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Reason for submission of evidence

I fear that greenhouse gas reduction options, including BECCS, are becoming a risk to near term decarbonisation action, and embody significant externalities if scaled globally. The UK government is leading the BECCS charge, and hence has a responsibility to ensure it is well managed, minimises the externalities and prevents the risk of reducing near term decarbonisation due to optimism that BECCS and other GGRs will save us later down the line.

Summary

Around 61 per cent of the largest emitting countries have committed to net zero targets, which are inherently reliant on carbon removal options, such as bioenergy with carbon capture and storage (BECCS).

A worst-case scenario of over reliance on BECCS policies and their poor implementation could delay or deter emissions reductions, and result in ‘imagined offsets’. One analysis indicates that this could cause an additional temperature rise of up to 1.4°C.

While scientists treat models as ‘experimental sandpits’, policymakers tend to see them as ‘truth machines’. As a result, there is a clear risk of policy and market support mechanisms developing ahead of resolving crucial scientific and engineering uncertainties. The UK is leading efforts to develop policies and market frameworks to support BECCS, and must do so cognisant of the risks of under-performance and supply chain impacts, especially if BECCS is scaled internationally.

This is particularly pertinent given that the ‘middle-of-the-road’ 2050 IPCC global pathway towards 1.5°C compliant scenarios envisages around 1.5 $GtCO_2$/yr of BECCS removals. If this were supplied solely by wood pellets it would require a scaling of supply by more than 12,000 per cent, relative to what Drax, the UK’s largest bioenergy producer, currently combusts at its Selby power plant.

Due to the potential scaling pressures on wood pellet supply chains, the risk of carbon debt1 remains of concern. As one recent study pointed out, ‘in the US coastal southeast there were fewer live and growing-stock trees and less carbon in soils with every year of milling operation than in the rest of the eastern US’. As such, a diversity of feedstocks should be pursued.

Biomass supply chains embody non-marginal emissions. Setting aside the risk of carbon debt, and assuming robust reporting of supply chain emissions, a future BECCS-to-power plant that combusts wood pellets is likely to exhibit a carbon efficiency of around 76 per cent. Significantly less than the 90 per cent capture rate targeted at the plant level and planned for in models.

In the UK, wheat straw may be the feedstock with the optimal carbon efficiency: 74–72 per cent of CO_2 is geologically stored, and 26–28 per cent emitted to the atmosphere. As such, for a finite land area, wheat straw based BECCS would remove more CO_2 from the atmosphere, compared to other feedstocks.

Based on the UK’s Committee on Climate Change (CCC) 2050 further ambition scenario for BECCS-to-power, if 100 per cent of the feedstock were provided by domestically grown wheat straw, 27–31 per cent of the UK’s current agricultural land area would be required, a substantial proportion that could have implications for food prices.

There is a clear trade-off between the energy generation efficiency and capture rate. There are indications that first generation BECCS-to-power facilities will exhibit lower power generation efficiencies than that envisaged by the CCC. Inefficient BECCS power plants would likely require a greater carbon removal subsidy to maintain operation as power revenues would be relatively low compared to efficient equivalents.

If BECCS is to play the crucial role that models, policymakers and net zero targets imply, then carbon efficiencies and the energy output–capture rate trade-off needs to be at the heart of policy development, otherwise there is a risk that already tight carbon budgets become unresolvable, leading to runaway climate change. As such, policymakers should:

- Enforce tighter bioenergy supply chain emission regulations that are well monitored and verified; likely to be more attainable if feedstocks are domestically grown.
- Prioritize reductions over removals, ensuring that proven low-carbon technologies are deployed with earnest, options for demand reduction are given political priority, and green hydrogen is swiftly developed.
- Legislators should consider separating net zero targets into reductions and removals, with an appropriate split that represents the current uncertainty in the overall BECCS system performance, inclusive of supply chain emissions. Overtime, a regular review cycle could expand the role of removals as BECCS performance moves from being masked behind commercial confidentiality to meeting key performance indicators.

Biomass land requirements

The land required to grow biomass for BECCS is significant and dependant on the choice of biomass feedstock, with potential consequences for food production and biodiversity. The IPCC 2019 report on climate change and land concluded that, 'although estimates of potential are uncertain, there is high confidence that the most important factors determining future biomass supply are land availability and land productivity. These factors are, in turn, determined by competing uses of land and a myriad of environmental and economic considerations.'[1] The IPCC SR1.5 report indicated that 1.5°C compliant pathways would require around 25–46 per cent of arable and permanent crop land in 2100.

