The Potential Role for Biomass as a Long-Duration Store of Energy – scoping study for the Supergen Bioenergy Hub and the UK Energy Research Centre

Full Report

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Headlines

- There is an increasing requirement for long-duration energy storage to accommodate seasonal and weather-related variations in wind and solar electricity generation. Government targets for the decarbonisation of the UK energy system are leading to large-scale deployment of these renewable generation technologies to displace the use of fossil fuels for electricity generation and in the heat and transport sectors.
- **Bioenergy infrastructure and supply chains**, such as seasonally harvested crops, waste wood and forestry by-products, **currently store energy at scale over relatively long periods**. There is the potential to use this characteristic to **facilitate greater flexibility** in the operation of **heat, gas and electricity** systems and markets.
- All current use of **biomass** within the UK energy system is **shaped by Government policy, incentives and regulation. These do not currently promote flexible operation** of bioenergy production particularly on smaller capacity sites.
- The **capital and operational costs** of bioenergy production are **well understood** and are already delivering **cost-competitive commercial operations**. This knowledge could be used to deliver a lower-cost solution to the **long-duration energy storage challenge**, complementing the other solutions currently being proposed.
- A current focus for **UK Government** bioenergy **policy** is the delivery of **negative emissions** from **large-scale bioenergy with carbon capture and storage (BECCS) operations**. There is also the potential for **smaller-scale biomass** operations to deliver both **BECCS** and other on-going system benefits, such as **providing a store of energy that can be used flexibly**. These opportunities shouldn't be ignored.

Background

This study has arisen from a collaboration between the Supergen Bioenergy Hub, the UK Energy Research Centre (UKERC) and Cultivate Innovation Ltd, exploring the potential for biomass to act as a flexible, low-carbon store of energy within the UK energy system.

The UK's National Energy System Operator (NESO) has identified that biomass "provides a renewable low carbon power source" that can be used as dispatchable generation to "help meet demand during times of low wind and solar output", contributing to the delivery of a more resilient energy supply. However, where carbon capture and storage (CCS) is installed to create a "negative emissions" BECCS system, NESO suggests that higher load factors would be desirable to "maximise carbon removal from the atmosphere". NESO also quotes the Climate Change Committee (CCC), who identified BECCS as the 'best long-term use of scarce bioenergy resources' in an energy generation context.

Whilst the study reported here does not challenge these assertions, it has drawn on knowledge from around 50 public, private and academic-sector stakeholders to explore the implications of this strategy on the biomass sector. It has sought to understand the role of biomass as a store of energy in gas and heat as well as electricity markets, and whether this role can be sustained alongside the delivery of BECCS in the medium and long term.

Approach

The study has been delivered through engagement with a range of relevant stakeholders, supplemented by reviews of both the academic and grey literatures, with the following specific aims:

- Establish existing evidence for the potential of sustainably produced biomass from a range of sources to act as long-duration stores of energy, delivering flexibility across the energy system through both 'firm' and 'dispatchable' delivery of electricity, heat and gas.
- Understand the combinations of technology, feedstock and geographical location that are most likely to facilitate the delivery of BECCS; provide a better understanding of the timescales for this transition; and explore where energy production from biomass without CCS may persist for longer while still delivering overall system benefits.
- Explore the implications (commercial, economic, environmental, social and technical), both for fuel supply chains and the energy system, of optimising the use of biomass in these contexts.

Specifically, the study has sought to address the following research questions:

- What are the technical and commercial implications of more flexible operating regimes on gas, heat and electricity production from biomass between now and 2030 and in the longer term?
- What fuel/plant types are best suited to these operational regimes, how do you ensure flexibility and availability of these plants, and what are the cost implications of doing this?
- In this context, what are the implications for bioenergy plant capacity up to 2030 and beyond?
- How, when and where is BECCS likely to become commercially viable in a wide range of operational scenarios and under what conditions would BECCS displace unabated operation?
- What are the constraints that might prevent delivery of these scenarios both in the fuel supply chain and with respect to plant investment/operation?
- What are the implications for biomass resource production in the UK, how is this likely to compete with international feedstock supply chains, and what are the relative implications from a carbon accounting perspective?

To deliver answers to these questions, the work has been structured around three equally weighted themes:

- **Plant, infrastructure and products:** current operation, future operation, best match to flexibility needs
- **Dynamics of BECCS:** timescales and feasibility of a transition to 100% BECCS
- **Supply chains:** UK and international - what are the impacts of flexible use of biomass

Findings

Potential

Bioenergy infrastructure and supply chains, such as seasonally harvested crops, waste wood and forestry by-products, currently store energy at scale over relatively long periods and have the potential to facilitate greater flexibility in the operation of heat, gas and electricity systems and markets.

The volumes of biomass currently available in the system are commensurate with the scale of need for long-duration energy storage, and there are operational assets at a range of scales that are capable of utilising these resources to support the system. Added to this, the flexibility potential of biomass operations is diverse, geographically as well as temporally distributed.

It is important to remember that bioenergy feedstocks act as a market. There are opportunities for greater commoditisation of this market and the potential for further expansion of UK feedstock supply chains for flexible bioenergy production.

Flexible operation will have an impact on supply chains. Incentivising the use of biomass for energy storage without also incentivising increases in plant capacity could reduce the amount of bioenergy in the system and have a detrimental effect on hard-won feedstock supply chains. Any decision that reduces the volumes or increases the price of biomass feedstock that is utilised in non-BECCS applications could adversely impact supply chains, and reduce the potential for future BECCS implementations.

Policy

All current use of biomass within the UK energy system is shaped by Government policy, incentives and regulation. These do not currently promote flexible operation of bioenergy production particularly on smaller capacity sites. Future policy seeking to address the need for long-duration energy storage in the UK's energy system should consider the potential for biomass to play a role in delivering these services.

Policy and regulation will play a key role in setting the future direction of bioenergy and this creates opportunities for government. However, there are also challenges, and examples exist where policy and regulation are or can be actively detrimental to the biomass sector. Without urgent action, there is a risk that operations currently supported by Renewables Obligation Certificates (ROCs) will be forced off-line as this support mechanism comes to an end. In these cases, assets may be decommissioned, operational teams disbanded, and the potential for energy storage and other flexibility benefits would be lost to the system.

There is significant pressure being placed on the UK Government to reduce the use of biomass for energy production on the basis of concerns about emissions and sustainability of supply chains. The use of UK-produced feedstocks, particularly waste streams that would otherwise go to landfill, may help to allay some of these concerns.

Current policy, incentives and regulations appear to be hampering industry's ability to use biomass flexibly. If it is accepted that it would bring additional value, governments could develop approaches that actively support such flexible operation. In common with developments in all parts of the energy system, development of policy and regulations that support flexible biomass operation will involve complex interactions between diverse actors, but research and innovation can make the problem tractable.

Costs

The capital and operational costs of bioenergy production are well understood and are already delivering cost-competitive commercial operations. This knowledge could be used to deliver a lower-cost solution to the long-duration energy storage challenge, complementing the other solutions currently being proposed.

Although feedstock flexibility brings technical challenges, new biomass plants designed to provide flexibility could do so with greater efficiency and larger turndown ratios, further increasing the potential of biomass to deliver benefits and a range of value streams to owners and operators.

There is also a range of existing, smaller-scale distributed operations that, with appropriate support, would have the potential to deliver flexibility in different ways. In particular, biomass to heat should not be overlooked, particularly in an industrial context. Biomass to heat can deliver energy system flexibility, especially when integrated with heat storage, but challenges remain, requiring incentives for innovation and new business models. With appropriate support, other smaller-scale operations could also be converted to deliver BECCS.

Smaller distributed operations could also be cost effective from a supply chain perspective. They can support local economies, make efficient use of indigenous resources, and reduce waste. This could have greater political viability than some larger-scale options for long-duration energy storage.

BECCS

A current focus for UK Government bioenergy policy is the delivery of negative emissions from large-scale BECCS operations. There is also the potential for smaller-scale biomass operations to deliver both BECCS and other on-going system benefits, such as providing a store of energy that can be used flexibly. These opportunities shouldn't be ignored.

There are many uncertainties about the timing and availability of CO_2 transport and storage solutions; however, some small-scale biogas operations are ready now to deliver BECCS and could combine this with seasonal energy storage and flexibility. In addition to negative greenhouse gas (GHG) emisions, these operations could provide both firm and dispatchable power to electricity markets whilst delivering similar services to both heat and gas markets. With appropriate support, other smaller-scale operations could also be converted to deliver BECCS.

There is a dividing line when considering whether BECCS plants would operate flexibly, based on an assumption that the negative emissions from BECCS are always the highest value use case for bioenergy in stationary applications. There's a belief that flexibility reduces this value. In many contexts this needs to be challenged. Making a BECCS plant flexible is very dependent on economics and geography, but there are specific cases/places where flexible BECCS plants could add value. This value would need to be delivered throughout the supply chain and may be dependent on the development of CO_2 transport and storage.

Conclusions and further work

This study has established that bioenergy supply chains already store energy over prolonged periods, and that there is potential to make use of this characteristic to address the seasonal variations in wind and solar renewables output that affect electricity, heat and gas markets. There are multiple options for delivering system flexibility with biomass. Additional work will be needed to establish the scale of this potential on a commercial basis and in the context of the wider economy.

Future work will also need to take account of the transition to BECCS and the relative value that both negative emissions and lower-cost energy stores deliver to the energy system. The current study has shown that the two are not mutually exclusive, but require regulatory frameworks and incentives that deliver commercial benefits from delivering both services to the overall system.

When considering the role of bioenergy in delivering both negative emissions and flexible stores of energy, it is essential that a whole systems approach be taken. Whilst the cost of energy production on any particular plant will be important to its commercial viability, the true value that the operation delivers has to be considered in a whole systems context, shaped by appropriate policy and regulation.

The work reported here has identified a number of areas where further research and development work would be needed, both to provide additional evidence to support these findings, but also to shape the policy and commercial models required to realise the lower-cost energy storage potential of bioenergy. Specific areas for further work include:

Exploring the system value of both flexibility and BECCS

- **Energy system modelling** – whole energy systems modelling to assess the value that could be delivered to the system by biomass energy storage, comparing this to the system-wide costs of other long-duration energy storage options and the system value of BECCS.
  - **BECCS** – address key uncertainties around the timing and feasibility of retrofitting BECCS to existing bioenergy plants, including the viability of small-scale BECCS, distributed CO_2 transport, and the commercial potential of flexible BECCS operations.
  - **Appropriate technologies** – more detailed UK-specific analysis to assess opportunities, system impacts, and commercial changes required for investment in energy storage and flexibility from bioenergy across a range of plant types and scales of operation.
  - **New flexible plants** – research to assess the opportunities for new flexible bioenergy plants that support energy storage, flexibility and other value streams, to identify optimal plant designs, and regulatory and market frameworks required to enable investment.

Bioenergy feedstocks

- **Feedstock modelling** – to help clarify a strategic role for bioenergy in delivering long-duration energy storage, taking account of the potential for sustainable imports and the influence of BECCS on feedstock pricing.
    - **Feedstock supply chains** – explore the investment and policy reform needed to unlock the long-duration energy storage potential of existing feedstock supply-chains through actor engagement, commercial incentives and wider market opportunities.
    - **Feedstock production** - stakeholders want to better understand how sustainable bioenergy feedstock production - via marginal land and crop rotation - could support long-duration energy storage from bioenergy while reducing reliance on imports.
    - **Fuel flexibility** – investigate impacts on energy system security, supply chain flexibility, and resource efficiency of expanding feedstock diversity on specific bioenergy plants, to assess the scale of benefit that can be achieved without compromising plant reliability.

Economics

- **Market mechanisms** – examine capacity market reform and other mechanisms for incentivising operational flexibility from bioenergy and BECCS plants, evaluating commercial value streams and system-wide costs relative to other flexibility solutions.
    - **Circular economy** – research to assess the impact on feedstock quality, supply and pricing of efforts to enhance the UK's circular economy, which is likely to reduce biogenic waste stream availability where these feedstocks have not been commoditised.

Wider Society

- **Place** – investigate the role of local markets, agronomy, energy planning and other political factors in the success of distributed bioenergy production and explore how these could support flexibility, particularly for heat delivery.
    - **Social acceptance** – investigate claims that some biomass technologies and/or scales of operation are more accepted by society. Do smaller scale plants, or technologies that don't involve certain feedstocks face fewer objections?
    - **Unintended policy consequences** – assess who would benefit from the value flows created by incentivising bioenergy production flexibility, and address timescales and transitional arrangements to ensure effective system adaptation and maximise impact.

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Chapter 1 – Introduction & Methodology

1.1 Introduction

This study has arisen from a collaboration between the Supergen Bioenergy Hub, UKERC and Cultivate Innovation Ltd, exploring the potential for biomass to act as a long-duration store of energy within the UK energy system.

Government targets for the decarbonisation of energy in the UK have led to large-scale deployment of wind and solar electricity generation capacity. This renewable electricity production is intended to displace the use of fossil fuels for heat and transport as well as in the electricity sector, and there is an expectation of significant further development of renewables-based electrification as a route to reducing greenhouse gas emissions from the UK economy. As a direct consequence of these changes, and to accommodate seasonal and weather-related variations in wind and solar generation output, there is an increasing requirement for long-duration energy storage integrated with both firm and dispatchable energy production capacity.

In their 7th Carbon Budget (CCC, 2025), the Climate Change Committee (CCC) defines 'firm power' as "sources of predictable and schedulable electricity generation with relatively inflexible generation profiles" like nuclear. They define 'dispatchable power' as "sources of generation that can be planned with a high degree of confidence to provide flexible, controllable electricity… to provide security of supply, in particular during periods of low production from variable weather-dependent renewables."

The UK's National Energy System Operator (NESO) has identified that biomass "provides a renewable low carbon power source" that can be used as dispatchable generation to "help meet demand during times of low wind and solar output", contributing to the delivery of a more resilient energy supply (NESO, 2024). However, where CCS is installed to create a 'negative emissions' BECCS system (bioenergy with carbon capture and storage), NESO suggests that higher load factors would be desirable to "maximise carbon removal from the atmosphere". NESO also quotes the CCC who identified BECCS as the "best long-term use of scarce bioenergy resources"(CCC, 2025) in an energy generation context.

Whilst the study reported here does not challenge these assertions, it has drawn on knowledge from public, private and third-sector stakeholders to explore the implications of this strategy on the biomass sector.

It became very apparent in the early stages of these engagements that, in a bioenergy context, it was also important to clearly define what is meant by 'flexible operation'. 'Flexibility' can be very broadly defined as operating energy assets – both supply and demand – in a controlled way to meet the needs of the broader energy system. The energy system requires assets that can deliver energy storage and flexibility services on timescales ranging from milliseconds (when delivering frequency response in the electricity system) to years (when providing long-term strategic stores of energy). For the purposes of this study, the focus was on three timescales:

- **Annual** – the flexibility needed to address TWh variations in renewables output from year-to-year
- **Seasonal** – the management of inter-seasonal TWh surpluses and deficits of energy production
- **Winter Wind Drought** (or Dunkelflaute) – extended, weather-dependent periods of extremely low wind and solar output requiring increases in both volume (TWh) and capacity (GW) of output from alternative energy production assets

In all three cases, the requirement is for a long-duration store of energy that can be converted into the forms required by end users (electricity, gas or heat) when those needs are not being met by weather-dependent renewable production. Other than during a 'wind drought', the primary need here is to have flexibility in the output of the asset across a defined load range – the ability to turn output up or down in response to the TWh energy needs of the wider system. It would not necessarily require the plant to 'two-shift' or to remain idle or on 'stand-by' for long periods, and for some biomass operations this sort of flexibility could be achieved by arbitrating plant output between different markets (e.g. gas and electricity or heat and electricity).

The study reported here has sought to understand the potential roles for biomass in delivering such long-duration energy storage, and how these roles might play out across the energy system, in gas and heat as well as electricity markets, and whether these roles can be sustained alongside the delivery of BECCS in the medium and long-term.

1.2 Methodology

This study has explored the use of bioenergy in the context of power and heat systems in the UK. Transport is another key use of bioenergy, however it was decided that this was outside the scope of the present report, and so it focuses solely on stationary applications. The study has been delivered through engagement with 51 participants from the public (15 participants), private (23 participants) and academic (13 participants) sectors. Participants partook in a 'narrative approach' to the exploration of three equally weighted themes.

- **Plants, infrastructure and products:** considered the technical and commercial implications of operating bioenergy plants more flexibly. This explored current operation and potential future operating regimes, establishing the best match between these regimes and system flexibility needs across electricity, heat and biogas markets. In addressing this theme, the study sought to gather evidence for the potential of sustainably produced biomass from a range of sources to act as long-duration stores of energy, delivering flexibility across the energy system through both 'firm' and 'dispatchable' delivery of electricity, heat and gas.
- **Dynamics of BECCS:** explored how the transition to BECCS impacts the ability of biomass to deliver flexibility in the energy system. This took into account the timescales and feasibility of the transition to BECCS across all existing biomass operations, to better understand when it would be complete and the impact it could have on any long-duration energy storage role for biomass. Issues covered included the combinations of technology, feedstock and geographical location that are most likely to facilitate the delivery of BECCS; providing a better understanding of the timescales for this transition; and exploring where energy production from biomass without CCS may persist for longer while still delivering overall system benefits.
- **Supply chains:** investigating the impacts of flexible biomass operations on both UK and international supply chains for sustainably produced biomass. Exploring the implications (commercial, economic, environmental, social and technical) both for fuel supply chains and the overall energy system of optimising the use of biomass in this context.

To explore these themes, a series of narratives were established based on initial stakeholder engagements and supplemented by reviews of both the academic and wider literature.
Three 'over-arching' narratives were established, with a series of diverse and in some cases contradictory sub-narratives, drawing on the three themes identified above, and considering three timescales: short (to 2027), medium (to 2035) and long (to 2050). These narratives were presented to a wider group of stakeholders in the forms shown in Figures A1-A3 (in the Appendix to this report), through a series of one-to-one interviews (28 participants), focus groups (10 participants) and larger facilitated workshops (13 participants). The outputs of these engagements were captured through responses written by the participants, supplemented by notes captured by the facilitators.

Participants in the process were recruited from across the networks of the collaborating partners, and were selected to ensure diversity in organisation type, technical background, career stage, role and gender. 80 potential participants were contacted, out of which 51 contributed to the data collection process.

Through facilitated discussions around the narratives set out above, the study sought to address the following specific research questions:

- What are the technical and commercial implications of more flexible operating regimes on gas, heat and electricity production from biomass between now and 2030 and in the longer-term?
- What fuel/plant types are best suited to these operational regimes? How do you ensure flexibility and availability on these plants, and what are the cost implications of doing this?
- In this context, what are the implications for bioenergy plant capacity up to 2030 and beyond?
- How, when and where is BECCS likely to become commercially viable in a wide range of operational scenarios and under what conditions would BECCS displace unabated operation?
- What are the constraints that might prevent delivery of these scenarios both in the fuel supply chain and with respect to plant investment/operation?
- What are the implications for biomass resource production in the UK, how is this likely to compete with international feedstock supply chains, and what are the relative implications from a carbon accounting perspective?

The resultant analysis and discussion below represents the range of views expressed by participants. Some of these views are conflicting, and these conflicts are highlighted throughout the analysis.

