TEESDALE MOORLAND BIOMASS PHASE 2 PROJECT REPORT

Barningham Moor, Teesdale, County Durham

REDACTED FOR PUBLIC CIRCULATION

REPORT PREPARED BY EWAN BOYD OF TEESDALE ENVIRONMENTAL CONSULTING Ltd
teclimited@btinternet.com
3rd February 2025

Executive Summary

The Teesdale Moorland Biomass Project was a three year project funded by the Department of Energy Security and Net Zero (DESNZ) through the Biomass Feedstocks Innovation Programme, and was a collaboration between Teesdale Environmental Consulting Ltd (TEC Ltd) and Barningham Estates, North Yorkshire.

The project sought to identify financially viable options for the creation of commercial products from moorland grown heather and other marginal land vegetation, as an alternative for the managed heather burning currently practised on many upland estates. Identifying a suitable harvesting method that would not damage fragile peatlands while replicating current outcomes from managed burning, along with developing methods to process heather, were the key objectives of the project. The initial focus was the production of solid fuel heather briquettes for the domestic fuel market, with a subsequent switch to developing peat free composts and growing media from heather and heather blends.

Harvesting was undertaken on Barningham Moor by a Loglogic Ltd Softrak low ground pressure machine with a flail head cutter and 'cut and collect' system. This was found to be effective, and detailed assessments of soil effects and moorland condition impacts indicated that such a system did not appear to adversely affect water table levels, peat compaction, or vegetation condition. Work was undertaken on yield assessments and harvest practicalities, leading to the development of the TMB Process Costs Calculator, a spreadsheet based tool providing a comprehensive yield and production cost assessment capability. This indicated that 40-50ha of heather were available annually for harvesting on Barningham Moor, that was projected to supply approximately [redacted] t/pa of cut heather, with the potential to provide around [redacted] m^3 of finished compost with a market value in the region of £[redacted]. Up to three times this output may be possible if the harvest was extended to rushes, *Molinia* and bracken.

The yield assessment methodology is readily applicable to other upland locations, and the ability to predict likely yields and operational and production costs is viewed as a significant outcome from the project. However, the project team were unable to generate a sufficiently robust assessment of the national scale biomass resource potentially available, although it was noted that if yields at Barningham were replicated on a wider scale, cropping of just 7.5% of UK upland areas could generate sufficient material to replace entirely peat use within the UK horticultural trade.

Processing heather for solid fuel through drying and pressing was found to be technically feasible and financially viable, with a purpose built dryer used to gather detailed data on the drying process. However, the resulting fuel failed smoke emissions tests, restricting its potential use to specialist commercial boilers.

In contrast, a number of methods for composting heather and heather and other moorland vegetation blends were also found to be be feasible, creating a range of products that were well received by a number of professional growers, with strong indications of robust market demand with the potential for premium pricing as traceable, single source, peat free feedstocks. Compost production methods successfully tested included traditional thermophilic composting, via both turned heaps and aerated static piles, alongside two types of rapid in-vessel processors, capable of creating good quality growing media from 100% heather within as little as two hours processing.

A significant amount of work was completed on commercialisation of the heather harvesting innovation, including a landowner survey, review of composting regulations and a study of the compost market. A new joint venture, Moorland Biomass Ltd, has been established by the project partners in order to take forward the innovation, and the first commercial harvest is anticipated in spring 2025, with Moorland Biomass peat free compost products anticipated for commercial supply shortly thereafter.

A business model based on landowner production clusters served by mobile harvesting machinery, remote monitoring of the composting process and centralised sales and marketing of the end product has been developed. This is seen as offering a readily scaleable solution for the exploitation of the geographically widely distributed the moorland biomass resource, with the business model offering a means to recruit landowners without requiring high capital finance contributions, while providing central support, expertise, practical monitoring and compliance/quality assurance to a diverse network of production clusters.

A further period of research and development is planned to develop and refine the production processes, pilot test the cluster based business model and seek to identify further commercial products from moorland biomass, and some additional funding is currently being sought from the Farming Innovate Programme under the UKRI.

Table of Contents

Index of Tables

Table of Figures & Images

List of Annexes

All annexes provided as separate documents

1 Provided by Professor Richard Lindsay, University of East London

1 Introduction and Background

This project is funded by the Department of Energy Security and Net Zero (DESNZ) through the Biomass Feedstocks Innovation Programme. The project is led by Ewan Boyd of Teesdale Environmental Consulting Ltd (TEC Ltd.) in collaboration with project partner Sir Edward Milbank of Barningham Estates. Both partners are micro-enterprises, with TEC Ltd an environmental consultancy and Barningham Estate a farming and landowning enterprise. Both are based within County Durham.

Barningham Estate includes Barningham Moor, a 2,000ha heather moorland. As a grouse moor, Barningham Moor is dominated by heather (*Calluna Vulgaris*) with approximately 600ha of heather present within the moor area[1]. (See Plan A1.1 in Annex 1 for a map of Barningham Moor.)

Grouse rearing relies on providing a mixed mosaic of different aged heather stands to provide younger areas of heather for feeding and older stands for nesting, and as cover against predation, resulting in a patchwork effect on heather moorland. (See Image A1.3 in Annex 1). Excessively dense heather prevents successful breeding of grouse and other ground nesting birds, leads to drying out of peaty soils and consequent carbon losses, and also represents a significant risk from uncontrolled accidental fires.

Management of heather on grouse moors has traditionally been by periodic burning, carried out between October and April on a 6 – 12 year rotation, with small patches typically less 0.3 – 0.5ha subject to burning of the above ground vegetation, leaving the peat soil and rootstock intact to encourage heather regrowth. (See Figure A1.4 in Annex 1).

The key objectives of the Teesdale Moorland Biomass Project were to assess and quantify the potential to replace heather burning with a biomass production system, along with producing useable biomass from other moorland vegetation species such as bracken, *Molinia* grasss and rushes, and to identify the techniques required to deliver this innovation at a competitive market price and quality.

Such an innovation would provide an immediate boost to biomass feedstock volumes without requiring any additional land, and as such is seen as of particular importance in the attempts to balance land use strategies with the need for an enhanced role for biomass in the UK carbon emissions reduction strategy. The key principle guiding the project was that to be acceptable to grouse moor owners, any moorland biomass production system would need to replicate the existing management outcomes and not adversely affect the grouse shooting industry.

2 Heather Moorland in the UK and Current Management Methods

Heather moorland is a globally rare habitat, with over 75% of the world's heather moorland located within the United Kingdom.[2] Heather moorland encompasses both blanket bog (peat >40cm depth) and drier heaths, and management of such predominantly upland areas is increasingly being undertaken with a broader range of landscape services in mind. These have always included recreational use, sports shooting and sheep rearing, but increasingly landscape scale environmental aspects of upland management, such as water management and carbon storage, are seen as vital roles for land managers. The extent of heather moorland in the UK is shown in Figure A1.2 in Annex 1.

Heather is an evergreen shrub growing to an ultimate height of 0.2m-1m in 2-5 years. As heather stands age, rejuvenation becomes slower, with a greater risk of invasion by grasses and sedges. If heather is allowed to grow unchecked, over time the plant collapses, leaving a bare centre, with substantially reduced chance of successful regeneration from either cutting or burning. This also exposes bare soil at the centre of the plant, encouraging invasive species and a reduction in the heather cover. Heather therefore requires periodic management, especially given the need for varied age swards on grouse moors. Bracken, *Molinia* and rushes (*Juncus*) are typically viewed as sub-optimal vegetation and are typically associated with degraded upland environments.

Sport shooting is a key economic activity on many upland moors. The total upland heath area in the UK is between 2m – 3m ha[3], with 1m ha used for grouse shooting in Scotland[4] and 348,029ha under grouse moor management in England and Wales[5]. Therefore at least 1.3m ha of upland heath in the UK are under active management. Traditionally, this has been achieved by rotational burning of heather, with approximately 10-15% of the heather burnt each year. Heather is also burnt on other land for wildfire control purposes, although data on this appears limited.

The main purposes of rotational burning is to is to increase the nutritional quality of heather through fast regeneration from seed or rootstock, and to increase the diversity of heather ages and structures for grouse management[6]. There is additional evidence that periodic controlled burning mitigates the risk of occasional wildfires, by reducing the fuel load present.

3 Teesdale Moorland Biomass Project Overview

3.1 Project Aims and Objectives

The objective of the Teesdale Moorland Biomass (TMB) Project was to identify a suitable harvesting and production system that could replicate current managed heather burning outcomes, while diverting cropped heather into the biomass feedstock chain. Post harvesting, the initial objective was to assess the potential for heather as a feedstock for biomass fuel, focusing primarily on the production of briquettes for the domestic fuel market. However, subsequent smoke emissions tests of the resulting fuel yielded poor results, to the extent that there was no realistic commercial option for using heather derived fuel, either solely, or in a blended form, other than in relatively restricted markets supplying specialist biomass boilers with electrostatic precipitators or similar. From September 2023 this focus therefore switched to the use of heather and other residual moorland crops for the production of peat free composts and growing media.

Five key questions were initially identified within the early stages of the project:

- What are the anticipated available yields, both in terms of biomass growth and ability to harvest?
- What is the most appropriate harvesting technique and does this create any adverse environmental impacts?
- What level of pre-processing drying, if any, is likely to be required, and how can this be delivered?
- What is/are the most appropriate method(s) of processing the crop into a finished biomass product?
- What is the most appropriate operational scale and model for an economic biomass supply business?

The issue of drying, while thoroughly investigated, became redundant following the switch to composting, although the findings are reported here.

3.2 Project Schedule and Budget

The Phase 2 project commenced in April 2022 and ran until end March 2025. There were significant variations in the schedule throughout the project, especially with regard to the switch from fuel production to compost processing, with these variations reflected through schedule amendments via the DESNZ Change Request procedure. This resulted in a number of additional work packages and deliverables, along with the cancellation of others. Alongside a number of work packages relating to project management activities, there were ten substantive work packages within the schedule. These are detailed in Table 1.

The original funding award was £405,633 with a further £19,503 added to the budget in November 2024 for additional work (Work Package 14), providing a total budget of £425,136, and the final spend matches this.

Table 1: Main technical work packages

Work Package	Description	Key Activities
2	Soil testing	Soil compaction & water table testing, condition surveys
3	Yield & Harvest Parameters	Standing crop & harvest yields, moisture content, assessment of harvestable heather, development of TMB Process Costs Calculator
5	Harvesting	Trial harvests on Barningham Moor
6	Drying Trials	Drying runs to achieve MC of 10%
7	Fuel Production & Testing	Production & testing of briquettes for energy outputs, ash characteristics and smoke emissions
8	Market Testing	Assessing marketability of end products
10	Off site research	Site visits to see if Barningham Moor findings replicated elsewhere
11	Commercialisation	Extensive work developing long term commercial plan (composting operation)
13	Composting trials	Trials of composting & processing methods
14	Additional harvest & compost trials	Harvest using new Softrak 140, aerated static pile compost trial + biodigester tests

NB: Work packages 1, 4, 9, and 12 were primarily management tasks and are not included here.

4 Technical Findings

4.1 Innovation and Technological Readiness Level

The Teesdale Moorland Biomass Project was less a single innovation but instead comprised a series of innovations that have been combined into a single production process. As such, charting the Technological Readiness Level (TRL) is somewhat complex. This complexity is enhanced by the mid-project switch to compost production. In light of this, from herein the TRL will be discussed in terms of the full process (eg harvesting, production and supply) rather than specific individual innovations within the process.

The original innovation was to identify a potentially viable economic use for moorland heather, which was previously discarded via the practise of heather burning. This was originally envisaged as via the production of solid fuel, and on the basis that there had been previous trials of heather harvesting for the production of pellet fuels (see references [7] and [8]), the starting TRL was classified as TRL6.

The switch to developing heather as a compost feedstock arguably materially alters the starting TRL. With no known previous work on this, it would be reasonable to assume the innovation was at TRL2 ('technology concept formulated') at the point where the decision was made to investigate the compost production option. By successfully demonstrating a sustainable harvest methodology, along with several options to produce useable growing media with a clear market value, the project has arguably moved into the deployment phase, reaching TRL7 by the end of the project with a clear path to TRL9.

4.2 Heather Cropping Techniques and Potential Soil Impacts of Harvesting and Crop Removal

4.2 Key Findings

1. Moorland soils are fragile, with compaction by machinery a significant risk. Use of 'Softrak' low ground pressure harvester mitigates this risk.
2. Harvesting does not appear to adversely affect moorland condition, or water levels. Some minor soil compaction was noted immediately post harvest but this did not persist.

Whether the removal of biomass has any impact on the moorland soil and condition compared to heather burning is a key issue. Moorland heather can be cut by conventional tractor driven cut and bale systems, although soft ground conditions represent a critical limiting factor, and rocks and obstacles making large scale cutting equipment harder to safely use. The transport of baled material from the moors, and the patchwork nature of the cuts required, also creates additional vehicle movements, with consequent risk of ground compaction. Conventional balers also rake the cut material into the baler, and previous research into novel biomass feedstock crops (including heather) by the Forestry Commission found that soil contamination from a conventional harvesting system was likely to reduce the quality of the resulting product (see refs. [7] and [8]). While this is particularly relevant for fuel feedstocks, the inclusion of stones in compost is also a potential problem.

