

The strategic aims for the proposed strategy are to:

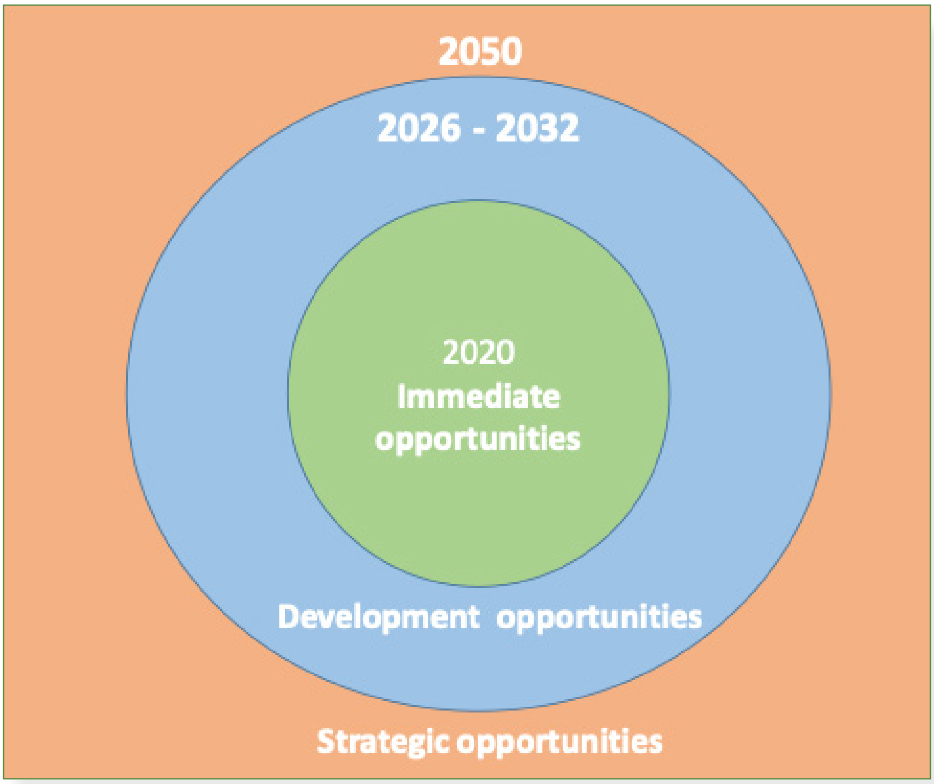
- Immediately expand the contribution to GHG savings from bioenergy based on well-developed and affordable technologies which also provide significant co-benefits
- Develop and deploy some additional technology options which can also contribute GHG and other benefits by 2032, while also opening up options over the longer term
- Demonstrate bioenergy production coupled to CCS or CCU by between 2023 -2026 and expanding the contribution to carbon savings substantially by 2032

The following sections identify and quantify specific opportunities for each-end use sector, noting that there are some cross-cutting options which could make a contribution to transport, heat or electricity depending on priorities and market developments.

The opportunities are classified into three groups as illustrated by **Figure 1**:

- Immediate opportunities – technologies which can be further deployed immediately
- Development opportunities – technologies or resources which need further technology or market development, but which could make a contribution to energy needs between 2026 and 2032
- Strategic opportunities – options involving carbon capture and use and/or storage which will be needed in the longer term, and which need to be demonstrated by 2026, and then deployed at a significant scale by 2032 with a view to further expansion thereafter

Figure 1 • Classification of Bioenergy Opportunities



The opportunities associated with each end-use sector are discussed briefly below – a fuller description is provided in Annex A to this report.

Bioenergy for Heat Supply

Bioenergy can contribute to the supply of heat in the UK in a number of ways:

- Through directly providing heat in stoves and boilers fuelled by biomass to meet heat demand in buildings for households, commercial and administrative premises, and or to meet heat demands in agriculture and industry. For relatively dry feedstocks this is the most efficient way of using the biomass with conversion efficiencies of around 90% achievable in well-designed boilers, similar levels to those of fossil-fuelled heating systems. Properly deisgned and operated biomass heating systems can meet stringent air quality criteria. The vision assumes that further controls will reduce the uncontrolled use of biomass fuels in open fires and inefficient devices

- Through producing “green gases” from bio-feedstocks which can directly substitute natural gas in pipelines, and also provide fuel to premises not connected to the gas grid in the form of bio-LPG. The gases are prodcued now through anaerobic digestion of a range of wastes, residues and crops, and further production will be possible in the medium-term through the thermal gasification of dry wastes and other feedstocks

- By providing the energy needed for heat networks, likely to be an important means of providing heat (and cooling) in urban situations

The production of biomethane or other biofuels can also be coupled with CCS or CCU producing further GHG reductions. Analysis of the potential role for bioenergy to provide heat for the UK has highlighted the opportunities shown in Table 2, classified using the system outlined above, depending on how soon they could make a serious impact on UK heat supply and the resulting emissions.

Table 2 • Opportunities – Bioenergy for Heat Supply

Immediate opportunities – 2020	• Expansion of use of pellets/chips for buildings and industry heating • Use of bio-based liquid and gaseous fuels as a substitute for fossil oil and LNG • AD based biomethane for gas mains injection
Development opportunities – 2025-2032	• Expansion of the use bioenergy in heat networks • Biopropane for buildings • Thermal biomethane and hydrogen
Strategic options – Post 2032	• Thermal biomethane and hydrogen plus CCUS

Immediate Opportunities

Expansion of pellets/chips for heating in buildings and industry

Opportunity:

- Immediate potential to replace fossil fuel use for heating in buildings and industry using fully commercial technologies and existing supply chains

Benefits:

- Using wood fuels provide the lowest cost low carbon option for building heating, particularly larger residential developments and for commercial and industrial sites

- Can make use of well-developed technologies and expanding fuel supply chains to provide heat in line with seasonal variations, without putting extra requirements on electricity infrastructure

- Installation of modern, well-designed systems meeting stringent emissions standards can provide an alternative to polluting open grates and poorly regulated wood stoves

- Development of local supply chains, which are well adapted to the dispersed nature of UK forest resources, can help stimulate improved forest management and afforestation, including some new planting on unprofitable agricultural land

Potential to 2025 and 2032

Industry believes that a sustainable level which would allow for market and supply chain development is around 700 MW/year (as achieved during the RHI). If installation rates grew to this level by 2025 and then continued at that level until 2032, the additional contribution to energy supply would grow from the current level of around 85 PJ now by 27 PJ/year by 2026 and by 67 PJ/year to over 150 PJ by 2032.

Likely costs of energy:

- The costs of the heat supplied would be between 3-20 p/kWh depending on the application

Constraints to potential:

- **The principal constraint to realising this potential is likely to be the rate at which the fuel supply chain can be developed**

Expansion of Biogas and Biomethane Production

Opportunity

- Immediate potential to expand the production of biogas and biomethane from biomass materials via anaerobic digestion of organic materials, including wastes and residues

- In some cases, the gas can be used at the site of production to generate electricity or in CHP applications where there is an immediate demand. For example, where industrial effluents from food industry can be digested and the gas used to meet local demand for electricity and hot water production such as in the dairy or drinks sectors

- Alternatively, the biogas can be upgraded to biomethane and injected into the gas network to replace fossil fuel gas for heating or for transport applications.

