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Biomass for UK energy

Overview

- Biomass, meaning organic material from living things, can be used for low-carbon energy generation. It is projected to play an important role in meeting UK net zero targets, requiring a substantial expansion in domestic production.
- The Climate Change Committee (CCC) expect demand for biomass in the UK to rise significantly in the coming decades to supply bioenergy with carbon capture and storage (BECCS). Demand is also expected to increase from other economic sectors needing biomass, such as aviation fuels. Meeting future UK biomass demand will require an expansion in domestic production to avoid increasing imports. This will require sufficient land.
- In addition to wastes and residues, dedicated energy crops could make a significant contribution to the domestic biomass supply and provide environmental, social and economic benefits in certain contexts. However, the expansion of UK biomass production faces social, economic and technical challenges.
- Stakeholders say that current policy frameworks fail to provide sufficient long-term certainty to provide confidence for potential energy crop growers. The upcoming Biomass Strategy will discuss how biomass use can best contribute towards net zero across multiple economic sectors.

Background

Biomass can be used to produce bioenergy in the form of electricity, heat, biogas or transport fuels, or to produce materials and chemicals (PN 410).

Bioenergy is currently the second largest source of renewable energy in the UK, generating 12.9% of the total UK electricity supply in 2021.[1–3] The demand for biomass in the UK is expected to increase.[4–6]

When combined with carbon capture and storage (BECCS), bioenergy may deliver negative emissions (PN 618), which could contribute towards the UK's legal commitment to reach net zero carbon emissions by 2050.[7–9] In all scenarios from the CCC, BECCS is a component. In the Balanced Net Zero Pathway scenario of the Sixth Carbon Budget, BECCS removes 22 MtCO_2/year by 2035 and 53 MtCO_2/year by 2050 (equivalent to 10% of all UK emissions in 2019).[10]

Such an expansion of BECCS would require additional CCS infrastructure, and the sufficient supply of suitable biomass materials, which are termed *feedstocks*.

At present, approximately one third of UK biomass feedstocks are imported. Wood pellets from North America are the dominant feedstock for use in electricity generation.[3]

NGOs and the European Academies' Science Advisory Council (EASAC) have raised sustainability concerns about biomass imports, and their effectiveness for mitigating climate change.[11–16] Alignment of regulations across countries is required to ensure robust oversight of overseas biomass sourcing.[12,17,18] Other academic researchers have disputed these concerns.[19–21]

In future, the UK may face increasing competition for biomass as global demand rises.[6] To reduce reliance on imports, options to expand the domestic supply of biomass are being identified by policy makers and researchers. The CCC recommend dedicated energy crops and forest residues as future sources of domestic biomass although it is acknowledged that imports will continue to play a role.[5,10]

While stakeholders suggest that expanding UK energy crop production could bring co-benefits, it also creates social, economic and technical challenges.

Biomass feedstocks

As of 2020, 121,000 hectares of land were used to grow biomass for energy, which corresponds to ~1.4% of agricultural land in the UK.[22,23] Approximately 92% of this biomass are food crops used for biofuels or biogas rather than electricity generation (Box 1).[22]

Other biomass feedstocks include perennial energy crops (Box 1), which are fast-growing, energy dense, and offer an alternative source of biomass for electricity and heat generation. These crops may not directly compete with food production if they are grown on less productive areas of 'marginal' land (Box 2).[5,10,24]

Under their Balanced Net-Zero Pathway scenario, the CCC Sixth Carbon Budget involves planting at least 30,000 hectares of such energy crops each year by 2035, with 700,000 hectares planted by 2050.[10]

Current biomass feedstocks used for UK electricity generation are predominantly imported wood pellets from forestry residues.[3] It is unlikely that similar quantities of forestry residues will be available from domestic sources but other feedstock types will be available, such as perennial energy crops.[25–28]

Box 1: Feedstock types

Food crop feedstocks

These are derived from edible biomass such as:

- Oil crops – oilseed rape, soybean, palm oil etc.
- Sugar crops – sugarcane, sugar beet etc.
- Starch crops – wheat, maize etc.[29–31]

These feedstocks are used to produce liquid biofuels, such as low carbon aviation fuels (PN 616), or biogas using biochemical conversion processes, such as anaerobic digestion (PN 387), rather than directly burned for electricity, heat, and BECCS.[32,33] Potential future biofuel feedstocks include biomass derived from marine and freshwater algal biomass, but these are still at research stages.[29,34,35]