Headline

Bioenergy infrastructure and supply chains, like seasonally harvested crops, waste wood and forestry by-products, currently deliver long-duration energy storage at scale and have the potential to facilitate greater flexibility in the operation of heat, gas and electricity systems and markets.

2.1 A role for biomass

The volumes of biomass currently available in the system are commensurate with the scale of need for long-duration energy storage. Added to this, the flexibility potential of biomass operations is diverse, geographically as well as temporally distributed.

Availability and storage

Energy storage is inherent to many technologies and energy vectors in the bioenergy sector, and a feature that is recognised both within industrial and academic circles. Both plant operators and feedstock producers pointed out that long-duration storage was already happening at different points throughout the feedstock supply chain. This was true for a range of feedstocks including woody biomass feedstocks and energy crops, although the technical specificities differed (with energy crops needing careful compaction in feedstock clamps, for example). Some also stated that while this storage could benefit from further investment, we are already seeing it work as a business model, with storage effectively being 'in-built'. This is an advantage that may not be shared amongst other approaches to storing energy over long periods.

A range of supply chain and operational models were reported, each utilising different degrees of storage; although small amounts of site-storage on the plants along with larger distributed stores throughout supply chain appears to be the norm. Participants felt that, with the right incentives, storage of this kind could expand and proliferate without presenting many technical challenges. Feedstock processing and upgrading were also raised as key elements in the delivery of energy storage from biomass, particularly for those raw feedstocks which do not lend themselves to storage (including sewage and slurries). This point arises in the literature (Schildhauer et al., 2021) and will be developed further in this analysis.

While the energy storage capabilities of bioenergy are not in dispute, the scale of their potential is more contentious. In particular, the total available volumes (in TWh) of feedstocks were a point of uncertainty for participants, especially when it came to future projections. Some participants predicted an increase in total volumes, while others believed they will remain largely the same with some changes in specific sources. Part of this uncertainty is due to the dynamics of domestic biomass production, although the greatest source of discrepancy seemed to be in beliefs around the future role of biomass imports. This difference was especially pronounced in expectations around the future of woody biomass resources. Some interviewees felt that total available volumes of these resources (particularly waste wood) currently far outstripped demand, while others anticipated a short-term increase in availability followed by a long-term decrease as global demand changes. Such divergences in predictions exist for most feedstocks, as can be seen in the differences between the predictions of the CCC and the Government (CCC, 2025; DESNZ, 2023). An analysis of the different assumptions and beliefs that lead to these discrepancies can be found later in this analysis, but the result is a very wide-ranging set of predictions as to the future availability of biomass resources (A. Welfle et al., 2020).

Having confidence in the future availability of feedstock resources is important as it allows for the development of plans for a secure and optimised energy system. As such, this high level of uncertainty is a challenge. There does, however, seem to be a consistent lower estimate of the total volumes, somewhere in the region 120-160 TWh of available feedstocks (ibid). The Royal Society recently conducted some analysis looking into the need for large-scale, long-duration energy storage (LDES) in the UK, focusing on hydrogen as a technical solution (The Royal Society, 2023). They found that there would be a need for approximately 30-90 TWh of energy delivered from long-duration stores of energy to meet the needs of an energy system largely supplied by intermittent renewable energy sources. Direct comparisons cannot be drawn between the findings of this analysis and the estimates of total available feedstocks laid out above. It can, however, be seen that they are of a similar order of magnitude, suggesting that it is reasonable to explore the potential role of biomass in contributing to the UK's need for long-duration stores of energy.

The detailed analysis needed to accurately assess the extent to which biomass could fulfil this energy storage role is outside the scope of this report. Where such analysis has been undertaken previously, it has largely focussed on the needs of the electricity system - biomass could and does play an important role in energy storage for heat too. Participants also pointed to the competing demands on biomass resources which could impact the total available volumes, something that would need to be considered in any future analysis.

Operational capacity

Sufficient volumes of available feedstocks are not the only element needed to deliver effective energy storage. There must also be plants and infrastructure to convert those stores into useable energy, be it heat, gas, or electricity. Analysis commissioned by the REA found that there is 5.5 GW of biomass capacity in the UK's power sector, compared with a peak demand on the power grid of a little over 60 GW (Baringa; REA, 2025). This represents a relatively significant quantity of controllable power output, which can – and to some extent does – operate flexibly, depending on the demands on the energy system. Yet, it is evidently only a fraction of the total required generation capacity needed by the grid. One interviewee claimed that some biomass generators (all combined heat and power plants) were occasionally ramping up generation from 1 to 5GW in a day to meet diurnal changes in power demand. However, as revealed in the REA report and from our interviews, biomass plants currently tend to run at more constant loads for a variety of reasons, including – but not limited to – incentive structures and technical know-how.

Nonetheless, this potential for biomass plants to operate more flexibly (that is to say, at a range of loads) is being recognised amongst key decision makers in the UK. In their 'Clean Power 2030' report, the National Energy Systems Operator (NESO) identified a role for biomass plants to provide flexibility to the power grid, especially over the next decade or so (NESO, 2024). The UK Government has also published its intention to support large-scale biomass plants to operate flexibly in the short-term – up to the early 2030s (DESNZ, 2025c). Participants highlighted the Government's desire to transition these plants toward more flexible operation as they could "play an important role in delivering security of supply". These plans exclude smaller biomass plants (below 100MW capacity), a point of concern for many operators and academics, and a point we shall return to. Suffice to say that using biomass power plants flexibly to make use of their controllable stores of energy is a well-recognised concept.

It is important, however, not to focus solely on electricity generation in any consideration of the output capacity of biomass plants in the UK. A key finding of this study is that it is equally important to consider the production of heat and biogas when discussing the role that biomass could play in energy storage. Analysis of DESNZ data sets (DESNZ, 2025a) showed that heating is still the greatest reason for energy consumption in the UK (industrial and residential combined). As such, the ability of biomass to directly produce heat is a key advantage and many interviewees raised the heat production flexibility of biomass as important when considering its role as a store of energy. Similarly, biogas and biomethane are key energy vectors which risk being overlooked if a focus on the power sector makes the analysis too myopic. The Baringa report referenced above found that the current end-uses of biomass were divided as follows: electricity generation – 66%, heat – 22%, transport – 18%, gas-grid injection – 4%. These end-uses are of course deeply intertwined, but in the analysis presented here it was considered appropriate to consider each individually, an approach that has been adopted throughout this report. As described in the introduction, while transport fuels are considered a key bioenergy end-use, they are not explored within this report. There are currently many bioenergy plants which produce heat and biomethane which will not be captured in the 5.5 GW of electricity generation capacity identified in the Baringa report, that is to say that just using this figure would result in an underestimate of the total energy production potential from biomass plants. The flexibility potential of these plants are considered further later in this report.

Biomass as a long-duration energy store

In undertaking this study, it quickly became apparent that the potential for biomass to act as a long-duration store of energy had not been widely considered. Yet, participants were keen to explore this potential with several ideas being presented.

As identified in the report by The Royal Society (The Royal Society, 2023), the UK often experiences large seasonal variations in renewable energy output, with the first three months of the year having a much lower average output than the rest of the year. Participants across all sectors believed that there was a case for exploring whether biomass operations could help to address this variation by increasing overall bioenergy output during that period. While this is a framing which centres on the power sector, it also has interesting interactions with heat generation as these months tend to be periods of lower temperature weather, increasing the demand for heat. As such, this was considered as a potential use case for a range of operators, within the power, heat and biogas sectors, particularly those operating combined heat and power plants. It was stressed that such operation would be quite different from current modes, however, and that different business models, operational models, and incentive structures would be needed to facilitate this kind of behaviour. A general interest in better understanding this potential was expressed by a plurality of participants.

A similar use case is for a winter weather phenomena known as a 'wind-drought' or 'Dunkelflaute', associated with a blocking high pressure which can become established over most of western Europe, reducing wind speeds and creating foggy conditions with low levels of light intensity. These can result in extended periods of low wind and solar availability, reducing the output from variable renewable generators to well below their average capacity. As the UK becomes more dependent on such variable renewable energy production, it will become more exposed to such extreme weather events which are highly unpredictable, a clear threat to energy security. Again, bioenergy operators believed they had the technical potential to help address such shortfalls in the energy supply. With adequate warning, they could adjust their operational outputs in a timely manner and contribute to making up for shortfalls in supply. Similar issues around incentives and operational models were raised as for addressing seasonal variation, but also concerns around the impacts of a highly uncertain demand on supply chains and stores of feedstocks. However, there was a sense that a technical potential existed within the bioenergy sector which may be being overlooked as other technical solutions took precedence.

Some participants also explored the potential for using biomass to solve shorter duration energy storage needs, such as load following, matching diurnal peaks in energy demand, and balancing out energy demand over a period of days. However, the prevailing opinion was that other solutions, such as battery storage and pumped-hydro, were better placed to address these challenges. It was bioenergy's capability to provide cost-effective storage for extended periods that seemed to have the greatest value in the opinions of those interviewed. This could be in part due to the uncertainty that exists around the potential solutions to the LDES and Low Carbon Dispatchable Power (LCDP) challenge. Comparisons to hydrogen were common as the apparent front-runner for addressing many of these challenges. Many pointed to the comparative costs of the two solutions as a clear reason bioenergy should be considered, alongside the relative certainty surrounding bioenergy as an assortment of well understood and proven technologies. Others were keen to point out that the two solutions were not necessarily mutually exclusive, and could potentially complement one another. One participant articulated this sentiment by saying that 'greater diversity in the makeup of our energy system should lead to greater energy security'.

Participants expressed a desire to see a thorough comparison of these different solution types along with whole systems analysis exploring how bioenergy could address some of these LDES needs in the coming years.

Geographical flexibility

While the potential for delivering energy storage is a key attribute of biomass, there are also potential benefits to be considered around its geographical flexibility, especially when the two attributes are considered in conjunction. Many of the participant discussions came to focus on smaller, distributed biomass plants and the role they could play in providing flexibility and security to local energy systems. More of the thinking around smaller, distributed plants will be discussed in later sections, but it is important to recognise this geographical flexibility role for bioenergy alongside its more temporal benefits.

The localised nature of smaller bioenergy plants was a key point raised by many participants. Often feedstocks are locally sourced, and the products of these operations become deeply entwined with the local economy. Heat producing plants were often held up as prime examples, with locally-sourced forestry residues, waste wood and other feedstocks providing heat to local communities. Heat, unlike electricity, does not lend itself to long-distance transport, and so heat-generating plants are by their very nature localised units. Some participants felt that the Government's plans seemed to be focussed on concentrating feedstock resources in very few locations, but that such an approach overlooked this fundamental value of biomass in providing heat services.

Controllable bioenergy production was also identified by some participants as providing additional advantages as part of localised energy systems, particularly in light of the increasing decentralisation of energy. As the energy system changes in response to the increasing use of variable renewable generation assets like wind and solar, which are more geographically dispersed, along with the proliferation of technologies such as heat pumps and electric vehicles, having distributed controllable bioenergy plants could help to alleviate many of the challenges such a system faces. It was also suggested that they could help to reduce the overall cost of the system, not least by reducing the need for grid infrastructure build-out.

The subject of smaller, distributed biomass plants will be discussed further through the report.

Technological details

For more detail on the specific bioenergy plant and vector types which can be used to provide LDES and consequent energy system flexibility, the IEA published a thorough report which summarises the landscape of technologies and their key attributes (Schildhauer et al., 2021). Specific technologies discussed with stakeholders as part of the data collection for the project reported here will be discussed in detail at various points, but a more holistic review of all technology options can be found in the referenced IEA report.

2.2 Markets

It is important to remember that bioenergy feedstocks act as a market. There are opportunities for greater commoditisation of this market and the potential for further expansion of indigenous feedstock supply chains for flexible bioenergy production.

Feedstock markets

Participants involved in the supply side of the biomass sector emphasised that feedstocks should be understood and treated as part of a competitive market when developing strategies and policies to support their delivery. This framing is crucial when considering how market dynamics such as competition, international trade, and demand certainty might shape feedstock availability and price. Sustainably-sourced biomass feedstocks are expected to remain limited, making them vulnerable to price pressures if demand outpaces supply (DESNZ, 2023). Several participants expressed this concern in relation to global markets, noting that international demand - and therefore competition - is likely to increase in the near to medium term. This, they argued, could drive up prices and potentially incentivise the use of unsustainable biomass sources, such as wood from virgin forests. (Sustainability issues are discussed in more detail later in this report.) The drivers of this growing demand include the increasing role of bioenergy in global decarbonisation strategies, as well as the anticipated growth of the bioeconomy.

However, these competitive dynamics are not limited to international markets. Within the UK, biomass feedstocks are used across multiple sectors, not just for heat and power. This means that biomass's role as a form of energy storage could face domestic competition as well. For example, participants pointed to panel board manufacturing as a competing use for woody biomass. They noted that competition between bioenergy producers and manufacturers has already led to price increases for certain forestry and wood residues in the UK.

Another frequently cited area of emerging competition was the increasing demand for sustainable aviation fuels and other bio-derived transport fuels, a key future demand highlighted by the CCC (CCC, 2025). While these end-uses themselves could be considered forms of energy storage, they fall outside the heat and power focus of this report. Nonetheless, they compete for many of the same feedstocks.

While most participants did not view market competition as fundamentally prohibitive to biomass-based energy storage, they stressed that feedstock market dynamics must be taken seriously when evaluating the role of biomass in future UK energy systems.

Supply stability

Participants with knowledge of biomass supplies started to analyse the requisite structures and features of feedstock markets needed to make biomass-based energy storage viable, centring around the idea of supply chain security. By 'security' participants meant ensuring a consistent and reliable supply of feedstocks at relatively consistent prices, matched by an equally predictable demand. They particularly highlighted the need to move away from viewing feedstocks as 'wastes' toward increased commoditisation, and the role incentives may need to play.

Participants stated that supply chains and their markets would need to be 'secure' to ensure a reliable volume of available feedstocks to meet any energy storage needs. This was viewed as important for both suppliers and consumers, as lack of security created an increased risk for both sides of the market. Not only would this likely reduce participation in the market and increase prices, but it would also run contrary to one core aim of a long-duration store of energy, to provide security to the system. Without this commercial certainty it was seen as likely that producers would focus on other end uses, like those discussed above. This was articulated by one attendee as: "the biomass provider holds the key. They always have a choice". Ways of establishing this required security – as identified by the participants – included long-term guarantees for incentives and 'base rate' prices, and the commoditisation of feedstocks.

Commoditisation, the creation of interchangeable, standardised, and/or certified bioenergy goods (Bacovsky et al., 2023), was often raised in response to narratives around the use of waste streams as feedstocks for bioenergy. Several participants took issue with the idea that bioenergy should be primarily built upon the use of 'waste streams' on commercial and sustainability grounds. Biogenic waste streams are projected to decline between now and 2050 (CCC, 2020), and participants questioned the viability of a bioenergy business model built upon decreasing feedstock supplies. There were also concerns that as waste streams become generally more commoditised for purposes other than energy, available volumes and prices of feedstocks could become prohibitive for bioenergy consumers. These participants often cited the move toward a circular economy DESNZ, 2023) as evidence that relying on wastes might be commercially unviable. As such, feedstock and product commoditisation were viewed by many participants as a key feature for future bioenergy markets.

Commoditisation of bioenergy goods, as defined above, can help to create stable markets. Consumers can have faith in the quality of their inputs, and it can lead to greater consistency of demand for suppliers. Participants pointed to the processing and upgrading which is needed in much bioenergy commoditisation, claiming that it can aid flexible use as well as better market operation. Some pointed to hydrogenated vegetable oil (HVO), fatty acid methyl esters (FAME), biomethane, wood chips and pellets as examples of where this is already working effectively. In each case, raw feedstocks are processed to create products which can then be more easily stored, traded, transported, and consumed. They pointed to the better storability enabled by feedstock processing as a key benefit when seeking to provide biomass-based energy storage.
Some interviewees suggested that this processing can help to solve some of the fuel flexibility issues experienced by many bioenergy production plants. Processing can also lead to energy densification, enabling more efficient transportation as well as storage. Participants discussed the challenges of developing a more commoditised model of bioenergy supply. The stricter standards that accompany commoditisation have the potential to exclude some feedstocks which could lead to an overall reduction in usable volumes. Processing of feedstocks can also lead to lag times in the production of materials in appropriate form, something which could represent a challenge

during short periods of intense use. There were also sustainability concerns for some participants when it came to tracing the sources of commoditised bioenergy products. HVO was given as an example of a commoditised bio-product which had led to some highly unsustainable production practices historically. Other participants stated that the lack of clear sustainability criteria and carbon accounting schemes made it difficult to treat bioenergy products as sustainable traded commodities, at least in global markets. The IEA, however, is keen to stress that when utilised effectively, processing and commoditisation can be beneficial to the sustainability of the biomass sector, especially when combined with adequate tracking and documentation (Bacovsky et al., 2023).

The potential need for incentivising the supply and storage of biomass – specifically over long periods – was also discussed , with some seeing it as key to making these supply chains viable. Participants raised concerns that while storage was already present within the supply chain, it was not currently set up to provide the long-duration flexibility needed. Particularly in the woody biomass sector, plant operators stressed that their storage was largely ‘off-site’, further back through the supply chain. Some worried that, without appropriate incentives, these stores and supplies may not be maintained for the plants if they were being operated more flexibly, and that these feedstocks would be diverted to more consistent consumers – such as those discussed above. Similarly, questions were raised by participants as to the scale of biomass storage within the system, and whether these stores would be able to adapt to the needs currently met by fossil fuel stores. Again, some queried what incentive structures would need to be in place so that this necessary storage capacity would be built out. Feedstock commoditisation was once again highlighted as a potential solution, making storage and flexible distribution easier to manage financially and practically. Addressing these concerns is likely to require a dedicated analysis of current storage systems and capacities, as well as future needs.

Indigenous feedstocks

Participants in the domestic biomass sector were keen to highlight ways in which domestic production and markets for sustainable biomass could be developed. These ideas intersect with other key findings of our report, helping to build the case for advancing certain bioenergy technologies, such as biogas/biomethane.

Dedicated energy crops currently make up a small percentage of the overall biomass supply, both nationally and internationally making up less than 2% of total biomass supply (DESNZ, 2023;CCC, 2025). Predictions of future biomass resource availability can be challenging and inconsistent, but there seems to be a general consensus that energy crop stocks have the potential to increase (ibid). In the UK, particularly, there are two avenues for expanding production sustainably that were highlighted by participants. Areas of marginal land which are unable to support food crops have been shown to support the production of energy crops such as miscanthus (Lait & Walker, 2022). While several participants viewed this kind of crop production as being an exciting frontier in the sector, others raised questions about the total area of such marginal land, and therefore the scale of its potential. The second avenue was to improve the integration of energy crops into crop rotations, a practice utilised by farmers for centuries. Some argued that energy crop integration into these rotations could have a host of benefits including improving soil health and revenue generation for producers. Both are done at smaller scales currently, but have the potential to expand.

Agricultural residues were another source highlighted by a few participants with the potential for expanded production. However, some cited similar issues to the 'waste feedstocks' points listed above, and once again pointed to the need for commoditisation to develop effective markets for these products. This is as true for energy crops as it is for residues.