Benefits:

- Producing and using biomethane makes use of existing infrastructure and appliances by extending the production of biomethane while significantly reducing the GHG impact of gas use

- Synergies with efforts to reduce waste going to landfill by offering alternative outlets for a range of waste materials including food and other biogenic wastes concentrated via separate collections

- Stimulus to develop markets for a range of agricultural wastes, residues and crops, so helping diversification of the rural economy

- On-site use of wastes as feedstock for digestion contributes to industrial efficiency and the demonstration of a circular economy

Potential to 2025 and 2032

- Currently most biogas (including sewage and landfill gases) produced in the UK (19 TWh) is used for power generation. In addition, 8 PJ of biomethane qualified for payments under the RHI, and biomethane production likely to reach 25 PJ in 2021 as new plants come online

- There is scope for expanding biomethane production, but that will require extension to a broader range of feedstocks beyond current supplies, for example of food wastes and other biosolids. These could include the use of more animal wastes and a range of crops which can be utilised to increase agricultural productivity without impacting on other crop production

- Assuming that sufficient raw material could be developed, then gas production could rise to around 180 PJ to a total of some 220 PJ by 2032. The gas could be used for heat, transport or for continued power generation depending on market developments. It is assumed here that the amount used for power declines slowly, and the rest of the growth is split evenly between heat and transport. Under these assumptions biomethane for heating reaches 67 PJ by 2026 and 107 PJ 2032, with biomethane for transport achieving 43 and 82 PJ by the same dates

Use of Bio-based Liquid and Gaseous Fuels as a Substitute for Fossil Oil and LNG

Opportunity

- Reduce the carbon emissions from oil-fired heating by using a blend of biofuels or other low carbon fuels

Benefits

- Reduces carbon emissions
- Uses existing heating systems and distributions channels

Potential to 2025 and 2032

- In 2017 oil supplied 369 PJ for heating in the UK (BEIS 2018c). Trials have indicated that biofuels can be used in 30% blends in heating oil without affecting performance
- If larger scale trials prove effective it is estimated that biofuels blend could replace 5% of heating oil fuel by 2016 and 10% by 2032. This would mean a contribution of 5.5 PJ by 2032 and 11 PJ by 2032

Likely costs of energy

- Around 9 p/kWh

Constraints to potential

- The performance of biofuel blends in heating oil still has to be confirmed by larger scale trials
- Availability of supplies of suitable biofuels from sources which meet strict sustainability criteria

Development Opportunities

Expansion of Bioenergy use in Heat Networks

Opportunity

- Provide low carbon options for heat networks (especially in urban contexts) by using biomass fuels. This could include heat from existing installations such as EfW CHP plant and sewage digestion facilities as well as new biomass-based installations

Benefits

- Bioenergy can provide the lowest cost low carbon option for heat networks
- Facilitates development of heat networks to make use of a range of sources (e.g. from CHP plant, waste heat recovery)

Potential to 2025 and 2032

- In 2017 heat networks supplied 67 PJ of energy in the UK – only 2% of total heat demands, and bioenergy contributed some 12% (8.4 PJ or 200ktoe) of this supply. The potential for bioenergy to contribute in this sector depends on rate of heat network development
- To estimate the contribution that bioenergy could make in this sector, it is assumed that heat networks could supply a further 1% of today's heat requirements by 2026 and 8% by 2032, and that bioenergy could supply 30% of the potential. This means a contribution of 16 PJ by 2032 and 83 PJ by 2032. Some 10 PJ of this could come from efficient CHP operations and the rest from specific biomass heat or CHP installations

Likely costs of energy

- Around 4-5 p/kWh

Constraints to potential

- The potential will depend critically on the timing and rate of development of heat network infrastructure. It will also depend on ensuring that such networks are based on low carbon supplies rather than on fossil gas, the current most common source for projects being studied or stiumlated under the BEIS Heat Networks Delivery Unit (HNDU) and Heat Networks Investment Project (HNIP) programmes (BEIS 2018d).

Production and use of Thermal Biomethane

Opportunity

- Potential to expand available supply of biomethane for grind injection and use for heating or transport through the conversion of solid biomass sources via thermal gasification

Benefits

- Extends supply to gas grid, allowing use of existing infrastructure and appliances/equipment but with lower GHG production than conventional natural gas, and with the potential to capture and either use or store the CO_2 produced during the gasification process

Potential to 2025 and 2032

- Given the technology is not yet fully commericalised, an objective of demonstrating 5 large scale (>50 MW) thermal biomethane production from wastes and from wood-based sources in the UK by 2025 would be realistic

- Such a fleet of plants would provide around 10 PJ of biomethane in 2032 and lay the basis for later expansion

Cost of energy

- Current cost estimates are around 60-80 p/kWh based on wood fuels and 26-34 p34p/kWh based on waste fuels but with significant potential for cost reductions (European Commission 2017).

Biofuels as a substitute for LPG

Opportunity

- Potential to replace LPG for buildings and industry using existing devices and supply/storage systems

- Bio-LPG can consist of bio-propane or of bio-dimethyl ether (DME) and can be produced from a range of potential feedstocks and processes. Current supplies are produced as a by-product from the production of HVO. Supplies from this source can be expected to grow as the production of HVO and some other advanced biofuels produced by thermal processes are extended, for example to supply bio-based aviation fuels

Benefits:

- Replacement of fossil-derived LPG and of oil as a heating fuel for off-gas-grid properties

- Provides option for low carbon heating of properties which are less suitable for heat pumps and without implications for power production and distribution infrastructure

Potential to 2025 and 2032

- Prioritise LPG replacement and off-grid domestic and commercial customers

- Assume growth of LPG market to around 42 PJ (1 Mtoe) by 2032 as oil constrained in rural heating sector. Given commitments from some major UK LPG suppliers to switch entirely to non-fossil LPG by 2040, a 70% market share for bio-LPG by 2032 is considered realistic - i.e. a potential contribution of some 29 PJ by 2032

Likely costs of energy

- Cost premium for bio-LPG estimated at £5/MWh compared to fossil LPG, with total heat costs around £94/MWh

Constraints

- Currently supplies of bio-LPG feedstocks are limited and developing the supply chain will be the most significant constraint on the rate of deployment

Photo shot by IvanJekic on iStock

Overall Heat Vision

Table 3 and Figure 2 summarise the potential contribution of bioenergy to UK heat supply from the opportunities discussed above, including a reduction in the inefficient use of wood fuels in poorly controlled systems.

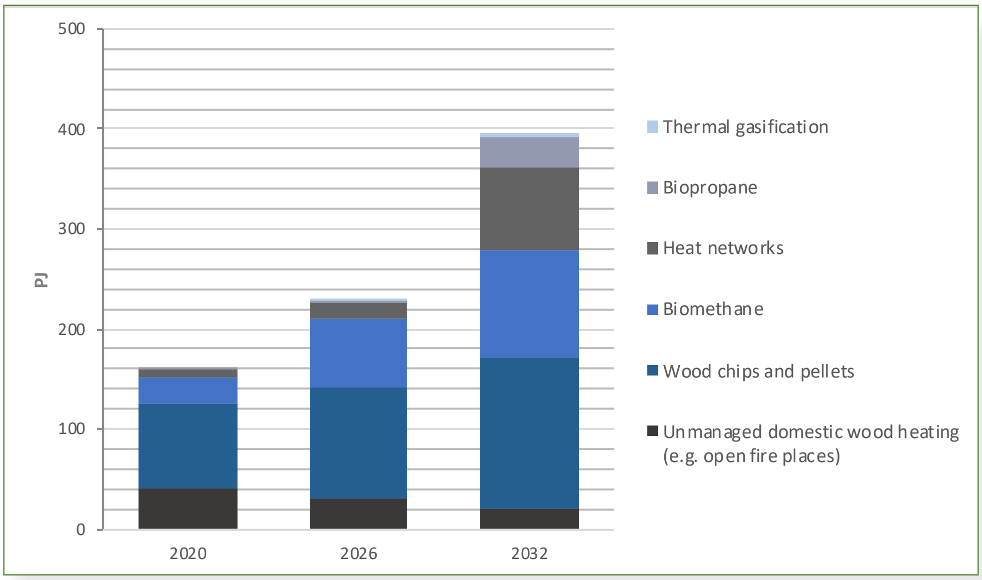
The contribution from bioenergy to the heating sector increases by nearly 40% by 2026 to 235 PJ (some 11% of total UK heating needs), and by a factor of 2.3 by 2032 to 407 PJ (20% of heating needs).

Table 3 • Summary of Potential Bioenergy Heat Supply to 2032

Bioenergy Heat (PJ)

	2020	2026	2032
Unmanaged domestic wood heating	40	30	20
Wood chips and pellets	86	112	152
Biomethane	25	68	107
Biofuel blends	0	6	11
Heat networks	8	16	83
Biopropane	0	2	30
Thermal gasification	0	0	5
Total	**159**	**235**	**407**

Figure 2 • Potential Total Growth in Bioenergy for Heat Production



This growth in bioenergy for heating raises the contribution to final energy demand in the residential, public, commercial and industry sectors from 6.6% in 2020 to nearly 10% by 2026 and 16.3% in 2032.

Bioenergy for Transport

Bioenergy can play an important role in the transport sector by providing substitutes for fossil fuels, which can mostly make use of existing infrastructure and vehicles since the fuels can either be blended with fossil fuels or designed as like-for-like replacements ("drop-in fuels").