Non-food feedstocks

These are derived from non-edible biomass such as:

- Perennial energy crops – lignocellulosic grasses like *Miscanthus*, and short rotation coppice (SRC) willow or poplar. Once established they last for multiple growing seasons. They are frequently termed *dedicated* energy crops.
- Short rotation forestry (SRF) – young trees specifically grown for energy (e.g., eucalyptus) are harvested and replanted when they reach 10-20cm in diameter while growth rates and wood-to-bark ratio are high. SRF is still in trial stages.
- Forestry residues – small branches and bark from forest thinning operations, conservation management operations, wood pellets, or wastes from wood processing industries such as sawdust. High quality stemwood or roundwood is not considered a residue. This feedstock is often termed *woody biomass*.
- Agricultural residues – material left after harvesting or processing of food crops. This can vary in quality and is not always suitable for bioenergy.[5,17,24,29]

Perennial energy crops are not replanted every year like food crops but instead are established and regrow with harvesting in multi-year rotations. This can increase soil carbon sequestration in agricultural soils over time (PN 662).[36]

Rotation periods vary between crops; *Miscanthus* can be harvested annually whereas SRC is harvested on 2-5 year cycles.[37] SRF follows a similar system to conventional forestry but on shorter timescales of 8-20 years.[37]

Box 2: 'Marginal' land

Biomass strategies usually rely on the expansion of biomass production onto so called 'marginal' land.[38] However, this term is poorly defined, which can create challenges when assessing the availability of land.[39]

The Agricultural Land Classification (ALC) ranks land in England based on its productive capacity for cropping and similar classifications exist in Scotland and Wales.[39] Under the ALC, Grades 3b to 5 are considered moderate to very poor productivity and 'marginal'.[40] However, in the context of energy cropping, marginal land is a relative term that will change depending on circumstances and can also include under-used, inaccessible, inconvenient, or degraded land.[41,42] Biomass yields may be lower from less productive lands, which needs to be accounted for when assessing potential availability.[43]

The CCC identifies a potential 1.4 million hectares of 'marginal' land in the UK that could be dedicated to perennial energy crops by 2050 but only half of this is involved in biomass production under their scenarios.[10] Analysis for the CCC suggests that some of this land may offer greater benefits for carbon sequestration and biodiversity if used for other purposes such as reforestation or habitat restoration (PN 678, PB 48).[44]

A multifunctional approach to land use (PB 42) offers the opportunity to efficiently incorporate energy crops into a mosaic of high-yielding agricultural land, energy crop production and semi-natural landscapes. This would deliver optimal desired outcomes for biodiversity, ecosystem services, food, and biomass production while managing trade-offs.[45–47]

Environmental impact

The environmental impacts of different feedstocks are influenced by spatial factors such as the location and scale of crop planting, and the management practices used.

Food crops grown for biofuel and biogas (Box 1) require freshwater, fertilisers and pesticides to maximise yields and this can be detrimental to water quality, biodiversity and the nitrogen cycling of the land (PB 42).[34,36,48,49] The annual cultivation can also cause regular disturbance of the soil that erodes soil carbon stocks (PN 662).[34,50,51]

In comparison, if perennial energy crops (Box 1) are planted on former arable land they can have positive environmental impacts:[36,52,53]

- they require limited fertiliser input, causing less greenhouse gas (GHG) emissions and water pollution (PN 661);[54]
- they can tolerate water-logged soils and can improve water quality (PN 668);
- once the crop is established, harvesting minimally disturbs the soil allowing soil carbon stocks to build up over time (PN 662);
- there is evidence that perennial energy crops can act as a natural form of flood management;[44,55–57]

- SRC agroforestry crops can provide shelter for livestock and other crops;[58,59]
- when integrated into existing farm systems, evidence from UK studies suggests perennial crops can improve biodiversity by providing structural diversity for different habitats, boosting pollinator species and through the reduced need for pesticides and herbicides relative to arable farmland.[44,60–63]

Potential benefits for ecosystem services are reduced or lost when undisturbed, high carbon, biodiverse peatlands, grassland, or woodlands are converted to energy crops.[36,52,53,64] However, energy crops are a viable option for degraded peatland where water levels are being raised (PN 668).