Participants involved in biomass production stressed the need for a considered approach to energy crops and residues. One highlighted that predictions about the future availability of energy crops in particular had changed several times over recent years, affecting and being affected by the responses of producers. Examples were given where energy crops had been incentivised for a short time only for those incentives to be cancelled and for producers to be commercially harmed. There was a sentiment amongst some that this had damaged trust in the sector, and that security and certainty around support and demand for energy crops would likely be needed to encourage producers to engage with these markets. Certain energy crops were also seen as needing greater support/incentives than others, with short rotation coppice (SRC) being given as an example of a crop which would likely not be commercially viable without incentives.

Biogas supply chains

One reason energy crops – and to a lesser extent agricultural residues – were discussed so broadly within these interviews is that they frequently intersect with discussions around biogas and biomethane production. This technology arose through many conversations as a leading potential solution for biomass-based energy storage – amongst other uses – as well as an effective end-use for these feedstocks.

One reason biomethane emerged as a viable store of energy was the flexibility participants saw it providing right the way through the production and consumption systems. We will come on to explore more about its output flexibility later, but some highlighted its significant input flexibility as well. As a technology, anaerobic digestion (AD, the most common way of producing biomethane) is robust to a wide range of feedstocks, including many of the energy crops and residues referred to above. While a single digester may predominantly use a single type or combination of feedstocks, plants can be configured to run on different inputs, depending on what is locally available. Some domain specialists stated that, on an individual plant level, a varied diet can even help production. Operators were keen to stress, however, that unplanned or poorly considered changes in diet for digesters could lead to negative consequences. As such, AD was viewed by many as a versatile solution for converting a potentially diverse and growing set of feedstocks into a more useful and commoditised form.

Biogas and biomethane were viewed by a wide range of participants as high potential technologies with significant room for growth. Predictions of its potential scale are discussed later in the report, however, many felt that the current policy landscape for biomethane was a limiting rather than enabling factor for the sector, and that with appropriate changes, production could increase substantially. Increased output could be achieved through a combination of current plant optimisation and new plant construction, both of which many in the sector advocated for. An increase in production would (beyond a certain point) necessarily require an increase in feedstock consumption. While feedstocks are available in sufficient quantities to enable this growth, this was not seen as certain by many participants for some of the reasons listed above. Given the range of potential end uses for biogas and biomethane, and the potential for its sustainable growth as a sector, several participants believed that supply chains should be developed and secured as a priority.

2.3 Flexibility impacts

Flexible operation will have an impact on supply chains. Incentivising the use of biomass for long-duration energy storage without also incentivising increases in plant capacity could reduce the amount of bioenergy in the system and have a detrimental effect on hard-won feedstock supply chains. Any decision that reduces the volumes or increases the price of biomass feedstock that is utilised in non-BECCS applications could adversely impact supply chains, and reduce the potential for future BECCS implementations.

Flexibility and overall consumption

Using biomass to provide an energy store for the UK's energy system will necessitate more flexible operation from producers of bioenergy. According to the majority of participants in this study, this would be a significant change in practice from baseload operation which is currently the norm, a finding which is supported by recent research (Baringa; REA, 2025).

Participants highlighted a key dynamic in such a system: operating generation assets more flexibly to meet these energy storage needs, without a concurrent increase in generation capacity, would lead to an overall decrease in the amounts of biomass consumed. The UK Government's published plans to incentivise the flexible operation of large-scale biomass plants recognise this fact. They intend for operators to use the same amount of total generating capacity but at a much lower average load, reducing the total feedstocks volumes consumed (DESNZ, 2025c). It was felt by some participants that this was in response to negative publicity around the feedstock sourcing of certain large plants, particularly around sustainability concerns.

However, reducing total volumes of feedstocks consumed by all plants was seen as a wasteful approach by some participants. The argument followed that there are significant volumes of sustainably-sourced biomass available in the UK, with good potential for delivering benefits to the whole energy system, which could be lost if feedstock demand were to reduce significantly. Lower overall consumption would reduce the impact bioenergy could have and would likely increase the UK's dependence on other forms of LDES and LCDP. To fully utilise the potential of biomass as a store of energy whilst maintaining similar levels of feedstock consumption, bioenergy production capacity would need to increase.

In addition, as stated previously, the electricity production capacity needs of the UK are much larger than the current total capacity of biomass plants. For bioenergy to play a significant role in tackling the UK's energy storage needs, the total capacity of electricity generation from biomass will likely need to increase. Exactly how much capacity would be needed and how much could be built were viewed by participants as open questions, and a key area in need of research. Participants believed that build-out of capacity would be key, but potentially politically and socially difficult, with supportive policy and strategy probably being essential. More discussion of the political requirements and challenges will follow.

Impacts of reduced demand

The commercial implications for feedstock suppliers of a reduced overall biomass demand were a key concern for many participants, particularly those in the biomass production sector. Several warned that such reductions in overall volumes could lead to the complete loss of certain supply chains, particularly if these changes were to occur quickly. They followed on by explaining that such losses could affect participation and trust in the sector and make it harder to establish supply chains for key feedstocks needed in the future.

Supply chains can be difficult to establish and participants pointed out that it would be much easier to maintain and develop those currently in place than build new ones. Both the CCC and DESNZ have articulated their belief that biomass will play a key role in a decarbonised future. BECCS, biofuels, and a broader bioeconomy will all depend on reliable biomass supplies, which will need to be part of a stable biomass sector. Pushing the bioenergy sector toward more flexible operating regimes without allowing the build-out of production capacity would put this future at greater risk.

Chapter 3 – Policy

Headline

All current use of biomass within the UK energy system is shaped by government policy, incentives and regulation. These do not currently promote flexible operation of bioenergy production particularly on smaller capacity sites. Future policy seeking to address the need for long-duration energy storage in the UK's energy system should consider the potential for biomass to play a role in delivering these services.

3.1 Policy

Policy will play a key role in setting the future direction of bioenergy and this creates opportunities for policymakers. However, there are also challenges, and examples exist of where policy is or can be actively detrimental to the biomass sector. Without urgent action, there is a risk that operations currently supported by Renewables Obligation Certificates (ROCs) will be forced offline as this support mechanism comes to an end. In these cases, assets may be decommissioned, operational teams disbanded, and the potential for long-duration storage and other benefits would be lost to the system.

Policy is key

Nearly all participants indicated that Government policy is, and will continue to be, a key influencing force in the bioenergy sector. Research by the IEA supports this assertion, demonstrating the fundamental role for governments in international biomass sectors (Daniela Thrän & Nora Lange, 2025). Participants gave examples such as limits on biomethane production and the commercial viability of energy from waste plants to illustrate the key impacts of Government policy and strategy. As such, many felt that delivering long-duration flexibility from biomass would require involvement from the Government in some capacity.

Incentives are seen as key mechanisms through which the Government can influence action within the sector. Taking biogas as an example, many AD plants would historically only produce up to the limit on output for which they could receive a tariff. However, as this tariff has decreased over time, industry respondents have seen this start to drive different behaviours in the sector.

Participants were keen to point out the special importance of policy and incentives in the case of BECCS, a point we will return to in the BECCS sections of this report.

Some participants stated that support mechanisms for biomass would need to be shaped to encourage flexible generation. This included calls for support in the construction of 'over capacity', referencing the need for greater generation capacity to meet the flexibility needs of the system (as discussed in the previous section). These calls stemmed from the belief that clean flexible operation was unlikely to be incentivised purely by market forces. As this was a more 'whole-systems' issue, it was seen as something in which the Government should take a leading role. However, participants stressed that this was not simply about responsibilities for the Government, but also about the industry identifying and participating in commercial opportunities.

Cost effectiveness was identified as a priority within Government, with value for money being a central element in all discussions. In this regard, many participants felt that biomass could compete well with other potential stores of energy. Decarbonised heating – and its consequent energy storage opportunities – was given as an example of where Government support was likely to be needed, and several participants stated that biomass offered a highly cost-competitive solution. This was one example amongst many where participants felt biomass needed to be more carefully considered amongst a range of energy storage technologies as an affordable option. IEA research from across the EU found that this was true across many countries, with bioenergy's storage potential being somewhat overlooked by a plurality of governments (Arasto et al., 2017).

Political challenges

Some participants highlighted that biomass was not being given due consideration as an affordable energy storage option, challenging the notion that cost-effectiveness is Government's primary concern. These participants often cited the political challenges surrounding biomass policy as a barrier. They pointed to bodies such as the CCC and NESO who they saw as having particularly cautious approaches to the use of bioenergy. Reasons identified for this caution included political pressure from a range of organisations and stakeholder groups, as well as supply chain concerns.

The roles of advocacy groups and Non-Governmental Organisations (NGOs) opposed to the development of bioenergy projects were raised by participants. Some even went so far as to say these NGOs were "the biggest challenge to progress in this area". Certain bioenergy activities were viewed as causing more controversy than others, particularly biomass imports. Converting land for bioenergy production was also outlined as a 'politically high-risk' option by some. Participants observed that groups and organisations opposing the use of biomass are often well resourced and organised, using simple narratives which make them highly effective. Some anticipated this being a particular challenge when it came to incorporating biomass into wider system strategies or creating effective policies.

Similar concerns were raised about the broader public perceptions of biomass, not least concerns that these perceptions are being shaped by the groups described above. One participant described the central role trust plays throughout the biomass sector, within biomass supply chains and in broader public consent for bioenergy. It was felt that this trust had become somewhat diminished in recent years, making development in the sector more difficult. Some also described how the complex stakeholder involvement in the sector could exacerbate these issues, emphasising the need for adequate public engagement in both policy and practice. One participant described this as not only needing effective policy, but 'support for people to understand policy'.

Thorough Government-sponsored analysis of these concerns and their roots was carried out in a public dialogue engagement (The National Centre for Social Research, 2023). It assessed both NGO and broader public views, finding "participants generally felt biomass has a role in achieving net zero…" but that there was "…concern about the potential environmental impact" this could have.

These challenges were seen as making it difficult for the Government to effectively engage with development in the sector. This worried many participants given the key role they had identified for Government. It was seen as likely that such barriers would also exist to developing the policies and support needed to enable biomass-based energy storage. A greater analysis of the UK's political challenges surrounding the biomass and bioenergy sectors and policy can be found in the work of Taylor et al. (Taylor et al., 2024).

Government-industry impasse

Participants described there being a certain impasse between government and industry currently. One participant described this as being a 'chicken and egg' problem: to make policy, the Government needs to see the value bioenergy can provide, but the bioenergy sector struggles to deliver that value without policy support. Some participants felt that, given the political challenges of biomass outlined above, the bar for bioenergy 'providing value' was quite high. The heightened political risk that would accompany any biomass project would diminish its appeal and value, sustaining this impasse.

The consequences of such an impasse were described by participants. Although there was "ambition and desire" within the sector, the lack of government coordination, policies, support and incentives made progress difficult. Bioenergy operators were left feeling 'stuck', repeating arguments and waiting for guidance on aspects such as sustainability.

Flexibility policy

Of the participants familiar with the current political environment, many believed that it could be challenging to create effective policy around biomass-based energy storage. Firstly, some felt that you would need a lot more policy support for flexible uses of bioenergy than non-flexible uses. On its own this would present a challenge, but especially so in a political environment where policy is difficult to create. Coordinating these policies between energy and land was also seen as essential, but something that would create additional challenges. One participant went so far as to say that a capacity market that incorporates biomass "doesn't seem credible in the current political climate", illustrating the challenge.

There were differences of opinion, however, when it came to policy surrounding smaller plants. Some participants pointed to the often-centralised approach to policy in Government, an approach which may not lend itself to making effective use of smaller, distributed plants. Some were of the view that such a dynamic could add complexity and make coordination more difficult. However, others were more optimistic about the potential for smaller scale operations to alleviate some of the political barriers surrounding biomass and its policies. They argued that smaller scale operations could be more resilient to discontent from advocacy groups and NGOs, especially regarding sustainability concerns. Such arguments will be explored further in the next section.
This assertion that certain – particularly smaller-scale – bioenergy applications face fewer public perception barriers likely requires further investigation.

System impacts

There were serious concerns as to the near-term impacts of a perceived lack of policy development in the biomass sector. While larger plants have received a greater degree of certainty from Government following the publication of details around the Transitional Support Mechanism (DESNZ, 2025b), many smaller plant operators are still highly uncertain about their future.

Renewable Obligation Certificates (ROCs) were identified as a key mechanism through which many smaller plants maintain their commercial viability. However, in the near to medium term, many of these agreements will be coming to an end, leaving these operators without key revenue streams.

There were serious concerns as to the near-term impacts of a perceived lack of policy development in the biomass sector. While larger plants have received a greater degree of certainty from Government following the publication of details around the Transitional Support Mechanism (DESNZ, 2025b), many smaller plant operators are still highly uncertain about their future.

Renewable Obligation Certificates (ROCs) were identified as a key mechanism through which many smaller plants maintain their commercial viability. However, in the near to medium term, many of these agreements will be coming to an end, leaving these operators without key revenue streams. ROCs agreements will start to expire in 2027, although different plants have different agreements ending at different points between 2027 and the mid-2030s. Some felt that this uncertainty was preventing many within the sector from exploring long-term solutions such as switching to more flexible production models.

Participants seriously questioned the survivability of many of these plants without support from Government similar to ROCs. The resultant loss of generating capacity could have serious impacts on the energy system and particularly on the biomass sector. Analysis conducted using the Government's Renewable Energy Planning Database suggests that around half of all currently active bioenergy plant capacity would not meet the requirements of the transitional support mechanism (DESNZ, 2025b). While some of these plants will operate under other incentive and support schemes, many are dependent on ROCs and so could face closure, without the opportunity to benefit commercially from additional value streams. This could have an impact on the ability of the energy system to meet demand in the short term but also impact long-term supply chains in a similar way to that described in the previous chapter.

To avoid unnecessarily detrimental impacts, participants suggested that Government policy should take a whole-systems view of the potential role for bioenergy. This included considering the overall emissions and cost impacts of different operating and incentive models, something that is already explored and modelled in literature for other countries (Dotzauer & Thrän, 2025). Participants also felt that publishing clearer intentions around how the UK Government (and associated organisations) are going to deal with the challenges of long-duration flexibility, and how this will be financed, would better allow the bioenergy sector to determine how it could contribute to these efforts.

3.2 Political pressure

There is significant pressure being placed on Government to reduce the use of biomass for energy production on the basis of concerns about emissions and sustainability of supply chains. The use of UK-produced feedstocks, particularly waste streams that would otherwise go to landfill, may help to allay some of these concerns.

Feedstocks

While the biomass sector is subject to various political challenges, controversies surrounding feedstocks were raised particularly frequently by participants. These concerns seemed to centre on the issues of guaranteeing feedstock sustainability to avoid any adverse environmental impacts from biomass production. This was a key issue highlighted in public dialogue work – sponsored by the government – investigating views on the biomass sector (The National Centre for Social Research, 2023).

A key source of concern, raised both by the public dialogue study cited above and by our participants, was that of biomass imports. Imports were seen by participants as the key area in which the Government is coming under pressure to reduce feedstock volumes. Currently the UK imports around 30% of the biomass sources it uses for energy production and future projections of this share vary (DESNZ, 2023). While some argued that sustainability issues surrounding imports should lead to their decreased use, others argued they are essential and that sustainability concerns could be addressed.

Beginning with the arguments in favour of imports, many based their reasoning around issues of scale. They stated that as the UK has a relatively high population density, and quite a limited land area, this almost inevitably leads to difficulty in producing significant volumes of biomass. Large plant operators, in particular, cited challenges they had faced in sourcing sufficient volumes of domestic feedstocks, in part blaming regulatory challenges. These participants pointed to the fact that the UK is a net importer of many goods and energy vectors, questioning why biomass should be treated any differently. Given the size of the UK's energy consumption, and the size of its biomass sector, many argued that imports would be necessary to meet this demand. Some acknowledged the sustainability concerns that accompanied import practices, but argued that these concerns were not insurmountable and, at times, over-inflated.

Several also made the case for the potential of biomass imports to achieve net sustainability and environmental benefits. The potential for biomass to displace fossil fuel consumption was one such case, felt to be the guiding ethos behind biomass consumption in the first place. Another was that by incentivising sustainable biomass production in other countries, the UK could help to establish bioenergy as a key global decarbonisation technology. Finally, some argued that the environmental impacts of transporting domestically produced feedstocks around the country could be even greater than international transport. However, it should be stressed that sustainability concerns around feedstock imports do not often centre on the direct impacts of transport.

It should be noted that many of these arguments came from bioenergy plant operators, but not exclusively. Some involved in the production side of the sector also shared these views.

As for the arguments against using biomass imports, these centred on the importance of reliable sustainability assessments, and the relative security of domestically sourced feedstocks. While some participants acknowledged there were questions over the economies of scale that could be achieved with domestic production, they felt that sustainability criteria would be easier to meet and guarantee in the UK. Particularly in a woody biomass and forestry context, some expressed greater comfort and trust when dealing with domestically sourced feedstocks. This was in part due to greater ease of monitoring and a belief in the rigour of the UK's regulatory bodies. This seemed to be especially true of commoditised goods such as wood pellets and hydrogenate vegetable oil (HVO), which some participants feared could be harder to trace. It should be noted that the IEA sees commoditisation as a pathway toward greater trust and reliability in bioenergy sustainability (Bacovsky et al., 2023).

Another sustainability concern centred around the transport-related emissions of importing feedstocks and fuels over long distances. HVO was given as an example of where this could be an issue.

Beyond the sustainability concerns, some participants also raised the issue of energy security. Two participants, in particular, felt that the UK was becoming too reliant on imported biomass to meet its energy demand spikes and that this threatened system security. They instead argued for a shift in focus toward growing rather than importing feedstocks. It should be noted that some participants who made these arguments were involved in the domestic biomass production sector.

In the previous Government's Biomass Strategy, they anticipate the continuation of at least some biomass imports between now and 2050, although the exact volumes remain an open question (DESNZ, 2023). The CCC, on the other hand, anticipated a steady decline in the use of imports to an almost negligible volume by 2050 (CCC, 2025). This is illustrative of the lack of consensus around the future role of imports, but also the pressures on government to reduce them.

Sustainability assessment

The assertion that sustainability criteria were inherently easier to manage with domestic feedstocks was questioned by some participants. They were keen to distinguish between perceived sustainability and "scientific, evidence-based" sustainability. These participants made the argument that while perceived sustainability may be better for domestically sourced feedstocks, this was not necessarily supported by the evidence. In particular, some participants feared that large scale domestic production could lead to "disproportionately large and negative" sustainability impacts.

However, others asserted that certification and transparency in international feedstock supply chains were significant issues. They followed the reasoning that the UK could control its own certification more effectively, making the sustainability credentials of domestic feedstocks more reliable. Points were raised around reduced transport emissions, as well as potential waste reductions, with a focus on domestic feedstocks leading to greater efficiency in resource use. Carbon accounting with biomass in an international context was also a concern for some participants, with worries around how double carbon accounting could be prevented.

Sustainability assessments are evidently a vital but complex element of the bioenergy sector and bioeconomy more broadly. While some participants did not feel that these assessments and criteria were yet working effectively, others were keen to stress that they already exist. The latter argued that it was more a matter of existing sustainability criteria and carbon accounting schemes being accepted and utilised. Work exploring how these assessments can be most effective was carried out by the Bioenergy Supergen (A. J. Welfle et al., 2023). Through this work, the authors arrive at the conclusion that – given the "broad dynamics and characteristics" of bioenergy projects – rigid approaches to sustainability assessment may not be appropriate. Also, they concluded that these assessments should go well beyond concerns around emissions alone. At the time of writing, a common sustainability framework to enhance existing schemes is expected to be published soon.