In the longer run, electricity is expected to play an increasing role in low carbon transport systems, especially for transport in urban areas and for light passenger travel. Bioenergy solutions can complement this approach because they can also be used for heavy and long-haul transport applications including aviation and shipping.

Even under scenarios which take an optimistic view of the prospects for electrification of transport, penetration will be constrained by the relatively slow rates of electric vehicle uptake and turnover of the vehicle stock. Under BEIS Reference Scenario in the Energy and Emissions Projections (2018), by 2032 electricity provides only 2.6% of UK transport energy needs (compared to biofuels 4.0%), meaning that 93.4% of transport needs are still provided by fossil fuels with the associated GHG emissions (BEIS 2019). Even if uptake is significantly accelerated as recommended by the CCC and others, fossil fuels are still likely to play a major role in the transport sector to 2032.

Biofuels can make an impact across the period to 2032 by reducing fossil fuel use without requiring amendments to the vehicle fleet and with minimum impact on infrastructure. The increased use of biofuels in no way obstructs the greater use of electricity in the sector as the technologies improve and become cheaper and the necessary electricity supply infrastructure is put in place.

Review of the main opportunities for biofuels to contribute to the decarbonisation of the transport sector has identified the options set out in Table 4, classified according to the time when they can make a significant impact. Opportunities relating to the production and use of biomethane are shared with the heating sector since the fuel could be used either for heating or for transport.

Table 4 • Bioenergy Opportunities in Transport

Immediate – 2020	Expansion of ethanol and biodiesel AD based biomethane
Development Opportunities 2025 – 2032	Aviation and marine fuels Thermal biomethane
Strategic Opportunities – Post-2032	Thermal biomethane, biofuels or hydrogen production plus CCUS*

*Opportunities shared with the heating sector

Immediate Opportunities

Expansion of Ethanol and Biodiesel Within and Beyond "Blending Walls"

Opportunity

- Currently about 2% of the energy used in transport comes from bioethanol and biodiesel supplied as low-level blends for road transport. This can be rapidly ramped up to further replace fossil road transport fuels with low carbon options within the conservative blending limits ("blend wall") by adopting an E10 blend of ethanol within gasoline

Benefits

- No changes in infrastructure or vehicles
- 70%+ GHG replacement for each unit of energy replaced
- Potential stimulus to UK agriculture sector

Potential to 2025 and 2032

- Potential to move to 10% blending of ethanol in gasoline and biodiesel in diesel by volume (between 6% and 8.6% in energy terms)
- This is equivalent to replacing some 2.3 Bn litres of biodiesel and 1.4 Bn litres of bioethanol with an energy equivalent of some 110 PJ by 2026 dropping to 106 PJ by 2032 if gasoline and diesel fuel use is constrained according to the profile in the BEIS scenario
- Initially fuel requirements can be met from supplies of ethanol and biodiesel from existing supply chains. As demand grows, and if there is regulatory incentive to move to fuels with better sustainability pedigree, then these fuels can be supplemented by advanced biofuels which can include ethanol from cellulosic residues and from thermal processing of wood residues, once these technologies are proven and commercialised
- There is also potential to go beyond the “blend wall” through the use of higher blends of gasoline and bioethanol (e.g. E85) and of biodiesel (especially in the commercial fleet, e.g. B20, B30) and through the use of “drop-in” substitutes such as HVO if available in sufficient quantities

Likely costs of energy

Prices of bioethanol are set by international markets and vary according to demand, the prices of feedstock costs, and import duties and tariffs. Typically the price of ethanol is in the range of £12-14/GJ and biodiesel between £15.5–23.0/GJ.

Constraints to potential

Potential supply of fuels meeting sustainability constraints

Biomethane for Vehicle Use

Opportunity

- Immediate potential to replace diesel using existing gas infrastructure for distribution and new vehicles designed to use biomethane

Benefits

- Low carbon option for transport notably for delivery and HGV sector, compatible with local air quality requirements

Potential to 2025 and 2032

- Potential growth of biomethane production discussed under the heat section of this report
- Assuming growth in biomethane shared equally with heat sector, then 43 PJ of diesel fuel could be replaced by 2026 and 82 PJ by 2032
- In addition, some 10 PJ of biomethane could be produced by 2032 from thermal processing of biomass, providing a further 5 PJ to the transport sector

Constraints to potential

- Feedstock availability and adaptation of technologies to new feedstocks (see heat section for discussion)

Development Opportunities

Aviation and Marine Fuels

Opportunity

- Replacement of aviation fuels with low carbon substitutes such as biofuels is seen as a long- term priority by both industry and government, due to growing energy use in the sector and the difficulties of decarbonising the sector in other ways. Sustainable biofuel use is a key component of the airline industry's plans to decarbonise the sector (IATA 2018).
- Although there are a number of biofuels which have been certified for use in aviation, and many trial flights with biofuels have taken place so far, only a very small proportion (estimated at 0.01% of total energy use) of jet fuel is replaced by biofuels (IEA 2018a). Current use is constrained by suitable fuel availability and by the higher costs of biofuels
- Similarly, biofuels have potential to replace marine fuels (which are generally considered less challenging), although here too only firsts steps have been made

Benefits

- Carbon reductions using existing engines and compatible fuelling infrastructure

Potential to 2025 and 2032

- Depends on supply constraints and level of ambition of aviation industry

- According to BEIS projections for growth of aviation and marine fuels within the UK to 2032, aviation use is likely to grow by 6% to 146.7 Mtoe (615 PJ) between 2020 and 2026, and by 13 % to 15.6 Mtoe (653 PJ) by 2032 (BEIS 2019). Shipping fuel use is expected to remain constant at 0.65 Mtoe (27 PJ). A 2% replacement of these fuels is envisaged by 2026 and 10% by 2032. This means around 13 PJ by 2026 and 68 PJ by 2032

- Current costs are 2-3 times those of current aviation fuels but there is significant scope for cost reduction as volumes grow

Constraints to potential

- Supply of suitable and approved fuels for aviation is currently constrained so production capacity and suitable feedstock supply will need to be extended

- International supply chains are expected to develop to supply this important global market

Overall Transport Vision

Table 5 and Figure 3 summarise the potential contribution of bioenergy to UK transport energy supply from the opportunities discussed above. The contribution for bioenergy rises by a factor of 4 by 2026, and by a factor of over 6 by 2032.

Table 5 • Summary of Potential Bioenergy Transport Energy to 2032

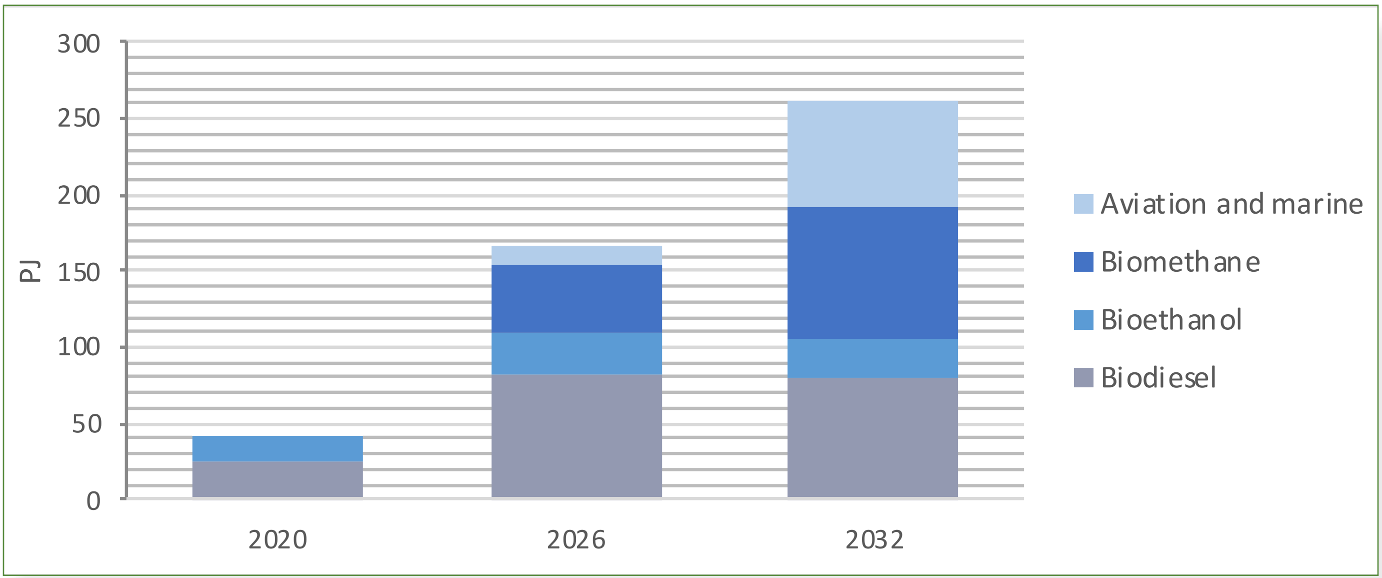
PJ delivered fuel

	2020	2026	2032
Bioethanol	18	28	27
Biodiesel	24	82	79
Biomethane	0	44	87
Aviation and marine	0	13	68
Total	**42**	**167**	**261**

*includes contribution from thermal biomethane.