Maximum power generation or CO_2 capture

An often-overlooked consideration is that to achieve the targeted 90 per cent, or higher, capture rates in BECCS-to-power plants, there is a significant energy requirement from the CCS equipment. Post-combustion capture requires heat to release the CO_2 molecules from the solvent that captures the CO_2, and additional energy is required to compress the captured CO_2 so that it can be piped to storage sites. This 'energy penalty' has the consequence of reducing the efficiency of the facility in converting the embodied energy of the biomass into electricity. As such, the capture rate and energy efficiency of the BECCS-to-power facility are intrinsically and inversely connected, creating a trade-off between power production and CO_2 capture. Or in other words, the more efficient at producing power a BECCS facility is, the less CO_2 that is captured.

Another way of looking at this is to start with the nameplate generating capacity of a BECCS power plant, and ask – how would a reduction in power efficiency impact the CO_2 capture potential? Given that Drax is seeking to become one of the UK's first BECCS power plants, it is interesting to start with its current bioenergy power plant and play through the thought experiment in this context. Drax's

[1] IPCC (2019), *Special Report on Climate Change and Land*, Geneva: Intergovernmental Panel on Climate Change, https://www.ipcc.ch/srccl/.

Selby biomass facility has a capacity of 2.6 gigawatts (GW), producing around 14.1 terawatt hours per year (TWh/yr) of power from 7,374 kilotonnes (kt) of wood pellets, which equates to around 38.9 TWh of embodied energy and 13.3 $MtCO_2$ of embodied CO_2 within the wood pellets.[2] As such, the efficiency of the wood pellet power plant is around 36.2 per cent, and the load factor[3] is around 62 per cent, meaning power was generated for nearly two-thirds of the year. It is the embodied CO_2 of the wood pellets that could, in the future, be captured by the CCS equipment.

Assuming a 90 per cent capture rate, there are two ways in which the volume of captured CO_2 could potentially be increased. Firstly, the power plant could run for a greater proportion of the year – increasing the load factor. This would require the dispatch protocol of the power plant to change, which – if the government chose to give BECCS-to-power plants priority dispatch to the grid – would be perfectly feasible, in effect turning BECCS-to-power plants into baseload power generators, rather than load following on the grid.[4] This would, however, lower system flexibility and hence reduce the amount of variable renewables that could be integrated into the network. Secondly, the BECCS-to-power plant could decrease its power efficiency, in doing so it would combust more wood pellets to generate the same amount of power, hence the CO_2 available to potentially capture increases. In both instances, the limiting constraint is the generating capacity of the facility (currently 2.6 GW at Selby).

As a result of this trade-off it would be reasonable to suggest that a future UK BECCS removal target should define a fixed amount of biomass to be used within BECCS facilities, either domestically grown within the UK or imported. And as such, the efficiency of future BECCS power plants should simply be as high as possible to provide maximum power generation, as this would in turn increase revenues and hence decrease the subsidy that BECCS facilities would require to capture CO_2.[5] This is a valid argument, but there are still downsides, principally that the number of BECCS facilities (or to be more accurate turbines) would need to increase. This is because the nameplate generating capacity of BECCS facilities running at maximum load factor limits the amount of biomass a given turbine can process. Efficient facilities generate more power and hence revenues, lowering the CO_2 capture subsidy, at the expense of more turbines being required. As each BECCS turbine has an associated capital expenditure (CAPEX), the cost to build the infrastructure is relatively high. Lower efficiency facilities each combust a greater volume of feedstock, capture more CO_2 per facility, but generate less power revenues. Meaning the aggregate CAPEX is lower, but the subsidy requirement would be relatively high.

Carbon efficiency of a UK Drax-like wood pellet supply chain

Before turning to the carbon debt of wood pellets, it is worth examining the potential carbon efficiency of a future UK BECCS power plant on the basis of Drax's supply chain emissions, as Drax itself reported in 2021.[6] Carbon efficiency can be thought of as the proportion of carbon input to the whole BECCS system that is geologically stored. Or alternatively, as the proportion of carbon input (i.e. CO_2 sequestered by biomass during growth) to the whole BECCS system that leads to net removal when accounting for life cycle emissions of the biomass feedstock. Carbon efficiency is synonymous with carbon negativity: a carbon efficiency of 0 per cent would result in BECCS being carbon neutral, rather than net negative.[7]

