The science of low carbon biomass

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Eilidh Forster, Head of Forest Carbon, Drax

Summary

This paper explains the conditions needed for woody biomass to be considered low carbon, the practical steps Drax takes to ensure it sources low carbon woody biomass, and why published studies on the carbon impact of woody biomass and wood-based bioenergy sometimes reach different conclusions.

All reference to biomass and bioenergy should be read as 'woody biomass' and 'wood-based bioenergy'.

1. Introduction

The carbon impact of woody biomass is critical in determining the overall contribution of bioenergy to decarbonisation[1]. Establishing the carbon impact of biomass requires contextual knowledge of the biomass supply chain, including forest location, forest type, forest management and feedstock type. It also depends on methodology choices made during evaluation, including counterfactual assumptions (what happens in the absence of biomass use), temporal and spatial boundaries, and biomass use. Biomass should not be treated simplistically as either automatically carbon neutral or inherently high carbon[2].

2. Key concepts

Three concepts are key for understanding and evaluating the carbon impact of woody biomass. These are the biogenic carbon cycle, carbon debt, and carbon payback, as explained below:

Definitions

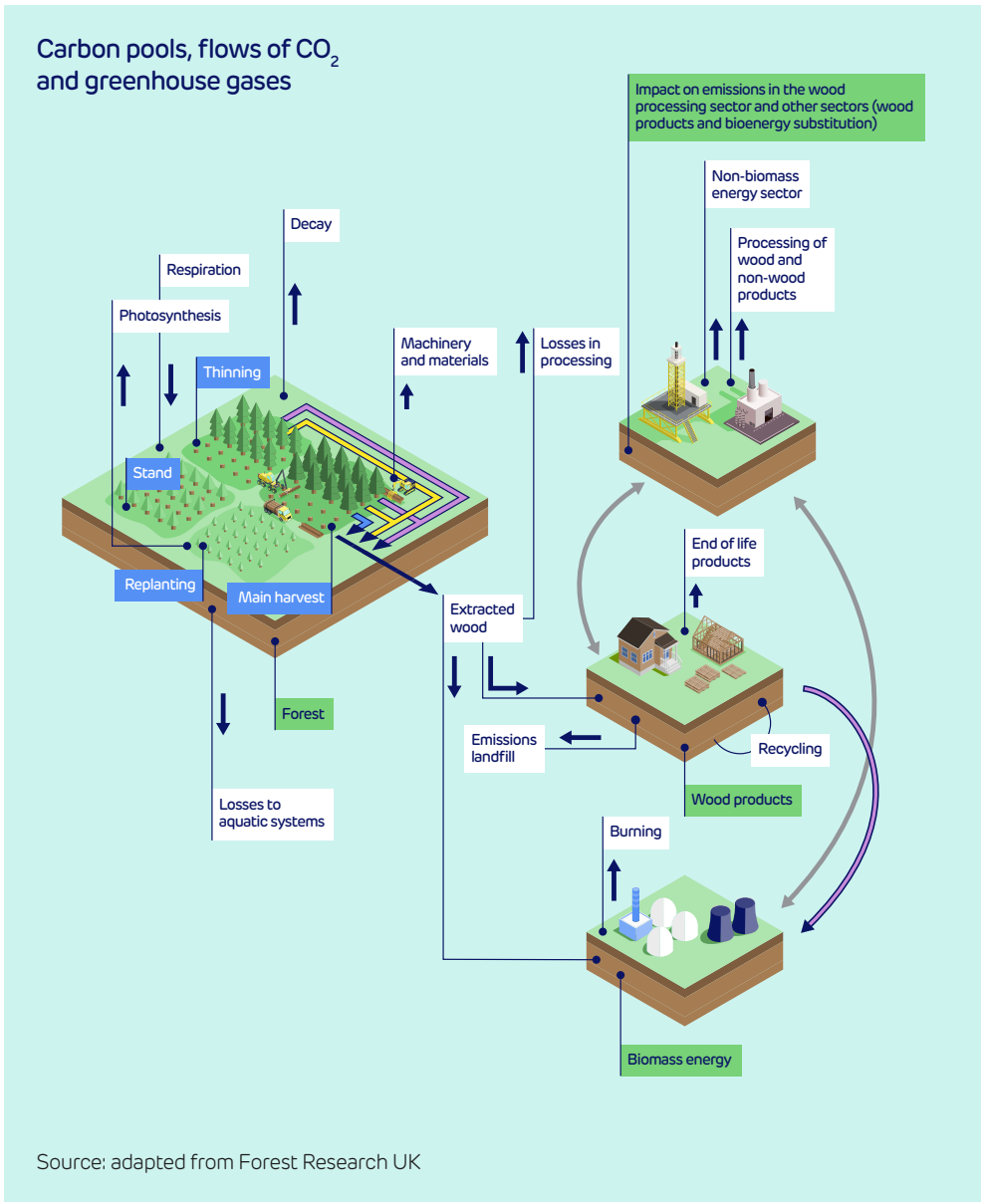
In the context of bioenergy:

- **The biogenic carbon cycle** describes the movement of carbon between forests, harvested wood products, bioenergy, and the atmosphere (Figure 1).
- **Carbon debt** is the net cumulative biogenic CO_2 emitted to the atmosphere following a change in forest management intended to increase biomass supply[2]. In other words, the extra biogenic CO_2 emissions or the reduction in forest carbon stocks, caused by the management change (Figure 2).
- **Carbon payback** is the time taken for a carbon debt to be balanced by avoided emissions from substituted products, for example from biomass substituting for fossil fuel[2] (Figure 4).

Biogenic carbon cycle

In a sustainably managed forest system (Figure 1), carbon is removed from the atmosphere as trees grow; areas of forest are harvested, and harvested areas are replanted or regenerated. This happens concurrently in a mosaic across the landscape. Growth and harvesting rates vary across regions and forest types. Carbon in harvested wood then moves into a range of wood products and energy uses before eventually returning to the atmosphere (burning or decomposing) when those products reach the end of their lives. Biomass used in bioenergy has a very short product life, whereas wood products used in construction can have very long lives (10s to 100s of years).

Harvesting yields products of varying quality and size, including high-grade roundwood, lower-grade roundwood, thinnings, and residues such as tops and branches (Figure 1). Given the substantial value differential between these product categories, forest management is primarily geared towards maximising the production of high-grade roundwood for construction markets.



Stand

A block of contiguous forest that is thinned or clear-cut as a single unit (typically containing trees of similar species and age)

Thinning

- A percentage of trees removed from crowded stands
- Reduces competition for light and nutrients
- Improves high-grade roundwood (sawlog) development
- Intensity/frequency of thinning depends on growing conditions, cost of harvesting and access to markets for thinnings
- Low-grade roundwood and residues generated – also referred to as 'thinnings'

Main harvest

- Clear-cutting of mature stands
- Harvested material sorted to maximise sawlog and other high-value markets (main income)
- Low-grade roundwood and residues also generated

- High-grade roundwood
- Low-grade roundwood
- Residues
- CO_2 and GHG flows
- Product substitution

Figure 1 – The complete system of carbon pools and flows of CO_2 and greenhouse gases for a forest under management to produce wood products and bioenergy. Also shown are the main wood product category flows from both thinning and main harvest

Carbon debt

Carbon debt (extra biogenic CO_2 emissions) can occur as a result of biomass sourcing but it is not inevitable. It may occur if harvest intensity increases to supply biomass, leading to extra biogenic CO_2 emissions and relatively lower forest carbon stocks (Figure 2).