The share of total transport energy grows from below 2% in 2020 to over 7% in 2026 and nearly 12% in 2032.

Figure 3 • Potential Total Growth in Bioenergy for Transport Energy to 2032



Bioenergy for Power Generation

The production of electricity from biomass sources has expanded rapidly in the UK in the last ten years, supported by the Renewables Obligation (RO), Feed-in-Tariff (FIT) and Contracts for Difference (CfD) schemes, and now provides some 11% of all electricity generated in the UK, from a wide range of sources (REA 2019). Bioelectricity is associated with very low greenhouse gas emissions compared to fossil fuel generation, and unlike wind and solar PV, is able to provide dispatchable generation, unaffected by resource conditions, thereby complementing variable sources of electricity. The generation of power from biomass sources, brings ancillary benefits - for example using wastes complements other efforts to move away from landfilling, and the sustainable use of wood fuels can stimulate better forest management practice.

There is scope to grow the production of bioelectricity in the UK. However, it is necessary to acknowledge the costs of generation from some bioenergy sources (measured in terms of the levelised cost of energy [LCOE] generation) are now sometimes higher than those of wind power and solar, and that the scope for cost reduction in the future is lower.

The costs of electricity generation from bioenergy have been reviewed (see Annex B). This analysis indicates that bioelectricity generation is most attractive when:

- Low cost feedstocks such as wastes can be used
- Use can be made of existing fossil fuel assets (for example by the conversion of plants previously fired by coal)
- Bioenergy plants are configured as combined heat and power (CHP) projects that are able to export a high proportion of heat in addition to power
- When large-scale operation leads to lower capital costs and higher generation efficiencies
- When bioenergy plants can play a role in providing firm and dispatchable power so facilitating integration of higher shares of variable renewable energy (VRE) from wind and solar generation.

In addition, bioelectricity production when linked to carbon capture and storage is a “negative emission” technology and can produce electricity while effectively reducing overall emissions. Large scale bioelectricity generation offers a cost competitive alternative to nuclear (Annex B), through modular and flexible plants which could be financed by the private sector over shorter lifetimes than those proposed for nuclear plant (25 vs 40+ years). The bioenergy plants also have no long-term issues relating to waste storage and decommissioning.

However, the capture and storage of CO_2 linked to power generation has yet to be demonstrated at a large scale in the UK. A potential route map to widespread implementation of the technology, in the absence of the necessary carbon storage infrastructure, is to first demonstrate CO_2 separation with use of the carbon to produce low-carbon fuels (CCU) from existing bioelectricity plants. This could be a precursor to the deployment of demonstration fleet of plants where CO_2 is captured and either used via CCU or stored when the necessary infrastructure is in place.

Taking these factors into account, a number of opportunities for bioelectricity in the UK have been identified and shown in Table 6, classified using the system outlined above, according to how soon they could make a serious impact on UK electricity supply and the resulting emissions.

Table 6 • Bioelectricity Opportunities

Immediate opportunities – 2020	• Maintaining current generation • Expand use of low-cost fuels, (MSW, waste wood) via CHP
Development opportunities – 2025 - 2032	• Large scale bio-power (with CCUS)

Maintaining Current Bio-Generation

Opportunity: The current level of generation is 33 TWh, supported by long-term contracts under the RO, FIT and CfD programs. It would be desirable to maintain generation from existing bioelectricity plants beyond current support mechanisms.

Benefits: Continuing environmental benefits from low carbon electricity and heat generation along with those relating to waste disposal and keeping developed supply chains in place. Maintaining current generation is also important for preserving confidence of current investors who are likely to invest in the next generation of bioenergy technologies/opportunities (including those involving CCU/CCS).

Potential to 2025 and 2032: The current level of generation could be maintained but some of the resources used could switch to other applications if they lead to improved utilisation of the resource, or if other markets become more attractive. For example, some biogas used for power generation is assumed to switch to biomethane production, reducing power generation by some 13 PJ.

Likely costs of energy: For existing generation, the capital cost element will have been repaid by the end of the support contract period. As such, the marginal costs of generation, related to fuel, maintenance and other operating costs are expected to lie in the range of £50-70 /MWh.

Constraints to potential: Access to markets providing sufficient economic rewards to cover fuel and operational costs.

Generation From Additional Low-cost Biomass Fuels Including Municipal Solid Waste (MSW)

Opportunity: To expand the use of residual biogenic wastes including those from municipal and commercial and industrial waste streams (after economic reuse and recycling activities), waste wood and other waste fuels for lower cost bioelectricity generation (where possible linked to CHP opportunities).

Benefits: Low carbon electricity generation and benefits to waste disposal practice associated with reducing landfilling of wastes.

Potential to 2025 and 2032: Potential additional 9 Mt residual biogenic wastes which are currently landfilled and which could be used to produce energy, making an additional 1.2 TWh/year (4.5 PJ) developed between 2020 and 2027 (Tolvik 2018).

Likely costs of energy: The costs of producing power from MSW are particularly variable depending on the “gate fee” received for the waste and the extent to which the heat can be used. In cases with an adequate gate fee and good heat yield, the resulting generation cost will be between £80 and £90 /MWh. (See Annex B)

Constraints to potential: Fuel supply available via long-term contracts, which can be enhanced by “push” policies such as rising landfill taxes, separate waste collections and restrictions on waste feedstock exports.

Large Scale Biopower (with CCUS)

Biopower (with CCUS)

Opportunity: To demonstrate and start to deploy large-scale bioelectricity generation with CCUS by:

- Demonstrating carbon capture on an existing biomass generation site with subsequent use or storage of the carbon (depending on infrastructure availability)
- Demonstration of new bioelectricity capacity specifically designed to be optimised for CCUS (probably c. 300 MW scale biomass pellet fired plants).

Benefits: Low carbon electricity which helps to fill the gap in dispatchable power from likely nuclear undershoot at lower cost and lays basis for large-scale BECCS rollout beyond 2032.

Potential to 2025 and 2032: Assume a series of plants demonstrating bioelectricity with CCUS at a scale of around 300 MW plants, starting from 2025, building up to a capacity of around 3 GW by 2032, and producing 22 TWh.

Likely costs of energy: Costs estimated at c. £75 /MWh excluding costs/benefits of CCU, assuming that system capital costs can be optimised for large scale operation, and that some significant economies can be made by reducing supply chain costs for the fuel.

Constraints to potential: Feasibility and development work needed to design optimum plants at large scale compatible with CCS/CCU. Extension of pellet supply by c. 12 million tonnes/year and demonstration at scale of CCU.

Overall Bioelectricity Vision

Table 7 and **Figure 6** summarise the potential contribution of bioenergy to UK electricity supply from the opportunities discussed above. The contribution rises by 20% by 2026, and by 70% by 2032.