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[2] Drax Group plc (2021), *Drax Group plc Annual report and accounts 2020*, https://www.drax.com/wp-content/uploads/2021/03/Drax_AR2020.pdf.
[3] Load factor: average load divided by the peak load in a specified time period.
[4] Load following: a power plant that responds to demand on the network, rather than either a variable renewable or a baseload facility like a nuclear power plant.
[5] This 'subsidy' does not necessarily need to take the form of a direct payment from the government to BECCS facility. It could be a market mechanism, for which consumers ultimately pay the cost.
[6] Drax (2021), *Drax Group plc Annual report and accounts 2020*.
[7] Fajardy, M. and Mac Dowell, N. (2017), 'Can BECCS deliver sustainable and resource efficient negative emissions?', *Energy and Environmental Science*, 10(6), doi:10.1039/c7ee00465f.

The supply chain emissions that Drax reports,[8] combined with assumptions as to downstream CO_2 losses from the uncaptured emissions, as well as those from transport and storage would see around 24 per cent of the aggregate embodied CO_2 emitted to the atmosphere, and around 76 per cent geologically stored. This of course assumes trees are planted to replace those combusted in the BECCS facility, and ignores the time needed for the growing trees to recapture the carbon emitted on combustion (see the discussion on carbon payback periods below).

In most policy discussions, the capture rate is often referred to as the principal loss of CO_2, and the wood pellets are assumed to be carbon neutral. Emissions from the pelleting, transportation, and piping of the CO_2 to storage sites are not insignificant. It should be noted that the 76 per cent value above does not touch upon or include any arguments surrounding carbon debt and that an equivalent mass of trees is grown to replace that comprising the wood pellets

The risks of wood pellet carbon debt as BECCS is scaled

As the number of net zero pledges by countries indicates, along with the forecasts of the IEA and IAM pathways of the IPCC SR1.5 report,[9] the future scale up of BECCS could be enormous. To scale BECCS-to-power solely combusting wood pellets to meet the UK CCC 2050 target of 51 $MtCO_2$/yr would require the combustion of more than four times that currently burnt at Drax, and 126 times greater to meet the 'middle-of-the-road' IPCC 1.5°C pathway, also by 2050. Such a significant global scaling of wood pellet demand risks putting significant pressures on the global supply chains. Clearly alternative feedstock choices are available, other than woody biomass. However, given that the leading BECCS developer uses 97 per cent woody biomass (3 per cent agricultural residues[10]) and the global supply of pellets comprised of other feedstocks remains marginal, the scaling comparison is an indicator of the upper limit to wood pellet scaling over the next 30 years. It is also interesting to note that the UK CCC BECCS removal target of 51 $MtCO_2$/yr would require 119 per cent of the 26 Mt of wood pellets consumed across the EU27 + UK, which in turn represents 50 per cent of global consumption.[11]

The initial combustion of biomass, along with the associated life cycle emissions of the biomass feedstock, create what is termed a 'carbon debt'. Over time, regrowth of the harvested forest removes this carbon from the atmosphere, reducing the carbon debt. The period until carbon parity is achieved is usually termed the 'carbon payback period'.

Calculating carbon payback periods is complex, because they depend not only on the type of feedstock used, but on the counterfactual – what would have happened to the feedstock if it had not been used for energy. The shortest carbon payback periods derive from the use of residues and wastes from forest industries that imply no additional harvesting and would otherwise be burnt as waste or left to decay, releasing carbon to the atmosphere in any case. The longest carbon payback periods derive from increasing harvest volumes in managed forests, harvesting natural forests or converting them into plantations, or displacing wood from other uses. Where whole trees are harvested and used for energy, not only is the stored carbon in the tree released into the atmosphere immediately, but the future carbon sequestration capacity of the tree is lost, and it takes time for the residual trees or new trees to compensate. Plantation forests have higher growth rates than natural forests and are typically harvested at a relatively young age, while naturally

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[8] Drax (2021), *Drax Group plc Annual report and accounts 2020*.
[9] IPCC (2018), *Global Warming of 1.5°C*.
[10] Drax (2021), 'Sourcing Sustainable Biomass', https://www.drax.com/sustainability/sustainable-bioenergy/sourcing-sustainable-biomass/.
[11] Bioenergy Europe (2019), *Report Pellet*, Statistical Report 2019, https://epc.bioenergyeurope.org/wp-content/uploads/2020/02/SR19_Pellet_final-web-1.pdf.

regenerated forests tend to be older and have larger trees when harvested; therefore, more stored carbon is lost when natural forests are harvested.