For this project, a method of harvesting was required that would enable safe access across as wide a variety of ground conditions as possible, which could provide a 'clean' harvest without soil contamination, following the findings of the previous Forestry Commission studies.

To safely access remote sites without damaging fragile peat, the project identified a Loglogic Softrak 120 low ground pressure machine equipped with a 1400mm forage harvester cutting head and integral 13m^3 tipping collection bin[9].

This technique has been successfully trialled in biomass production on very wet reed bed areas[10] and is also currently in use for peatland restoration work in the North Pennines. This allows for an all in one ‘cut-and-collect’ operation, reducing both harvesting time and vehicle movements on the fells, along with very low ground pressure of 1.35psi. The Softrak 120 was available locally on a contract hire basis, and this option was incorporated into the project design.

Under Work Package 2 (WP2) a research programme was originally scheduled to be delivered by Durham University, investigating the impacts of heather harvesting on the moorland soils, compared to burning. However, the contract was not delivered adequately and was terminated in April 2023. An alternative programme was devised by Professor Richard Lindsay, University of East London, working under commission of the Biomass Connect Lot 2 support project, with a brief to deliver a research programme to assess the relevant impacts of Softrak harvesting on the Barningham Moor area that could be delivered within the project timetable and budget by the TEC Ltd in-house staff team.

Three measures were selected: pre and post harvest condition surveys, soil compaction measurements, and measurements of the water table level and fluctuation, with all of these measurements comparing the cut sites with paired control plots. Initially it was envisaged that the control plots would be subject to heather burning, as this is the treatment designed to be replaced by the harvesting system, but due to prolonged poor weather across the two winters that WP2 was undertaken, no burning was possible on the control plots, so the control plots were all uncut aged heather stands.

While harvesting trials commenced in 2022, the project team were unable to progress the soil impact research under WP2 until later harvests in 2023 and 2024. All the assessment under WP2 therefore took place on the areas harvested in these latter years.

A series of twelve paired plots (six pairs in total) were established prior to harvesting. One plot in each pair was subsequently harvested. In each plot, 5 monitoring points were selected and recorded. To achieve full coverage of the moorland area available, the paired plots were divided equally between the Low Moor area, typified by shallow peat depths of less than 40cm, and the deeper blanket bog areas on the High Moor, with peat depths in excess of 40cm, with three pairs of plots on each. Each plot was approximately 300m^2. Within each pair, the selected plots were adjacent to each other to enable direct comparison.

Condition surveys were undertaken for each monitoring point following a methodology developed by Prof. Richard Lindsay, involving measurements of microtopography, vegetation structure and heather height, which is then recorded on a Peat Bog Microtope Recording Matrix to determine an overall assessment of the bog condition. (The recording matrix is included in Annex 2). The assessments were undertaken by TEC Ltd staff following training provided by Prof. Lindsay).

Condition surveys were conducted on the plots at various points throughout 2024, before and after harvest activity, with surveys repeated again after a full growing season after harvesting as far as was feasible. No substantive changes were noted at the sites cut in 2023 and 2024 (HP23 and HP24), other than a general growth of vegetation compatible with normal seasonal growth. At a separate site cut in the Phase 1 trial in 2021 (HP21 site), it appeared as if there was more rapid regrowth of heather on the cut site compared to the burn site, although the condition survey classification was unaltered and there is no baseline data to provide firm conclusions. The cutting activity did not appear to substantially alter the overall bog condition, compared to either burning or no treatment, although the number of data points for the burned areas were limited to the HP21 site only.

Water table measurements were undertaken by ‘rust rods’, lengths of untreated mild steel buried in perforated tubes into the peat, which over time show rust marks across the region where wetting and drying takes place (see image in Image A1.5 in Annex 1). Below this level there is little corrosion, as the rod remains under constant water, so the rust region gives an approximate depth of water table. A rust rod was inserted at each monitoring point and these remained in place for at least twelve months. Two measurements were recorded during regular inspections. Firstly, the water table variation was noted, using the upper and lower bounds of the rust region as measures, and the mid point of these was also used to calculate a rough average water table depth.

On the Low Moor plots, with thinner peat, initial readings (summer 2024) suggested there was some evidence that the cut sites had a greater range and lower average level of water table than the control sites, with average mean depth of 21.18cm compared to 18.39cm and a range of 4.91cm compared to 4.07cm. These were cut in 2023 and are referred to as the HP23 plots. However, neither the difference in average depth of water table between the cut and control sites or the range were statistically significant[2].

At the High Moor sites, with deeper peat, a general trend on all plots for higher water table was noted compared to the Low Moor sites. Alongside this observation, a similar but less pronounced pattern between the cut and control plots was observed, with a mean water level depth of 15.1cm at the cut sites and 14.0cm on the control plots, with respective ranges of 10.3cm and 9.3cm. These were cut in 2024 and are referred to as the HP24 sites. Again, none of these differences were statistically significant.

2 Analysis by paired t-test with $p < 0.05$.

Later readings (October to December 2024) showed a narrowing or reversal of the earlier findings, with the differences between the cut and control sites on the Low Moor sites reducing. Average water table depth was 17.54cm and 16.54cm on the cut and control sites respectively and the ranges were 4.55cm and 3.75cm. None of the differences were statistically significant. On the High Moor sites, the cut sites average depth was 10.04cm compared to 12.15cm for the control sites, reversing the previous pattern, while the respective ranges were 6.42cm and 8.92cm. Again, these differences were not statistically significant.

Given the relatively short timescales and rudimentary nature of the measurement technique, it is difficult to draw definitive conclusions from this data. Several factors may affect soil moisture, but the lack of statistical significance and limited set of observations is such that no definitive conclusions can be drawn at this stage, with longer term monitoring required to assess the relative impacts of the cutting regime on water levels.

Taken together, the condition surveys and rust rod data do not suggest that harvesting heather leads to any notable alterations to peatland characteristics. While there was some evidence of greater fluctuations in water table depth on cut sites compared to uncut, because of the ability of peat to retain high moisture levels even when the water table drops, this variation of water table depth had no noticeable impact on the moisture readings taken as part of the condition survey, with the microtopes as defined by the dry peat depth showing no change before and after cutting.

Soil compaction was monitored by use of a soil penetrometer, as designed and supplied by Prof. Richard Lindsay. The penetrometer is a simple device that works by releasing a weight of known mass from a fixed height onto a rod which then penetrates the peat to a depth determined by the softness of the soil. As the mass and drop of the weight is pre-determined, the before and after depth reading of the rod can be used to determine the resistive force of the peat, measured in units of kg/cm^2.

Repeat penetrometer readings were taken at each of the sites. At each of the five monitoring points on each plot, five independent penetrometer measurements were taken for each sample period. The averaged results are summarised in Table A3.1 in Annex 3, which shows the average mean resistive force calculations for each plot, tabulated by month. Mean resistive force is a measure of soil density (resistance to the penetrometer) with a higher reading indicating denser soil. In the case of peat soils, wetter, softer soil denotes healthier environmental conditions.

There is some evidence that the cut sites may be marginally softer than the control sites. In nearly all sets of measurements the cut sites were found to be softer than the control (uncut) with the only exception being the March 2024 data from site HP24-3, which may have been the immediate after effects of harvesting causing some transient compaction on the cut site. Although this effect was not apparent on other sites, the differential between the cut and control sites did appear to widen over time following harvest.

There is also some evidence of a seasonal effect, especially on the control sites (uncut) on the Low Fell (HP23) sites. Here, while there is little difference in mean resistive force in the summer data from the cut sites, the three control sites show significantly higher readings than in the winter. This effect is present to a limited degree on the HP24 sites on deeper peat, and may indicate the fact that standing heather acts to dry out peat in the summer months on shallow peat, with this effect less pronounced where the peat depth is greater.

The data suggesting cut sites are softer than the control sites was found the be statistically significant for the High Moor sites, especially in the readings some months after harvesting, while the statistical significance of the Low Moor data was more sporadic. (Significance measured by t-test $p < 0.05$).

Unfortunately the only site for which there is directly comparable data from cutting and burning is the Phase 1 trial cut site (HP21) which was harvested in 2021. This is a very small plot and harvesting was by a different method, so not directly comparable to the Phase 2 results. However, at the HP21 site a series of penetrometer readings were undertaken which show that the cut area is marginally softer than the burn area, with a small but significant advance in the proportion of ground that has been recolonised by new growth.

Overall, the data suggest that harvesting does not appear to exert any clear impacts on the peat soils in terms of soil compaction, either in the immediate aftermath of harvesting or in the following months.

While the timescale for the project was relatively limited in terms of the development of environmental and ecological impacts on peatlands, the conclusions of the WP2 studies within the project are that the method of harvesting adopted and the removal of the resulting biomass crop does not appear to exert any significant short term adverse impacts on the peat and vegetation characteristics, and such evidence that there is may indicate this is a more environmental positive method than burning.

4.3 Assessment of Moorland Crop Yields and Accessibility for Harvest

4.3. Key Findings

1. TMB Moorland Terrain Classification System successfully developed to predict harvestable vegetation on moorland areas.
2. Harvested heather yields ranged from XXt/ha – XXt/ha (fresh weight) with annualised yields of Xt/ha – Xt/ha. Yields of *Molinia* and rush lower at XXt/ha and XXt/ha respectively, with uncertain annualised yields.
3. Heather height is a strong predictor of yield.

Developing an understanding of the likely biomass yield that can be reasonably achieved from moorland vegetation is one of the defining questions of the project. The wider impacts on biomass supply arising from potential harvestable yields are discussed in more detail in Section 5.2 ‘Contribution to UK Biomass Supply’. In this section the key technical activities and findings within the Phase 2 project are discussed.

The project focused on two measures of harvest yield; firstly the total biomass of vegetation and secondly the proportion of this that can reasonably be expected to be available harvesting.

One factor that must be accounted for is the distinction between dry weight yields (harvested material after drying to ~0% moisture content) and ‘fresh weight’ yields, which are the standing crops as harvested. The emphasis on dry and fresh weight yields shifted during the project, reflecting the switch from fuel supply to composting as the projects critical path. For fuel supply, dry weight yields are more relevant, as processing can only be undertaken once moisture content (MC) falls below 10%, whereas successful composting requires a MC of 45% – 60%, making fresh weight yield more relevant for an economic assessment. Both yield measurements have been used within the project, with the suffix ‘DW’ representing dry weight and ‘FW’ fresh weight.

To assess yields, randomised sample site measurements of heather stands were conducted, comparing heather growth height and stem density with cut volumes. Two methods were used. Firstly, small sample patches of heather were cut by hand on a $1m^2$ basis, after random sampling of multiple sites. A total of 57 spot yields were taken from across the moor. The cut heather was then weighed and scaled to produce yield projections per hectare. Sample points were selected randomly within the areas of the moor with aged heather cover that was due for burning under normal moorland management processes.

While these data are presented in terms of tonnes/hectare (t/ha), it is important not to read across from these yield measurements to aggregate a total figure for the average standing heather crop across the full moorland area, as these data represent the measured yields only on those sections of the moor where there is heather cover, and furthermore, where that heather cover is approximately 10 years old and due for burning. The measure therefore represents the tonnage per hectare only for the older stands awaiting burning, and is used here because any commercial exploitation of heather will be based on such areas, rather than younger stands.

The second method was to make an assessment of the yields during harvesting. This method involved detailed measurements of the area cut by the Softrak for each full bin load, where the capacity of the bin is known from the technical specifications of the Softrak. Sample density measurements were then made of the cut load, enabling calculation of yield by area. For both methods, samples were dried to allow calculation of both fresh and dry yields.

Both methods are subject to sources of potential error, with multiple samples taken for each methodology to account for normal statistical variation and to attempt to overcome any such errors. It should be noted that harvest yield calculations for the first harvest (H22 in December 2022) have been discarded due to a failure of GPS monitoring equipment to measure the cut areas sufficiently accurately. Following this experience a method of manually measuring the cut patches was developed and applied in the 2023 and 2024 harvests (H23 and H24).

Results from the hand sampling show average spot yields of [redacted] t^{DW}/ha. This is an average figure with wide variation, from [redacted] t^{DW}/ha to [redacted] t^{DW}/ha. However, one interesting observation was that there appeared to limited correlation between the stem count and yields, to the extent that this measure was quickly abandoned as ineffective, whereas the height of the heather growth showed an extremely close correlation with measured yields. Figure A3.2 in Annex 3 shows a plot of dry weight yields/ha with the R^2 linear regression also shown. The R^2 value of 0.95 demonstrates an extremely close correlation, and with limited scatter from the line of best fit for the majority of data points, this suggests that the height of the heather in aged stands is a strong predictor of potential yields.