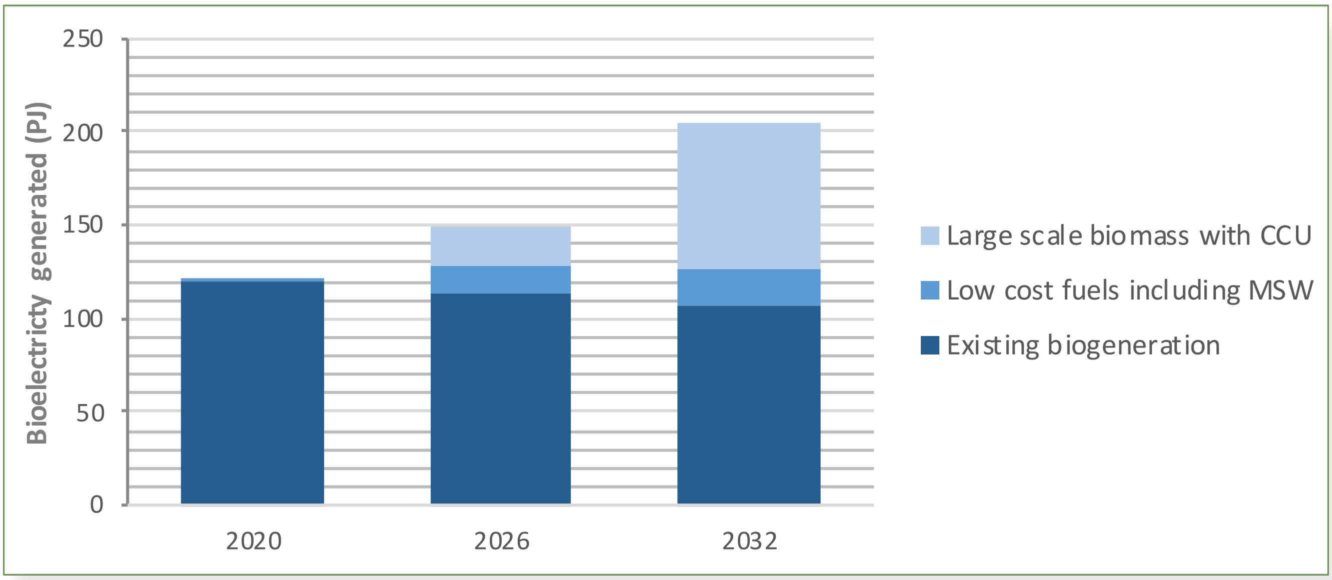
Table 7 • Summary of Potential Bioelectricity Supply to 2032

Bioelectricity Supply (PJ)

	2020	2026	2032
Existing bio generation	120	113	107
Low cost fuels including MSW	1	16	19
Large scale biomass with CCU	0	20	79
Total	**121**	**149**	**205**

As a share of overall electricity generation, bioelectricity rises from 11% in 2020, to 13.5% in 2026 and over 17% by 2032.

Figure 4 • Potential Total Growth in Bioelectricity Production



Development of Strategic Options with Carbon Capture and Storage or Use

The strategy outlined above will enable the demonstration of a number of technology options that can be linked to carbon capture use or storage (BECCS) by 2032, notably

- Large scale power generation
- Thermal gasification of bioenergy to produce biomethane or (other fuels) for heat or transport fuel production.

The deployment proposed will lay the basis for widespread adoption of BECCS post 2031, and open up routes to biomethane, and a range of other fuels and chemicals, including biojet (produced from synthesis gas by Fischer Tropsch processes) or hydrogen.

In addition to the CO_2 captured by newly installed systems there are other sources of CO_2 already produced in bioenergy production that could be collected and used or stored – for example when biomethane is separated from biogas, or during the fermentation processes involved with producing bioethanol.

Carbon capture associated with bioenergy production has been demonstrated in a number of cases in the UK, with the gas used for various economic purposes such as in the food industry and for enhancing growth in greenhouses. However, the carbon benefit of these uses is doubtful (unless the carbon is being specifically produced from fuels) and the scale of such potential uses is limited. Carbon capture and storage, when carbon is taken out of the atmosphere permanently stored, has not yet been demonstrated at scale in the UK and no infrastructure is currently in place. If such infrastructure is developed (for example around a “Heavy Industry Hub”) then nearby bioenergy sources could make use of it.

In the absence of such infrastructure, a “half-way house” is to capture and then use the CO_2 to produce fuels through its combination with hydrogen (bioenergy with carbon capture and use – BECCU). While not taking carbon definitively out of the atmosphere such processes have a carbon benefit because the fuels produced displace additional fossil fuels. Using the carbon in this way effectively increases the volume of low carbon products from the biomass feedstock. These can either be fuels (including methane and methanol) or a range of more complex chemicals that could be used either as fuels or as building blocks within an expanded sustainable bioeconomy (Hannula and Koponen 2017).

The ability to use the carbon in this way can provide an opportunity to demonstrate the capture process even in the absence of carbon storage infrastructure and may have merits in the long term in its own rights. Carbon capture and use can be demonstrated at a scale appropriate to the bioenergy production facility and does not require large-scale capture and storage infrastructure. However, such projects do need access to supplies of hydrogen. This would ideally be produced by electrolysis using renewable electricity rather than from methane.

While CCU systems can be deployed now, further R,D&D is needed to identify the optimum routes for using captured CO_2 in terms of product value and the associated GHG benefits (to be discussed in Phase 3 of this project). A potentially interesting option is to “integrate” the carbon re-use into the gasification process by adding hydrogen during the gasification stage. This turns the CO_2 formed during gasification into further hydrocarbons, with little or no emission of CO_2. One effect of such a process is to very significantly increase the yield of biofuels from a given amount of biomass (IEA 2017b).

To stimulate both BECCS and BECCU projects, a favorable policy and regulatory framework which indicates that making BECCS or BECCU financially rewarding (or mandatory) will be a prerequisite before companies commit to the necessary investment in R, D and D to develop and demonstrate the technologies. The options for this will also be considered in Phase 3 of this project.

Overall Vision for Bioenergy Contribution

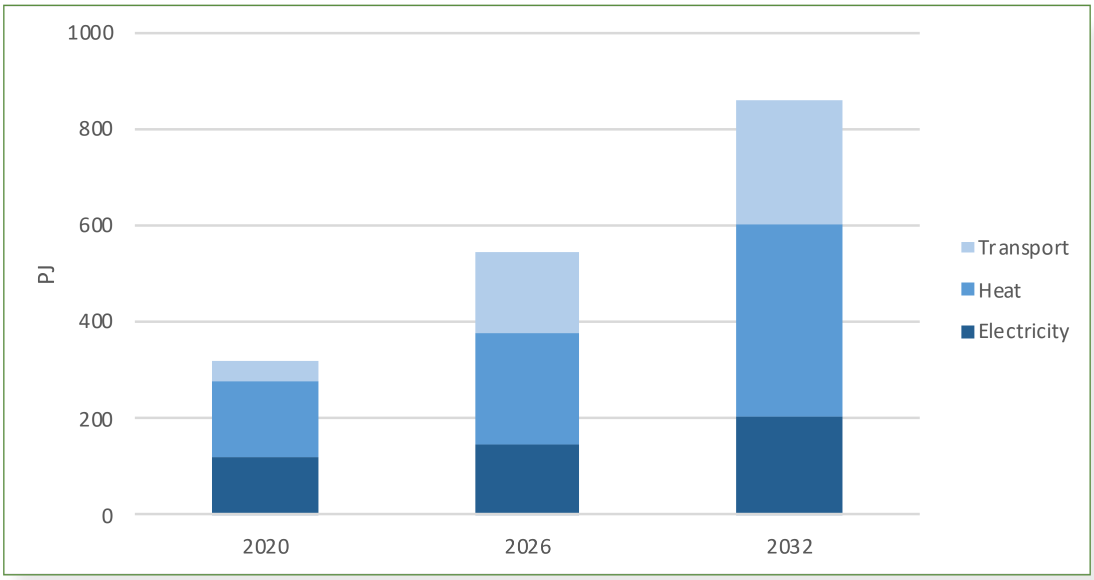
Table 8 and Figure 5 summarise the potential contribution of bioenergy to UK energy supply in the electricity, heat and transport sectors as discussed above. The overall contribution to energy supply rises by a factor of 1.6 between 2020 and 2026, and by a factor of 2.6 by 2032.

Table 8 • Bioenergy Vision to 2032 – Summary of Contributions

Contribution to UK Energy Supply PJ

	2020	2026	2032
Heat	159	219	376
Transport	42	167	261
Electricity	121	144	205
Total	**323**	**530**	**843**

Figure 5 • Potential Overall Growth in Bioenergy to 2032



Growth is targeted particularly at the heat and transport sectors, where bioenergy can play a unique role in decarbonisation efforts. The vision also embraces important stepping-stones in the development pathways for technologies that can be adapted to carbon capture and storage when the need arises and to the development of the supply chains that will be a prerequisite for an enhanced future role for bioenergy.