On the other hand, in the absence of forest management, the rate of net carbon absorption by most forests falls as the incidence of dead and diseased trees increases, and over time the forest may also become more vulnerable to wildfire or other disturbances. There can, therefore, be benefits over the long term from some level of management, and in the absence of demand for wood for energy or other products, many forests may not be managed in a manner that can increase forest carbon stocks.[12] However, this assumes that forest management for conservation is not subsidized in the way that biomass for energy currently is.

It is often claimed that using thinnings of trees from forest management practices – which account for about 30 per cent of Drax's feedstock – results in shorter carbon payback periods because they promote tree growth and allow higher stocking of trees.[13] It should, however, be noted that the evidence on thinning practices indicates forest carbon stocks are either redistributed (to the remaining trees),[14] or decline.[15]

While using wastes and residues as feedstock minimizes the carbon payback period, the volumes available are limited. Thus, as BECCS is developed at scale, there is a risk of using feedstocks with longer and longer carbon payback periods. Particular attention needs to be paid to the carbon payback period if roundwood from mature trees[16] enters the supply chain. This is principally because mature trees take many years to grow, and support greater soil carbon, meaning any next generation tree replacement (plantation saplings) would be subject to a significant carbon payback period. The carbon payback period of a mature tree is likely to be at the upper end of the range of 44–104 years (calculated for a clearcut forest),[17] but could be longer,[18] meaning geologically stored CO_2 from mature trees should not be considered carbon negative until the next generation of trees has grown for this period of time.

The energy requirement to dry high-moisture-content woody biomass, and conversion of mature forests to plantations represent the major potential supply chain emissions. The sustainability criteria in place currently in the UK and EU do not place limits on feedstocks by category, though in July 2021 the European Commission published proposals for modifications to the EU's sustainability criteria, which would end incentives for using saw or veneer logs, stumps and roots, and also prohibit sourcing from primary forests. Transparent monitoring and enforcement of sustainability criteria is often challenging. This is illustrated by investigating the sourcing of wood pellets from the US southeast.

[12] Dale, V. H. et al. (2017), Status and prospects for renewable energy using wood pellets from the southeastern United States, *GCB Bioenergy*, 9(8), doi:10.1111/gcbb.12445.

[13] Garcia-Gonzalo, J., Peltola, H., Briceño-elizondo, E. and Kellomäki, S. (2007),' Changed thinning regimes may increase carbon stock under climate change: A case study from a Finnish boreal forest', *Climatic Change,* 81(3): pp. 421–454, doi:10.1007/S10584-006-9149-8.

[14] Schaedel, M. S., Larson, A. J., Belote, T., Goodburn, J. M., Page-Dumroese, D. S. and Affleck, D. L. R. (2017), 'Early forest thinning changes aboveground carbon distribution among pools, but not total amount', Forest Ecology and Management, 389: pp. 187–198, doi:10.1016/j.foreco.2016.12.018; Zhang, X., Guan, D., Li, W., Sun, D., Jin, C., Yuan, F., Wang, A. and Wu, J. (2018), 'The effects of forest thinning on soil carbon stocks and dynamics: A meta-analysis, *Forest Ecology and Management*, 429: pp. 36–43, doi:10.1016/J.FORECO.2018.06.027.

[15] Lin, J-C., Chiu, C-H., Lin, Y-J. and Liu, W-Y. (2018), 'Thinning Effects on Biomass and Carbon Stock for Young Taiwania Plantations', *Scientific Reports,* 8(1), doi:10.1038/s41598-018-21510-x; Bravo-Oviedo, A., Ruiz-Peinado, R., Modrego, P., Montero, G. and Ponce, A. R. (2015), 'Forest thinning impact on carbon stock and soil condition in Southern European populations of P. sylvestris L.', *Forest Ecology and Management*, 357: pp. 259–267, doi:10.1016/J.FORECO.2015.08.005.

[16] Mature tree: CO_2 absorbed through photosynthesis near equals the CO_2 output via respiration, hence additional sequestration is significantly lower than that of a fast-growing immature tree

[17] Rolls, W. and Forster, P. M. (2020), 'Quantifying forest growth uncertainty on carbon payback times in a simple biomass carbon model', *Environmental Research Communications*, 2(4), doi:10.1088/2515-7620/ab7ff3; Sterman, J. D., Siegel, L. and Rooney-Varga, J. N. (2018), 'Does replacing coal with wood lower CO_2 emissions? Dynamic lifecycle analysis of wood bioenergy, *Environmental Research Letters*, 13(1), doi:10.1088/1748-9326/aaa512.