Life-cycle emissions of domestic biomass production

The carbon accounting of biomass feedstocks includes the emissions produced during harvesting, transportation and processing along the supply chain (Figure 1). However, Life Cycle Assessments (LCA) of biomass feedstocks can give differing results with high levels of variability about emissions.[65–71] In order to avoid double-counting of GHG emissions, the UNFCCC reporting protocol determined that emissions from biomass should be reported under the land use sector of national accounting frameworks rather than the energy sector. Biomass produced within the UK will be accounted for under the land use sector in national accounting frameworks, whereas combustion emissions from imported biomass are not included.[18,72,73]

There is potential for biomass to generate negative emissions through BECCS if full life cycle emissions of feedstocks are monitored and managed and sustainability criteria applied (see below, PN 618).[74] The carbon absorbed by biomass during growth is captured during combustion and permanently stored, with an overall removal of carbon from the atmosphere.

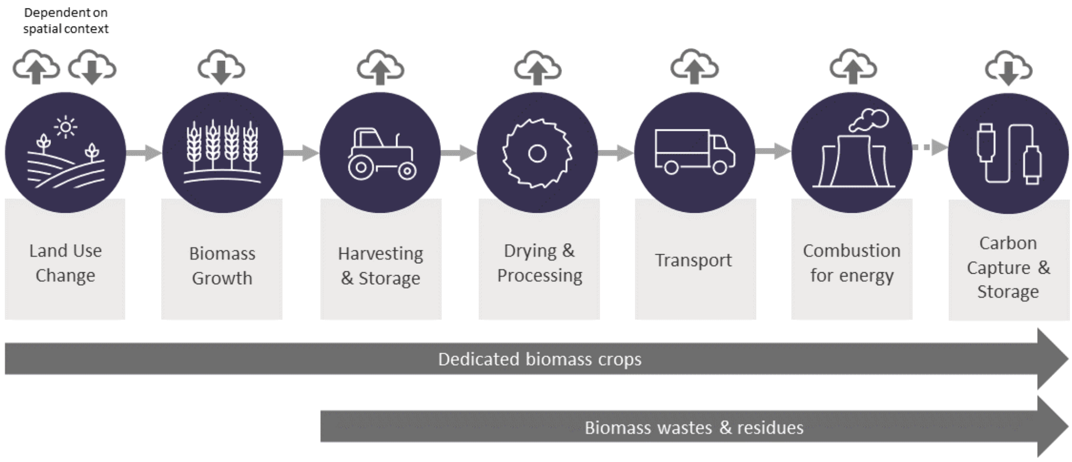
There are currently no commercial scale BECCS operations within the UK, but several are under development.[75] The CCC recommends that the Government's Net Zero Strategy should avoid over-reliance on engineered GHG removal solutions, including BECCS, but state that they will be required to meet Net-Zero.[5,10]

Some NGOs and EASAC question the assumption that combustion emissions will be reabsorbed in the future when the biomass regrows and suggest that the timeframes for regrowth and combustion are mismatched, with an initial rise in carbon emissions, creating a 'carbon debt'.[4,13,17,18,72,76,77] Other researchers dispute this and recommend a landscape-scale accounting method where emission changes are calculated across an entire landscape in GHG reporting.[19,20,70]

The literature refers to the time taken to repay the carbon debt as the *carbon payback period* and this varies between different feedstocks; perennial energy crops (Box 1) are considered to have a short carbon payback period.[17,37,53,78–80] Due to the time-dependent relationship between GHG emissions and the climate, the longer emitted GHGs remain in the atmosphere, the greater the warming effect.[81,82]

Some commentators have expressed concern that using feedstocks with long carbon payback periods increases the risk of missing the net zero 2050 target or crossing key climate tipping points, such as the collapse of the Greenland ice sheet.[12,13,17,18,83]

Figure 1: GHGs emitted and sequestered along the biomass supply chain



Source: based on information from Energy Transitions Commission (2021) [84]

Opportunities

Carbon sequestration

Scaling up UK energy crop production could contribute towards the net zero target through BECCS; by increasing soil carbon stocks on agricultural land; and by reducing land use emissions.