Domestic land-use

The sustainable and responsible use of land is key to a well-functioning bioenergy sector. The consensus amongst participants was that domestic biomass production volumes could only be maintained or increased if these land use considerations were adequately dealt with. Participants raised several ways in which further integration with the bioenergy sector could contribute toward more effective land management. These would allow domestic biomass production to be maintained or increased while alleviating some of the most prevalent political concerns.

Participants discussed the potential benefits of incorporating energy crops into crop rotations as a way of assisting with land management. As discussed previously, this is seen as a viable way of significantly increasing the volumes of available energy crops. However, some highlighted how it could also contribute to soil health and prevent the spread of certain weeds. This kind of temporal displacement was seen as a much more viable option for energy crop production than geographic displacement – e.g. dedicating entire fields to energy crop production. In part, this is due to soil health considerations but also because of concerns around food security.

Some crops were also identified as working better than others when employing such a multifunctional land use model. Maize and straw production, for example, were seen as conducive to more standard farming practices, whereas woodland did not 'fit well'. Participants also pointed to the opportunities this might provide farmers for diversification, a strategy many have been seeking to employ following the loss of EU subsidies in the UK.

Participants in the production sector did assert that it would be difficult for farmers to make these kinds of changes without support and advice. As highlighted in the previous sections, certainty and long-term support are key enablers in this sector. However, some felt that there was a general desire among producers to see land become more multifunctional, especially when compared with approaches that would change land function completely.

Some participants did articulate messages they had encountered in public debates around biomass, one of which was that biomass should be "left in the ground". This idea was vehemently opposed by participants involved in the biomass production sector. They argued that effective land management necessitated a certain amount of biomass extraction, especially if the aim was to maximise carbon sequestration. The management and coppicing of woodlands was a frequently given example. This extracted biomass, it was argued, could serve certain energy storage needs well. Some participants went on to say that this extracted biomass could be most effectively used in localised energy plants, an argument that is further explored in the next chapter.

Waste streams

Another key finding of the Government-sponsored public dialogue work on perceptions of biomass (The National Centre for Social Research, 2023) was that the public was most supportive of using waste streams for bioenergy production. The use of waste was also broadly supported by participants in this study. However, as discussed previously, there were serious concerns with the framing of bioenergy feedstocks as wastes.

Some participants highlighted how the combustion of waste streams could help to reduce the overall emissions from waste. By burning these waste streams, 'fugitive emissions' from rotting waste can be avoided. With appropriate 'back-end' clean up, any additional combustion emissions can be effectively avoided. Some took this idea further, claiming that CCS from waste should be a priority for the biomass sector.

However, as stated previously, participants identified the likely decline in waste stream volumes in the coming years making it difficult to build a bioenergy sector on waste alone. The role for upgrading and commoditisation was also championed with such feedstocks and products. Not least because this could allow them to be stored and used more flexibly within the energy system.

Biomass for energy storage

Evidently, there are pressures on the UK Government to reduce the volumes of biomass feedstocks used within the UK, particularly from imports. If such reduction were to be enacted, it would reduce the scale of the potential for biomass to provide an energy store for the system. However, it is not widely expected that there will be a decrease in overall feedstock consumption, as highlighted in the opening section which discussed questions of feedstock volumes. Differences in expectations around future imports, however, do significantly impact expectations around the future volumes available.

On the other hand, domestic feedstocks are generally expected to face fewer political pressures, and production is expected to either remain at current levels or increase. A key point raised by participants was the security of supply afforded by domestic biomass production. This could be a particular advantage when considering the potential for biomass to act as an energy store, a point explored further in Chapter 2. As such, if biomass-based energy storage was to be pursued, domestically produced feedstocks could be a particularly viable option.

3.3 Policy impacts

Current policy appears to be hampering industry's ability to use biomass flexibly. If it is accepted that it would bring additional value, the Government could develop policies that actively support such flexible operation. In common with developments in all parts of the energy system, policy development to support flexible biomass operation will involve complex interactions between diverse actors, but research and innovation can make the problem tractable.

Negative impacts of policy

As discussed in previous sections, the flexible use of bioenergy is likely to require effective government policy and support. However, creating such policy was anticipated to be highly challenging by participants familiar with the UK's history of bioenergy policy.

The negative impacts of past and present government policies were discussed by participants. Many of these impacts were viewed as being more by-products or 'unintended consequences', rather than as the direct intention behind the policies. Not least amongst them was the serious uncertainty that government policy, or the lack thereof, was having in the bioenergy sector. This perceived uncertainty was attributed to causing a host of detrimental consequences by most of these participants.

The Renewable Heat Incentive (RHI) was cited by several participants as a prime example of where UK Government policy around biomass had unintended consequences. They accused it of being poorly designed and incentivising the use of cheap fuels rather than establishing effective supplychains, or encouraging the development of efficient technologies. The consequences of this policy were felt to be far reaching, impacting the fundamental way the Government and the public engaged with the whole biomass sector. One participant went so far as to say "Government created this issue and industry is paying the price".

Other policies were viewed as either having, or being likely to have, unintended consequences. Numerous participants cited ROCs, others raised the Government's policy intentions around BECCS. As discussed previously, participants involved in smaller scale operations felt that the Government's focus on larger biomass plants meant a significant proportion of the sector, made up of smaller plants, was left with highly uncertain futures. The approaching end of many ROCs agreements, without a proposed replacement scheme, was seen as a significant risk for the sector. It was viewed by some as stemming from an overly myopic view of the biomass sector, with the UK Government struggling to reconcile the different forms that bioenergy plants can take.

Some participants described seeing the Government as currently taking a 'nothing but BECCS' approach to new biomass plants, which was stifling development for a range of biomass technologies. Concerns were raised that such a position was adding "significant complexity into any new developments". It was felt that this would also apply to developments in flexible biomass technologies. Those with knowledge of the Government's position on BECCS also stressed that there were still many questions to be answered around its future role. These factors compounded to create even greater uncertainty, as both operators with and without the capacity to deliver BECCS struggle to make plans.

One reason so many participants raised this issue of uncertainty was the investment risk it created. It was felt that this risk was stifling investment in the sector. An example given was that the UK currently seems to lag behind the EU in terms of bioenergy feedstock legislation. This was seen as representing a risk for investors as they anticipated similar changes to follow in the UK and so did not want to invest prematurely. The consensus was that for greater capital to become available in the sector, investors would need greater clarity and confidence in the future of bioenergy policy and support. This is inherently dependent on the actions of the Government and governmental organisations.

Need for Government support

Multiple participants felt that the UK Government was overlooking the potential role of bioenergy to deliver long-duration flexibility into the system. Some said this was partly due to the bioenergy community's inaction, stating that they 'weren't getting their voice out there'. Others focussed more on government approach, looking ahead to the release of the DESNZ clean flexibility roadmap, anticipating that bioenergy was unlikely to be mentioned. However, since these interviews took place the roadmap has been released where biomethane is highlighted as a key long-duration flexibility technology (DESNZ et al., 2025), suggesting that there is some positive movement in this direction.

A variety of participants pointed to the need for greater awareness of bioenergy's flexibility potential within Government. Some even suggested a need for greater appreciation of the energy system flexibility challenge in general, particularly the role for long-duration flexibility. The locations and situations in which bioenergy could be effective were thought by some to be quite specific, and needed identifying by policymakers. However, researchers were keen to stress they could also play a pivotal role in this assessment.

Instead of supporting flexible operation, some participants illustrated the ways in which policy is incentivising baseload operation. This was particularly true of biomethane operators, many of whom explained that AD plants were often run to maximise the tariffs they could earn, rather than to optimise the output they could achieve. It was felt that these plants could operate at greater output, or with greater flexibility, but that there are no incentives to encourage this. Instead, they were seen to be defined and limited by the structure of UK Government incentives. Participants pointed to examples of other countries such as Germany where biogas policy was seen to be working more effectively. Those operating under ROCs agreements highlighted similar behaviour in trying to maximise throughput to achieve the greatest total funds from the scheme. This was seen as effectively negating the flexibility and storage potential inherent within bioenergy.

The consensus amongst participants was that flexible bioenergy was neither a well understood nor appreciated energy system solution. As such, many felt that raising awareness within government would be a vital first step.

Government as an 'enabler'

Work by the IEA identified government policy as a key enabling tool in the flexible use of bioenergy (Thrän et al., 2024), a finding supported by the present study. Thrän et al. found, however, that much of the current support for bioenergy flexibility was quite indirect in countries across Europe, including the UK. More direct support in the UK could take several forms which were discussed by participants.

Some felt that a market-based approach was most appropriate. Establishing an effective market mechanism was seen as key, with contract for difference (CfDs) or another form of incentive scheme being essential. The speed at which such a scheme could come into effect was seen as its key advantage, with one participant claiming that Government should "enable the market with policy and bioenergy flexibility can happen now". Some argued that this would best complement the Government's current approach to broader energy policy.

However, others believed there may need to be more consistent drivers for bioenergy operators to produce energy flexibly. Some highlighted the guarantees needed when seeking capital for new projects, and argued that these guarantees may need to come from Government. Some pointed to this being especially true when dealing with relatively novel modes of operation.

Finally, some felt that Government should play an even more involved role by directly owning flexible bioenergy plants and bringing in private sector partners to optimise operations.

Whichever method was selected for achieving more flexible bioenergy production, policymakers would need to consider the wide-scale implications of such a scheme. Any scheme would likely involve political choices, and an understanding of the benefits and to whom they flow would be essential. Timescales and transitional arrangements would also be important to ensure supply chains and the energy system could adapt. The scale at which bioenergy could contribute to addressing the UK's long-duration flexibility challenges may also need addressing. These are all uncertainties which would require investigation to create truly effective policy, and this could be a key role for the research and innovation sector.

Chapter 4 – Costs

Headline

The capital and operational costs of bioenergy production are well understood and are already delivering cost-competitive commercial operations. This knowledge could be used to deliver a lower-cost solution to the long-duration energy storage challenge, complementing the other solutions currently being proposed.

4.1 Upstream and downstream considerations

Although feedstock flexibility brings technical challenges, new biomass plants designed to provide flexibility could do so with greater efficiency and larger turndown ratios, further increasing the potential of biomass to deliver benefits and a range of value streams to owners and operators.

When discussing bioenergy plant flexibility, it is important to consider both upstream and downstream flexibility. Upstream can be defined as the flexibility in processes occurring before the conversion of feedstocks into energy carriers (e.g. feedstock selection and supply chains before combustion or digestion). Downstream, conversely, can be defined as flexibility in the conversion process or in the use of energy carriers after conversion (e.g. biomethane grid injection or heat storage). The distinctions between these categories of flexibility can become blurred in certain cases, but they can be useful for discussions around bioenergy flexibility

Plants and infrastructure

For bioenergy to provide long-duration flexibility to the energy system, participants stated that a build-out of new plants and infrastructure would be needed. As discussed in previous chapters, there would likely be a need for greater generation capacity to have a significant impact on the UK's energy security. Similarly, this increased capacity would be needed to make full use of the available biomass resources in a flexible way. Storage capacity (the volumes of storable fuels) was also seen as an area in need of development, both on-site feedstock storage, and throughout the biomass supply chain. Without effective storage systems, demand centred use of bioenergy could not be achieved.

Some operators saw replanting as a viable option as current plants come to the end of their lives, with the opportunity to install units capable of greater flexibility. Several also highlighted the potential for a build-out of existing infrastructure, for example adding additional digester units to current AD plants. Construction and development of more flexible bioenergy units was seen as entirely possible, but quite dependant on the incentives put in place. However, the appetite for such development was not unanimous across operators, partly because it was seen as creating very different business and operational models. Some struggled to see how such models could become commercially viable, an idea that will be explored later in the chapter.

There was a view amongst others that a build-out of this relatively well understood and proven infrastructure could be an effective solution to the UK's energy storage needs. They believed that this could be a far more cost-effective option than the deployment of other long-duration flexibility options currently being proposed.

Biogas

As highlighted previously, a detailed discussion of different flexible bioenergy technologies, their relative advantages, and technology maturity can be found in the work by the IEA (Schildhauer et al., 2021).

The findings of this report coincided with the findings of the present study in several areas. Notably, both highlighted the potential role of biogas and, in particular, biomethane as key bioenergy flexibility solutions that can act as long-duration stores of energy. Participants consistently expressed a positive view of the role this technology could play, with specialists setting out a more detailed set of arguments. These views were shared across participants in the bioenergy sector, but also among whole energy systems specialists, it had broad appeal. Again, one key benefit of this technology was seen to be its maturity and proof of concept, both in the UK and abroad. The rollout of new biomethane production plants, be it AD or biorefineries, was broadly viewed as a strong option for the future energy system.

Specialists in biogas and biomethane production pointed to several characteristics that make it a valuable LDES technology. Firstly, it was described as a "cost competitive source of low carbon dispatchable energy" that was both well demonstrated and scalable. Participants described how it could be operated to make use of upstream as well as downstream flexibility. Differing volumes of feedstocks could be fed into the digesters at different times, with different 'residence times' inside the digesters, flexibly producing different amounts of product. These feedstocks could be stored onsite for long periods in structures known as 'clamps', before being used as demand arose. As discussed previously, AD plants were also considered to be quite adaptable, able to utilise a wide range of feedstocks, with the correct configuration.

The downstream flexibility could be provided through the storage of biogas and upgraded biomethane for flexible consumption. This includes both on-site biogas storage as well as biomethane injection into the grid which itself has been shown to have significant storage capacity (UK Energy Research Centre, 2019). In this context, biomethane was seen as being interchangeable with natural gas, which was seen as a key strength. Downstream flexibility is also supported by the ability of AD plants, when installed with appropriate additional infrastructure, to produce either grid injected biomethane, or generate electricity and heat, depending on the greatest need in the local energy system.

While not directly flexibility related, some specialists pointed to the range of outputs produced through AD and biorefineries as another key benefit of the technology. The digestates, non-gaseous products of the digesters, were viewed as an additional potential source of revenue for such plants. Similarly, the CO_2 produced in the upgrading of biogas to biomethane was seen as a potential revenue stream. This will be discussed further in Chapter 5 of this report. While these products would not directly contribute to the energy storage potential of these plants, they could provide other flexibility benefits and the revenue they generate would help their overall commercial viability. One participant compared this to the range of products created from the distillation of crude oil, arguing that stacked value streams are a key advantage of the technology.

Academic literature has been demonstrating this potential for some time, with biogas plant flexibility being well understood (Dotzauer et al., 2019; Lauer et al., 2017; Lauer & Thrän, 2018), albeit with a focus on overseas energy systems. However, there are signs that biomethane is increasingly being recognised as an important energy storage vector in organisations such as NESO. In the most recent Future Energy Scenarios pathways report, biomethane is recognised alongside natural gas and hydrogen as a key dispatchable energy vector (NESO, 2025). This potential is also being recognised by commercial actors, with participants identifying it as "a key point of potential investment in the future". Some producers are even beginning to operate under business models that do not require government incentives. A more detailed case study of one such investment is provided in the next chapter.

Biomethane challenges

Biomethane production is not without its challenges, however, and participants raised many concerns and questions about the technology.

Gas storage and distribution infrastructure were seen as key issues in this context. Some argued that the UK's gas storage capacity is quite poor compared to many countries, which could be a challenge when using biomethane as an energy storage solution. Similarly, on-site biogas storage presented challenges for operators around health and safety, financing, operation and maintenance.
Others pointed out that the use of biomethane was highly dependent on the future of the natural gas grid and infrastructure which will need maintaining. Questions were raised as to the political will for supporting this network maintenance.

Other considerations raised included the flexibility resolution of AD plants. By this, participants were referring to the speed at which these plants could respond to system needs, and the flexibility needs they were best suited to address. It was pointed out that you can't turn an AD plant off, you can only ramp its biogas output up and down, leading to less downstream flexibility. This ramping also takes time, and so biogas production was seen as unable to track variations in demand on a within-day resolution, for example. Advanced monitoring and assisted decision-making tools were also said to be needed to maintain digester health while flexing biogas production. However, the combustion of the biogas in onsite gas engines to produce electricity and heat was thought to have a much greater flexibility resolution, especially when combined with onsite gas storage (Dotzauer et al., 2019). This would allow AD plants to provide much quicker responses to system needs.

The biogas industry is also currently operating highly inefficiently, according to some participants. Due to the behaviour encouraged by current policy measures, many plants are producing far less biogas than they could from their feedstock inputs. It was also felt that many were not planning and maintaining the digester health within their plants particularly well. Participants believed that there was room for significant innovation and improvement within the AD sector, and that new AD plants could be designed to better deliver many of these production and flexibility benefits.

All of these innovations and challenges will likely require further investment within the sector. As discussed in previous chapters, it was felt that this investment was unlikely to materialise without greater confidence in the future policy landscape around the use of biomethane in the energy system.

Energy from waste

Biomethane was not the only well-established technology to be championed by the participants of this study. Energy from waste (EFW) plants were also seen to have flexibility potential, particularly upstream flexibility. Again, EFW was viewed by participants as a well-understood technology with the potential to be scaled. They include plants such as chain grate boilers and fluidised bed combustors which many felt were simple, cost-effective units that served multiple purposes.

Commercial operators felt that EFW plants could be run to deliver downstream flexibility, especially when utilising differing loads. Some also raised these plants' potential to produce heat as a key source of flexibility.

However, the main flexibility value raised in relation to these plants was their ability to be relatively 'omnivorous', providing upstream feedstock flexibility. Such capability was seen by some as a priority for research and innovation in the UK, since it has important implications for the effective utilisation of the UK's diverse biomass supply. Being able to produce energy from a wide range of resources would provide a greater degree of security to the energy system. Security, as discussed previously, is a key attribute needed in a long-duration flexibility technology, with reliability being an essential facet of any solution. They also provide the added benefit of making full use of resources that might otherwise be disposed of. However, such feedstock flexibility can present a range of challenges, as discussed below (New Power, 2021).

It should be noted that these plants were less widely supported than biomethane technologies, primarily due to concerns about combustion emissions.

Fuel flexibility challenges

The UK has significant diversity in its biomass feedstocks (DESNZ, 2023). While this diversity can be a strength, it also presents a challenge for some bioenergy plants. Larger plants were highlighted as key examples where specific feedstocks and feedstock blends were required, with many sources not 'making the cut'. Some pointed to smaller plants, claiming they could be much more fuel flexible. Many EFW plants fell into this 'smaller plant' category, by which participants tended to mean 50MW capacity plant and smaller. Operators were keen to stress that this did not apply to all smaller plants, however, with several arguing their small plant depended on very specific, localised feedstocks. The question of fuel flexibility was, evidently, quite nuanced and highly plant specific.

Much of the concern for operators around fuel flexibility centred on the impacts on plant performance, arguing that some plants could deal with it better than others. This was due to several feedstock variables including thermal energy content and moisture content. For direct combustion plants, it was argued that specifically fuel flexible designs could be needed if they were to be taken forward in a long-duration flexibility context. The same was somewhat true for AD plants, the most well-regarded potential bioenergy-based energy storage solution. Domain specialists described how omnivorous AD would likely need specialist management with advanced decision-making tools. Managing omnivorous plants well was seen as a key challenge, with one participant saying "fuel flexible plants are easy to design, but hard to run". As such it is likely that specialist skills and personnel would be needed, representing a further investment that would need consideration.