While there is still some variation in yield at any given height, which arises primarily through stem density and canopy structure, in practise it was found that the project team were able to judge such variances reasonable accurately based on observation of the heather canopy alongside the height measurement.

While this finding of a strong height to yield relationship is not in itself overly surprising, the finding of such a close correlation has enabled the project team to develop a robust but highly simply method for a rapid assessment of yields, based on a simple yield factor derived from the tonnage per hectare represented by each 1cm of average growth. This factor could be readily applied to drone or satellite based vegetation measurement to allow for rapid yield assessment across a wide area, and this is one aspect of the project that is being taken forward to full commercialisation. Developments in drone technology are advancing rapidly, and recent research indicates vegetation height resolution to >2mm is feasible.[11]

Harvest yield assessments proved more challenging, largely because of the difficulties of measuring the actual volume of each Softrak load (as opposed to the theoretical volume of a 'full' load'), as well as difficulties in measuring the density of the cut crop. Load variation was noted as the blower sometimes missed the bin, particularly in higher wind conditions when a proportion of 'fines' were not collected, and the bin was rarely filled to a flat level. The density measurements were also a potential source of error, where measurements at the transfer point on the fells found that the emptied load had wide variations in density due to compaction, depending on whether the sample was taken from the base of the harvester bin or near the top. It was also found that further handling (collection by tractor bucket for transfer into transport trailer and subsequent tipping out) could also affect load density (positively and negatively).

The initial yield estimates from the H23 sites were [redacted]t^{DW}/ha to [redacted]t^{DW}/ha, which was widely divergent from the [redacted]t^{DW}/ha derived from the spot samples. A review of the data collection methods found that part of the discrepancy could be explained by the fact that the harvester left a significant proportion of stems uncut, due to the settings of the cutter head, but doubts also emerged about some of the detailed measurement methods of the harvest crop.

These methods were refined for the 2024 harvest, and the harvester also altered the cutting regime to ensure a greater proportion of the standing crop was taken. The results for the H24 cut were much more consistent and notably higher than H23, at [redacted]t^{DW}/ha (range [redacted]t^{DW}/ha to [redacted]t^{DW}/ha). [See Table A3.3 in Annex 3]. The remaining discrepancy was felt to be more reasonably explained by residual stem left by the cutter (the spot values crop everything above ground level) and by natural variation (the measured values of the H24 cut were closer to the heather yield by height regression values than the overall spot yield average). It therefore appears likely that the older heather stands that would be subject to harvesting would yield somewhere in the range of [redacted]t^{DW}/ha – [redacted]t^{DW}/ha of cropped heather at the point of harvest.

Following the release of additional funding a further harvest was undertaken in October 2024, this time with the Softrak 140 with DC1700 cutter head, which was not available for the initial three trial harvests. The 140 is both a more powerful machine, enabling a faster rotation of the flail heads, has a wider cutting head (1700mm compared to 1450mm) and also provides a ‘double chop’ rather than single chop, with a second cutting unit in the hopper feed delivering a smaller particle size. The trial also looked to harvest rushes and *Molinia* grass, to provide a mixture of green material for composting with the heather. The 140 harvest trial confirmed a significantly reduced chip size as well as an improved harvest efficiency, with like for like volumes harvested approximately [redacted]% faster with the 140.

As the objective had by this time switched to composting, there was less emphasis on dry weight yields, and the results in Table A3.4 (see Annex 3) show the harvest measurements in fresh weight yields. Moisture content measurements were taken for comparison with earlier harvests, and were averaged at 42.3%, 34.7% and 42.10% for heather, *Molinia* and rushes respectively, indicating respective dry weight yields of [redacted]t/ha, [redacted]t/ha and [redacted]t/ha. The heather figure is slightly above the March 2024 results.

To assess the accessibility for harvesting, a classification system to determine the suitability of local terrain for biomass harvesting was developed, based on the Forestry Commission Technical Note 16/95. This classifies ground conditions (softness), ground roughness (presence of obstacles) and slope, as factors determining accessibility for harvest operations. The project developed the TMB Moorland Terrain Classification System (MTCS) using these three variables with the added variables of density of crop cover and distance to access tracks for harvest upload. A full description of the principles adopted and specific findings is contained in Annex 4, with Figure A4.4 summarising the moorland cropping parameters identified within the MTCS.

The MTCS was applied to the Barningham Moor area via a series of 22 transects. These were 1,000m in length and randomly selected (start point and orientation) with detailed observations taken at 20m intervals. Overall, the MTCS found an average of 75% heather cover across the project area, of which 76.5% was deemed to be harvestable. This translates into approximately 447ha of harvestable heather, with 40ha – 50ha per annum available for cropping. Total annual harvestable heather on Barningham Moor is therefore approximately [redacted]t^{DW} – [redacted]t^{DW}, equivalent to [redacted]t^{FW} to [redacted]t^{FW} available for composting (heather only). This would be sufficient for a significant compost production centre, with production of approximately [redacted]m^3 of finished growing media with a market value in the region of £[redacted]. Notwithstanding this, to justify the capital investment and maximise the utilisation of the harvesting equipment, further cutting areas would be required. These issues are discussed in more detail in Section 6.

4.4 Moisture Content of Heather and Pre-Processing Drying Requirements

4.4 Key Findings

1. Internal (vascular) moisture content of heather found to vary within a relatively narrow range with highest levels found in March.
2. Overall moisture content much more varied and dependent on ambient conditions.
3. Moisture content of harvested crop less important for composting than fuel production.

Moisture content (MC) of biomass feedstocks is a critical parameter in the production process for fuel production, although it is of less immediate relevance to composting. However, composting does require an ideal moisture content range of 45% - 60%[12] to enable the microbes to thrive, so studies into the moisture content of standing crops continued throughout the project.

Regular tests of the moisture content of the standing heather crop were made throughout the project period via regular sample testing to identify optimal harvest conditions (excluding the March – June period when access to the moors was not available). From November 2022 this included ‘air dried’ samples, which were dried in ambient air conditions for 24hrs prior to the moisture content test, in an attempt to identify the contribution to overall moisture content coming from surface water and vascular (internal) water content.

The monthly averages for standing heather MC (wet basis) are shown in Figure A3.5 in Annex 3. Fresh samples ranged between 29.0% to 46.2% (average 37.0%) while the 24hr air dried samples averaged notably lower at 21.2% with a range from 15.0% to 30.0%. Fresh samples tended to reflect ambient conditions, as would be expected, while the air dried samples may be a more accurate reflection of the vascular MC of the heather, with the highest levels recorded in March as the plants commence spring growth.

Aggregated moisture content data by month was also tabulated to see if a seasonal pattern could be identified. This was done for the air dried samples only, in an attempt to remove the variability of the surface moisture, and the results are shown in Figure A3.6 in Annex 3.

The data suggests that average vascular moisture levels vary around 20% for most of the year, with some evidence of drying in August and a notable increase in March. When compared to the annual mean, the only month with a statistically significant difference was March, and this may be explained by spring growth in the heather drawing up moisture into the plant, while ambient conditions are less likely to dry the foliage through heat and drought or freezing conditions, both of which are known to reduce moisture content in heather.

4.5 Heather Harvesting

4.5 Key Findings

1. Four harvests undertaken with two different Softrak models.
2. TMB Process Costs Calculator provides an accurate cost model.
3. Harvest costs including shipment to processing area but excluding capital costs measured at ~£XX/t (fresh weight)

Trial harvests with a Softrak 120 and DC1450 cutter were undertaken in December 2022, September 2023 and March 2024, with an additional harvest in October 2024 using the more powerful Softrak 140 with the DC 1700 cutter. [See images A1.6 – A1.9 in Annex 1].

One of the critical considerations for commercialisation of the heather harvesting innovation is the production efficiency of both the harvest and the post harvest processing. Moorland harvesting takes place in a challenging environment, and while the Softrak was found to be capable of operating safely across much of the area under study, practical issues of managing the crop post harvest required detailed study. The Softrak requires a suitable area for unloading the rear tipping collection bin, so harvesting was required to take place reasonably close to a level and firm unloading area that is accessible for a tractor and trailer. Once tipped, the heather has to to be transferred to a trailer and taken to the processing site. [See Images A1.7 and A1.8 in Annex 1]. Detailed monitoring of the time taken for each process has enabled an economic model of the harvesting operation to be constructed.

The TMB Process Costs Calculator (see Annex 5) provides a spreadsheet based application that incorporates yield assessments and harvest operational metrics, plus full commercial inputs required for Moorland Biomass composting. This goes well beyond the original Biomass Yield Calculator developed in Phase 1 and now represents a far more comprehensive process and business planning tool.

Using the TMB Process Costs Calculator the study found that harvesting costs on the Barningham site using the Softrak 120 were calculated to be between £[redacted]/t - £[redacted]/t fresh weight[3], depending on the basis of the employment used (estate staff or contracted labour). The analysis excludes capital costs and assumes ownership of the Softrak, but does include shipment from the cut site to the processing centre by a contractor. The corresponding results for the Softrak 140 were £[redacted]/t - £[redacted]/t, approximately % cheaper, reflecting the faster cutting time. The 140 also produced a markedly finer chop size with significantly fewer long strands.

3 Data in this section refers to cropped heather only. Rush and *Molinia* achieve different cut weights due to variation in density. These crops were not tested with the Softrak 120.

In the latter stages of the project, discussions with Loglogic Ltd, the manufacturers of the Softrak, revealed that the new 140 model could be fitting with a high tipping trailer, extending to a vertical height of 3m. This could represent a significant efficiency improvement, dispensing with the need for any trans-shipment and substantially speeding up the process. As the Loadall used was also the heaviest vehicle in terms of ground pressure, this is seen as a significant potential benefit when working on sensitive sites.

Overall the harvest trials were deemed to be highly successful. The TMB Process Costs Calculator provides a methodology to assess all the relevant operational parameters needed to replicate harvesting on other sites.

4.6 Crop Drying

4.6 Key Findings

1. Heather successfully dried to 10% MC in forced air dryer.
2. Drying process is energy efficient (more energy gained than expended on drying).
3. Possible to dry naturally, depending on conditions.

During the early half of the project there was a considerable focus on testing the practical and economic aspects of heather drying, as a necessary precursor for processing into solid fuel. As part of this a bespoke dryer unit was constructed, comprising ofmild steel chamber of 2.5m by 2.5m footprint and 1.2m high, giving a total of 7.5m^3 of drying capacity in each pass. The dryer was constructed with a 100mm underfloor space with the upper floor comprised of perforated steel sheets. A 400mm inlet manifold with baffles directing the flow into the underfloor cavity allowed ducting to be attached, with a series of directional vanes in the underfloor cavity directing the airflow around the side and rear sides of the drier before entering into the middle section, to alleviate any issues of re-condensing of vapour on the side walls. Two opposing sides of the dryer were hung on side hinges to allow the material to be pushed out of the drier by a tractor with a specially fitted push plate, and the entire dryer was designed with box sections at the base to allow it to be lifted with forks.

The drier was connected to an AL400 EC-01 axial duct fan with variable speed control, allowing a maximum flow of 9,000m^3/hr, which was in turn connected to a 5kW electric duct heater element before connection to a length of insulated ducting conveying the warmed air to the dryer unit. The fan and heater arrangement was mounted on a wheeled trolley to allow for easy manoeuvrability. An access port was fitted on the 400mm flange on the dryer to allow for airflow and temperature probes to be inserted to take flow readings.

Drying efficiency was tested by the use of temperature and relative humidity (RH) data loggers placed at varying depths within the drying load. Three monitoring points were used, with the data loggers placed at low level (10cm above the dryer floor), the mid-level (60cm above the floor) and the top level (immediately below the surface). A 10 minute sample interval was selected for the loggers, and the operational time and electrical consumption recorded for each run using a dedicated supply meter installed for the purposes of the trial. A fourth data logger was used to gather simultaneous data on the ambient air temperature and RH at the Sawmill site at Barningham where the trials took place. [See Images A1.10 and A1.11 in Annex 1].

A total of eight loads were dried within the drier, with three sample loads subject to detailed analysis. The three sample loads were dried under varying conditions, with the first two completed with forced air and heating under differing ambient conditions, while the third was undertaken during mainly dry summer weather with forced air only.

Once loaded, moisture content (MC) readings of the heather were taken to provide a starting value. One finding of note was that a woodchip moisture meter probe purchased by the project was found to be ineffective, as the heather was insufficiently dense to allow the probe to function. This meant that readings had to be undertaken via a small drying over, with the heather samples heated at 105°C until the sample weight stabilised to calculate MC.

Monitored test runs took place in March, May and September 2023 under varying ambient conditions. The dryer consumed 140kWh/day with heating and 17kWh/day in fan only operation. Figure A3.7 in Annex 3 shows the data from the loggers from the March run. As drying commences, the RH level (red line) increases to 100% at the base, middle and surface top monitoring points. This shows drying is occurring, with high RH levels reflecting the presence of saturated air. At the base, RH remains at 100% until around 16 hours, when a fall indicating drying it occurring at this level. At the mid point level, RH remains stable at 100% until around 52 hours, when a sharp fall indicates the 'drying front' has passed this level. By 71 hours the RH level at the surface was starting to fall rapidly, with approximately three days of forced drying being sufficient to push the drying front through the full depth of heather.