The overall share of bioenergy in final energy demand rises from 5.5% in 2020 to 9.5% in 2026 and nearly 15% in 2032.

Biomass Resources

UK Feedstock Availability

There have been many reviews of the availability of bioenergy feedstocks for use in the UK. Most notably, BEIS have a UK supply model, recently updated by Ricardo. This provides provides estimates of both UK and internationally available resources, taking into account appropriate sustainability criteria, competing non-energy uses and potential barriers to making the feedstocks available (BEIS 2017). Their estimate of the accessible UK based supply feedstock supply for 2030 is summarised in Figure 8 The total resource amounts to between 580 and 672 PJ, made up of the following categories:

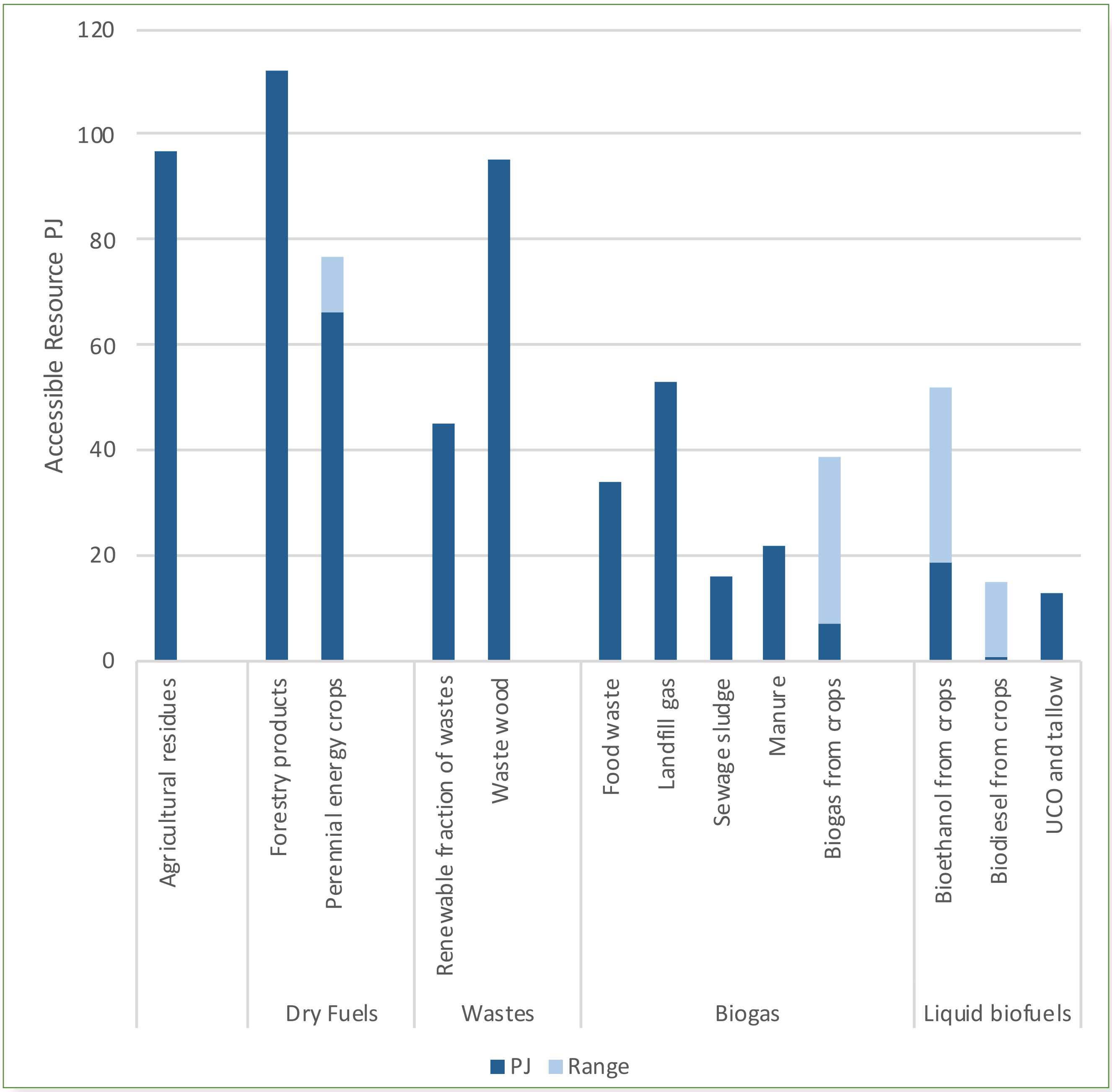
Relatively dry feedstocks appropriate for combustion or thermal treatment including:

- Agricultural residues (principally straw)
- Products from forestry and timber industries including forest residues, stemwood, sawmill coproducts and arboricultural arisings
- Perennial energy crops (such as miscanthus and short rotation coppice)
- Wood waste
- The renewable fraction of wastes (RFW)

- Feedstocks suitable for anaerobic digestion to produce biogas or biomethane including:
    - Food waste
    - Sewage gas, sludge and landfill gas
    - Livestock manures
    - Crops appropriate for biogas production

- Feedstocks for biofuels production including
    - Bioethanol and biodiesel crops
    - Used cooking oil (UCO) and tallow

Figure 6 • Accessible UK Bioenergy feedstocks resource, 2030



Source: BEIS Feedstock supply model (BEIS 2017)

Bioenergy Vision - Feedstock Requirements

The curent pattern of bioenergy production in the UK makes use of a wide range of these UK feedstocks such as municipal solid waste, landfill and sewage gas, wood wastes and wood fuels, animal wastes and bedding, and straw, along with some crops grown for energy, notably for biofuels production but with only small quantities of dry crops such as miscanthus and short-rotation forestry. The UK also uses imported materials in the form of biofuels for transport (biodiesel and bioethanol) and of wood pellets for use in large scale power generation.

The use of the higher levels of bioenergy proposed in the vision set out above implies a greater use of biomass resources by 2032. Table 9 shows how the feedstock demand would need to increase to meet bioenergy demand in the heat, transport and electricity sectors.

Table 9 • Bioenergy Vision – Feedstock Requirements to 2032

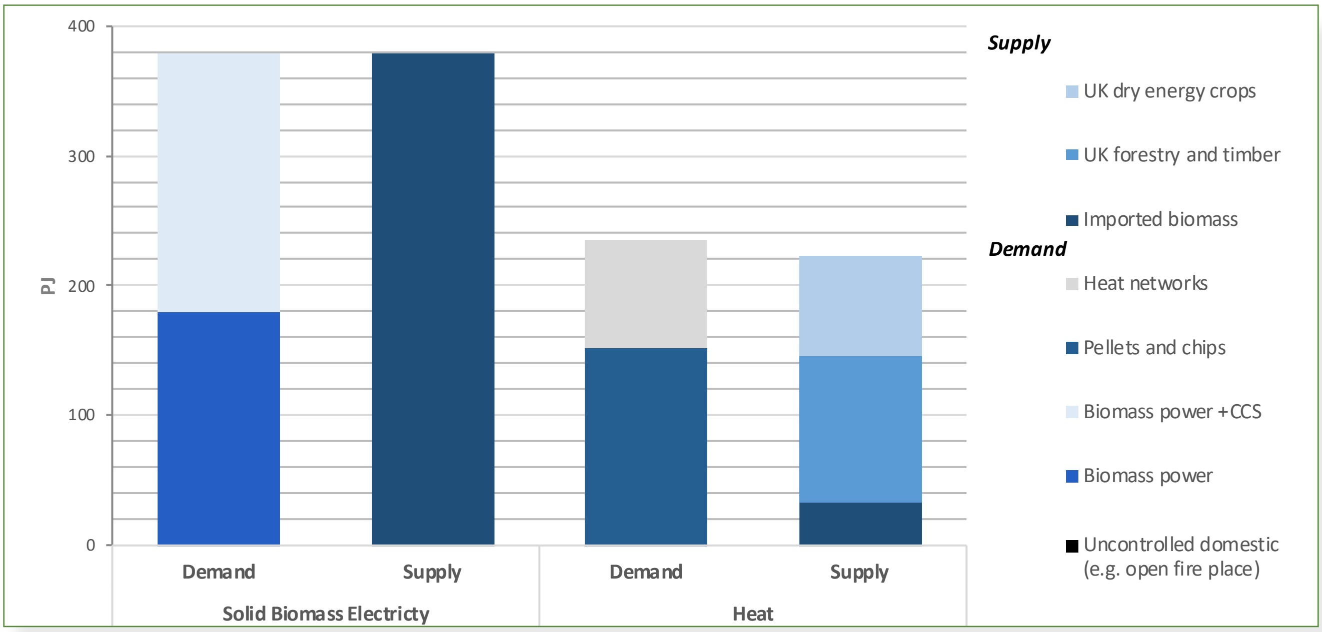
Bioenergy Vision – Feedstock Requirements to 2032