Participants highlighted some external forces which could impact the fuel flexibility of bioenergy operations. Commercial risk was raised as a key influence on plant design. As such, commercial decisions could have definite impacts on the feedstocks a certain plant was designed to use. Another external factor was that of carbon accounting requirements. As discussed previously, the sustainability of bioenergy operations is an essential requirement, not least in the public eye. Consequently, carbon accounting can be a key tool in ensuring the effective operability of such plants. The greater the diversity of feedstocks you use, the more difficult it is to account for the carbon impacts of those feedstocks, making sustainability harder to verify. Therefore, fuel flexibility, while potentially environmentally beneficial in its waste utilisation capacity, does face sustainability difficulties.

Input and load flexibility

The exact approach to providing flexibility matters at the plant level, and there are multiple ways of achieving this. When discussing plant flexibility with operators, some instantly assumed that this must mean 'two-shifting', the process of cycling a plant on and off in response to changes in demand. In a long-duration flexiblity context, such operating models would likely result in mothballing plants for extended periods until the need for the energy system was great enough for these plants to be reactivated. Operators had many concerns about such an operational model: staffing such plants when they would only be operational for short periods of the year was seen as challenging; ramping plants up after extended off-periods would also be potentially difficult. This mothballing approach was viewed as challenging for direct combustion plants, but practically impossible for AD plants. Some participants did, however, point to the use of HVO fuels in 'start and standby' plants as an example of bioenergy being used in applications specifically designed for this purpose.

The challenges around two shifting were seen as particularly important when considering plants designed for baseload operation. Again, this relates to the incentive structures under which many of these plants were designed and constructed, with them having been built to deliver maximum throughput. These points apply to plant flexibility more broadly, whichever form of flexible operation might be chosen, plants designed to run at baseload will face challenges when trying to deliver flexibility. As such, a bioenergy sector centred around flexible operations would likely benefit from new or upgraded plants specifically designed to deliver flexibility.

An alternative method discussed for achieving long-duration flexibility was part-load operation. The idea behind this approach is that plants could run at lower loads, generating less output and consuming less fuel for large parts of the year. Then, as the energy system needed it, these plants could 'ramp-up' for periods of greater need, running at closer to a full capacity or load. This was viewed by some participants as a more practical way of achieving long-duration flexibility, avoiding some of the issues raised with the moth balling approach (Thrän et al., 2015).

Some did raise operational challenges for this approach, however. For direct combustion plants there is a lower limit to the load they can run at, referred to as the minimum stable generation (MSG). This MSG would necessarily be a limiting factor for many existing plants, with a high MSG reducing a given plant's flexibility potential, with less headroom for ramping up. This could necessitate severe alterations to current plants or the build-out of entirely new units. Similarly for AD plants, it was felt that this approach could present challenges, but also benefits. While infrastructure changes may also be needed, such as adding new digestor tanks, it was felt that a range of loads could already be achieved by many AD units. In fact, running at lower loads has the potential to increase feedstock residence times and therefore efficiency, according to some participants. However, the ramping times for AD were felt to be quite slow making them better suited to more long-term changes in demand. This could be mitigated by increased on-site biogas storage, however there are challenges to such infrastructure build-out, as discussed previously.

Participants took an interest in this part-load operation method of achieving long-duration flexibility due to its potential to help deal with seasonal variation in renewable energy output. The Royal Society demonstrated in their analysis that the UK faces relatively consistent shortfalls in renewable energy generation during the first three months of the year (The Royal Society, 2023). Some participants felt the part-load operation model could be used to address this consistent challenge, running at higher loads during this season, and at lower loads in others. Similarly, some felt that it could address some of the challenges around 'Dunkelflauten' or wind droughts, ramping up production during these low output periods. Plant ramping speed was seen to be more of a challenge in such situations, especially for AD plants, but with adequate weather warnings this was not felt to be insurmountable.

Part-load operation would likely require careful feedstock management, according to participants. While some feedstocks are storable, others – particularly waste streams – often aren't. As such, some participants argued that upstream flexibility would likely need to be carefully managed, retaining storable feedstocks for high load periods, while using less storable fuels more consistently. Additionally, for AD, certain feedstocks can accelerate the production of biogas in a digester, allowing for faster production ramp up.

Cost comparisons

While bioenergy clearly has the potential to provide a store of energy, a key question that participants asked was how the cost of this solution would compare to others. As highlighted in previous sections, cost-effectiveness is a key priority for government who will likely need to be deeply involved to deliver any kind of long-duration flexibility solution. When compared to other low carbon solutions, there were mixed views around how bioenergy would perform. Hydrogen was the most frequently cited comparison, with many feeling that biomass could provide a cheaper alternative to the largely undemonstrated technology. The maturity of bioenergy compared to hydrogen, particularly biomethane, was also seen as a key advantage.

Energy system specialists were keen to point out that cost comparisons should be carried out in particular ways. When dealing with long-duration flexibility, some felt that levelized cost of energy approaches were not appropriate. When comparing costs in this context a more holistic systems view would be necessary to compare the overall system costs associated with the different options. This includes taking into account factors such as broader infrastructure, local economic benefits, carbon capture and accounting, and waste management costs.

4.2 Distributed plants

There is also a range of existing, smaller-scale, distributed operations that, with appropriate support, would have the potential to deliver flexibility in different ways. In particular, biomass to heat should not be overlooked, particularly in an industrial context. Biomass to heat can deliver energy system flexibility, especially when integrated with heat storage, but challenges remain, requiring incentives for innovation and new business models.

Smaller plant advantages

Various literature has investigated the impacts of smaller, distributed generation plants on energy system flexibility (Muller et al., 2019; Schulz, 2017). This literature highlights a range of benefits including increased energy security and whole system energy efficiency. However, the literature illustrates how these flexibility benefits are difficult to quantify within power markets. Some participants of the present study believed flexibility was most demonstrably provided by smaller, distributed biomass plants through their heat production capabilities (Department for Business, 2021). They also pointed to their ability to use localised feedstocks, a point we will return to in the next section.

Both the literature above and the participants in this study highlighted how distributed plants need greater system coordination to provide flexibility. However, many believed that if such a coordination mechanism were to be established then heat producing biomass plants could be an effective system flexibility option. Perceived advantages include that these plants would be relatively easy to run flexibly. They also have the potential to benefit from advances in technologies such as heat storage. Affordability and political feasibility benefits were also cited as key advantages of these smaller heat producing plants. Finally, participants were keen to stress that such plants were already quite prolific in the UK, reducing some of the deployment barriers that may exist for other technologies.

The role of heat

Many of the existing small scale bioenergy plants in the UK are heat producers or CHP plants, many using locally sourced feedstocks. Operators of these plants and their supply chains described the ways in which they are already operating flexibly and providing a form of energy storage. Some described how they are utilising stockpiles of biomass – largely woody biomass – and flexible distribution systems to consume feedstocks as they're needed. Through these stockpiles, energy is being stored throughout most of the year, and in some cases being used with a high degree of flexibility. Some CHP operators also described the ways they are arbitrating between power and heat production to provide additional flexibility. At points of high heat demand they are adjusting their output to rebalance in favour of heat production while reducing their power output.

There was a perception amongst some that biomass's heat production potential was in danger of being underestimated in conversations about flexibility. One participant stated that "biomass to heat should not be overlooked as a solution for delivering energy system flexibility". This concern is particularly relevant when we consider that demand for heat is the single greatest reason for energy consumption in the UK. Analysis conducted on the "DESNZ Energy Consumption in the UK (ECUK) 2023" data tables shows that more energy was consumed for heat production than either transport or electrical appliance operation. Considering how biomass can act as a store of energy is also important in this context as demand for heat is not evenly distributed throughout the year. The winter months see significantly greater heat consumption than the average, and the summer months much less. Demand is also highly variable, right down to the hourly resolution, creating a need for flexibility in production (Watson et al., 2019).

The previous Government's biomass strategy (DESNZ) acknowledges the role bioenergy can and will play in the production of heat in the near-to-medium term. It recognises the potential of biomass to decarbonise heating, including through the injection of biomethane into the gas grid. However, it does articulate a diminishing role for bioenergy in heat production out to 2050 as BECCS becomes the primary focus for bioenergy, with non-BECCS heat production being limited to select locations (DESNZ, 2023). While many participants were glad to see this recognition for heat from bioenergy, some still feared that this approach was overlooking bioenergy's heat flexibility potential.

These fears stemmed from the belief that a BECCS-focused bioenergy strategy would lead to many bioenergy-for-heat plants ceasing operations. This would necessarily lead to the concentration of feedstocks and consumption in fewer plants and locations. As heat production, unlike power production, must be relatively close to its end users, it was felt that this 'BECCS first' approach would necessarily reduce the spatial, and therefore overall, flexibility of bioenergy heat production. One participant stated that, when it comes to heat "it doesn't make sense to concentrate all our biomass energy in one place". There were also concerns that this focus on BECCS would drive up the costs of feedstocks, making even the most small-scale heat producing units inoperable. As such, the overarching fear was that a 'BECCS first' approach implicitly prioritised the UK's power system over the heat system, meaning the heat-flexibility benefits afforded by biomass might be lost.

Not all participants agreed with the sentiment that BECCS would reduce the UK's heat provision flexibility, however. Some argued that as the UK increasingly pursues the model of developing industrial clusters, heat from bioenergy could be achieved alongside BECCS. We will return to this point later in this section. However, given that domestic heat consumption is currently larger than commercial (including industrial) – according to ECUK (DESNZ, 2024b) – many felt that this impact would be relatively limited.

Heat markets

Being able to operate within heat markets was seen by power sector operators as a one way of achieving greater flexibility. The method of arbitrage between heat and power production, as described above, was a key mechanism for this. Such methods have been studied in the case of biogas in particular (Dolat et al., 2024). Bioenergy was seen by many as a cost-effective way of producing heat, and heat production was seen as a highly efficient use of biomass, without the losses inherent in power generation. All of this pointed toward biomass being an economic heat production technology, both for the producers and consumers of that heat.

The ability to access heat markets was seen as dependent on the development of district heating network technologies for many plants. While some plants were able to access commercial consumers for their heat, access to domestic consumers was viewed as essential for this bioenergy use case in the UK as a whole. Being able to play into these markets would allow for much greater system flexibility, with CHP plants able to respond to the greatest needs of the energy system. Small scale examples were given where heat networks operated with hybrid heat production technologies, including biomass, to provide cost effective flexibility. Some believed there was a strong case for scaling up such a hybrid approach with existing heat-producing bioenergy plants.

Industrial heat flexibility

Industrial heat was seen as another energy end use with the potential to provide whole energy system flexibility using bioenergy. Industrial sector participants described the ways in which high temperature heating processes could benefit from hybrid heat sources. Many furnaces and kilns can run in a hybrid state whereby they can switch the percentage of gaseous, liquid, and electrical energy sources used. While these are often currently run to optimise costs, with the right incentives and price signals they could also be used to help provide flexibility to the energy system. Bioenergy sources could be prioritised for periods of low renewable power output and saved during periods of high power availability.

Given that many of these industrial consumers are located in the industrial clusters referenced above, this also presents the opportunity for BECCS operation. As carbon capture and storage is likely to be most readily available in these clusters, such a use of bioenergy could present an opportunity to provide BECCS and flexibility simultaneously. While there are still questions around the role CCS will play within industry, this idea is indicative of the kinds of innovations bioenergy for heat could support.

Challenges for heat

Heat plants can and do run flexibly in the UK, however, expanding this approach may require new incentives and business models. For bioenergy to effectively provide flexibility to the energy system in this way, the sector will need to evolve its operations and behaviours. Participants felt that there is currently little incentive or support to do this.

Firstly, some pointed to the need for increased heat-market access and demand for heat from bioenergy. As discussed, a key way of achieving this would be to increase the number of heat networks for which bioenergy plants could provide heat. This was coupled with a desire for a more mature heat market, with some pointing to countries such as Denmark for examples of what could be achieved.

As with all bioenergy, the role that government would need to play was stressed, with a need for greater certainty and strategic clarity in the sector. Discussions of business model support will follow in the next section.

Participants identified other challenges with using flexible bioenergy for heat production. Firstly, people need to depend on heat production, and so treating heat as a by-product of power generation is likely to be unviable. Heat would need to be viewed as an equally valuable product of any bioenergy plant providing it, especially for domestic consumers. Hybrid heat source systems were viewed as being costly, both in terms of capital and operational expenditure, meaning support was likely to be needed if their flexibility benefits were to be realised. Concerns were also raised around workforce and skills issues, with some feeling there was a potential shortage in the sector.

Finally, concerns were raised that heat from bioenergy could be difficult to convert into BECCS. While some felt an 'everything must be BECCS' approach was overly dogmatic, others felt that it would be the best use of limited biomass resources. We will discuss these disagreements further in the next chapter. However, some of those who took the view that the bioenergy sector should prioritise BECCS were concerned that using bioenergy for heat in this way could lead to long-term challenges. Either such heat production could indenture the use of biomass in ways that are hard to convert to BECCS. Or, these systems could be left vulnerable when their biomass feedstocks are redirected to BECCS applications, leaving them without a controllable source of heat.

Role for innovation

Participants believed there was the potential for innovation to aid this use of bioenergy, both technical and governmental. The use of heat storage was viewed as potentially transformative for the sector, providing additional flexibility for these heat production units. Some also felt that central government could take a more innovative approach to flexibility when considering the role heat production could play. This was an area where participants felt greater departmental coordination would be highly beneficial, with woodland management often having a bearing on local feedstock availability.
Others highlighted the role local government could play in supporting bioenergy for heat, especially given the highly localised nature of heat distribution. This was seen as especially important when considering the common use of locally sourced feedstocks.

Business and operational models

The majority of participants, including plant operators, stated that long-duration flexibility was entirely possible in the bioenergy sector. They believed that technologies and understanding were developed enough to make such a use viable. However, flexible operations were expected to require vastly different business models to those currently employed for most bioenergy plants. Participants stressed that most plants' business models currently require them to operate at baseload, producing consistent outputs all of the time. To provide long-duration flexibility, the consensus was that these business and operational models would have to change, although there were different ideas as to how this change could be achieved.

Barriers to change

The commercial barriers to flexible operation were seen as potentially prohibitive to such changes. Some questioned what the 'commercial pull' for flexible operation would be. Under current policy, many believed that flexible operation would likely hinder profitability. The additional costs associated with increased storage and generation capacity were seen as being difficult to justify when there was little-to-no additional income to be earned from building such infrastructure. These difficulties with profitability would make plants less competitive and they could face challenges when seeking capital investment for development.

The baseload operational philosophy outlined above also means that skills and 'know-how' could be a barrier to change, according to some participants. While the possibility of operating more flexibly was recognised, some operators had no experience of doing so. The commercially motivated business models that have shaped the current baseload operational philosophy were felt to be so ubiquitous that other modes of operation were viewed as 'unknowns'. This could represent a challenge for some plants, as the way they operate is highly dependent on the skills and experience of the people operating them.

Change will likely require innovation from actors in the sector. Some participants felt that innovation was difficult for many plants, particularly smaller plants, under current policy conditions. Biomass support through schemes like ROCs is coming to an end for many smaller plants, as discussed in Chapter 3. This change was described by some participants as feeling like a 'cliff edge', making it difficult to come up with innovative responses. However, some participants took the opposite view, feeling that the conclusion of these support schemes may prompt certain bioenergy operators to seek newer, more flexible models to generate revenue. Either way, government policy and support was still expected to be highly important within the sector.

Alternative models

Participants suggested several ways biomass-based energy storage could be made operationally and/or commercially viable. These solutions varied in things like scale and Government involvement, but demonstrated a range of options for making this use case a reality.

The most frequently cited solution was the creation of a biomass-based capacity market, or the inclusion of bioenergy in similar markets that already exist. Participants felt that this was relatively consistent with the Government's current approach to long-duration flexibility more broadly. However, some did raise concerns that such an approach could exclude smaller plants from participating, pointing to examples of smaller grid battery operators. Others suggested a cap and floor mechanism could be appropriate, such as those used to support the development of electricity interconnectors.

Incentives for building out storage capacity were suggested, with some stating that this could facilitate a rapid increase in flexible storage. Others proposed much more direct Government involvement than just incentives and market mechanisms. Government ownership of plants was viewed by some as a more economically efficient and politically viable way of ensuring sufficient maintained capacity. The role for the private sector in such a model would be in the operation of these Government-owned assets.

Some participants illustrated ways in which flexibility could be achieved commercially without the need for dedicated bioenergy support. LDES schemes are already in place and some participants felt they could be a good, pre-existing method for securing the required revenue. Others pointed to private sector agreements which didn't involve Government intervention, such as green gas purchase agreements. In these cases, industrial partners would pay a premium for a guaranteed supply of low carbon methane, which could be supplied flexibly depending on the structure of the agreement. Some also pointed to examples where localised processing hubs were cooperatively owned, providing local, low-carbon heat. However, it was stressed that this was only likely to be viable at relatively small scales.

4.3 Supporting local economies

Smaller distributed operations could also be cost effective from a supply chain perspective. They can support local economies, make efficient use of indigenous resources, and reduce waste. This could have greater political viability than some larger-scale options for long-duration energy storage.

Local supply chains

A recurring view was that many small, distributed plants operate best with localised supply chains. One reason for this was the belief that localised supply chains were generally more secure and reliable. Suppliers and consumers of feedstocks could build consistent relationships and operate with fewer concerns around things like quality and delivery times. This is due to benefits like better, easier oversight and faster feedback right through supply chains. Another reason was the simpler logistics afforded by more localised transport, reducing both transport-related emissions and complexity.

Economic benefits

Such localised supply chains were viewed as having much broader benefits beyond those for plant operators, however. Participants regularly cited the economic benefits for the localities surrounding bioenergy plants, particularly smaller plants. The economic benefits of these smaller plants were perceived to be less abstract, with clearer impacts on local jobs and industries.

For example, the use of local feedstocks can directly support local biomass production industries, like farming. Biomass production can act as a form of diversification for farmers, providing additional value streams. This diversification can also become well integrated into conventional farming practices as discussed previously. For example, integrating energy crops into broader crop rotations can both produce a useful product for the energy system while supporting farmers in managing their land. Some bioenergy conversion processes, such as AD, can also produce by-products which, when returned to farmers, can aid crop production. In these ways, bioenergy can aid not only the local economy, it can also support important industries such as food production.

In a similar example, the bioenergy industry was seen as being able to support local forestry and woodland management industries as well. Such support was seen as beneficial for the creation of local jobs in a key sustainability industry. Woodland management was viewed by participants not just as economically beneficial but also environmentally beneficial, when carried out sustainably.

Indigenous resources

As discussed in section 2.2, certain participants felt that indigenous resources should be prioritised in the bioenergy sector. This was for a host of reasons relating to both efficiency and sustainability, and as an approach it garnered relatively strong political support (The National Centre for Social Research, 2023). Localised supply chains are necessarily indigenous, and some suggested the broad political appeal of indigenous sources could especially apply in this context. Some felt that the localised nature of such operations gave local communities greater 'buy in' and understanding, helping to address concerns.

Using indigenous resources was also associated with ideas of resource efficiency and the circular economy. Participants believed that making full use of the UK's varied biomass envelope would benefit from such localised operations. Given the limited nature of biomass resources, this was viewed by many as essential for bioenergy to have a significant impact on the UK's long-duration energy system flexibility. Localised EFW plants were included by some as a key method for achieving this efficient resource use.