A second monitored drying trial was conducted in mid-May 2023, with larger load (c 7.5m^3 and during warmer ambient conditions (temperatures between 9°C – 18°C). A similar pattern was observed in terms of the drying front progression, although in this case, full load drying to an average 11.4% MC was achieved in 79 hours under the same airflow and heat conditions. The first two drying runs are summarised in Table A3.8 in Annex 3.

A third monitored drying run took place from 6th September 2023, coinciding with a period of hot, dry weather, with ambient daytime temperatures at 20°C or above for several days along with warm night time temperatures. This run took place without added heat, relying only on forced ambient air. Drying took place over 8 days (196 hours in total) over which time the average MC fell from 33.55% to 11.1%. While this was appreciably longer, due to the absence of the heater element, only 140kWh of power was used throughout the full trial, compared to just over 450kWh for the first two trials with additional heat. (The fan only trial used less that a days equivalent power for 8 days drying).

These results indicate that forced air heather drying is feasible, and that this does provide a substantial net energy gain. Best results are achieved if the heather can be harvested at lower moisture levels and if drying takes place in warmer conditions. If a source of waste heat could be found, such as glasshouse ventilation or waste process heat, then this would be a low cost, highly efficient operation.

Finally, some success was also achieved with passive drying of the heather. Some of the first crop from 2022 was left out to dry in a thin layer on the concrete apron at the Sawmill site, and so long as 2 - 3 dry sunny days could be found, a significant amount of drying was observed. In one trial, a MC of 12.9% was achieved. Passive drying would be an option if there was sufficient space, and if undertaken during dry and warm periods.

While the concept of heather as a solid fuel feedstock was abandoned, the drying research is considered to be one of the major successes of the project, providing detailed findings that may have future relevance for other initiatives utilising heather if drying is required.

4.7 Fuel Production and Testing

4.7 Key Findings

1. Dried heather has excellent properties for pellet/briquette pressing, with successful trials concluded.
2. Product is high energy with good ash characteristics.
3. Failure of smoke emissions tests led to termination of option for fuel.

Following drying, approximately 2 tonnes of dried heather chip were shipped to RUF Ltd for test pressing. The material was found to press well and the briquettes were considered to be of high quality (see RUF Ltd Briquette Test Report, Annex 6). The heather was pressed on an RUF400 press, producing 8 briquettes a minute with average weight of 0.929kg, achieving a throughput of 444kg/hr. Due to the chip size, RUF Ltd recommended use of a screw feed and an issue of wet material was noted in part of one of the eight dumpy bags of material which caused damage to one of the piston rings in the press. It is thought that this was caused by water ingress during shipment. Overall, the briquette press trial was viewed as being highly successful.

A small batch of 50kg of heather chip was also successfully pressed into pellets by Go Green Pelleting Solutions Ltd. Unlike the briquettes, the heather chip required hammer milling before pressing, with a Christy Turner X26 mill used to create a 3mm shred prior to pressing on an Orbit 175 pellet press. [Both of these machines are significantly over capacity for the volumes trialled, but generally representative of the scale of operation that would be required for a commercial pellet operation].

Following pressing, samples were sent to A.H.Knights Ltd for testing. Test results for the briquettes and pellets are included in Annexes 7 and 8. Both products performed well on the physical parameters and ash characteristics, although relatively high levels of ash were noted. Both pellets and briquettes achieved high net calorific energy values. However, a number of results from the chemical constituents of the ash were of concern. The pellets failed a number of criteria for the Enplus Pellet standards regarding chemical constituents, where significant discrepancies with the briquette results were noted. The reason for these discrepancies are not known, but the project team noted the presence of visible contaminants in the pellets, such that the pellet results may not be reliable.

The briquettes were also sent for a smoke emissions test, conducted by Kiwa Ltd. The test was a preliminary Smoke Authorisation Tests to BS3841 standard, although it did not constitute a full BS3841 test as this requires multiple repeat tests and the intention here was to assess the likelihood of passing the standard prior to committing to the cost of a full test schedule.

The resulting report is included as Annex 9. The initial results were disappointing, with smoke emissions measured at 25.1g/hr, against a required standard under the England 'Ready to Burn' standard of ≤5g/hr. Under the Ready to Burn legislation, England is effectively treated as a smoke control area and the sale of solid fuels must meet this standard, unless given an exemption. The project team contacted senior staff at DEFRA to discuss the possibility of gaining such an exemption, but were informed that an exemption for such a high emission fuel was extremely unlikely, and that the standards were liable to be toughened in the future.

Given this information, and the fact that the divergence from the standard was such that it was highly unlikely that heather could be used, even in diluted form with other low emission material to form a blended product, the project abandoned the solid fuel option for harvested heather.

The emissions results were used to calculate the potential emissions from current heather burning practices. It should be stressed that these are indicative figures only, but based on the yield/ha data generated by the project and extrapolating from the smoke emissions test result, heather burning probably results in smoke emissions of 0.22t/ha of burned ground at the low end. These are not precise figures because of the way the smoke emissions tests are conducted means there is no precise data on quantity of smoke per kg fuel burned, so are based on some basic assumptions about the proportion of total test fuel load burned per unit of time over which the tests were conducted. Against that, volumes of smoke from moorland burning are likely to be far higher due to the 'wet burn' nature of moorland burning compared to the 10% MC of the pre-dried heather briquettes.

Based on the low estimate of total acreage of UK heather burned per year we are using in our project (112km2 or 11,200ha) that would suggest total annual UK smoke emissions from controlled heather moor burning in the region of 2,465t, which is equivalent to 3.8% of the 2022 PM2.5 emissions total of 65,000t[13]. In reality, given the conservative nature of this analysis, managed heather burning may be responsible for smoke emissions several orders of magnitude greater the this.

4.8 Off Site Research

4.8 Key Findings

1. Research on other sites confirmed validity of the TMB Cost Calculator methodology for assessing harvestable crops.
2. Regional/national scale yield assessments not possible at this stage as was originally hoped.
3. Possible to apply the TMB Cost Calculator parameters via drone/AI technology for more efficient data acquisition and this option likely to be subject of future R&D.

The project plan included four extended off site visits scheduled for 2023 and 2024, designed to test the moorland harvesting parameters and yield assessments in other locations. The objective was to be able to provide an indicative national level assessment of likely harvestable heather yields. The first of these took place in October and November 2023, focusing on the Mid Argyll area in western Scotland and the Isle of Mull, with these sites originally selected when the focus of the project was still on heather as a solid fuel source.

In the Argyll field work a variety of marginal land areas were assessed. Overall biomass yields were relatively high, with average spot yields found to be [redacted] t/ha^{FW}, although in common with all the site visits outside Barningham, there was no data on the age of the stands so a detailed annualised productivity figure could not be calculated. The sites visited were also grazed, both by sheep and variable densities of wild red deer, further complicating yield assessments.

Three sites were visited on Mull, with site measurements and assessments undertaken. Two of these were classified as upland moorland while one was coastal bog. These produced spot yields averaging [redacted] t/ha (range [redacted] t/ha^{FW} – [redacted] t/ha^{FW}). These are broadly in line with the Barningham data, albeit at the lower end of yields, which would be anticipated for sites further north and with higher rainfall.

Translating these yields into annualised harvestable totals was difficult, due to the different land use. Whereas the Barningham site is closely managed for grouse, with a regular burn cycle of known duration, none of the sites visited were managed for grouse shooting, and were instead grazed by sheep and wild red deer. This made assessing the annual growth impossible, so although approximate figures were derived for the standing crop, annualised yields were not possible.

Another key observation was that none of the sites displayed the density of heather as found on typical grouse moors, with much more broken heather cover interspersed with bilberry, bog myrtle, cotton grass and other coarse grasses. While this would have been an issue for fuel production, where a focus on woody, high lignin biomass is preferable, the more varied vegetation found at these sites is likely to be better for composting, where an increase in higher nitrogen ‘green’ matter will help to rectify the high carbon/nitrogen ratio found in heather. This led to the observation that the switch to composting is likely to bring more upland areas into possible contention as biomass production areas than was likely for fuel production, and may thus extend the reach of the project innovation.

The second year review (February 2024) concluded that the value of these visits was limited, in the context of the original objective of providing a national assessment of harvesting potential. The remaining visits were restructured and redesigned to test the TMB Process Cost Calculator yield assessment methodology in a variety of different environments, and to broaden the scope of the work to assess non-heather moorland biomass crops in the wake of the decision to switch from fuel supply to compost production.

A further series of site visits were subsequently undertaken to upland and bog sites in 2024 to sites in Yorkshire, Cumbria and Mull. In conjunction with the additional Work Package 14, the intention was to assess the potential for harvesting sufficient ‘green’ vegetation from moorland areas alongside heather, to allow for a single harvest mix that provided sufficient nitrogen to allow composting to occur without the addition of further material.

As with the 2023 visits, generating annualised yield figures was not possible, and in all areas visited comments regarding grazing from the 2023 visits also applied. However, the use of the TMB Cost Calculator for assessing site yields and harvest potential on specific sites was further confirmed as a valid methodology, and is likely to provide a good basis for appraising the business case for individual sites. The site work summarised here has indicated that the TMB harvest parameter approach is one that is readily transferable to other areas, but the objective of developing a robust annual available national upland biomass crop total is significantly more complex. Under the future commercialisation plans the project team is exploring how the TMB Process Cost Calculator parameters can be assessed by drone and AI technology, as a way to enhance accuracy and efficiency, removing the need for time consuming manual assessment. This will both speed delivery of data gathering for specific sites and may also lead to the ability to accurately quantify regional and national scale upland biomass resource availability.

The project team is indebted to Prof. Chris Bell of UKCEH and the lead for Biomass Connect, who arranged for the provision of vegetation land cover data.

4.9 Compost Trials

4.9 Key Findings

1. Heather has high C:N ratio and is very resistant to decomposition without mixing with other vegetation.
2. Biodigester and Ompeco Converter capable of rapid production of growing media from 100% heather feedstock.
3. Thermophilic composting via aerated static pile method offers opportunity for scaled up production incorporating heather and other moorland crops (rushes, bracken, *Molinia*) and significantly extends potential for the innovation.

From September 2023 a number of composting trials were undertaken, at various scales and using widely differing methods. Three small scale composting trials were initially undertaken. The first was an in house test of small scale tumbler style composters, from September 2023 – May 2024. Approximately 75 litres of fresh heather chip was added to each of two insulated chambers in a twin chambered Joraform JK400 compost tumbler (see Image A1.12 in Annex 1), with one of the chambers having an additional treatment of a proprietary enzyme mix selected to aid decomposition. This was provided free of charge by Bio Global Industries Ltd (BGI).

Hourly temperatures were recorded using temperature loggers. While the green parts of the heather browned in each chamber, no significant evidence of active decomposition was noted throughout the trial. Neither of the chambers showed any signs of the heather breaking down, there were no significant differences in temperatures, and there was no volume reduction, with the failure to compost likely to be due to the pure heather mix containing insufficient nitrogen.

A small mulching trial was undertaken from September 2023 – May 2024. Two adjacent plots of approximately 2m^2 were used, with one left bare and the other treated with a 10cm depth of unprocessed heather chip. Soil acidity levels were checked and soil moisture and temperature levels were monitored in each plot by a Tomst TMS datalogger. Weed cover was also monitored.

There was very limited evidence of the breakdown of the heather during the trial period, although a small number of worms were noted within the litter layer. Soil pH levels were unaffected, with tests suggesting levels of pH 6.2 – 6.9 across the two plots with no difference between plots throughout the trial. Some differences were noted in the temperature and moisture levels, with a notable retention of moisture in spring on the mulched plot and some evidence of slightly higher temperatures.

There was a notable difference in weed cover, with 23 weeds per m^2 on the bare plot and zero weeds on the mulched plot. While this provides evidence that heather would serve as an effective weed suppression mulch, and could be a useful means of assisting in planting methods, particularly for tree planting, this is not thought likely to be a commercially viable option.

The third trial, [redacted], was a composting test to assess the potential of heather for the use as horticultural substrate or as a substrate ingredient, using $2m^3$ of heather chip in a Johnson-Su bioreactor (a static compost pile with steady aerobic conditions) for 6 months. Chemical composition tests before and after, with monitored temperature and humidity throughout, plus microbial analysis at the end of the process was gathered.

The results confirmed the findings of the in house small scale trials, with very limited decomposition noted after six months, with the trial report concluding that "..heather is extremely resistant to decomposition, the most resistant parent material we've found without the inclusion of nitrogen rich materials". [redacted] the trial was not successful, mirroring the home composting trial.

Tests [redacted] with limited nutrients but importantly, low levels of problematic chemicals (sodium, chlorides etc) which at high levels can require dilution with other materials. The carbon:nitrogen (C:N) ratio is known to be high for 100% heather mixes, as is the case with coir fibre and processed bark, currently the main peat free alternatives. However, mixing with other high N materials for composting may help balance this.

