TEESDALE MOORLAND BIOMASS PHASE 1 PROJECT REPORT (TEC-293-1-M)

FINAL VERSION

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1 Introduction and Background

This project is funded by the Department of Business, Energy and Industrial Strategy (BEIS) through the Biomass Feedstocks Innovation Programme. The project is led by Ewan Boyd of Teesdale Environmental Consulting Ltd (TEC Ltd.) in collaboration with project partners Barningham Estates, County Durham, and Durham University.

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 Figure A2.1 in Annex 2 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 Fig. A1.1 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 – 10 year rotation, with small patches typically less 0.3 – 0.5ha subject to burning of the above ground vegetation while leaving the peat soil and rootstock intact to encourage heather regrowth. (See Figure A1.2 in Annex 1).

The key objectives of the Teesdale Moorland Biomass Project are to quantify the potential to replace heather burning by a biomass production system, along with producing useable biomass from other moorland vegetation species such as bracken (*Pteridium aquilinum*) 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 energy strategy.

The key principle guiding the project is 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. The approach of the project is therefore to identify the feasibility or otherwise of replicating current heather burning outcomes with an alternative regime that diverts waste crops into the biomass feedstock chain, as well as to identify any other biomass cropping opportunities in upland areas.

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 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 A2.2 in Annex 2.

Heather is an evergreen shrub growing to an ultimate height of 0.2 - 1m and spread of between 0.1 - 0.5m in 2 - 5 yrs. 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 by contrast is viewed as an invasive species, with many of the developing Environmental Land Management Scheme (ELMS) agreements including payments for bracken suppression measures, usually cutting or chemical treatment.

Sport shooting is a key economic activity on many upland moors, with many moors managed specifically for grouse shooting. The total upland heath area in the UK has been assessed as between 2 and 3 million hectares[3]. Scottish Land & Estates estimate that 1 million hectares are used for grouse shooting in Scotland[4], with 348,029 hectares under grouse moor management in England and Wales[5]. Therefore at least 1.3 million hectares 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 Description

Five key questions have been identified within the Phase 1 project that need to be addressed:

- 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?

3.1 Assessment of Moorland Crop Yields and Accessibility for Harvest

Developing an understanding of the likely biomass yield that can be reasonably achieved from moorland vegetation is probably the defining question of the project. The detailed findings of the Phase 1 project regarding potential yields are discussed in more detail in Section 4 ‘Contribution to Biomass Supply’. In this section the key activities within the Phase 2 proposal are discussed.

The two measures of harvest yield are the mass of vegetation grown and the proportion of this that can be harvested. A test harvest indicated yields of 30t/ha (eight years after last burn). To develop a robust methodology to assess the standing heather crop, Phase 2 will conduct randomised sample site measurements of heather stands, comparing growth height and stem density with harvested volumes. This will enable moorland managers to determine likely harvest yields with a validated field methodology.

To assess the accessibility for harvesting, a classification system to determine the suitability of moorland 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 TMB Moorland Terrain Classification System (MTCS) uses these three variables with the added variables of density of crop cover and distance to access tracks. 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. It is proposed that these will be applied and refined as appropriate within the proposed Phase 2 research, possibly also working with the Hennock International Ltd Marginal Land Biomass Extraction project if appropriate.

Within Phase 1 a trial Teesdale Moorland Biomass (TMB) Calculator has also been developed (see Annex 5) which provides a spreadsheet based application that is intended to provide land managers with the ability to assess moorland for biomass supply potential. The Phase 2 proposal will build on this to refine the input data and test the results.

3.2 Heather Cropping Techniques and Potential Soil Impacts of Crop Removal

A key issue with heather cropping is whether the removal of biomass has any impact on the moorland soil compared to heather burning. In Phase 1 the project compared the impacts on soil from three different treatments on adjacent test plots; conventional burning; cut and removal to simulate a biomass harvesting operation; a control plot whether the heather was left untouched. Soil samples were analysed by Dr John Bothwell of Durham University Biosciences Department to determine where periodic crop removal had any short-term impacts on soil elemental composition or the soil metagenome (the bacterial diversity which is a proxy for soil health). While the initial results are positive, a longer term study of these impacts across different seasons is needed to confirm these findings, and soil testing will continue throughout Phase 2.