[18] *Holtsmark, B. (2010), Use of wood fuels from boreal forests will create a biofuel carbon debt with long payback time,* Discussion Papers No. 637, Oslo: Statistics Norway, https://www.ssb.no/a/publikasjoner/pdf/DP/dp637.pdf.

As noted above, Drax complies with the UK's sustainability criteria for solid biomass. The company's 2020 annual report indicates that 36 per cent of its wood pellets are derived from low-grade roundwood. While this may be parts of trees not utilized for wood products, there is a risk that it can contain whole trees, even mature trees. Of the total supply, 63 per cent is sourced from the US southeast, of which 38 per cent is low-grade roundwood. Although Drax diligently reports the categories of feedstock sources used within its own mills, only 20 per cent is currently sourced from pellet mills it directly owns.[19] To ensure wood pellets sourced from suppliers are compliant with regulations, supply chain emissions are minimized and forests sustainably managed, Drax requires suppliers to be certified under the Sustainable Biomass Program (SBP).[20] However, concerns surround potential flaws in SBP standards,[21] with critics concerned SBP certification leaves open loopholes that could undermine the sustainability of wood pellets.

Reporting by saw and pellet mills in the US as to their forest extraction practices is not mandatory. The US Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) programme utilizes sampling techniques to estimate the timber product output (TPO). The TPO data provides a means to estimate the feedstock sources used in the mills, as well as the health of forest and carbon stocks.[22] At the forest level, rather than the mill level, the vast areas of the forests and large number of plots necessitates the sampling approach adopted by the FIA. In the state of Mississippi, in 2019, there were nearly 4,000 plots that were forested, with around 10–20 per cent of those plots visited and measured by field crews each year.[23]

Utilizing the FIA data, a 2020 study investigated the impacts of recent wood pellet production expansion in the US. While the study found 'largely positive trends in timberland conditions… potentially negative trends suggests that continued monitoring of localized impacts of wood pellet mill operations is important'. [24] When looking at the specifics of pellet mill procurement areas in close proximity (within 122 km) to exporting ports in the US coastal southeast, the study found around 400 million fewer live trees compared to other eastern US procurement areas, equivalent to 554 fewer live trees per hectare. And importantly the study states that, 'in the US coastal southeast there were fewer live and growing-stock trees and less carbon in soils with every year of milling operation than in the rest of the eastern US'. It should be noted that this is only one study. However, very few studies have recently investigated the specifics of wood pellet demand pressures on forest management and sourcing practices in this region. Given wood pellet sourcing in the US southeast has rapidly expanded in recent years, and the potential drawbacks of mill reporting and SBP certification, this study is an early indicator of the risks that increased demand pressure can place on supply chains. If these trends continue the risks of carbon debt associated with wood pellets could correspondingly increase. Considering the 44–104-year carbon payback periods, and that carbon budgets to limit global warming to 2^{o}C run till the end of the century, pressure on wood pellet supply chains should be minimized to mitigate carbon debt risks.

For an importing country, such as the UK, this future risk could be mitigated by sourcing woody biomass domestically as tight regulations are more easily enforced within a domestic supply chain, rather than import compliance being reliant on voluntary reporting, sampling or inadequate certification schemes.

[19] Drax (2021), *Drax Group plc Annual report and accounts 2020*.
[20] Drax (2021), 'Sourcing Sustainable Biomass'.
[21] NRDC (2017), *The Sustainable Biomass Program: smokescreen for forest destruction and corporate non-accountability*, https://www.nrdc.org/resources/sustainable-biomass-program-smokescreen-forest-destruction-and-corporate-non.
[22] Young, J. B. and Edgar, C. B. (2019), *Advancing Estimation of Timber Products Output in the Lake States Region of the Northern United States*, Minnesota: University of Minnesota, https://conservancy.umn.edu/handle/11299/215045.
[23] USDA (2020), 'Forests of Mississippi, 2019', https://public.tableau.com/views/FIA_OneClick_V1_2/Factsheet?%3AshowVizHome=no
[24] Aguilar, F. X., Mirzaee, A., McGarvey, R. G., Shifley, S. R. and Burtraw, D. (2020), 'Expansion of US wood pellet industry points to positive trends but the need for continued monitoring', *Scientific Reports*, 10(1), doi:10.1038/s41598-020-75403-z.

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