The CCC estimates that expanding the growing of perennial energy crops by around 23,000 hectares per year would deliver 2 $MtCO_2e$ emissions savings in the land sector by 2050 and an additional 11 $MtCO_2e$ from the harvested biomass when used with CCS.[10,85] Analysis by the CCC suggests that biomass could provide 75 – 350 TWh of energy to sequester carbon via BECCS in the UK.[5]

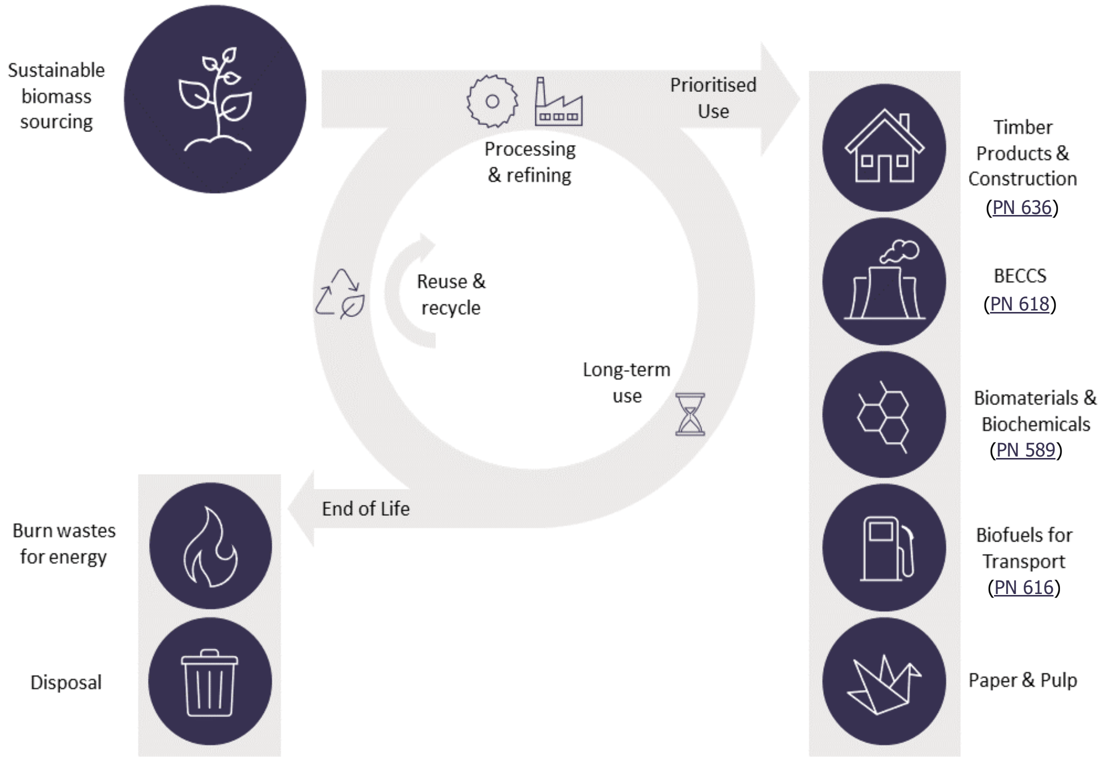
Optimal uses of domestic biomass

The CCC recommends prioritising the most effective biomass end-uses for GHG abatement, such as long-term timber use in buildings (PN 636).[5] The UK Government is developing a 'priority use framework' that follows this principle and aims to ensure that biomass is targeted towards use in sectors where options for decarbonisation are limited, such as biofuels for aviation.[4]

This framework will be explored further in the UK Government's upcoming Biomass Strategy.[86] Biomass could also be recycled as part of a circular bioeconomy (PN 646, Figure 2).[87–89]

At present, biomass makes a significant contribution to the generation of electricity in the UK, generating 39.9 TWh of electricity in 2021 (12.9% of total UK electricity supply).[2,3] Due to the decreasing cost of other renewable technologies, and prioritised use of biomass resources towards other sectors, biomass is expected to supply a smaller proportion of electricity to the UK grid by 2050. [5,90]

Figure 2: Circular bioeconomy with competing end uses for biomass



Source: based on information from Stegmann et al. (2020) [84,87,91,92]

Social & economic co-benefits

The Supergen Bioenergy Hub[¨] suggest that planting perennial energy crops in the right place could provide social and economic co-benefits alongside their climate mitigation potential and benefits for ecosystem services.[34,63]