The microbial assay also identified the mildly antibacterial properties of heather, a factor which encouraged the use of heather as a bedding material for livestock before the widespread availability of straw. This opens the possibility of supplying heather into the agricultural bedding market, where straw is currently £80/tonne. While a relatively low price compared to the compost market, this option requires no post harvest treatment and may provide some local market opportunities for a low input heather harvesting operation in certain locations.

Larger scale processing was undertaken in a further four trials. The fact that heather has a high lignin content (measured at 40.6% and 49.0%[14]) was initially identified as a positive benefit for the production of pressed fuel products, but as highlighted by the small scale trials, this represents a potential barrier for composting, where woody, lignin based material is slower to break down. Additionally, the high C:N ratio of heather also impedes decomposition. Any processing method designed to produce growing media would need to be able to overcome these natural characteristics.

Four processing options were trialled within the project period. Bulk composting was achieved via thermophilic composting, where heather was mixed with varying proportions of silage and turned periodically. Small batch processing was trialled [redacted] A second rapid processing option employed a biodigester [redacted]. Finally, a trial of aerated static pile composting (ASP) was undertaken, initially at a very small scale by BGI, followed by a large scale ASP trial at the Barningham site by the project team, with this trial using heather mixed with rushes and *Molinia* grass cut simultaneously from the Barningham site.

Standard thermophilic (high temperature) composting took place at the Barningham site, using three compost bays formed from precast concrete panels to form bays enclosed on three sides on a pre-existing concrete apron, with each bay 3m high by 3.5m wide with a length of 6m. It was intended that two composting bays only would be used at any given time, with a third bay to facilitate turning, (see Images A1.13 and A1.14 in Annex 1). In the first trial the heather crop was mixed with grass silage as a nitrogen source to aid microbial activity.

Two of the bays were filled in early March 2024. One of these was filled with heather left over from the September 2023 harvest which had been previously mixed with a small amount of silage and left in an open heap at a nearby farm. The second heap was a silage/heather mix from the third harvest in March 2024, with an estimated [redacted] heather/silage mixture by mass, which involved some estimation of the differing densities of the two materials.

There were some concerns about chip size, with ongoing issues regarding pre-shredding of the material. Because the heather chip is not sufficiently large to be fed into standard wood chippers and most compost production system shredders are too large a scale, this has been an ongoing concern. Two small garden shredders were trialled to see if the shred size could be reduced, but these both failed, with the thin strands blocking the shredder feed mechanism. An attempt was made to test a larger size shredder, with heather samples sent to Allium Energy Ltd of York, who use a hopper fed tractor powered shredder for a garden waste composting operation. However, this trial also failed, as the heather was again too fine and tended to block the feed hopper.

The project team aimed to maintain thermophilic composting temperatures across all parts of the heap above 60°C for 21 days to comply with PAS100 standards[15] on pathogen removal, while keeping the peak temperatures below 66°C - 70°C to maintain ideal conditions. Temperatures were monitored using a 1.4m temperature probe. The heaps heated rapidly and were turned initially twice weekly, with the objective of mixing being to ensure the outer layers were placed into the middle of the heap. Reheating back to the target temperature range was rapid, occurring within 24 – 36 hours. Turning was reduced to weekly by the end of March, as the risk of the heap temperature exceeding the maximum target range appeared to recede. From late April the turning frequency was reduced to fortnightly and both heaps appeared to maintain a suitable core temperature with minimal intervention.

By mid May the older (2023 crop) heap was showing clear signs of material breakdown, with a crumblier texture in much of the heap. Both heaps lost around 50% of their starting volume by mid June. As the heaps entered the maturation phase, the new (2024 crop) heap displayed a notably cooler temperature profile, ranging from 45C° - 55C°, while the older heap retained slightly higher temperatures. The reasons for this are not known. It may be an artefact of different silage/heather proportions but it is thought more likely to be caused by variation in moisture levels, as the 2024 heap temperatures recovered and became more consistent across the pile following a period of heavy rain. It is therefore possible that the 2024 crop had insufficient moisture at times. Maintaining moisture levels is an issue that is under active consideration by the project team for the commercial phase of the innovation roll out.

The heaps were left until October, with occasional turning, before samples were sent for testing. Both heaps appeared to successfully compost, although both had relatively high levels of residual coarse stems remaining, which would require screening before any commercial sale. This is a result of the large chip size at harvest. Overall approximately [redacted] tonnes of compost were produced from the thermophilic system. Test results are discussed in Section 4.10.

Rapid processing was trialled [redacted] under

(see Images A1.15 and A1.16 in Annex 1).

Some difficulties were experienced due to the heather being too wet, impeding the friction generated heat. An initial batch was mixed with poplar chips supplied by BGI Ltd, which produced a sufficiently dry blend for the process to work. A second batch of 100% heather was also processed using some of the heather previously dried for briquette processing mixed with the fresh cut. The converter was run to [redacted] in a [redacted] minute cycle, with an input rate of approximately [redacted] kg per batch. A total of 285kg of dried flock was produced. The dried flock was subject to standard composition tests and the results shown in Section 4.10.

The second rapid process tested was a vessel biodigester with tests carried out [redacted]. A biodigester converts organic matter into a growing medium in a chamber through accelerated microbial action, using added enzymes, heating and physical agitation. The initial tests [redacted] proved successful, with approximately 1.8 tonnes of material produced from a 100% heather batch supplied from the March 2024 harvest. The [redacted] can accommodate approximately [redacted] kg per load, with each load running for [redacted] – hours, with results in Section 4.10. The material was pre-shredded before processing. Image A1.17 in Annex 1 shows the [redacted] biodigester unit while Image A1.18 shows the finished heather product.

A second biodigester trial took place on the same basis following the October 2024 harvest with the Softrak 140 machine. While the heather shred was markedly finer than previously, [redacted] material prior to the biodigester cycle, but this time process times of [redacted] hours were used, with the tests also including heat treating to 70°C. Usable compost was produced [redacted], which significantly improves production efficiency.

An additional small scale composting trial was undertaken in August 2024. This was in collaboration with BGI Ltd, and took place at their facility at Chesham, Buckinghamshire. The trial was designed to test heather composting with the addition of MAD Frass[16], a soil conditioning product developed by BGI Ltd. While TEC Ltd provided the heather, the trial was conceived and run by BGI Ltd at their own expense, for which the project team are grateful.

The trial was of the aerated static pile (ASP) composting method, where heaps are not turned, but temperature regulation and provision of oxygen to maintain aerobic microbial action is maintained by the periodic injection of forced air through perforated pipes and timer controlled fans at the base of the heap. The trial used approximately 2m^3 of heather material, which was provided from the partially composted heaps at the Barningham Sawmill site. This was mixed with additional grass and built into two small ASP heaps. One of the heaps was treated with MAD Frass, a product developed by BGI Ltd from insect frass, designed to provide both microbial stimulation for composting processes as well as moisture retention improvements and nutrient enrichment, while the other pile was left as the heather/grass mix. Both piles showed good signs of heating, with the MAD Frass treated pile showing slightly elevated temperatures during the initial hot phase.

Following the additional November 2024 harvest using the Sofrak 140, a second large scale thermophilic compost trial took place. Unlike previous harvests, where the focus was exclusively on heather, this trial sought to test whether combining heather with other moorland crops could produce a combination suitable for composting without any additional biomass. (See Section 4.3 for yield and harvest performance data). While bracken is known to produce good compost when blended with other materials, the trial was unable to harvest any bracken, but several loads of rushes and *Molinia* grass were gathered in addition to heather.

Approximately 140m^3 of material overall was harvested, with most of this used to construct a commercial scale aerated static pile (ASP). The ASP was designed by TEC Ltd and was based on a fan unit with timer plug feeding three lengths of perforated pipes over which a well mixed heap of heather, rush and *Molinia* was built. (See Images A1.19 and A1.20 in Annex 1). Heap conditions were monitored by use of temperature and relative humidity data loggers as described in Section 4.6 'Crop Drying'. Remote monitoring of the heap via 4G enabled temperature recorders was also tested.

While the ASP design was successful, with experiments clearly showing the airflow was capable of regulating heap temperatures throughout the pile, the trial was abandoned at the end of December as the ASP heap was failing to heat sufficiently. This problem was caused by inevitable timing issues, with the project team constrained to specific harvesting dates by the availability of the Softrak 140, leading to the harvesting taking place a month prior to the ASP site being ready. During this time, the material was placed into the composting bays and turned every 3 – 4 days, with monitored temperatures of 62°C – 68°C, cooling slightly in the fourth week. Once placed into the ASP, much of the starting heat was lost, and after failing to recover it was decided to remove the ASP and return the material to the bays.

The project team has full confidence in the ASP methodology, with the issues experienced within the trial highlighting that the ASP must be constructed and ready for loading up at the point of harvest, to ensure that the hot phase is utilised within the ASP process and avoid the need for any moving of the material.

4.10 Compost Product Testing and Results

4.10 Key Findings

1. Heather based growing media is an opportunity for low pH (acidic) replacement for peat and coir products.
2. These are generally low in nutrients, with particularly low nitrogen levels.
3. Some forms of processing can utilise 100% heather products for specific markets.
4. Addition of other moorland vegetation can improve heather based composts, and post-processing blending with additives/other materials will allow targeting of specific product qualities for different markets.

A variety of tests were applied to finished compost samples to ascertain their physical and chemical properties, summarised in Table A3.9 in Annex 3. In general, heather derived growing media products appear to have reasonable water holding capacity (WHC) comparable to coir. Peat WHC is generally 80%+ depending on the grade of the peat[17] (defined by particle size). Air filled porosity (AFP) for the heather products was low, and would ideally be at least 15% – 20%. (Values for peat generally from 10% - 30% again depending on grade[18]). Acidity levels varied depending on the precise blend and process used, but are acceptable for a wide range of uses. The heather derived materials are generally low in nutrients, particularly nitrogen, so blending and balancing with additives is likely necessary to produce finished composts, and this forms part of ongoing research.

Test results for the second biodigester trial following the October 2024 harvest using the short process times, [redacted] are shown in Table A3.10 in Annex 3. While the results are broadly similar, the density is lower than the longer time trials, and the nitrogen totals are somewhat higher, although still low. Heat treatment does not appear to alter the results to a significant degree, and the lower density may improve the AFP results.

A number of germination and growing trials were undertaken, with positive results from tests of lettuce seedlings, with high proportions of germination within both the biodigester and thermophilic compost materials. The converter material was less effective, largely due to the finer particle size and the need for a wetting agent.

Specialist trials have been undertaken by Floralive Ltd, a horticultural specialist in the supply of peat free bog plants, which require specific erricacious (acidic) growing conditions. The initial results from these have been very positive, and longer term trials are now underway, with further trials under the auspices of the RHS planned for 2025. The project team is indebted to Sean Higgs of Floralive Ltd for this work.

4.11 Key Performance Indicators

4.11 Key Findings

1. Annual heather crop from the Barningham research area XXXXt^{FW}, likely to be 2-3 times higher with the inclusion of non-heather vegetation.
2. Annual yield XXXt/ha^{FW} – XXXt/ha^{FW}
3. Net value added (NVA) equivalent to £XXXXX - £XXXXX/ha over ten years

Three Key Performance Indicators (KPIs) were initially adopted by the project team. These were;

a) Finished biomass produced (t/ha)

b) Total available annual yield (finished biomass) (t/yr)

c) Production energy efficiency of finished biomass (kWh/t)

These were conceived when the project focus was on the production of solid fuel, and the relevance of the third KPI measuring overall energy efficiency of the process was deemed of particular relevance.

With the failure of the solid fuel option as a commercial innovation, this KPI became less relevant, and by agreement with DESNZ a new KPI was selected to replace c), Net Value Added (£/ha), which more accurately reflected the key measure that would be most relevant to landowners. The net value added (NVA) measure is in essence a measure of the additional profit that can be generated by harvesting and composting.

While the development of these KPIs is still at a relatively early stage, provisional estimates from the experience of the project are that heather composting can produce finished biomass in the form of compost at a net yield of [redacted]t/ha. This is calculated by a weighted average of the heather, *Molinia* and rush yields from Section 4.3 in the proportions required for composting, multiplied by a factor to represent the loss of mass through the composting process. For the outputs from the [redacted] and [redacted] processes which use 100% heather the finished biomass yields are [redacted]t/ha – [redacted]t/ha.

It should be noted that these figures relate only to the cut area, not the full moorland, and do not equate to an annual yield, due to the lengthy harvest interval. Annual yields would be in the order of [redacted]t/ha – [redacted]t/ha based on a normal management interval of approximately 10 years. By comparison, typical grass silage fresh weight annual yields in the UK are around 45t/ha[19] while average annual UK wheat yields are typically 8.4t/ha[20].