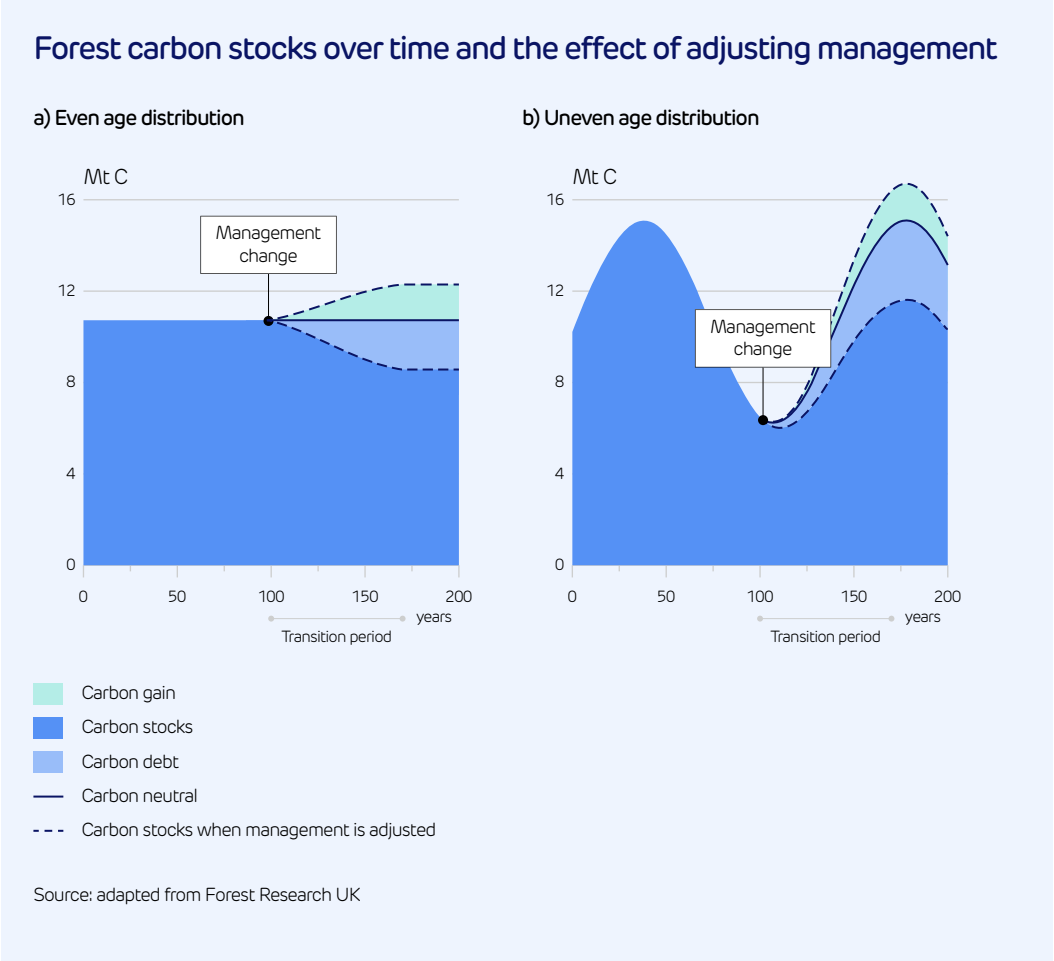


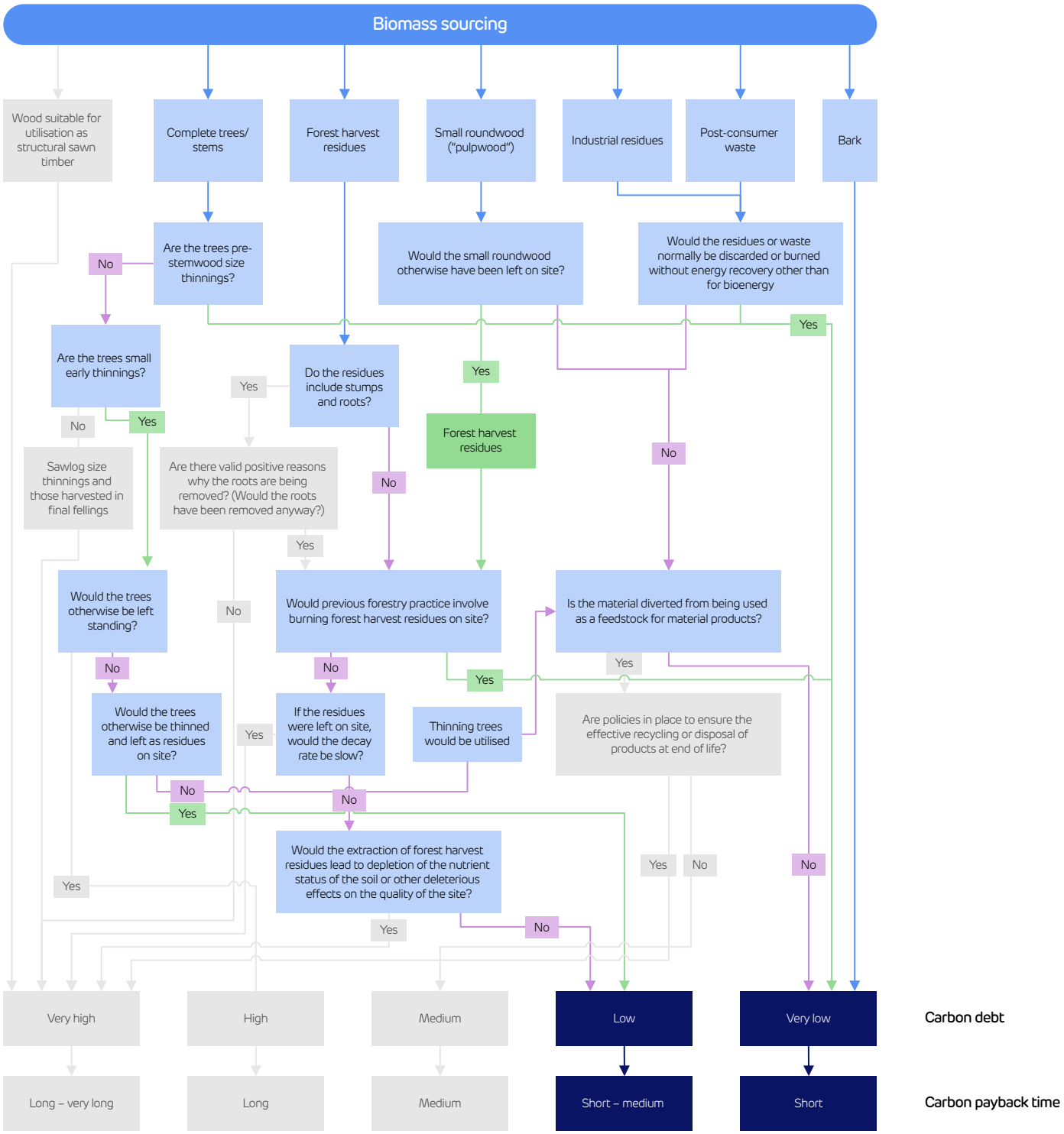
Figure 2 – The graphs illustrate two identical forests managed in the same way, but a) has an idealised even age distribution and b) has an uneven age distribution, which leads to the 'wavy' pattern. A management adjustment can lead to carbon debt, gain or neutrality. The effects are clear in the even age forest but they are obscured in the uneven age forest. The uneven age forest can show rising carbon stocks even when there is a carbon debt; or falling carbon stocks even when there is a net carbon gain. This illustrates that changes in carbon stocks alone do not provide a reliable indicator of carbon debt or gain, underscoring the need for multiple complementary safeguards to mitigate carbon debt (section 3. Drax Safeguards).