Biomass sourcing, production and use can support the diversification of rural economic activities and provide new income streams for farmers.[34,44,93,94] The growth of biomass supply chains also provides the potential for rural and community development through the adoption of new skills and businesses.[34,44]

The benefits of energy crops for flood management suggests that strategic planting in flood prone regions may help prevent financial losses from flooding, with evidence of what works for natural flood management in different contexts emerging (PN 623).[44,55,57,95]

[¨] The Supergen Bioenergy Hub is a collaboration between academia, industry, government, and societal stakeholders that aims to develop sustainable bioenergy systems. The Hub is jointly funded by the Engineering and Physical Sciences Research Council (EPSRC) and the Biotechnology and Biological Sciences Research Council (BBSRC).

Challenges

Managing land use trade-offs

Land is a limited resource in the UK due to competition with other land uses than growing biomass energy crops including: [85,94,96]

- Food production
- Renewable energy
- Housing and infrastructure
- Woodland creation (PN 636)
- Timber production
- Nature conservation and biodiversity enhancement (PN 678)
- Culture and heritage preservation
- Recreation

As 64% of all UK land is used for livestock pasture and feed,[97,46] dietary change may lead to land becoming available for other uses, including for energy crops if suitable.[46,85]

The House of Lords Land Use in England Committee recommended the creation of an independent Land Use Commission that would oversee the monitoring of a national multifunctional land use framework.[98] At the time of publication, the Government response was not yet available.

Sustainability criteria for domestic biomass

There is no universal consensus on the definition of *sustainable biomass* and a major challenge for biomass use is ensuring that it is sourced sustainably.[99,100] For bioenergy generators to be eligible for UK Government support schemes such as Renewable Obligation Certificates, they must meet certain sustainability criteria when sourcing biomass.[5,101–105] The same standards apply to other economic sectors that use biomass. Criteria are tied to subsidy schemes and do not apply where non-subsidised biomass is used.[5] Criteria include:

- land criteria – restrictions on the land from which biomass is sourced. This includes protections for biodiversity and the carbon stocks of forest, peatlands, and wetlands;[4]
- GHG criteria - thresholds for the life cycle emissions of the biomass;
- social criteria regarding labour rights.

Commentators have suggested a need to improve and clarify reporting standards and sustainability criteria across all sectors and the whole supply chain.[17,34,106,107]

Climate change will also require sustainability criteria to be regularly updated to reflect changes in context.[108–110]

There is considerable ongoing uncertainty surrounding the potential impacts of different biomass feedstocks when grown at larger scales. This suggests a precautionary approach is needed when developing biomass policy frameworks. The Supergen Bioenergy Hub, the UK Centre of Ecology and Hydrology, EASAC, and numerous NGOs recommend that criteria should: [11,13,17,18,34,44]

- consider the carbon payback periods of feedstocks;
- address the uncertainties in the LCAs of different components of the biomass supply chain;
- have an improved consideration of land use synergies and trade-offs (multifunctional land use);[94]
- include indicators for biodiversity, soil and air quality as well as social and economic measures.

Barriers to expansion

Financial barriers

Energy crops can have a high upfront cost relative to food crops and require 3-5 years to establish before a land manager would see financial returns.[93,111,112] Despite UK energy crops being an eligible feedstock for UK electricity generation under the Renewables Obligation and Contracts for Difference, there are currently only limited numbers of buyers offering long-term contracts for UK energy crops, creating a financial risk for growers.[42,44,113,114]

Perennial energy crops could provide new income opportunities for less productive land that is unsuitable for food crops, but they are presently less profitable for farmers than food crops. Commentators suggest that incentive schemes need to support both supply and demand, as a self-sustaining, stable market will incentivise farmers to plant biomass for energy.[42,112,115] Companies like Terravesta are working to address this (Box 3).