While the projected finished yields are relatively low, in terms of conventional agricultural yields, the ability to produce such quantities of new origin biomass from marginal land with no impact on continuing land use patterns, is considered by the project team to be a remarkable advance. This is seen as of particular significance, given the huge area potentially available for exploitation.

Total available annual harvest yield was calculated from the project area at [redacted] tonnes, based on the identified area of heather and assuming a 10 year harvesting cycle. However, the actual yield is likely to be significantly higher than this, given that unlike for solid fuel, composting can utilise other moorland vegetation such as rushes, *Molinia* grass and bracken. The additional harvest and ASP trial in November/December 2024 confirmed that these crops are readily harvestable and can form a single compostable blend, with some yield calculations for rushes and *Molinia* provided in Section 4.3. However, there was insufficient time within the project schedule to conduct detailed assessments of the area covered by these crops, and unlike heather, where the approximate age of the stands was known, it was not possible to calculate annualised yields. However, it remains highly possible that the overall total biomass yield from the project area could be 2 – 3 times greater than for heather alone, based on the wider potential harvest area and the fact that these alternative crops are faster growing.

The final KPI of Net Value Added (NVA) has been calculated from the TMB Process Costs Calculator, and indicates a net value added of between £[redacted]/ha to £[redacted]/ha, depending on the compost process adopted. Again, these figures relate only to the area harvested, and in this case exclude finance costs. Nonetheless, in the context of the economics of upland farming, the NVA figures suggest there is the potential for a remarkable additional income stream for upland areas that has to date been almost entirely untapped.

5 Key Project Successes and Wider Implications of the Innovation

5.1 Key Project Successes and Lessons Learned

5.1 Key Findings

1. Heather harvesting for production of finished goods is feasible and cost effective, with a detailed business appraisal tool successfully trialled.
2. Bulk handling of moorland cropped material presents practical challenges, and largely dictates the need for processing facilities to be located close to the harvesting sites.
3. Ability to assess regional and national scale resource was an over ambitious objective, as yields are dictated by site specific factors, with this shortcoming being addressed by future research.

Overall, the project team view the Teesdale Moorland Biomass Project as being highly successful and as representing a highly impactful level of research for upland management within the UK agricultural sector. Specific project successes are seen as the successful demonstration of cost effective harvesting on sensitive upland peatlands, along with initial research demonstrating that the harvesting system selected can be deployed successfully without damage to the upland environment.

The development of accurate available harvest yield assessments, and in particular the continued development of the TMB Yield Calculator from Phase 1 and the development of the subsequent combined yield and economic assessment in the TMB Process Costs Calculator, are also seen as critical successes, allowing the production methodology to be applied to other upland sites.

The production of finished biomass products was judged a key success, both for solid fuel but particularly for peat free compost. Both required a series of technical challenges to be overcome, and while the option of using heather as a fuel source was found to have limited commercial opportunities due to the excessive smoke emissions, the role of heather for upland derived peat free compost products does have the potential to become a market disrupting innovation and has substantial relevance in terms of finding a sustainable replacement for peat extraction.

Significant knowledge has been gained regarding the processing needs of heather in terms of the production of composts and growing media. This includes gaining experience about processing parameters, methods and the production of horticultural products with specific chemical and physical characteristics.

The ability to produce high value products from 100% heather feedstocks in rapid processes is an important option alongside the traditional bulk volume thermophilic composting methods, and future development is likely to focus on how these methods can be refined to add value to the resulting horticultural end products.

Linked to the above, the ability of the project team to translate practical process based innovation to a costed economic analysis is seen as a key success in terms of the future commercial opportunities afforded by moorland biomass. The ability to apply a tested economic appraisal to widely varying upland sites and process configurations is a critical element of any future expansion of heather harvesting, and is seen as a critical business development tool for the project partners.

Along with the successes there were plenty of lessons learned. In hindsight the project was highly ambitious for the original grant requested, and although the project delivery was considered to be a success, there was insufficient allowance built into the original bid for the level of uncertainties and mid-stream adjustments that such a project was likely to generate.

The failure to address the solid fuel emissions issues earlier was a significant issue, as this curtailed the time available to devote to the alternative of compost production. Ideally the entire project period would have included composting as a point of focus, alongside the solid fuel option, and the issue of emissions controls should have been identified at the outset. [It is also worth noting that there was a three month backlog at Kiwa International Ltd for the smoke emissions tests, which added to the delay in terminating the solid fuel option, although ideally the original project timetable would have allowed for an earlier resolution of this key issue].

Practical issues of bulk handling of biomass material can also be viewed as a case of lessons learned. While attention was paid to ensuring the necessary machinery was available to the project team, the preliminary planning for the project bid in Phase 1 did not adequately address the likely volumes that would be produced and the processing space these would require. This is a material consideration with regards a potential roll out of commercial production, and as the project progressed there was a good deal of experience gained in understanding the implications for working space that the physical processing required.

One substantive area where the project has only made limited progress is in calculating the national potential for heather and moorland harvesting. While it has been possible to develop a clear understanding of the area of heather and other vegetation types that could be subject to harvesting, it has not proved possible within the project time frame to provide an assessment of the proportion likely to be available for harvesting, nor of likely aggregate yields.

The original intention was highly ambitious for the available budget, and while the TMB Moorland Terrain Classification System (MTCS) was successful, it cannot be readily applied beyond the site level without integration into some form of remote sensing data acquisition system. This remains an as yet unrealised future potential benefit arising from the project.

Overall, the project findings are viewed as highly positive. The ability to generate large volumes of commercial biomass from marginal upland areas comes with no obvious trade-offs; there is no change in existing land use patterns, no loss of productive food growing land, no identified impact on local and regional ecological considerations, and no known impact on hydrology or the use of peatlands for watershed management. In addition, there are no impacts on recreational use or local wildlife, other than the recreation of an established management pattern via harvesting as opposed to burning. In contrast, reduction in smoke emissions, enhanced CO_2 storage and the creation of rural employment opportunities are all major new benefits.

Moorland harvesting should rightly be viewed as an overwhelming net environmental gain, largely eliminating the need for heather burning on large areas of upland moor.

5.2 Contribution to UK Biomass Supply

<u>5.2 Key Findings</u>

1. Annualised heather yields appear significantly higher than earlier modelled estimates.
2. Non-heather moorland biomass likely to have similar yields.
3. Tentative projections indicate that harvesting just 7.5% of UK uplands would be sufficient to entirely replace current peat usage, with the additional potential to significantly reduce reliance on imported coir.

In terms of biomass production, heather growth responds to climatic variation, and so varies widely, particularly in relation to both latitude and altitude, but also in response to soil and ground conditions. This makes an overall assessment of total UK biomass productivity from heather difficult.

A previous study has attempted to predict heather growth rates and biomass energy value (Worrall and Clay 2014[21]) using a climatic region model first developed for the assessment of productivity of upland sheep grazing areas. This divides the UK into 10 climatic regions, representing progressively poorer growing conditions broadly aligned with latitude. Within each region, the effect of altitude was also modelled, with reduced biomass production (measured in above ground kg dry matter ha/year) as altitude increased. The result is an indication of likely heather production per annum for any given location within the UK, with the model suggesting the Barningham test site should have a biomass production level of around 350 kg^{DW}/ha/year.

The data generated by the project suggests that this modelled figure significantly underestimates annual heather yields. The most accurate harvest measurements showed a mean dry weight biomass yield of [redacted]t/ha – [redacted]t/ha, with a probable burn cycle of 10 years, suggesting annualised dry weight yields of [redacted]t/ha – [redacted]t/ha, [redacted] to [redacted] times greater than the Worral and Clay estimate. While it was not possible to derive annualised yields of *Molinia*, rushes and bracken, these are likely to equal or exceed heather, due to faster growth.

There is clearly a very substantial and hitherto untapped biomass resource in upland areas. In terms of the supply of composts and growing media, there appears to be considerable potential for a new industry of upland biomass supply. Peat usage within the UK horticulture sector was 2.2 million m^3 in 2020[22], falling to around 1.6 million m^3 in 2021[23]. A voluntary end to peat use by 2020 failed, and there remains pressure from some parts of the sector to retain some peat use, as suitable alternatives have not yet been sourced.

Many of the existing alternatives, such as coir fibre, are imported, and thus carry risks of supply disruptions. A key advantage of heather and other moorland crops as a feedstock for growing media production are that they are domestically available in bulk quantities, they share some characteristics with peat (most notably a low pH) and as virgin single source crops are entirely free from contaminants, with excellent traceability, all attributes that attract value within the sector.

This work has also demonstrated that hitherto discarded upland crops also represent a very substantial potential biomass energy source, although this is more difficult to exploit due to the emissions issues. However, there remains the potential to supply specialist boilers fitted with appropriate stack filters and other mitigations. Supplying large scale thermal energy or anaerobic digestion plants remains technically possible, but does create bulk transport issues, along with the need to dry large volumes to capture the best energy output (for combustion plants).

While the project has been unable to generate robust national yield and output projections for heather harvesting and compost production, with 1.3m ha of moorland under active management for grouse shooting (see Section 2) there is a clearly a significant potential. As part of the support received from the Biomass Connect Lot 2 project, the project team were provided with access to data from the UK Centre for Ecology and Hydrology (UKCEH) database on land cover, with detailed data on a 10km grid scale showing shrub heather cover as well as mixed heather and grassland. Combined, these vegetation types constitute 3.49m ha, of which 1.03m ha is shrubby heather. These are sizeable areas, but there is no ability to identify the standing crop yields or the proportion of this areas that would be suitable for harvesting.

Barningham Moor project is capable of generating approximately [redacted] t/ha/pa of finished compost from the harvestable portions of the moor. Assuming a standard 400kg/m^3 density for finished compost, this equates to an annual production of [redacted] m^3/ha. If the yields from Barningham were replicated elsewhere (these would likely be lower further north but higher in more southern and eastern regions) then it is possible that the entire current peat consumption could be met from 256,000ha of UK uplands, just 7.5% of the available area of heather and mixed heather and grass.

While these are only projections, it does raise the very real possibility that a concerted effort to exploit moorland biomass harvesting for the production of peat free growing media could end the need for peat extraction within the UK horticultural sector, along with substantially reduce reliance on imported coir growing media.

5.3 Barriers to Deployment

<u>5.3 Key Findings</u>

1. Start up capital costs are found to be high, especially for harvesting equipment, with landowners reluctant to commit significant resources at this stage.
2. The distributed nature of the resource requires production by networks of production clusters.
3. Further R&D is required, particularly to refine processing and identify appropriate market access approaches.

Capital costs of start up are a critical barrier, particularly in relation to the supply of the Softrak and associated harvest equipment. This remains an issue for many upland estates and farmers. Confidence in both the process and the market would need to be gained, given that this is an innovation that has never been undertaken on a commercial basis before, and this factor may make landowners reluctant to enter as ‘first movers’. Some level of investment support would be advisable to speed up adoption, and the project team has developed the commercial plan on the basis of providing landowners with opportunities to engage with the innovation without committing to substantial long term capital investments.

The geographical distribution of the moorland biomass resource was identified as a potential barrier early on in the project. Heather and other moorland vegetation is, by definition, spread across a large area, and is usually found in more remote and inaccessible locations. As a raw material, harvested biomass is also bulky and costly to transport long distances, and this distributed nature of the basic resource works against the concept of large scale, high efficiency production centres.

Instead, the project team worked on the assumption that processing would be likely to be best undertaken in relative low throughput centres located close to the harvest areas, potentially working in clusters to share harvesting machinery across several local sites, but organised as a dispersed network of producers. This issue, and some potential solutions, are discussed further in Section 6 Commercialisation.

There is also a need for more research and development (R&D) to refine the product range and process efficiency. The current project has only been assessing the production of compost and growing media from heather for less than eighteen months, and while a great deal of knowledge has already been gained, there are still significant knowledge gaps. In particular, how to extract best value from the rapid composting options (biodigesters and/or [redacted] method, particularly whether there is any value in the effluent extract) and how to manage the scaling up of thermophilic composting across multiple processing centres remain areas of uncertainty.

Further work is also needed to identify the best mixing regime for the blended products within the bulk thermophilic composting strand, with implications for the harvesting of bracken, rushes and *Molinia*, all of which would be likely to increase landowner interest in the innovation as these are all vegetation types where control is desirable.

A final identified barrier is market access. To date, no commercial sales of Moorland Biomass derived compost have been made, and while the project team has strong signals of high levels of market interest and direct evidence of product suitability, the point of entry to the market remains unclear. Selling direct to end users, either domestic customers or professional growers, would be preferable, as this avoids the wholesale mark-up and captures greater value for the producers, but this is contingent on selling a finished product, and it is not yet certain whether moorland biomass can provide this, as opposed to an input feedstock for blending into final growing media products. In this latter case, this may restrict the market access to large compost producers and reduce the available price.

This factor interplays with the previous point about the need for further R&D into the deliverable product(s). The initial indications are that a direct sales option is likely to be feasible, with the quality of the composts produced at least as good, and more like significantly better, than many of the recycled peat free composts on the retail market. Discussions with professional growers have also indicated that many of them purchase bulk raw ingredients and create their own final blends, altering these to suit specific crops, so direct sales to the professional horticultural sector also looks feasible, although a period of further market development alongside product R&D to refine the offer is required.