High carbon debt is most likely when trees are harvested intensively, solely for bioenergy. In contrast, low carbon debt is likely when sourcing thinnings, harvesting residues, salvage wood, mill residues and other low-value material from well-managed productive forests[2]. The decision tree (Figure 3) illustrates key criteria impacting likely carbon debt associated with different feedstock types, including counterfactual management or uses of that feedstock in the absence of biomass sourcing.

Carbon neutrality may occur if biomass sourcing does not cause extra biogenic CO_2 emissions, for example, sourcing harvesting residues that would have otherwise been burned in the forest (burning of residues is practiced in some regions to mitigate spread of wildfire). Carbon gain is also a possibility, if forest management improves because of biomass sourcing, leading to less biogenic CO_2 emissions and relatively higher forest carbon stocks.

Feedstock choice is critical in determining carbon debt and therefore, whether woody biomass is likely to be low carbon.

Biomass sourcing pathways



Source: adapted from Forest Research UK

Figure 3 – Assessing carbon payback times and carbon debt of forest bioenergy sources. Drax biomass sourcing pathways are indicated in blue. Note, when studies model grey pathways (e.g. Peng et al.[3]) they conclude biomass use has high carbon debt and long payback time.

Carbon payback

Carbon payback time is directly linked to carbon debt. Higher carbon debt leads to longer carbon payback time so the route to short carbon payback begins with minimising carbon debt in the first place through responsible feedstock choice.

Carbon payback time is also impacted by what biomass is used for, the product it is substituting and the associated rate of avoided emissions accumulation (Figure 4). For example, biomass substituting for coal would likely have a shorter payback than biomass substituting for natural gas, since coal typically has higher associated greenhouse gas emissions than natural gas. Biomass used in a bioenergy with carbon capture and storage (BECCS) plant, which displaces fossil fuels and simultaneously avoids release of biogenic CO_2 emissions, would significantly shorten carbon payback due to the parallel avoided emissions benefits.