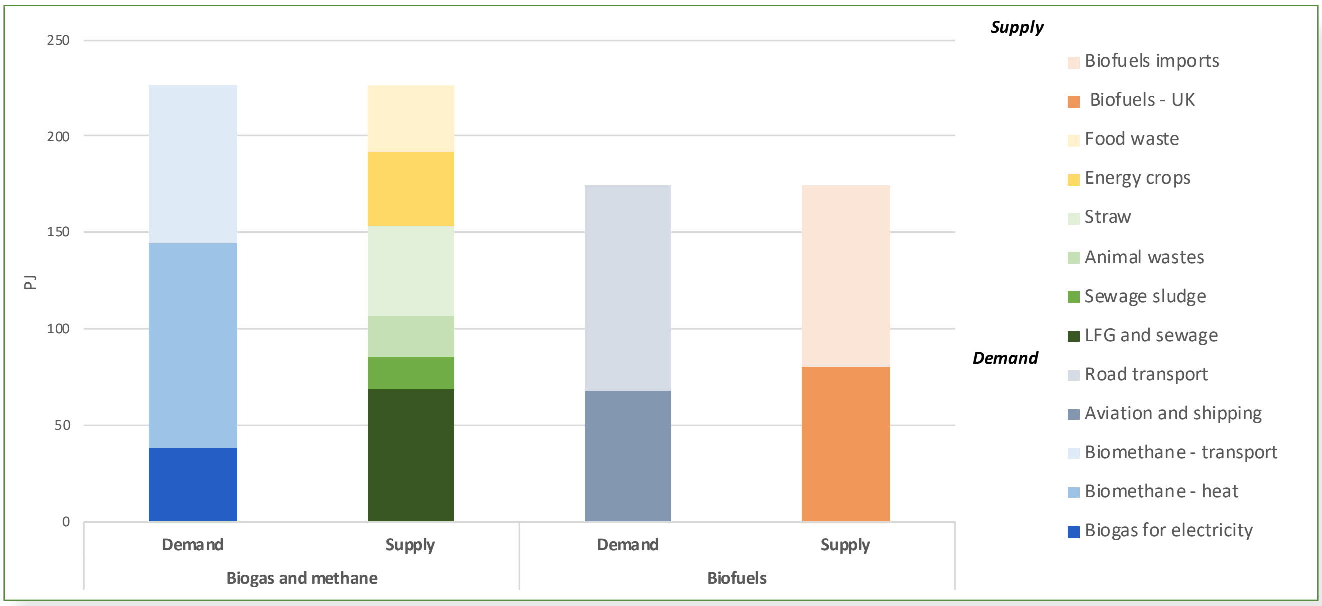
	2020	2026	2032
Heat	159	219	386
Transport	42	167	261
Power generation	316	359	490
Total	**517**	**731**	**1051**

Meeting these levels would make full use of the potential feedstocks that are available or that could be developed within the UK by 2032 according to the Ricardo study. Fuel use is made of the potential supplies from forestry and wood industries and from wastes (helping to push the UK to a sitation where there is no landfilling of organic wastes by 2026). In addition, the strategy relies on the development of energy crops like “dry” cellulosic crops such as miscanthus, short rotation coppice and crops suitabe for digestion. An active programme will be required to develop the necessary supplies and infrastructure. Additional imported resourcesimported would be required, notably solid biomass pellets for large scale power generation where the volumes imported would need to double to around 400 PJ.

Additional liquid biofuels for transport would need to come from international markets (between 100 and 150 PJ, depending on the volumes available from the UK), but in industry's view the necessary materials could be procured while respecting stringent sustainability criteria. **Figure 7** shows a simplified pattern indicating the principal ways in which feedstocks are likely to be used by 2032, taking account of the characteristics of the fuels involved.

Figure 7 • Principal Availability and Use of Feedstocks – 2032 (PJ)





Wood fuels: the UK-based supplies of wood fuel from forestry, sawmill residues and arboricultural applications are assumed to be principally used to supply heat markets, where there is good matching between the widely dispersed nature of the supply which aligns well with the most likely markets in rural areas.

Perennial crops (such as miscanthus and short rotation forestry): will also be used to supplement the products from forestry and timber industries in the heating market. The volumes required by 2032 imply a planted area of some 450,000 hectares by then (assuming a yield of around 10 oven-dry tonnes/ha/year).

Solid biomass fuels (such as wood pellets): from overseas markets, currently used for large scale generation, are likely to be the fuel of choice for expansion of this type of use, given the need for such large scale supply. Delivering the fuels in quantity by sea and rail has cost and GHG benefits.

Waste fuels (such as MSW and waste wood): are assumed to be principally used in large scale CHP plants given the neeed for the plants to be fitted to meet Waste Incineration Directive Emission standards. They will supply a proportion of the heat required for the expansion of urban heat networks. Some material could also be diverted to thermal gasification when the technology is in operation, or used in industrial processes such as cement manufacture.

"Wet wastes" (such as food wastes, sewage sludge and animal manures): will be primarily used to produce biogas (along with landfill and sewage gas) which can either be used directly or upgraded to methane for heat and transport uses.

Crops designed for biogas production: will be used to complement wet waste supplies.

Agricultural wastes (mostly cereal straw): will be used in a number of applications, but its characteristics favour its use to complement other agricutural resources as a feedstock for anaerobic digestion, or as a feedstock for making cellulosic ethanol as a supplement to other ethanol feedstocks, rather as a feedstock for combustion or gasification.

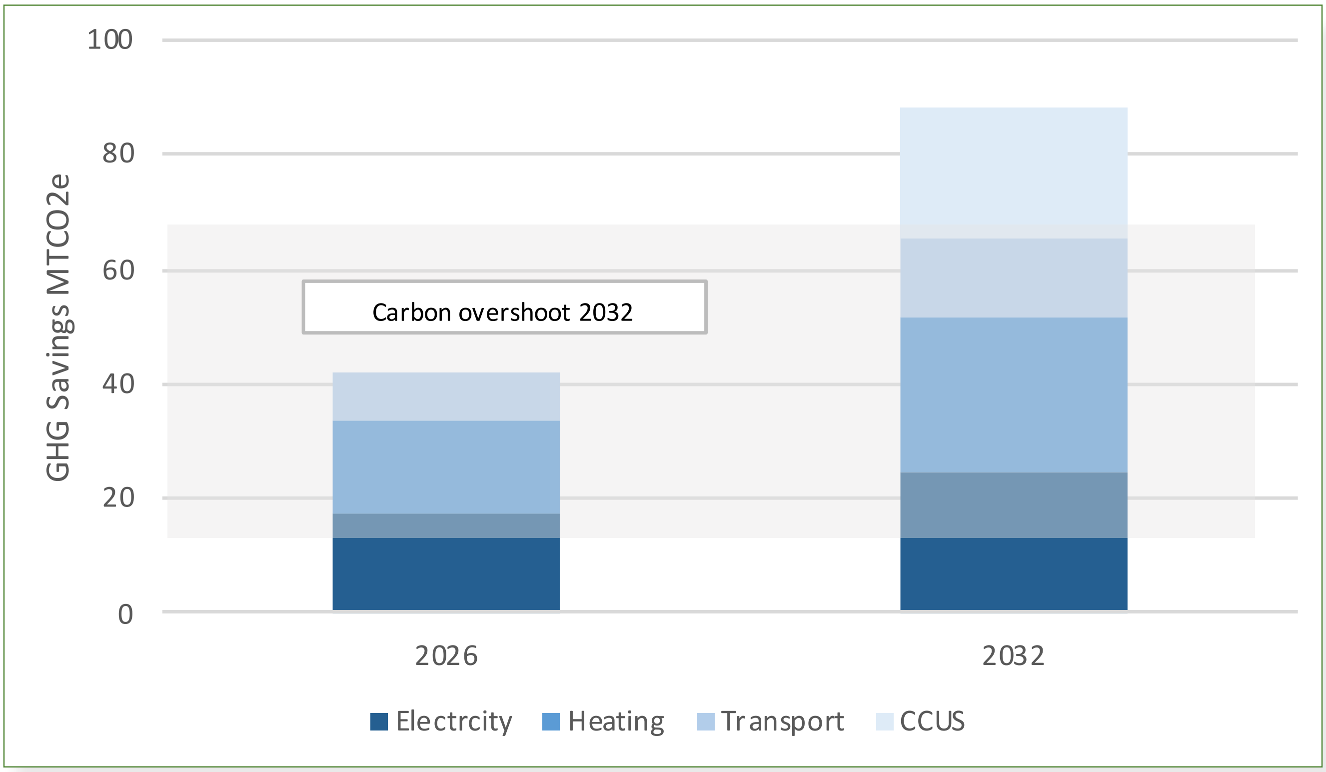
Other biofuels crops: can be produced where this provides agricultural benefits without impacting on food production, and supplemented by fuels imported from the international market (principally to serve the transport market but with other applications such as biopropane for heating, or as a blending fuel in heating oils).