A recurring view was that full and efficient use of indigenous resources was not yet being achieved, particularly in the biogas sector. Many pointed to the potential of existing and new plants to be developed to make better use of domestic feedstocks in the sector to produce greater volumes of biogas. This sentiment was shared in the waste wood combustion sector as well, and participants felt that with appropriate policy such efficiencies could be achieved.

Waste reduction

The important relationship between localised plants and waste disposal was regularly discussed. Participants pointed out that wastes could often be relatively hard to store and transport, meaning they needed localised conversion and/or combustion plants to be efficiently utilised. Some viewed these waste streams as low-value by-product feedstocks which were garnering greater interest in the sector. Regardless of their labelling, participants often cited the need to prioritise these feedstocks in the bioenergy sector's future development. This was seen as an important way of meeting local energy needs, but also reducing waste-related emissions, greenhouse gases and otherwise.

Political viability

The range of benefits above were cited by many as arguments for why localised supply chains should have greater political viability than imports, for example. However, some also felt that these benefits could make biomass-based energy storage even more politically viable than some other long-duration flexibility solutions. Some cited natural gas with CCS as a leading solution for long-duration flexibility in the UK, while others cited hydrogen (NESO, 2025). Many felt that bioenergy sourced from localised supply chains could garner greater political support than either of these options. This would likely require sufficient public engagement and consultation, but some felt it would still be an easier 'political sell' than some of these alternatives.

Chapter 5 – BECCS

Headline

A current focus for government bioenergy policy is the delivery of negative emissions from large-scale BECCS operations. There is also the potential for smaller-scale biomass operations to deliver both BECCS and other ongoing system benefits, such as long-duration energy storage. These opportunities shouldn't be ignored.

5.1 Timing and availability

There are many uncertainties about the timing and availability of CO_2 transport and storage solutions, however, some small-scale biogas operations are ready now to deliver BECCS and could combine this with seasonal energy storage and flexibility. In addition to negative GHG emissions, these operations could provide both firm and dispatchable power to electricity markets whilst delivering similar services to both heat and gas markets. With appropriate support, other smaller-scale operations could also be converted to deliver BECCS.

Slow progress

There was a general view among stakeholders that BECCS has not progressed at the speed that was expected or hoped for. Although there is an expectation of significant commercial delivery of BECCS by 2030, some are starting to cast doubt on whether this will be possible.

The reasons for this have been attributed to a lack of government policy creating uncertainty, but also that there is currently no market for BECCS that would drive investment in the necessary infrastructure (C. L. Donnison et al., 2024). Some argue that it should not be BECCS driving this market, but instead that it should be driven by the need for CCS on fossil fuels. Some argue that it should not be BECCS driving this market, but instead that it should be driven by the need for CCS on fossil fuels.

The Seventh Carbon Budget from the CCC (CCC, 2025) calls for far fewer engineered removals than previous budgets suggested, potentially reducing the demand for BECCS. Also, BECCS is seen as having drawbacks, especially in the way it is viewed in the public discourse. There is a fear that opposition to BECCS on large-scale thermal plants will cause a political backlash and this will impact on the potential to deliver BECCS at smaller scale. There are also concerns being expressed around the way that negative emissions from BECCS could be used to allow the continued consumption of unabated fossil fuels, albeit in limited volumes, and the risk that this will further indenture fossil fuels in the system.

Policy uncertainty

To some extent, uncertainty around the policy direction for BECCS, reflects the large number of options for how BECCS could be delivered, through retrofits or new plants, and on both large and small-scale sites.

From an operator's perspective, the current Government focus for BECCS appears to be retrofitting of existing large-scale thermal plants, seeking to establish an effective business model for large-scale power BECCS. As part of these negotiations, it is likely that these large-scale operators will have to demonstrate effective feedstock sustainability criteria, but the approach used to verify any CO_2 removals has yet to be determined.

Many are questioning the potential for further development of large-scale power BECCS beyond the limited number of existing plants and are arguing for the potential of delivering BECCS with smaller-scale plants (C. Donnison et al., 2020). Some operators are currently exploring practical options for delivering this, and many of them see it as a relatively straightforward technical challenge. There are examples of commercial AD operations already producing CO_2 for utilisation or storage, alongside biomethane, demonstrating how BECCS could work at a smaller scale. However, there appears to be a broadly shared assumption that operations would need to be large-scale to be cost effective. These views on the role that small-scale BECCS could play were a key point of contention amongst participants, and therefore could be an area in need of further investigation.

There are concerns around the incentives that will be needed to deliver significant BECCS deployment and the impact these will have on existing biomass markets. For instance, non-energy users of biomass, such as chipboard manufacturers who rely on low-cost waste-wood feedstocks, are worried about the distorting impacts of these incentives on their supply chains.

In other areas, UK Government guidance on 'Decarbonisation Readiness' (DESNZ, 2024a) does not currently distinguish between biogenic and fossil CO_2. In its current form this guidance requires any new or refurbished combustion plants to be ready to burn hydrogen or deliver 90% CO_2 capture. This would necessarily mean that any new bioenergy plants constructed under this guidance would be delivering BECCS.

Many participants believed that for BECCS to be an effective solution in the pursuit of net-zero carbon emissions, much of this policy uncertainty would need to be resolved.

Feedstock considerations

There was a range of views on the impact of BECCS on feedstock markets. These are generally associated with beliefs around the types of bioenergy operation most likely to implement BECCS. Large-scale thermal plants tend to be relatively limited in the range of feedstocks they are designed to handle. This raised questions about the price impacts on these feedstocks as and when BECCS incentives are introduced. As discussed previously, smaller plants vary in their fuel flexibility and some participants were concerned about these plants having similar feedstock price impacts, although these fears seemed less pronounced. It was felt that caution should be taken, especially when dealing with feedstocks that could have impacts on areas such as food production or biodiversity. Decisions around the type of plants that will be incentivised to deliver BECCS will, therefore, impact on future feedstock markets.

Regardless of the technical solution used, the efficiency penalties associated with CO_2 capture processes mean that the implementation of BECCS increases the overall feedstock consumption of any particular plant for the same energy output. This could have further impacts on feedstock prices, depending on the business models that emerge for BECCS plants.

The issues of feedstock imports were once again raised in context of BECCS. The UK has unique geological CO_2 storage opportunities making it an ideal international location for the development of BECCS. Consequently, some participants advocated the use of biomass imports to increase the amount of BECCS delivered in the UK since this would “move resources from where they are most efficiently grown to where they can be most effectively used”. Some participants believed that if imports were to be used in this way, supply chains may need to be secured as a priority. They cited the likely increase in global demand for feedstocks as a key motivator for ensuring sufficient supply for BECCS application, arguing that this will become more difficult with time.

CO_2 transport and storage

The geographic implications of BECCS were seen as key to discussion around bioenergy flexibility. Where in the country BECCS plants would be viable proved to be a point of disagreement amongst participants.

Some argued that only plants able to directly access CO_2 pipelines would be able to deliver BECCS. The argument followed that this would limit BECCS plants to being: in specific locations, and to being sufficiently large-scale to justify the necessary infrastructure. Others argued that some non-pipeline transport would be an option, enabling BECCS for some smaller-scale plants, but only within a limited distance from CO_2 pipeline infrastructure. This would likely still restrict BECCS operations to a limited number of locations within these distances.

However, not all participants agreed with these assertions, arguing that non-pipeline transport may present greater opportunities than these arguments suggest (Freer et al., 2022). Non-pipeline transport was viewed by many as being a potentially cost-effective, essential method for delivering BECCS, especially from smaller-scale plants. These smaller-scale plants, as discussed in previous sections, were widely considered as having the potential to deliver bioenergy-based energy storage.

Future CO_2 logistics are currently a key unknown in these discussions, as is the development of BECCS more broadly. Many participants believed that the development of CO_2 transport logistics would be dependent on the finance systems facilitating BECCS markets. If the incentives were strong enough, some argued, non-pipeline transport issues would be overcome and smaller-scale, distributed plants would be able to participate in the markets. A view was expressed that the geographies of BECCS would come down to a balance of costs: whether it is cheaper to transport feedstocks or CO_2. While it is currently much cheaper to transport feedstocks than CO_2, some pointed out that CO_2 transport was currently being widely researched, and that these costs could come down. Again, market forces and economies of scale would also have an impact on these costs.

Carbon utilisation was viewed as another potential option for bioenergy plants located far away from CCS infrastructure. This could reduce some of the logistical challenges and transport costs associated with dealing with captured CO_2, especially for plants geographically central to the UK far from coastal CO_2 pipelines. However, others questioned the scale of such solutions, arguing that storage, rather than utilisation, was the only way of achieving meaningful emissions reductions in this context. The demand for CO_2 in domestic industry, in the eyes of these participants, is simply not high enough for biogenic CO_2 utilisation to have a significant decarbonising impact.

Evidently, there were many uncertainties around the dynamics of CO_2 transport and storage that would have an impact on bioenergy's potential as a form of energy storage. This represents a key area for investigation amongst the research and innovation community.

A potential role for biogas

While many BECCS technologies were considered relatively underdeveloped, biogas was cited as a relatively practical solution by participants. Production of biomethane or hydrogen from biogas was regarded as a BECCS solution with potential by many participants since AD seems both scalable and flexible.

As discussed previously, AD and biogas from waste plants can provide long-duration flexibility both in their electricity and storable-energy-vector production. They also benefit from being well understood and commercially proven technologies which received broad support from a range of participants.

There were different estimates as to the scale of the role biogas could play in meeting the UK's long-duration flexibility needs. Estimates from the Green Gas Taskforce suggested up to 120 TWh of biomethane could be produced in the UK by 2050 (Green Gas Taskforce & Lucy Hopwood, 2025). Although, other participants were more sceptical about the potential role of biogas, a key reason many considered biogas technologies as having such potential were their negative emissions capabilities.

Biogas - a flexible BECCS energy vector

For AD plants currently producing 'injection grade' biomethane, CO_2 is a co-product which can be utilised or stored, effectively making AD a 'BECCS ready' technology (IEA, 2025). This form of pre-combustion CCS through biogas upgrading was viewed by many participants as being one of the most practical and cost-effective currently available. This pre-combustion CCS could allow the subsequent flexible use of an effectively carbon-negative energy vector, allowing for 'the best of both worlds' – negative emissions and energy storage. Some questioned the extent to which this technology would be able to scale up, especially given the CO_2 transportation limitations discussed above. However, many still felt the potential of this technology was greater than some alternatives.

Biomethane also has the potential to be used in conjunction with post-combustion CCS, much like natural gas with CCS. This would increase the overall negative emissions achieved, however post-combustion CCS is widely considered more difficult than pre-combustion with biogas. Some participants discussed the potential of using biomethane in CCS gas turbines built to use natural gas. This could be a cost-effective option from the perspective of infrastructure capital investments. However, there are uncertainties around the practicalities of scaling up biomethane production to this level and the ability of gas distribution and transmission networks to support such operation.

The effective use of biomethane to achieve BECCS was also seen as being dependent on minimising upstream emissions and leakages. Methane leakages were considered to be highly consequential, with methane having far greater global warming potential than CO_2. Similarly, upstream CO_2 emissions through biogas production and feedstock & CO_2 transport could negate the positive impacts of capturing the carbon in the process.

Biomethane was not the only storable energy vector identified by AD specialists, who claimed that hydrogen production is also possible. Hydrogen gas can become a substantial proportion of the output from an AD plant if certain upgrades are installed that allow dark fermentation (D'Silva et al., 2023). However, this process is not currently widely practised, in large part because markets for hydrogen do not currently exist. As such, it could be considered a less mature technology, especially when considered next to biomethane production. However, as hydrogen is being widely explored as a long-duration flexibility solution, participants felt that it could become a key product of AD plants.

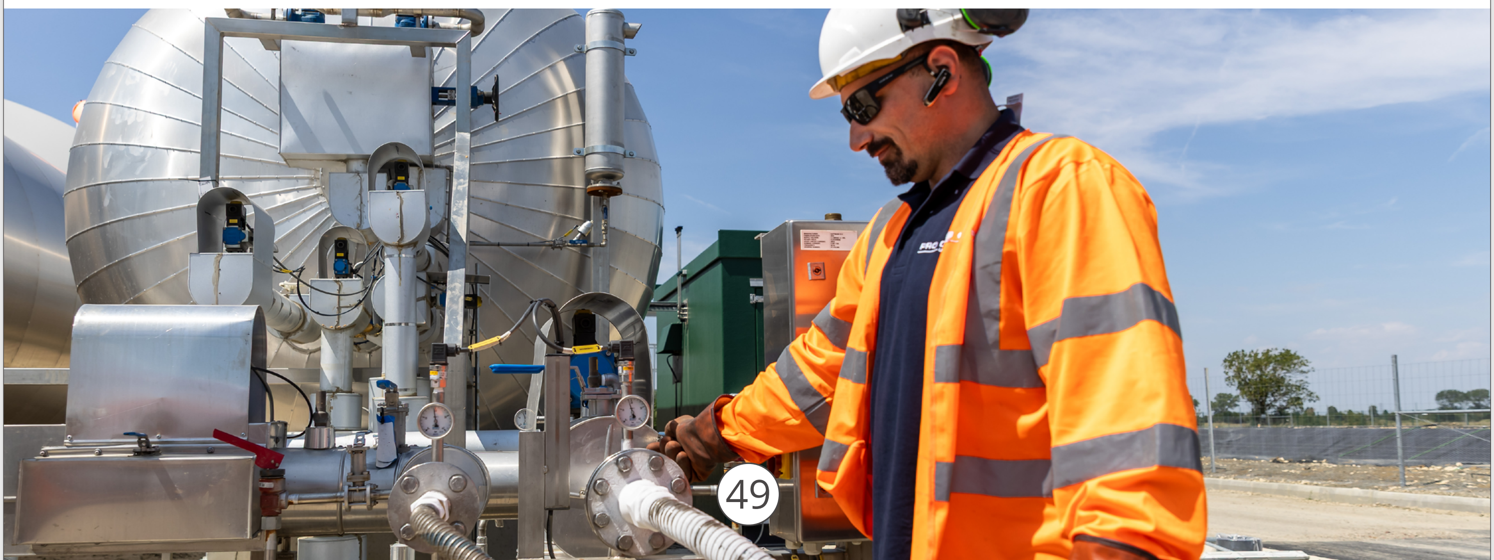
Below is a case study of an AD plant which is already producing grid-injection biomethane, as well as CO_2, ensuring this production is sustainable and carefully accounted for.

Moor Bioenergy Case Study

The Moor Bioenergy plant located in Gonerby Moor, Lincolnshire, is owned and operated by Future Biogas. It is the UK's first unsubsidised biomethane plant, supplying 100 GWh of renewable energy annually to AstraZeneca UK.

It does this by injecting sufficient gas into the grid to match all the demand for gas at AstraZeneca's R&D and manufacturing facilities in the UK. This is equivalent to 20% of the Company's total global gas consumption, displacing approximately 18,000 tonnes of carbon dioxide equivalent (CO_2e) emissions per year by replacing fossil gas. The partnership supports AstraZeneca's 'Ambition Zero Carbon' goal which aims to achieve science-based net zero by 2045, with the interim target of a 98% reduction in absolute Scope 1 and 2 GHG emissions by 2026, subsequently compensating for any residual Scope 1 and 2 emissions through high quality removals including BECCS.

The innovative investment at Moor Bioenergy features membrane-based carbon capture technology, which collects the CO_2 produced during biomethane generation. This food-grade CO_2 can be used in other industries, or in the longer-term, as CO_2 storage facilities come on-stream, it could be permanently geologically sequestered underground, delivering negative emissions as part of a BECCS operation.



Feedstocks for Moor Bioenergy are crops sourced within a 15-mile radius of the plant, with local farmers supported to drive sustainable farming practices. Long term feedstock contracts, typically of five or more years, offer farmers greater financial security, helping to mitigate the challenges of fluctuating food crop prices and climate change. Feedstocks are certified by International Sustainability and Carbon Certification (ISCC) – an independent body which verifies that crops are traceable and grown in accordance with strict social and environmental criteria.

Energy is stored at Moor Bioenergy both upstream in feedstock clamps and downstream in a gas store that acts as a buffer for the output of the plant. Across both on-site and off-site storage, the plant can store sufficient feedstock for a whole year of operation. The on-site buffer storage of gas is far more limited, since it is one of the highest capital cost elements of the plant design, however, connection to the gas grid provides unlimited energy storage capacity downstream of the plant. Although the plant is currently operated to optimise throughput, it is possible to adjust feedstock inputs to vary the gas output from the bioreactors and, if the need were there and the commercial incentives were available, it would even be possible to add an additional digester allowing greater flexibility of plant output. However, one of the key advantages of producing biomethane from plant like Moor Bioenergy is that it can use existing infrastructure to store energy and support the delivery of system flexibility.

Small-scale BECCS

Pre-combustion CCS for biogas to biomethane upgrading is just one – although arguably the most developed – example of how small-scale BECCS could operate. Other pre-combustion CCS technologies have been explored widely in the academic literature (Schildhauer et al., 2021). Post-combustion CCS is also an option for smaller-scale bioenergy plants, although this was a more controversial idea among participants of the present study. While some have argued that smaller-scale, distributed BECCS can be optimum (C. Donnison et al., 2020; Freer et al., 2022), others believed that it would simply diminish the negative emissions delivered by bioenergy. For participants, the decision around whether smaller bioenergy plants should be used to deliver BECCS hinged on beliefs about the most valuable use of biomass. This idea will be explored in the next section.

5.2 Flexibility and BECCS

There is a dividing line when considering whether BECCS plants would operate flexibly, based on an assumption that the negative emissions from BECCS are always the highest value use case for bioenergy in stationary applications. There's a belief that flexibility reduces this value. In many contexts this needs to be challenged.

Divided opinion

Through discussions with participants it became clear that some fundamentally doubted the value of providing any kind of flexibility with bioenergy. This view hinged on the idea that BECCS was always the "highest value use case for bioenergy" (in stationary applications) and that nothing should hinder the potential of biomass to deliver negative emissions. However, there appeared to be a broad consensus that biofuels would be essential to non-stationary applications like transport where BECCS would be far more difficult to achieve.

While this 'BECCS first' view was by no means shared amongst all participants, beliefs about BECCS did widely impact the extent to which participants saw bioenergy being able to provide long-duration flexibility in the long-term. As such, views of participants were split between those who took a 'BECCS first' approach, and those who saw BECCS as just one of bioenergy's many potential uses. This categorisation was not absolute, with views existing on a spectrum between these two perspectives.

'BECCS first' at baseload

Some of those who believed negative emissions are the highest-value use case for bioenergy argued that these could only be effectively achieved using large-scale BECCS plants configured for baseload operation. These large-scale plants were widely expected to be biomass combustion units with post-combustion CCS capabilities.

There were several arguments for running these plants at baseload. As their primary function will be to produce negative emissions, then achieving the highest average loads possible for these plants will be key. This would maximise the negative emissions achieved for a given plant capacity. Commercial viability was also a core argument for such an operational approach. One participant described how the high capital costs of BECCS plants would incentivise you to "sweat assets" (run them as much as possible) to deliver required financial returns. Flexible operation by its definition would mean not operating these plants at baseload, running counter to this logic. Some also argued it would be easier to get measurable, reliable removals from baseload operation which could be essential for the certification of carbon dioxide removals (CDRs).