5.4 Impact on Greenhouse Gas Emissions

5.4 Key Findings

1. It is possible that Moorland Biomass composting could ultimately entirely displace peat consumption, potentially saving 0.55MtCO_2e.
2. Further GHG reductions may arise from carbon sequestration in soils.
3. Replacement of managed burning also likely to reduce GHG emissions along with significantly reduce particulates

The impact of the innovation on greenhouse gas (GHG) emissions is significant, but very hard to quantify. Three key areas where the project is likely to delivery substantial emissions reductions have been identified.

Firstly, the replacement of peat extraction will have a direct benefit on GHG emissions. DEFRA estimate that 0.55MtCO_2e were emitted due to peat extraction to service the UK market in 2019[24], and given the observation that upland harvesting has the potential to entirely replace peat within the supply chain, the overall GHG emissions impacts of the innovation are likely to be considerable. How much of this potential benefit can be realised is contingent on the ability to roll out the innovation across a broad area of uplands.

A second key mechanism that is likely to reduce GHG emissions is via the route of carbon sequestration by soil. While a proportion of the carbon content is released to atmosphere during the composting process, a significant proportion remains within the compost, which is then recycled into soil. A full analysis of this process is not available, but the observed resistance of heather to natural decomposition suggests that a relatively high proportion of carbon may be sequestered in this manner.

Finally, the innovation is designed to replace managed periodic burning of aged heather on grouse moors, and burning necessitates the immediate release of significant atmospheric carbon emissions. These will obviously arise from the burns themselves, but there is also evidence on the impact on carbon emissions from peat soils exposed by burning. This is a contested area of research, but campaigners against burning suggest that UK peatlands are net contributors to GHG emissions and that 75% of these can be directly attributable to managed burning[25]. The Committee on Climate Change has also called for a total ban on rotational burning as a management tool[26]. Replacing managed burning with harvesting would clearly avoid the immediate GHG emissions arising from large scale fires, but in a way that mitigates the risk of uncontrolled wildfires that can be encouraged by the accumulation of high fuel loads.

Related to atmospheric pollution is the observation of significant particulate emissions released from managed burns. While technically not a greenhouse gas, as previously stated in Section 4.6, this practice is likely to contribute anything from 4% - 10% of UK particulate emissions, such is the scale of the pollution released from the projected areas burned. Ending or reducing this practice could therefore contribute significant reductions in short term atmospheric pollution.

6 Commercialisation Plan

6.1 Applicability to Other Sites and Scalability

6.1 Key Findings

1. There are no inherent barriers to scaling up production, other than biomass resource and harvest accessibility.
2. Based on an aerated static pile model, a cluster of XX production centres could be supported by a single mobile harvester.

The innovation is theoretically scalable to any degree, via the addition of more harvesting machinery and the development of additional processing sites. The issue is whether there is sufficient appetite among landowners for adoption, and if so, how the investment is funded and how production is managed. Landowner attitudes were tested by a survey and follow up focus group discussions facilitated by the Carbon Trust as part of the NZIP Accelerator support. The overwhelming response was one of keen interest, so long as the innovation was shown to be cost effective. In general, the responding landowners were less interested in securing significant profit from any harvesting initiative, as successfully harvesting heather was viewed as delivering required moorland management while avoiding the problematic issue of burning. The predominant view was that such an innovation would solve a problem, and if there was a small income or saving arising, that was sufficient. Similarly most landowners were less keen to commit significant capital into their own new harvesting and processing venture, but were open to ideas of collaborative/cooperative or contract led ventures. A fuller report is contained in Annex 11.

While the innovation is theoretically scaleable, the key aspects identified by the project team are the development of a production system that reduces the initial investment required, the provision of knowledge and experience to new entrants, and a mechanism to develop ready access to market that does not require high management inputs from producers.

The production systems tested within the current project offer widely differing capital investment structures, with the cheapest being the standard thermophilic composting, [redacted]. The latter two are higher capital options ([redacted], with a purchase cost of £400,000) best applied to relatively low throughput, high value products. Bulk composting is likely to require thermophilic composting. Within this, the options of standard windrows or the ASP approach have a material effect on the labour required. A summary of the main approaches can be found in Table A3.11 in Annex 3.

The project successfully trialled a remotely monitored production scale aerated static pile (ASP) compost heap in the latter stages of the project, and has developed a low cost packaged plant model which can be readily scaled. This model envisages a single mobile Softrak servicing up to [redacted] production centres operating ASP units, with periodic harvests through the year and a regular throughput of finished composts. Other than the available resource, there is in theory no reason why multiple clusters cannot be established to rapidly scale production.

6.2 Route to Market

<u>6.2 Key Findings</u>

1. Business model developed based on centrally coordinated harvesting with landowners collaborating via distributed production centres supplied with remotely monitored packaged ASP plant.
2. Model also utilises central coordination of sales via branded products.

The project team has developed a business model that can facilitate widespread adoption of the innovation. This will be delivered by a new enterprise, Moorland Biomass Ltd, which is a joint venture between TEC Ltd and Barningham Estates, the project partners.

Combining the demand for reduced capital input and the provision of experience and expertise to new entrants, the project team believes that delivery can be scaled by the provision of packaged ASP plants (see Section 6.1). Some further R&D testing is required to refine management protocols and product specification, but the calculations and trial results to date suggest that there is support from sufficient interested landowners to establish harvesting clusters, utilising a centrally provided Softrak for periodic harvests, with on-site ASP composting under the guidance of Moorland Biomass Ltd (MBL).

The ASP system offers an ideal opportunity for a standard system which is both relatively cheap along with being easy to construct, with MBL providing the ASP plant as a pre-packaged kit with self assembly instructions provided. Packaged kits would either be sold or leased to landowners, with harvesting costs from an MBL owned Softrak either charged at the point of use or extracted from the consequent sale price of the finished products. Producers may also opt to operate a biodigester, which can be provided on a lease contract basis, with the precise configuration of each production centre subject to an initial review and consultation prior to design. Subject to further R&D, MBL may also operate a mobile [redacted].

Operational guidance would be provided by MBL, while low cost remote sensing equipment currently available on the market would be used to directly monitor the temperature and humidity of the piles, such that ASP systems could be effectively managed centrally by MBL, both ensuring product compliance and quality control, as well as removing one of the main responsibilities for operational management from individual landowners.

The initial investment will be focused on the Barningham site, with the purchase of a Softrak and the establishing of a composting operation based on an ASP operation. Initial calculations suggest that a two week harvest window (10 working days) would be sufficient to fill [redacted] ASP units of around m^2 each, generating a total of [redacted] m^3 of finished compost per harvest cycle.

The packaged ASP plant could be supplied to another [redacted] landowners in the local region with the Softrak likely to be able to support these [redacted] producers across [redacted] harvesting cycles per year. Depending on the sale price achieved, each production cluster should be capable of securing a gross annual revenue in the region of £[redacted] - £[redacted], based on ASP thermophilic composting production.

Some further development and testing is required to confirm that such a system would be viable in the format envisaged, but given that the project has already secured proof of concept for thermophilic composting, the outstanding research is largely a matter of testing system design and operational parameters, rather than assessing fundamental issues. Such an approach, delivered on a cluster basis with modular design, is readily capable of widespread replication.

Collaboration regarding market access is also seen as important. With production overseen by MBL, it makes sense to also manage sales centrally. Discussions between the project team and end users have been very positive (see Section 6.4) and it seems likely that a mix of direct bulk sales, along with supplying packaged products to the retail market will be feasible. The bulk sales in particular are likely to be of a scale that an individual production centre will struggle to supply, so a centrally coordinated marketing and sales operation makes sense, enabling a loose collection of collaborating production clusters to both access and service large volume purchasers, supplying a product of known origin and where MBL can verify standards and production criteria.

It is likely that this will include product branding under the '[redacted]' brand, for which a proportion of the final sales value will remit to MBL. Further work is ongoing around the issue of branding, quality assurance and certification marks, with a working brand title of '[redacted]'. A growing media market assessment was undertaken with the assistance of the NZIP Accelerator support and the Carbon Trust, which can be found in Annex 12.

6.3 Financial Support Mechanisms

6.3 Key Findings

1. Supported period of further R&D with capital investment support required for rapid deployment.
2. Successful 'Moorland Biomass Ltd' cluster based on Barningham area will help encourage investment by de-risking uncertainties and demonstrating market potential.

The project team believes that a relatively short period of further R&D is required to test the harvest and production systems at scale, and also to provide for a further period of product development and testing, to provide assurance that the production system outlined is sufficient to deliver market ready product in sufficient volume. Beyond this, the research undertaken during the project suggests that there is a ready market for peat free products that can further displace coir imports, and that this market is likely to be profitable and sustainable over the long term. Table A3.12 in Annex 3 gives an indication of the currently anticipated production costs, which suggest this can be a highly cost effective investment.

Capital costs are seen as a potential issue however, as the initial start up costs for a new cluster are relatively high, and a limited appetite for large scale investment was identified in the landowner engagement activities. While this is likely to change over time after the entry of early adopters proves the market viability, access to the required finance is still likely to be an issue for some time.

The project team is currently looking at UKRI support for a demonstration R&D project designed to finalise the long term shape of a production cluster, which will then help to encourage new entrants and underwrite start up costs. It's also likely that a proven Moorland Biomass Ltd initiative will encourage lenders and help de-risk investments by providing clarity and experience, so the emphasis is currently on securing funding for an operation based around Barningham.

6.4 End User Discussions

6.4 Key Findings

1. Strong support among landowners and managers for productive harvest systems for upland areas, for both economic, conservation and security of supply chains purposes.
2. Widespread support within horticultural sector for Moorland Biomass products and willingness to accept such products.

As the project progressed the project team have been approached by several industry participants expressing an interest in purchasing heather based products. Some of these are likely to lead to initial contracts from spring 2025 onwards.

A number of samples of [redacted] output (100% heather) were supplied to Floralive, a specialist bog plant grower interested in peat free media for acid living plants, where ericaceous conditions are important (see Section 4.10). Initial growing trial results are very positive, especially for the biodigester material, and feedback was very positive, describing the heather compost as “the most significant development in the peat free market for four decades”. Further trials are planned, with small scale sales currently under negotiation.

A second series of discussions took place with [redacted] Ltd, [redacted], with an annual demand for thousands of tonnes of coir. They expressed strong interest in the potential for heather derived compost as a replacement for imported coir fibre, and the [redacted] output appears to be ideal pH and structure for [redacted]. Full growing trials are anticipated in 2025.

Contact with the retail sector has also taken place with a southern England based retail garden centre chain who are requesting bagged Moorland Biomass compost for retail sale. This potential outlet is being pursued and it is intended to test sales potential later in 2025.

Discussions have also commence with Take Root Bio Ltd, following an approach to the project team. Take Root Bio Ltd aim to revitalise derelict industrial land and buildings by developing agricultural products in those locations, creating sustainable food chains based on a circular economy with strong community engagement. Discussions to date have focused on the supply of suitable substrates for a number of projects, including a potential mushroom farm on Teeside.

A strong underlying feature of these discussions is an acceptance that peat as a horticultural input is increasingly undesirable and unacceptable, with growers reporting significant pressure from customers for peat free products. Strikingly, this pressure is also now beginning to be felt in relation to coir fibre, the main peat replacement product, with supermarkets and others looking for greater security in supply chains and reduce ‘food miles’ and carbon emissions. These pressures are to an extent easing the pricing competition, such that locally derived, sustainable growing media products will be able to command a premium price.

Discussions have also taken place with a number of organisations representing landowners. These include the Heathland Connections Nature Recovery Project in Surrey, a land restoration project seeking to restore heather dominated heathland across a substantial area. As with other conservation focused projects, management of moorland vegetation is still required to avoid wildfire risk, and integrating such management with Moorland Biomass composting would provide an ideal blend of productive management for conservation outcomes.

Overall, landowners and managers are highly supportive of the concept of heather harvesting and the horticultural market appears very willing to accept heather based products, and the concept of Moorland Biomass derived products has been met with strong support.

6.5 DESNZ Accelerator Support

Throughout the project the team have received strong support from the NZIP Accelerator Support programme delivered by the Carbon Trust. The value of the support given in the three financial years from April 2022 to March 2025 was £26,996. The support has been invaluable and has enabled a significant broadening of the project scope. The NZIP support was particularly helpful in overcoming the issues raised by the mid-project pivot to compost, and the project would like to issue heartfelt thanks to Rhiannon Turner of the Carbon Trust, the NZIP Acceleration Support Manager, along with the many Carbon Trust staff members who assisted.