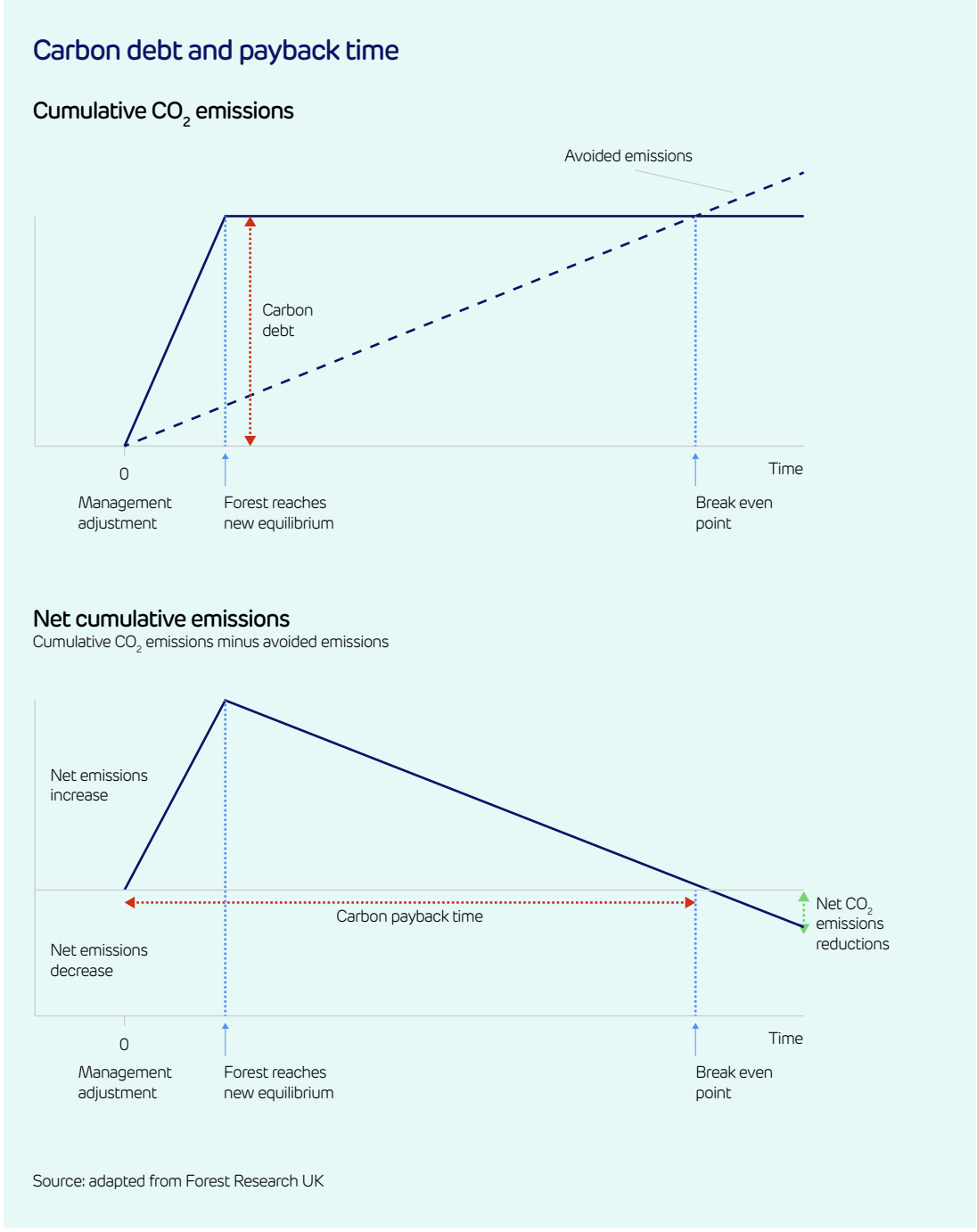


Figure 4 – Illustration of carbon debt accumulation (top) and repayment (bottom) following a forest management change, with repayment driven by avoided greenhouse gas emissions (through product substitution or carbon capture and storage of biogenic CO_2).

Evidently, it is not a given conclusion that biomass is low carbon. Safeguards are required to ensure responsible biomass sourcing that mitigates the risk of longer-term carbon debt and enables biomass to be credibly referred to as 'low carbon'. That is, mechanisms ensuring sourcing of biomass feedstocks with low-associated carbon debt (and short payback time), from well-managed productive forests with stable carbon stocks over the long-term. With those safeguards in place, the Intergovernmental Panel on Climate Change (IPCC), UK Climate Change Committee (CCC) and others agree that biomass can make a significant contribution to decarbonisation, particularly where it displaces coal and gas from the energy mix.

3. Drax safeguards

Drax seeks to minimise carbon debt in its biomass supply chain through a broad framework that includes responsible sourcing requirements, certification, monitoring, traceability, stakeholder engagement, and compliance requirements.

Drax's Biomass Sourcing Policy[4] sets out its sourcing approach, which focuses on material with low carbon debt and short payback times, including forestry residues, thinnings, other low-value roundwood from well-managed productive forests, and residues from wood processing facilities. In 2025 Drax's biomass composed of 53.4% wood processor residues, 40.6% low-grade roundwood and thinnings, 3.5% forestry residues (branches and tops), 2.2% non-woody biomass and 0.3% salvage trees[5]. Drax does not source from clear-cutting unless the material is a residue or other low-value material that cannot be utilised by a sawmill. The Policy also sets out a number of climate positive (and nature and people positive) principles, including a commitment to monitor carbon stocks in forest sourcing areas and to only source from areas where forest carbon stocks are stable or increasing over the long term.

Drax uses globally recognised, independent third-party certification to verify that biomass is sourced from legally compliant, sustainably managed forests and to provide traceability and transparency throughout the supply chain. Drax relies primarily on Forest Stewardship Council® (FSC)[6], Sustainable Biomass Program (SBP)[7], Programme for the Endorsement of Forest Certification (PEFC)[8] and Sustainable Forestry Initiative (SFI)[9] certification schemes.