The assumption that BECCS would mostly be delivered by larger-scale plants came about for several reasons. Firstly, BECCS delivered by fewer, larger plants was seen as being easier from a governance perspective. Many argued that effective BECCS operations would require regulation and monitoring which would be simpler for such arrangements. CO_2 transport was also raised (an issue discussed earlier in this report) - the argument follows that BECCS will be most effective when plants are connected to CO_2 pipelines, and that this may only be viable for larger-scale plants. This would also limit the number of locations at which BECCS would be practical, making fewer, larger plants a more pragmatic approach.

While BECCS was seen by these participants as the best ultimate use for biomass, there were disagreements about the best transitional approach. As discussed in the previous section, the development of BECCS has been slower than many had anticipated. These participants noted that it was unlikely large-scale biomass plants would be able to transition to BECCS until at least the 2030s. Some argued that in the meantime these plants should operate flexibly, an idea also championed by NESO (NESO, 2024). It was argued this would be the most effective use of limited resources, and reduce the UK's dependence on biomass imports.

However, others countered these arguments, claiming such an approach could do more harm than good. As discussed in Chapter 2, reducing the amount of feedstocks consumed via flexible operation could have negative, long-term supply chain impacts. If supply chains are not established and maintained for these plants in the short term, then sourcing sufficient volumes to provide maximum throughput could prove challenging. This would hamper these plants' long-term ability to provide negative emissions, running counter to the primary function of such plants.

Barriers to flexibility with BECCS

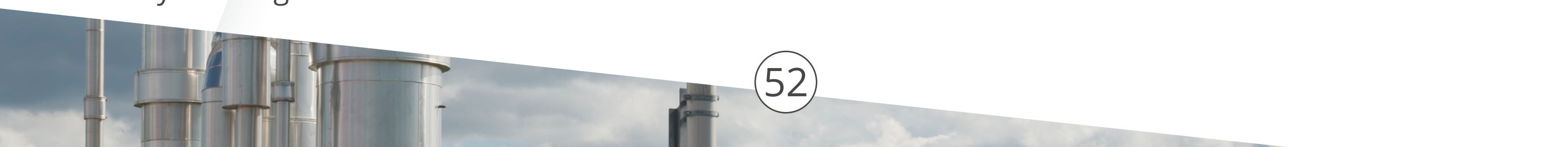
Some participants highlighted technical, economic and carbon budget barriers to the flexible operation of BECCS. As described above, running a given capacity of BECCS flexibly would result in fewer negative emissions overall than if you ran it at baseload. This concerned the 'BECCS first' participants as it would negate the most fundamental value of biomass, giving you less carbon dioxide removals (CDRs). Many of these participants believed that CDRs would be so essential to meeting the UK's overall carbon budget that any decrease in production would put decarbonisation efforts in jeopardy. Some cast doubt on this idea following the CCC's Seventh Carbon Budget which reduced the predicted need for engineered CDRs (CCC, 2025). However, many of these participants maintained that maximising CDRs should be a priority.

Others made the argument for maximising CDRs from large-scale plants on a commercial basis. For many of these plants it was believed that CDRs would be an essential part of their business models, and that maximising throughput may be the only way to generate profit. This was largely down to the capital costs of the BECCS plants setting a high income threshold for profitability. As such, planning to operate these plants flexibly could make the business case harder to justify, especially when trying to attract capital investment. While some participants discussed the possibility of over-building capacity on these plants to deliver both CDRs and flexibility, many felt their capital intensive nature could make this approach unviable.

Mechanisms that would support flexible operation, such as a capacity market were also discussed. While some believed that this could improve the business case for delivering BECCS over-capacity, many felt it would be insufficient to overcome the financial barriers. However, many were keen to see such models investigated by the research and innovation community before ruling out this possibility entirely. It was felt that such research should compare the system costs of flexible BECCS to those of other leading energy storage solutions to provide relevant context.

Other frequently cited challenges for flexible BECCS operations were the technical restrictions it would face. Current CCS technologies require consistent operation, meaning ramping CCS-enabled plants up and down may be impractical. However, participants stated that this should not be an insurmountable challenge. Variable load operation – as discussed in Chapter 4 – was raised as one solution for achieving flexibility without the need for start-stop operation. Others anticipated developments in CCS technologies allowing for such flexible operation. Indeed, another leading solution for long-duration flexibility is natural gas with CCS, which would itself require flexible CCS operation.

Ultimately, these 'BECCS first' participants viewed flexible-BECCS as too complicated and costly, as well as potentially jeopardising the negative emissions potential of the technology which would always be its greatest value.



Alternatives to flexibility with BECCS

Those who subscribed to a 'BECCS first' philosophy often believed that there were other, better-suited solutions to the long-duration flexibility challenge. Such solutions included the use of interconnectors, hydrogen-to-power, and natural gas with CCS turbines. Not only did they see these solutions as more technically suitable, but they also believed them to be more politically and economically viable.

However, others disagreed. Many participants felt solutions such as hydrogen and natural gas with CCS were relatively underdeveloped and would be challenging to roll out. They also believed that cost comparisons would reveal a relative strength for bioenergy-based energy storage as an already commercially viable solution.

Some of the participants subscribing to a 'flexible-BECCS' argument also felt that many of these arguments against flexibility with BECCS centred on post-combustion CCS processes and noted that pre-combustion CCS could circumvent some of these issues.

BECCS with energy storage

Many participants who felt negative emissions were the highest value use of bioenergy were not so sceptical of combining BECCS with energy storage. In this sense, we could consider them being further toward the pro-flexibility end of the opinion spectrum. These participants stressed that delivering negative emissions and long-duration flexibility did not need to be mutually exclusive. Such participants often believed that pre-combustion BECCS technologies were the optimum way of achieving both bioenergy benefits, although options for delivery of flexible post-combustion BECCS were also discussed. Pre-combustion CCS technologies vary in their technology maturity and perceived potential, and are all explored further in work by IEA Bioenergy's task 44 group (Schildhauer et al., 2021).

As discussed previously, biogas upgrading with the capture and storage of the consequent biogenic CO_2 stream was seen by many as both a mature and scalable technology. The negative emissions achieved through this method are dependent on minimising upstream CO_2 emissions and methane leakages. Upstream emissions could come from feedstock transport, feedstock fertiliser use, and other production process emissions. However, if these emissions can be minimised, then biogas upgrading was viewed as being one of the most cost-effective BECCS options available. The biomethane produced is an energy vector with good energy storage potential, with uses in heat, power, and transport applications. It also has the potential to be used in dispatchable CCS gas turbines, increasing both its flexibility and negative emissions value.

Gasification was another – albeit less mature – technology cited as having both BECCS and long-duration flexibility potential. Through this pre-combustion process, several energy storage vectors could be produced, including biogas and hydrogen, alongside a biogenic CO_2 stream. As such, the CO_2 could be separated and stored while the energy storage vectors are used to provide long-duration flexibility to the energy system. While hydrogen produced through gasification was particularly valued for its lack of post-combustion emissions, many were sceptical of this technology's potential. Concerns about commercial viability and technical feasibility were often discussed, with some arguing it was unlikely to ever work.

Other pre-combustion CCS technologies discussed included biochar. Some methods for producing biochar can also produce storable energy vectors such biogas or hydrogen. However, biochar production technologies are not yet widely implemented commercially, making predictions about co-production of gases difficult. Some believed that a dependable biochar market would need to be established before biogas or hydrogen could be produced at a useful scale using these technologies.

Value of non-BECCS applications

At the other end of the opinion spectrum from the 'BECCS first' participants were those who believed there was still long-term value in non-BECCS bioenergy applications. These participants all believed in the value of negative emissions provided by bioenergy, however, they did not believe that all biomass needed to be used in this way. They identified circumstances in which biomass could be beneficially used to deliver LCDP without CCS technologies.

One such set of circumstances was the case of bioenergy-based heat, a subject covered in more detail in Chapter 4. Heat-producing bioenergy plants must necessarily be located near the end users of their heat. As such, most take the form of smaller-scale, distributed heat-producing or CHP plants, close to, or co-located with their consumers. These distributed plants often make use of highly localised supply chains and feedstocks from local producers.

Participants argued that these plants would be difficult to convert to BECCS operations, especially the smallest of these units. They also argued that diverting feedstocks from these plants to larger-scale, BECCS-enabled units would likely be unviable. These feedstocks are often highly heterogeneous and distributed, making them difficult for large-scale BECCS plants from a supply chain and quality assurance perspective. One participant suggested such an approach would be "dogmatic and impractical". It would also fundamentally overlook the value that bioenergy-based heat could provide to the UK's energy system.

Another non-BECCS use case cited by participants was for 'peaking plant' which provide power to the UK energy system at the times of greatest need. Some participants believed that current policy direction could require such plants to install CCS capabilities to reduce carbon emissions. This would make these plants much more difficult to operate commercially, potentially creating additional challenges for the UK energy system.

Participants argued that replacing the fuel supplied to these units with bioenergy-based alternatives could be an effective, low-carbon option. Suggestions included using biofuel such as HVO, and biogas combustion engines. There are already examples of such 'peaking plants' using biofuels in operation today. However, the higher cost of these fuels compared to fossil fuel alternatives and a range of regulatory and supply chain issues mean that these options have not been widely adopted on a commercial basis.

5.3 Flexible BECCS

There is a dividing line when considering whether BECCS plants would operate flexibly, based on an assumption that the negative emissions from BECCS are always the highest value use case for bioenergy in stationary applications. There's a belief that flexibility reduces this value. In many contexts this needs to be challenged.

Likely BECCS flexibility scenarios

There are certain places and cases where participants thought flexible BECCS applications were most likely to add value, under a range of broader system scenarios. Biogas upgrading to biomethane, and the use of BECCS for industrial high-temperature heat were two such applications. Their alignment with government decarbonisation priorities was perceived to improve their potential, making them 'likely winners' out of flexible BECCS options.

Biogas upgrading produces a high-purity CO_2 stream as a by-product, making it relatively straightforward to integrate CCS. As discussed previously, the biomethane produced can provide a form of energy storage, giving it a dual role as both an energy system flexibility option and a source of carbon removals. This solution has the potential to be scaled up as discussed in Chapter 4 and earlier in Chapter 5. As a mature and versatile solution, many considered it a cost-effective option that the Government could support – given their stated focus on 'value for money'. The main uncertainty concerned the scale of deployment of this solution, although many saw some amount of biomethane-BECCS as likely.

Industrial heating was identified as another likely pathway for flexible BECCS. Although electrification and hydrogen are expected to dominate in the long term, bioenergy with CCS will likely continue to play a role (CCC, 2020; DESNZ, 2023). This was considered to be viable only in locations with established CCS infrastructure, such as industrial clusters. As discussed in Chapter 4, several industrial processes lend themselves to the flexible use of different fuel sources, including bioenergy. Consequently, some argued that these industrial heat applications presented another likely pathway for the flexible use of BECCS, allowing industrial users to access bioenergy's flexibility and CDR value.

These flexible uses of BECCS will be dependent on certain geographic factors. As discussed earlier in Chapter 5, there is uncertainty around the future of CO_2 transport, and the impacts this will have on the BECCS sector. Flexible BECCS in industrial heating was seen as likely since there is likely to be readily available CCS infrastructure in the industrial clusters. It was considered unlikely that such applications would come about outside of these clusters. Geographic limitations were also seen as likely for biogas applications, with distance from larger CO_2 infrastructure likely to have an impact on where AD plants and biorefineries with CCS capabilities could be located. However, advances in CO_2 transport logistics and technologies were anticipated to mitigate some of these limitations.

Flexibility from necessity

Some participants suggested that large biomass plants retrofitted with CCS might operate flexibly, not by design, but due to market conditions. If near-term demand for carbon dioxide removals (CDRs) proves limited, plants may need to maximise revenues through power markets, leading to more flexible operation. This view was speculative and seen as a short-term possibility only; most participants expected rising demand for CDRs to incentivise steady, rather than flexible, operation in the long run.

Hydrogen

Other BECCS applications were considered to be much more dependent on developments in the wider energy system and economy. Hydrogen is a key example of this.

Some participants were very optimistic about the role that hydrogen could play in the future of the UK's energy system as a form of LDES. They also believed that biomass-derived hydrogen (bio-H2) could significantly contribute to overall hydrogen production as well as carbon capture. However, others were much more sceptical about the role that hydrogen would play, especially bio-H2. These participants would argue that it is too expensive and inefficient to be a viable future long-duration flexibility solution.

According to some participants, it is currently difficult to produce hydrogen from biomass resources. Gasification of woody biomass to produce hydrogen is an expensive and complex process that has not worked commercially to date. Alternative methods for bio-H2 production, such as dark fermentation, were also considered relatively unproven at the commercial scale. There were concerns about the practicalities of storage and transport, as well as efficiency losses in the conversion processes (both to hydrogen and to end uses). Some also believed it could negate the value of biomass's inherent storability, producing a less storable, and therefore less flexible, energy vector.

However, many still considered hydrogen production a good use of biomass resources. They believed that hydrogen could play a key role as a low-carbon source of energy storage, producing no CO_2 emissions at the point of combustion. Producing hydrogen from biomass through processes such as gasification and dark fermentation also allows for pre-combustion BECCS. These produce a biogenic CO_2 stream which can be captured and stored – creating a negative-emission, storable energy vector. For this reason, some participants claimed bio-H2 could provide "the best of both worlds", negative emissions and energy system flexibility. They believed that technical challenges could be overcome and that bio-H2 production could support a broader hydrogen economy. Such a method of production was also believed to be more controllable and dependable than methods like electrolysis using power produced from renewables.

Participants considered the circumstances under which bio-H2 might be produced and used in this way. Incentives to produce hydrogen would likely improve the commercial viability of such methods. Simultaneously, developments in the hydrogen production and consumption sectors would influence the amounts of biomass needed to meet hydrogen demand. Evidently, technological developments will also have an impact on whether bio-H2 will be able to meet a significant proportion of demand. If these technologies do develop sufficiently, production will become dependent on their commercial rollout. This rollout could be challenging, especially given the capital costs of infrastructure like gasification plants. For these whole-system reasons, participants believed there was significant uncertainty in the role bioenergy would play in future hydrogen production.

Supporting co-products

Another important factor to consider in the economic viability of flexible BECCS applications is the role of by-products. Some flexible BECCS technologies create by-products such as biochar or digestates. Participants articulated how these by-products can be useful beyond the energy sector, in both agriculture and the broader bio-economy. The AD plant case study referenced in Section 4.1 (Moor Bioenergy) is an example of this, where digestate by-products are used as fertilizers by local farmers.

Making full use of this range of by-products was seen as essential to the long-term, commercial operation of the bioenergy sector. Some participants discussed the idea of 'stacking' value streams to maximise the value of these processes and feedstocks. This was considered especially important for those applications which had been commercially unsuccessful to date, such as gasification. Some also related this to the idea of the 'circular economy', a key concept championed in the previous Government's Biomass Strategy (DESNZ, 2023). They argued that by-products should be considered more as co-products, taking the view that all products should be valued and not treated as wastes.

While these ideas apply to the bioenergy sector more broadly, participants stressed that they could be especially important for flexibility use cases. As some of these applications have not been commercially viable to date, making full use of their range of products could be essential to their commercial viability.

This study has established that energy storage is already part of existing bioenergy supply chains, and that there is potential to make use of this characteristic to address the seasonal variations in wind and solar renewables output that affect electricity, heat and gas markets. There are multiple options for delivering system flexibility with biomass. Additional work will be needed to establish the scale of this potential on a commercial basis and in the context of the wider economy.

Future work will also need to take account of the transition to BECCS and the relative value that both negative emissions and lower-cost long-duration flexibility deliver to the energy system. The current study has shown that the two are not mutually exclusive, but require policy frameworks and incentives that deliver commercial benefits from delivering both services to the overall system.

When considering the role of bioenergy in delivering both negative emissions and energy storage, it is essential that a whole-systems approach be taken. Whilst the cost of energy production on any particular plant will be important to its commercial viability, the true value that either service delivers has to be considered in a whole-systems context, shaped by appropriate policy and regulation.

The work reported here has identified a number of areas where further research and development work would be needed, both to provide additional evidence to support these findings, but also to shape the policy and commercial models required to realise the low-cost energy storage potential of bioenergy. Specific areas for further work are set out below.

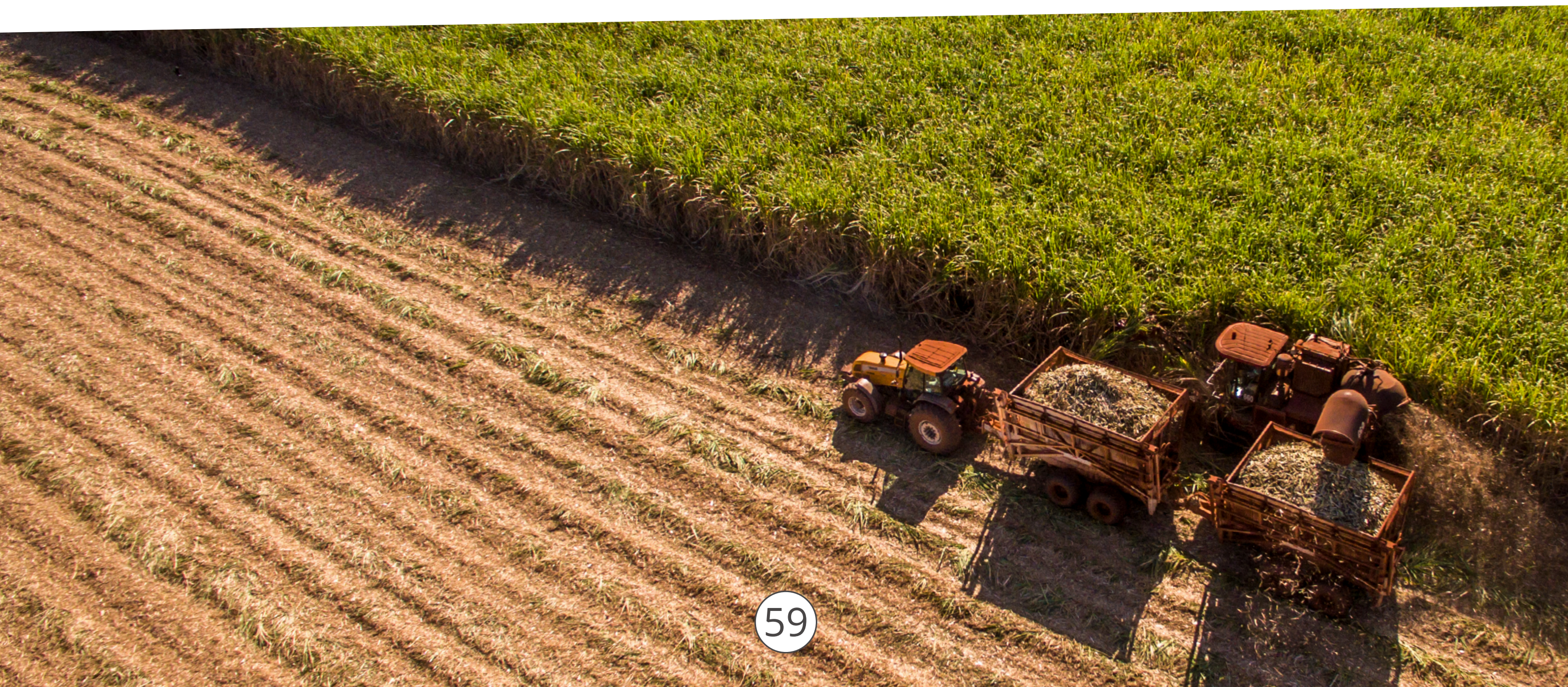
6.1 Exploring the system value of both flexibility and BECCS

- **Energy system modelling** – it is widely accepted that current bioenergy plant configurations could deliver long-duration flexibility, however, the total energy storage and production capacity needs from different forms of LDES are less well understood. Likewise, the extent to which these needs could be met with bioenergy requires further exploration and analysis. Whole energy systems modelling research could explore this potential along with the opportunities for plant modification and other investments to increase the energy storage potential of bioenergy. The relative whole system costs of these improvements need to be understood in the context of wider system impacts and in contrast to other LDES options under consideration, as well as the value that BECCS could deliver.
- **BECCS** – narratives around bioenergy's potential as a form of energy storage are significantly influenced by expectations around the future development of BECCS options and, in particular, the dynamics of CO_2 transport and storage. Key questions remain around the timing and feasibility of the transition of existing bioenergy plants to BECCS operation. Research is also needed to address uncertainties around a range of future options including the delivery of BECCS from smaller-scale operations, the potential for CO_2 transport from distributed locations, and whether it will be commercially viable to operate BECCS plants flexibly.
- **Appropriate technologies** – diversity in the bioenergy sector has led to a range of plant configurations and scales of delivery with varied benefits and challenges from a long-duration flexibility perspective. It would be beneficial to develop more detailed evidence of the energy storage opportunities for a range of specific bioenergy operations in the UK. This work would take into account wider system impacts, as well as the changes to commercial models and operation and maintenance regimes required to justify additional investment in energy storage capability. In particular, there is a need to establish how the whole systems costs for biomethane compare to other LDES options.