The specific assistance provided was as follows;

- Regular mentoring meetings with NZIP Acceleration Manager to guide the support required and co-create the bespoke tasks; this included an initial detailed needs analysis and proposed plan for the support that might usefully be provided.
- Task 1 – review of potential market for heather biomass as a fuel.
- Task 2 – examination of relevant regulations for proposed composting activities.
- Task 3 – advice on approach to branding and trade mark registration options and procedures.
- Task 4 – trade mark clearance search for MOORLAND BIOMASS.
- Task 5 – brief analysis of sources of information for compost market.
- Task 6 – support to engage with potential market including focus groups with land managers.
- Non-task support from Philip Hunt of Sustainable Ventures to assist in development of business model and business vehicle.

7 Secondary Project Benefits

7 Key Findings

1. The innovation has the potential to support significant job creation efforts in rural areas.
2. Substantial IP has been generated, in both specific items, branding, and production methodology and data.

The project has attracted some significant media coverage and was featured in an article in The Times[27], along with a televised feature on Tyne Tees[28]. There has also been a number of local press articles and coverage in the specialist press[29].

While the number of jobs created from the project has to date been limited to supporting existing jobs within the project lead and subcontractor organisations, the eventual job creating potential of the innovation is considered to be considerable. A dedicated position for a project manager in 2025 to run the planned Barningham cluster is anticipated, and Moorland Biomass Ltd (MBL) has been formally constituted as a harvesting and production enterprise. Consultancy roles delivering guidance for other landowners wishing to develop harvesting and processing clusters have been retained by the project partners. This structure was adopted in order to allow for a straightforward exit strategy should the MBL partners opt to sell the company in future.

Longer term the project team views this innovation as having significant potential to create jobs in upland rural areas as the system is rolled out and production increases, although the full potential for additional employment is difficult to calculate at this stage.

A number of new partnerships have been developed. The creation of Moorland Biomass Ltd has formalised the relationship between the project partners, and other partnerships that arose during the project are anticipated to continue in some form or another. The project team continue to work closely with [redacted] to newly established production clusters, as will the relationship with [redacted]. The clusters themselves are likely to be based on a commercial partnership arrangement.

There have been close links between the Biomass Connect Lot 2 project led by UKCEH, which has included working closely with a number of academic institutions as well as BGI Ltd, and discussions are underway to retain some engagement from these bodies post March 2025. Current consideration is being given to establishing an advisory steering group to enable collaboration to continue.

There is a considerable amount of intellectual property (IP) generated during the project. Alongside the data generated, which covers a variety of aspects of yield, harvest and processing results, the '[redacted]' and '[redacted] ' branding is an element of IP the project team are keen to exploit. Work is underway to register these

The TMB Process Costs Calculator is a specific IP element that has a considerable practical use for any new entrant looking to joining the Moorland Biomass initiative. Both the calculator overall and many of the specific parameters within it are derived from detailed research undertaken during the project, and TEC Ltd will be looking to exploit this through a consultancy offer advising landowners and assisting MBL in establishing new production clusters.

Beyond these specific areas of IP, there is a significant volume of experience based knowledge and practice that while collectively amounting to a significant body of IP is not readily protectable, as the individual elements are existing processes conjoined and repurposed to a novel activity. Protection of these aspects of IP comes primarily from occupying a role as market leader and through a process of continuous development through R&D to establish a clear market lead in this industry.

8 Project Management

8 Key Findings

1. Project management seen broadly as successful, with a small, agile team able to respond quickly to new findings and information. This model has been adopted for future development through Moorland Biomass Ltd.
2. Management of subcontractors was generally good, although at times the demands of the project did outstrip the management resources available to a degree.
3. DESNZ administration requirements were felt to be adequate and not overly onerous, with excellent Monitoring Officer support throughout.

The bid was constructed on the basis of a very small and agile management team, deliberately configured to enable rapid decision making and fast responses to changing circumstances. While technical knowledge at the start of the project was limited, management of the technical aspects of the project were considered to have been a success, with rapid learning and an ability to absorb and react to new information quickly and easily. The different skills and experiences of the project partners are felt to have combined well, and the continuation of the project mission through Moorland Biomass Ltd has sought to replicate the management style and structure of the Teesdale Moorland Biomass project.

In general, the management of external contractors was also successful, although the ultimate failure of the contract with Durham University was one example where a more proactive management team could have picked up problems earlier. It is also true that as the project developed, especially with the mid-stream pivot to compost, there were periods when management capacity was constrained and more attention to project management demands in the original bid would have been useful.

While there were some initial concerns that DESNZ reporting and administration requirements would detract from the practical research tasks within the project, these turned out to be unfounded, with the support provided by the DESNZ Monitoring Officers and other members of the programme team being invaluable. Once familiar with reporting system, it was relatively straightforward to maintain the administrative requirements.

In accordance with DESNZ project reporting requirements, The Project Plan (Gantt chart) is shown in Annex 13 and the TMB Project Risk Register in Annex 14.

9 Conclusions and Next Steps

The Teesdale Moorland Biomass Project has successfully demonstrated the technical, practical and financial feasibility of the original innovation concept – to produce commercially valuable products from upland heather as an alternative to the existing practice of periodic heather burning. Furthermore, while the aim of providing a national scale biomass resource assessment proved overambitious for the project budget and work schedule, the work on yield assessments and harvest availability does suggest a very substantial, hitherto untapped, biomass resource is available in the British uplands, that can be readily exploited, without any implications for existing land use, food production, or consequent adverse environmental impacts. In addition, the net environmental gain arising from heather harvesting compared to periodic burning appears very substantial.

The project found that heather has significant potential as a fuel source, generating substantive data on the economics and net energy gain from the drying process, while also demonstrating the capability to be processed into a range of solid fuel types. However, the finding that smoke emissions are significantly above the DEFRA ‘Ready to Burn’ threshold effectively limits this potential to larger commercial boilers with appropriate stack emissions mitigations, limiting the potential market, and introducing likely complications from longer transport distances to a restricted number of larger end users.

In contrast, the production of heather and blended heather, rush, *Molinia* and bracken based compost products was found to be technically feasible and economically viable. The different production methods tested offer a variety of options for landowners, allowing the development of bespoke production hubs to suit local resources, and the resulting products appear to have high value in the horticultural growing media market.

Set against the context of the UK government's stated objective of eliminating peat from the horticultural sector, along with a longer term desire to reduce the reliance on imported coir peat replacement products, the development of upland biomass supply chains is seen as potentially a very significant advance. If the yields generated during the project from the Barningham Moor site were replicated elsewhere, it appears that harvesting just 7.5% of UK uplands would potentially generate sufficient compost to entirely displace current UK peat consumption.

Alongside the development of the TMB Process Costs Calculator, a spreadsheet based tool capable of assessing site yields, production output and a full operational economic appraisal, the project team have also developed a business model capable of delivering production at scale. This model of mobile, centrally owned harvesting equipment servicing a production cluster model, with remote process monitoring for compliance and product quality assurance, along with a centralised sales system, overcomes the innate complications of the geographical distribution of the biomass resource and the pattern of stakeholder ownership. This model also enables the scaling up of the innovation without placing high capital finance demands on landowners, while also enabling the provision of expertise and process oversight.

The project partners have established a new venture, Moorland Biomass Ltd, to take this forward, and the first commercial harvest is anticipated in spring 2025. The rate of future expansion is contingent in part on accessing sufficient capital, and funding is being sought from the UKRI Farming Innovate Programme, among other potential sources.

Acknowledgements

The authors would like to thank the following for their assistance in the Teesdale Moorland Biomass Project:

Sir Edward Milbank Bt, Barningham Estates
Will Morris, Barningham Estates
Wayne Green, Barningham Estates
Paul Leadbitter NPAONB Partnership
Forest Research Unit, Forestry Commission
RUF UK Ltd, Staffordshire
Staff at the DESNZ Biomass Feedstocks Innovation Programme
Rhiannon Turner and colleagues at the Carbon Trust NZIP Accelerator Support Programme
Prof. Richard Lindsay, University of East London
Prof. Chris Bell and colleagues at Biomass Connect, UKCEH
The Moorland Association
BGI Ltd
Sean Higgs, Floralive

Disclaimer

The information contained in this report is based on a variety of survey evidence, research and practical experience. In developing the findings a number of assumptions have had to be made, and while every effort has been made to ensure all data is accurate it is inevitable that there will be some variation and potential inaccuracies. The report has been checked by TEC Ltd for consistency and validity. Where assumptions have been made these have been stated, and a number of areas of uncertainty have been highlighted. The results contained in this report do not constitute guarantees of performance or cost, and TEC Ltd will not be liable for any losses arising from acting on the conclusions of this report.

Ewan Boyd
Teesdale Environmental Consulting Ltd.

3rd February 2025

[1] Area of heather produced by report author from assessment of Google Earth satellite imagery. Images access 25/11/2021 and satellite images dated 27/6/2018.
[2] Aebischer N E and others 'Driven grouse shooting in Britain: A form of upland management with wider conservation benefits', In: Allen, P. (editor.) Ecologic and Economic Benefits of Hunting, 2010: pages 186-201.
[3] UK Biodiversity Action Plan Priority Habitat Descriptions: Upland Heathland, Joint national Committee on Conservation 2008
[4] Scottish Land and Estates & Scottish Moorland Group 2013
[5] https://www.moorlandassociation.org/ [Accessed 27th December 2021]
[6] https://www.moorlandassociation.org/wp-content/uploads/2015/03/Research-White-Paper-Grouse-shooting-and-management.pdf [Accessed 27th December 2021]
[7] https://www.forestresearch.gov.uk/documents/5073/FC_HWF_Assessment_of_the_use_of_landscape_management_arisings_as_a_feedstock_f_i8Lx8r4.pdf [Accessed 27th December 2021]
[8] https://www.forestresearch.gov.uk/documents/5074/FC_HWF_Assessment_of_the_use_of_gorse_and_heather_arisings_as_a_feedstock_for__absrhhS.pdf [Accessed 27th December 2021]
[9] See https://www.loglogic.co.uk/index.php/product-range/all-terrain-vehicles/softrak140 [Accessed January 4th 2022]
[10] DECC, 2016 (author Mills, S.) Wetland Conservation Biomass to Bioenergy End User Report
[11] See https://www.nature.com/articles/s41598-023-32167-6
[12] See https://www.lsuagcenter.com/articles/page1651158185675
[13] See https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-particulate-matter-pm10-and-pm25 [Accessed 27/01/2025]
[14] Anderson J L and Hetherington S M 'Temperature, nitrogen availability and mixture effects onthe decomposition of heather [Calluna vulgaris(L.) Hull]and bracken [Pteridium aquilinum(L.) Kuhn] litters' Functional Ecology 1999: volume 13
[15] See https://knowledge.bsigroup.com/products/specification-for-composted-materials?version=standard
[16] See https://madcompany.com/for-growers/
[17] See https://www.pthorticulture.com/en-us/training-center/sphagnum-peat-moss-influence-on-physical-properties-of-growing-media
[18] See https://adas.co.uk/wp-content/uploads/2021/09/Growing-media-methods_FINAL_7_June_2016.pdf
[19] See https://www.nnfcc.co.uk/files/mydocs/Farm-Scale-Anaerobic-Digestion-Plant-Efficiency-NNFCC-11-015.pdf
[20] See https://assets.publishing.service.gov.uk/media/5fdcc2fad3bf7f3a30ec487f/structure-jun2020final-uk-22dec20.pdf
[21] Worral F and Clay GD 'The potential use of heather, *Calluna vulgaris,* as a bioenergy crop' mass and Bioenergy 2014: volume 64, pages 140-151
[22] See https://consult.defra.gov.uk/soils-and-peatlands/endingtheretailsaleofpeatinhorticulture/supporting_documents/Consultation%20Impact%20Assessment%20%20Ending%20the%20Retail%20Sale%20of%20Peat%20in%20Horticulture%20in%20England%20and%20Wales.pdf
[23] See https://hta.org.uk/media/omiojakk/2021-growing-media-monitoring-report-vf.pdf
[24] See https://consult.defra.gov.uk/soils-and-peatlands/endingtheretailsaleofpeatinhorticulture/supporting_documents/Consultation%20Impact%20Assessment%20%20Ending%20the%20Retail%20Sale%20of%20Peat%20in%20Horticulture%20in%20England%20and%20Wales.pdf
[25] See https://www.rspb.org.uk/helping-nature/what-we-do/influence-government-and-business/policies-and-briefings/moorland-peat-burning
[26] See https://www.theccc.org.uk/wp-content/uploads/2020/06/Reducing-UK-emissions-Progress-Report-to-Parliament-Committee-on-Cli.._-002-1.pdf
[27] 'Composting heather could replace controlled burning on moorlands', The Times, January 7th 2024
[28] See https://www.dropbox.com/scl/fi/o71qrwdf8eaoscthdkwqh/ITV-Tyne-Tees-6-Sep-2023.mp4?rlkey=jtrqeu0umhjcn2pnwfjxsvlcy&e=1&dl=0 and https://www.itv.com/news/tyne-tees/2023-09-06/harvesting-energy-from-the-moors-how-heather-could-be-fuel-of-the-future
[29] See https://www.countryside-alliance.org/resources/news/heather-compost-another-beneficial-byproduct-of-grouse-moor-management