Benefits

GHG Benefits

The GHG benefits associated with the contribution from bioenergy in 2032 have been estimated based on emission factors for the fuels most likely to be replaced (Figure 8).

Figure 8 • Emissions Savings Associated with Bioenergy Vision – 2032



In total the reduction in GHG emissions due to fossil fuel replacement amounts to some 41 $MTCO_2e$ in 2026 and to 65 $MTCO_2e$ in 2032. A further 23 $MTCO_2e$, could be saved due to recycling or storage of CO_2 separated from bioenergy processes (existing processes and newly installed capacity with purposed designed capture systems by 2032.

This means that implementation of the proposed vision and strategy could play a major role in reducing the predicted emissions overshoot of 10-65 $MTCO_2e$ for the end of the 4th and 5th carbon accounting period (CCC 2018a).

Energy Demand and Security

The proposed deployment would contribute an additional 215 PJ – 60 TWh to the supply of heat in the UK without calling on the electricity supply and distribution system. The additional bioelectricity generated would amount to some 57 TWh.

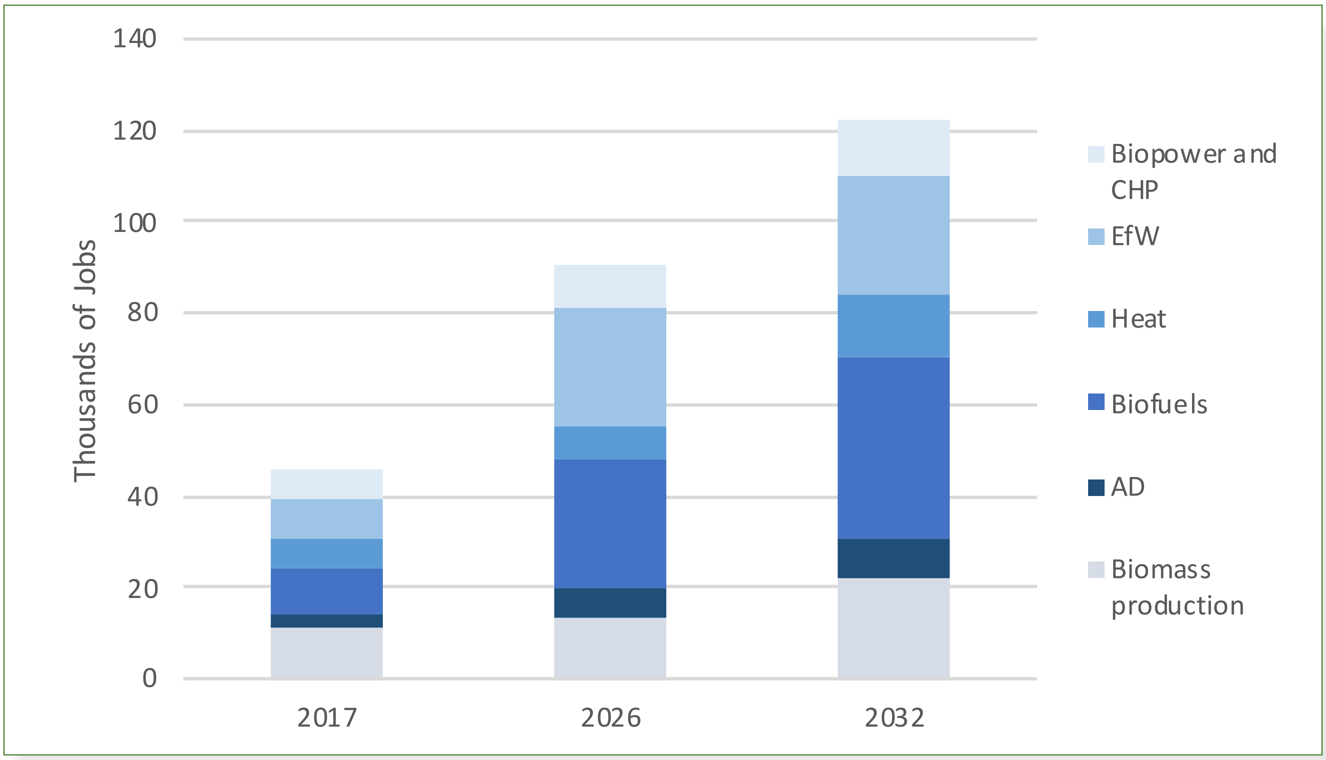
Taken together these two contributions reduce the need for other low carbon generation needed to supply the growing demands for heat, transport and other uses by 117 TWh – more than enough to close the predicted "nuclear gap" of 72 TWh (Carbon Brief 2019).

Jobs

In 2017 the REA economic survey indicated that there were over 46,000 jobs associated with bioenergy activities in the UK, and provided a sectoral breakdown (REA 2018).

A preliminary estimate has been made of the number of jobs that would be stimulated if the vision presented here was delivered, by scaling up the number of jobs in each sector according to the proposed increases in energy delivered. The results are shown in Figure 9, which indicates that the total might rise to 90,000 by 2026 and to 120,000 jobs by 2032.

Figure 9 • Employment in Bioenergy Sector



This estimate may overstate the level of employment as some economies of scale should be possible. Further work would be needed to identify more precisely the number of jobs and other socio-economic benefits associated with such growth in the sector. Nonetheless the total is likely to rise to over 80,000 by 2026 and over 100,000 by 2032.

4. Bioenergy Strategy – Next Steps

This report has spelled out a vison for the further development of bioenergy in the UK until 2032, making an immediate contribution to carbon savings while also laying the basis for the deployment of technologies with enhanced carbon benefits. It has also quantified some of the benefits and explained how such developments can assist delivery of the UK's low carbon strategy.

However, such a vision will only be realised with a supportive policy and regulatory framework, which provides long-term confidence to investors while setting strict standards for sustainability management. The CCC point out that such a policy and regulatory framework is a sine qua non for the whole of the UK low carbon strategy, and this is particularly the case for bioenergy.

As pointed out in the first report produced under this project, progress in bioenergy over the last ten years has been stimulated by a number of supportive policy measures, but they have been progressively removed in the last few years and there is now a policy gap inhibiting further development and investment. A new framework is urgently needed which reflects the increased maturity and improved cost effectiveness of a number of bioenergy sectors, while recognising the need to support the emergence of a further range of technology solutions which can play a role in increasingly challenging carbon targets.

In the third and final phase of this project a set of proposals for such an appropriate policy and regulatory framework will be developed in discussion with industry and government stakeholders, along with a set of further actions which will be required to deliver the vision set out here.

Units of measure and conversion factors

Units of Measure

kilo (k)	103
mega (M)	106
giga (G)	109
tera (T)	1012
peta (P)	1015
exa (E)	1018

EJ	exajoule
GJ	gigajoule
ktoe	kilotonnes of oil-equivalent
kWh	kilowatt-hour
Mtoe	megatonnes of oil-equivalent
MJ	megajoule
GW	gigawatt
GWh	gigawatt-hour
TWh	terawatt-hour

Conversion factors

1PJ = 277.8 GWh = 23.9 ktoe

1ktoe = 41.868 TJ = 11.63 GWh

1 MWh = 3.6 TJ = 85.98 toe

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