- **New flexible plants** – there is a need to better understand the opportunities for investment in new more flexible bioenergy plants that are designed to provide energy storage capabilities alongside other value streams. Key research questions include exploration of the best plant configurations to deliver flexibility and the regulatory and market conditions needed to drive such investments.

6.2 Bioenergy feedstocks

- **Feedstock modelling** – opportunities for delivering energy storage with bioenergy have not generally been taken into account in energy system modelling work. Consideration of the energy storage potential of biomass within these models may help to create greater certainty in the role of biomass within the overall system. Such modelling work would also need to consider the role of sustainable feedstock imports in future bioenergy production and the impact of BECCS on feedstock prices.
- **Feedstock supply-chains** – successful delivery of energy storage with bioenergy would also require active supply-chain engagement. There is already significant storage capacity within existing bioenergy feedstock supply chains, but the commercial incentives and market interactions would need to change for this capability to be utilised for long-duration flexibility and there may be a need for investment in additional feedstock storage capacity to fully realise the potential of bioenergy to deliver this flexibility. Analysis of these opportunities would need to consider the benefits of commoditisation and alternative markets for feedstocks as well as the changes to policy and regulation that might incentivise necessary supply-chain investment.
- **Feedstock production** – stakeholders are seeking a better understanding of the potential to increase sustainable bioenergy feedstock production from both marginal land and through integration into food crop rotations and the role this could have in the potential for bioenergy to deliver long-duration flexibility whilst avoiding the need to increase levels of feedstock imports.
- **Fuel flexibility** – the ability to produce bioenergy from a wider range of feedstocks has the potential to increase both energy system security and flexibility in upstream supply chains. It can also make use of additional feedstock streams that might otherwise go to waste. The magnitude of these impacts on energy systems and the economics of bioenergy is not fully understood, nor is the extent to which fuel flexibility of specific technologies can be increased without affecting plant reliability.



6.3 Economics

- **Market mechanisms** – researchers could usefully investigate the potential for a range of market mechanisms, including changes to capacity markets, to incentivise greater flexibility in the bioenergy sector including the changes that would be needed to make BECCS operations more flexible. This work would need to explore the key commercial drivers for current bioenergy and future BECCS operations and the level of incentives needed to encourage the investment needed to make them more flexible. Consideration would need to be given to the range of value streams available to such plants and the overall system costs of flexible bioenergy and BECCS when compared to other long-duration flexibility solutions.
- **Circular economy** - efforts to increase the 'circularity' of the UK economy are expected to reduce the availability of biogenic 'waste streams'. Commoditisation of biomass feedstock supply chains helps to reduce this risk but also opens up alternative markets to suppliers. Research is needed into the potential impacts of these changes on feedstock quality, availability and prices.

6.4 Wider Society

- **Place** – the distributed nature of many bioenergy operations suggests that there are specific locations and situations in which flexible bioenergy could be more effective. Evidence for this would require investigation of issues such as local agronomy, markets, energy system needs, local area energy planning, local economics, and political discourses. The delivery of heat from bioenergy is more likely to play a role at a local level, as is the use of district heating networks, and research into these opportunities would need to consider the impact of bio-heat flexibility on the whole energy system.
- **Social acceptance** – Some stakeholders claimed that certain technologies and scales of operation face less backlash from political, societal and NGO groups. This was felt to be especially true for smaller scale plants and infrastructure, and technologies which avoided using feedstocks such as imported wood pellets. Such claims would need investigating, and reasons for any apparent differences analysing.
- **Unintended policy consequences** – stakeholders are concerned to understand the value flows that might be created by any incentivisation of energy storage from bioenergy, and who would benefit from these changes. Specific research is also needed to understand the timescales and transitional arrangements required to ensure effective adaptation within the energy system and its supply chains, and the impact of these on the overall level of bioenergy's contribution to long-duration flexibility.

Appendix

Narratives presented to stakeholders as part of engagement process

Key to figure box colours:

Blue	Pink	Green
Dynamics of BECCS narratives	Plant, infrastructure and products narratives	Feedstock supply chain narratives

Figure A1 - BECCS with flexibility

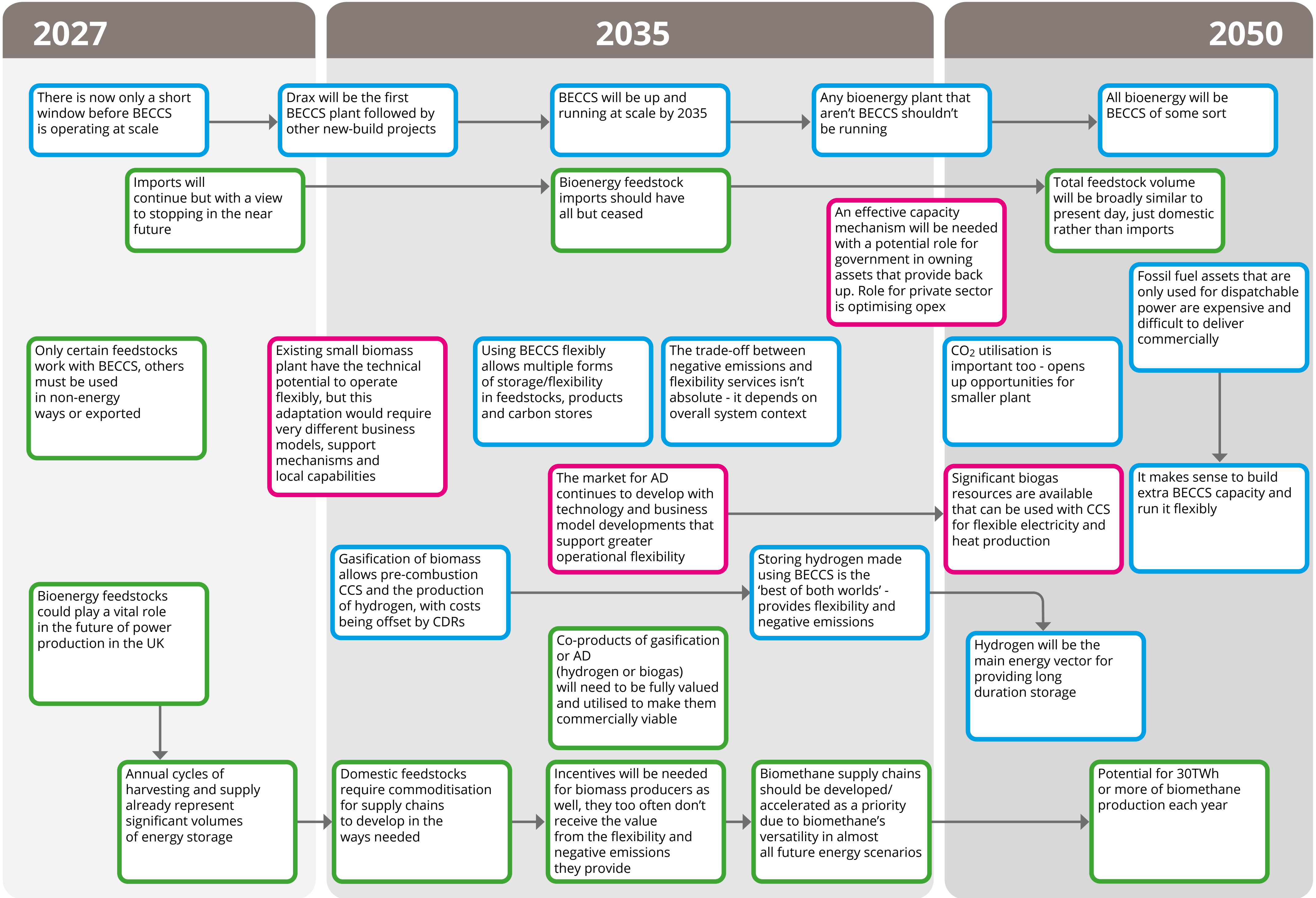


Figure A2 - BECCS with no flexibility

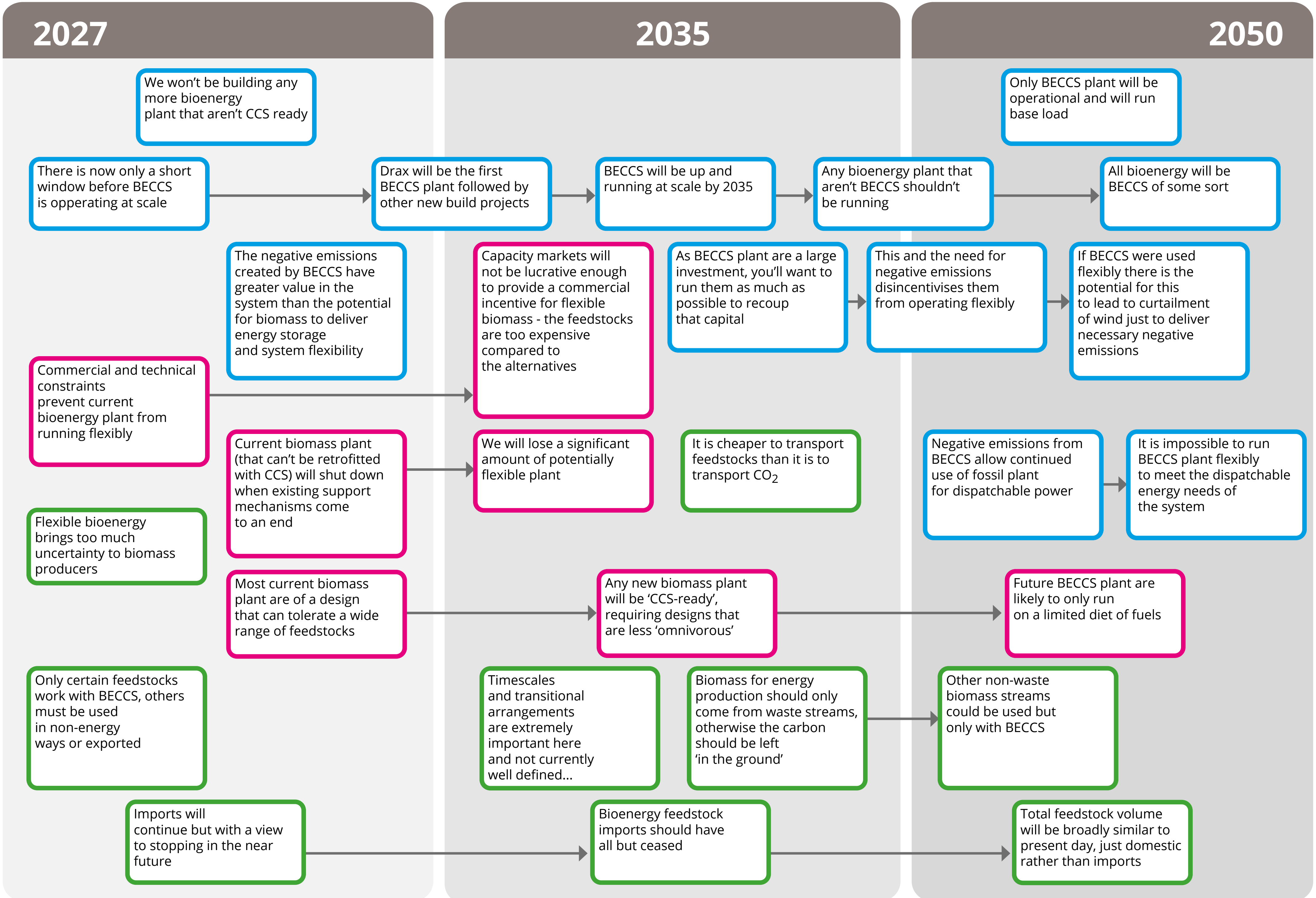
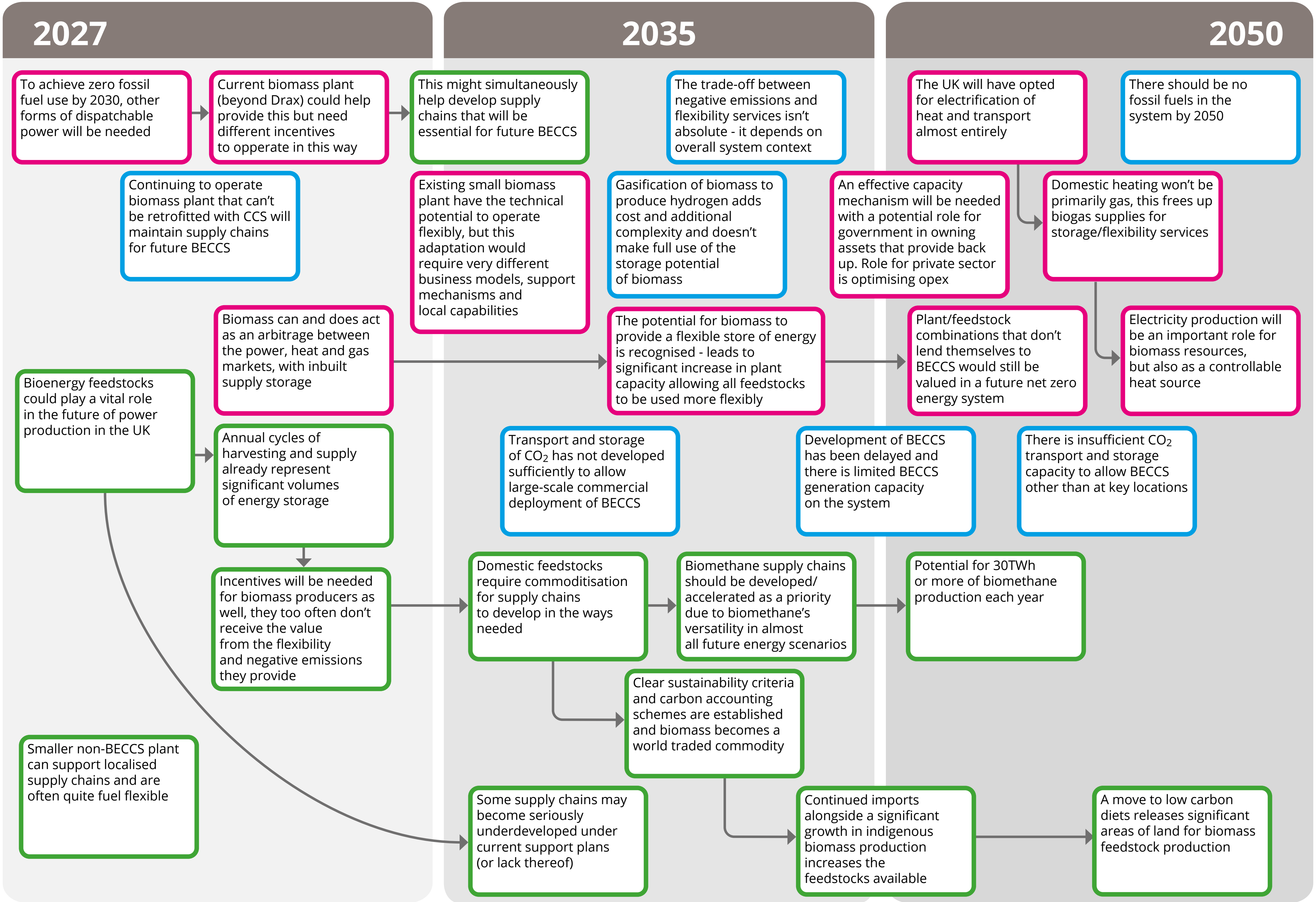


Figure A3 - Additonal non-BECCS flexible biomass



List of abbreviations

AD	anaerobic digestion
BECCS	bioenergy with carbon capture and storage
CCC	Climate Change Committee
CCS	carbon capture and storage
CDRs	carbon dioxide removals
CfDs	contract for difference
CHP	combined heat and power
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DESNZ	UK Government Department for Energy Security and Net Zero
ECUK	energy consumption in the UK
EFW	energy from waste
EU	European Union
FAME	fatty acid methyl esters (the main component of biodiesel)
GW	gigawatt (a unit of power)
H2	hydrogen
HVO	hydrogenated vegetable oil
ISCC	International Sustainability and Carbon Certification
IEA	International Energy Association
LDES	long-duration energy storage
MSG	minimum stable generation
NESO	UK National Energy System Operator
NGO	non-governmental organisation
REA	the UK's Association for Renewable Energy and Clean Technology
RHI	Renewable Heat Incentive
ROC	Renewable Obligation Certificate
TWh	terawatt hour (a unit of energy)
UKERC	UK Energy Research Centre

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Built upon experience of working at a senior level with both the private and public sectors, Cultivate is recognised by its clients as an organisation that can bridge the gap between academia, industry and consumers by understanding that engineers and investors speak very different languages and that these conversations take place in a context framed by policy regulations and broader societal needs.

The Supergen Bioenergy Hub is the UK's national research consortium dedicated to developing sustainable bioenergy systems that support the UK's transition to a sustainable, affordable and resilient low-carbon future.

Funded jointly by the Engineering and Physical Sciences Research Council (EPSRC) and the Biotechnology and Biological Sciences Research Council (BBSRC), the Hub takes a whole-system research approach, covering the full chain of biomass and bioenergy, including research on biomass resources, pre-treatment and conversion technologies, energy vectors, bio-based chemicals and materials, and whole systems analysis.

Working with stakeholders from industry, policy and the wider community, the Hub aims to identify pathways for delivering biomass and bioenergy solutions with wider social, economic and environmental benefits.

The Potential Role for Biomass as a Long-Duration Store of Energy – scoping study for the Supergen Bioenergy Hub and the UK Energy Research Centre - Full Report:

https://doi.org/10.82226/543.p.000002

Executive Summary:

https://doi.org/10.82226/543.p.000001

- supergen-bioenergy.net
- ukerc.ac.uk
- cultivateinnovation.co.uk