In combination, the components of this broader framework work together to ensure that Drax's biomass is made from feedstocks with low carbon debt, sourced from well-managed productive forests, verified through independent certification, monitored through forest carbon and sourcing assessments, traced via a Biomass Tracker[10], and governed by requirements prohibiting deforestation and forest degradation. With these elements in place, Drax's biomass can be justifiably considered to be low carbon.

Furthermore, Drax utilises its biomass at Drax Power Station, contributing significantly towards decarbonisation of the UK energy mix; and supplies it to customers globally, supporting decarbonisation in those markets.

4. Why studies reach different conclusions

Published studies on the carbon impact of biomass can reach conflicting conclusions because they evaluate different contexts and use different methodology assumptions[2,11,12]. This includes different forest types and conditions, forest management practices, spatial boundaries, locations, timeframes, system boundaries, feedstock types, and counterfactual scenarios[13,14]. The study objective (the question it sets out to answer) and methodology determine the answer, so conclusions should be interpreted in light of the assumptions used, rather than hand-picked and applied to support a fixed narrative without considering whether they are valid or defensible in that context[2].

Studies that find high carbon impacts often 1) rely on assumptions that are not representative of Drax's sourcing model, such as using stemwood that is suitable for conversion to higher quality long-lived product to supply bioenergy[15,16] 2) compare biomass use with an unrealistic no-harvest counterfactual[2,15,17] or 3) evaluate a single theoretical forest stand rather than a managed landscape[18,19].

On the other hand, studies finding low carbon impacts often 1) rely on assumptions that are representative of Drax's sourcing model, such as using thinnings or sawmill residues[20] 2) compare biomass use to a plausible lower harvesting counterfactual[11,18] or 3) use a landscape scale analysis[21]. Note, 'On the Science of Carbon Debt'[2] report (a landmark scientific paper providing an evidence-based framework for identifying and avoiding carbon debt in bioenergy systems) recommends that bioenergy assessments should be undertaken at landscape scale, because point-in-time changes in one stand may not reflect long-term carbon dynamics across a managed forest system.

Counterfactual assumptions around biomass use are especially important. If biomass sources include residues or low-value material that would otherwise be burnt or left to decompose[22,23], or is material that has become available due to changes elsewhere in the market (e.g. pulpmill closure), the carbon debt may be very low[2]. Alternatively, if a

study assumes widespread additional harvesting or shortened clear-cut rotations solely to supply bioenergy, it can produce long payback times[2], but this may not be a realistic representation of actual supply chains. These assumptions can substantially shape the conclusions reached about the carbon impact of biomass, highlighting the importance of context[13].

5. Key takeaways

- Carbon debt is a recognised risk, not a certainty; it depends on feedstock type, forest type and condition, forest management, location, spatial and temporal boundary, and counterfactuals.
- Woody biomass is considered low carbon where feedstocks with short carbon payback times are sourced from well-managed forests where carbon stocks remain stable or improve over the long term.
- Low-value material, residues, thinnings, and processing residues from well-managed forests, generally have the lowest carbon debt and shortest payback times.
- Drax sources feedstocks associated with low carbon debt for its biomass pellets, supported by a broad framework that includes responsible sourcing requirements, certification, monitoring, traceability, stakeholder engagement, and compliance requirements.
- Carbon debt is repaid where biomass displaces fossil fuels and where bioenergy is coupled with carbon capture and storage (it may also be repaid where biomass power supports increased contribution of intermittent renewables in the energy mix).
- Studies on the carbon impact of biomass should be assessed critically, especially for assumptions about feedstock type, management change, spatial and temporal boundary, and counterfactual land use.
- Communications on the carbon impact of biomass should avoid simplistic claims and should explain that low carbon biomass requires responsible sourcing, strong governance, traceability, certification, and monitoring.

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