Box 3: Case Study - Terravesta

Terravesta is a Lincolnshire-based biotechnology company with the aim of improving and expanding UK production of *Miscanthus* (Box 1). They are involved in both the supply and demand of *Miscanthus*, currently working with over 200 UK growers on approximately 5000 hectares.[116] By supplying long-term supply contracts of 5-15 years, growers can experience greater certainty and reduced risk. Terravesta then supply the unprocessed biomass resource to UK bioenergy plants or for other end-markets like equine bedding and construction materials.[117]

Terravesta are also involved in *Miscanthus* research and innovation, in collaboration with Aberystwyth University, where they are working to develop new *Miscanthus* varieties and seed-based hybrids that would help enhance the multiplication rate of the planting material.[117,118]

Social and cultural barriers

Energy crops can be an unfamiliar crop for land managers and the potential benefits or ways in which energy crops could be integrated into existing farm management systems are not well understood.[93,119]

Studies have found that many farmers perceive energy crops as risky and unprofitable, and can have a cultural aversion to them as they see themselves as providers of food rather than energy.[42,44,63,120] It has been noted by stakeholders that unclear messaging around energy crops and 'marginal' land has led to a negative perception of energy crops among many farmers who do not consider their land 'marginal enough' to be used for energy crops.[120,121]

Recent media controversy around imported biomass may affect UK bioenergy's social license to operate (community and public consent – see PB 45) .[122–124] It could be challenging to expand either biomass production or bioenergy generation in the UK without social legitimacy.[125–127]

Policy certainty

At present, there is a consensus among stakeholders that existing policy frameworks fail to provide sufficient long-term certainty to provide confidence for potential energy crop growers.[42,44] There is evidence that past policy interventions delivered increased planting rates in the UK but subsequent cancellation stopped this and consequently numerous studies have found a lack of trust among farmers that there will be a reliable energy crop market (Box 4).[58,128,129]

However, policies such as the Environmental Land Management Scheme and 2023 Land Use Strategy may provide opportunities to design more robust frameworks and incentive schemes.[27,34,130–132] The Government's Biomass Strategy was intended for publication in 2022 and is now expected in 2023; it will outline the policies required for biomass deployment into priority sectors for net zero alongside support frameworks for sustainable biomass sourcing, air quality, and GHG accounting.[4]

Box 4: Case Study - Project ARBRE

The Arable Biomass Renewable Energy (ARBRE) project was the first planned UK biomass power station that aimed to demonstrate electricity generation from energy crops using gasification technology.[133] The project ran from 1994 – 2002 and signed contracts with farmers to supply *Miscanthus* and SRC crops for the planned 40MW power station.[119] The UK Government introduced the Energy Crops Scheme in 2000 to incentivise energy crop planting, offering a fixed rate payment per hectare.[134] However, the grant payments were not deemed attractive enough to encourage substantial deployment.[58,119] The ARBRE plant never reached commercial operation and many farmers suffered financial losses.[119,133] The project failure and the lack of any stable bioenergy markets resulted in a considerable confidence loss in energy crops among farmers, which remains a barrier to expansion.[58,119,135]

Technical barriers

Technical improvements may minimise the practical challenges for biomass production (Box 5). However, upskilling across all elements of the UK supply chain (PN 659) and knowledge exchange would be needed for the sector to grow.

The process of planting and harvesting energy crops is labour intensive and the process of storing, drying and processing material into a useable form can be energy or time intensive.[5,136] Most bioenergy generators require consistent, energy dense feedstock with low moisture content or contamination.[137–139] This can be difficult to achieve, especially when sourcing from dispersed growing locations.[24,140]

Scaling up of transportation, machinery availability, infrastructure and the CCS network will be required alongside increases in production.[42,44] The availability of planting material will remain limited without further research into new, more resilient crop varieties.[141–143]

Box 5: Case Study - Biomass Feedstocks Innovation Programme

The BEIS Biomass Feedstocks Innovation Programme was a £36 million funding scheme (2021-2022) that aimed to increase sustainable biomass production by improving productive breeding, planting, cultivation, and harvesting.[144] Phase 1 supported 25 projects to produce commercially viable proposals for biomass innovation.[145] Phase 2 then funded 12 organisations to deliver their proposed schemes.[146] Innovations included:

- Development of higher yielding energy crop varieties that can be more easily multiplied and propagated.[118,147]
- Development of robust, mobile pelletising technology to enable affordable domestic processing to displace imported biomass.[148]
- Biomass Connect: a multi-site demonstrator project and knowledge-sharing platform that provides independent information and facilitates the sharing of skills and experience. The 8 UK demonstration sites each grow up to 11 varieties of energy crops to explore how they grow under different conditions.[149]

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