In terms of cropping methodologies, moorland heather can be cut by conventional tractor driven cut and bale systems, similar to hay and silage. However, ground conditions represent a critical limiting factor, with soft ground requiring low ground pressure double wheeled machinery, 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 on fragile peatlands. 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 there are cases of cutting back vegetation in order to control sward composition, typical moorland management practices do not require harvesting of standing crops. In cases where cutting is practised, it tends to be targetted action against a specific species, such as bracken or rushes, and the cut material is usually left to decompose. Heather is however, sometimes cut and cropped for conservation purposes, both to maintain enhanced biodiversity[9] and also through a relatively new technique of collecting heather brash to spread on bare peat areas to aid peatland reclamation.[10] In the latter case, the objective is to gather the resulting vegetation, which is usually a mix of heather, billberry, sphagnum and cotton grasses, for transport to depleted moorland sites as part of specialist conservation efforts. The objectives of such harvesting is not to process the resulting crop, but instead to use the crop as the basis for reseeding peatland vegetation elsewhere, with the material blown into large dumpy bags and transported by helicopter to the recipient site. This harvesting approach is not viable for an ongoing biomass supply project, where transport methods must be more cost effective and there is a requirement to minimise adulteration of the crop with any wet material or soil.

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 with as little soil contamination as possible, following the findings of the previous Forestry Commission studies. A harvesting method that was sufficiently small scale to allow for the replication of the mosaic patchwork and was capable of being safely transported to relatively inaccessible areas of moorland was also desirable.

During Phase 1 a small-scale harvesting method was tested on 200m2 of heather using a single axle tractor unit with bar cutter and mini round baler provide by Rapid Tractors Ltd. This yielded 30 mini-round bales of 20kgs each, 600kg in total, at a yield of 30t/ha-1. (See images A1.3 and A1.4 in Annex 1). The BEIS Monitoring Officer Ravi Raichoora and Programme Manager Dr Victoria Honour were both present during the cropping trial and witnessed the quantities harvested.

However, the required labour inputs were excessive, with six man-hours needed to complete the operation. It is therefore proposed to use a Loglogic Softrak 140 low ground pressure machine with a DC1700mm double chop forage harvester cutting head and integral $18m^3$ collection bin which can be tipped into an awaiting trailer[11]. This technique has been successfully trialled in biomass production on very wet reed bed areas [12] and is also currently in use for peatland restoration work in the North Pennines (see ref. 9).

Key advantages are an all in one cut-and-collect operation, reducing both harvesting time and vehicle movements on the fells, and very low ground pressure of 1.35psi, around seven times less than a normal human foot. The design of the harvester head can be easily modified to add or remove blades which allows adjustments to the particle size[13], an important factor for biomass processing, and previous field trials have found that the ‘J’ shaped blades operate in such a way that reduces the required suction while preventing the chopped material from contacting the ground before being removed (see ref. 12).

The Softrak 140 is available locally on a contract hire basis, and this option is incorporated into the project design for the Phase 2 project, with the objective of undertaking trial cuts of 1 – 3ha annually within the three year period. While the long term commercialisation plan involves the purchase of a dedicated Softrak harvest system to enable production to be scaled up, the use of contractors within Phase 2 avoids the lengthy 12 months+ lead time currently for new orders, while still allowing for adequate sampling harvesting days as required.

3.3 Moisture Content of Heather and Pre-Processing Drying Requirements

Moisture content of biomass feedstocks is a critical parameter in the production process. Any level of moisture reduces the overall calorific value of biomass, and high moisture levels can also reduce the combustion temperature leading to incomplete combustion, with smaller boilers tending to be more susceptible to fuel moisture content[14]. For these boilers, fuel moisture content of 20% - 30% is required. Pre-processed firewood typically has a moisture content of 50% or above, and woodchip production requires either an extended period of ambient temperature seasoning or forced drying through mechanical heated dryers.

The standing moisture content of heather is significantly lower. Previous trials producing pellets from cropped heather found spring harvested heather with a standing moisture content of 20% (see ref. 7). Another study found cut heather with moisture content ranging from 10.52% in October to 15.72% in August, with these values measured after 5 days drying at ambient temperatures[15]. Research also indicates that harvesting heather under the right conditions can substantially reduce the crop moisture content, with rapid reductions in live fuel moisture content experienced by heather in cold winter conditions as the heather rapidly desiccates[16]. The low moisture content of cropped heather raises the possibility that if cropped under optimal conditions, heather could be processed into fuel without additional drying. Where drying is required, ambient temperature drying may be possible.

In Phase 2 the moisture content of the standing heather crop will be monitored throughout the year via regular sample testing to identify optimal harvest conditions. This will identify suitable conditions for heather to be cropped at low moisture levels, permitting processing without further drying. However, Phase 2 will also test alternative drying methods to optimise the process efficiency and minimise the energy inputs required, allowing a wider harvest window.

Three drying methods will be tested. First, ambient drying will lay samples on a hard floor in a covered barn with periodic turning. This may include use of fans for gentle ventilation, and possibly the addition of some heated air. Second, a simple low cost drying floor will be constructed, using a raised mesh floor with ducted forced air (ambient temperature and heated). Preliminary designs for a 3.75m2 dryer capable of drying around 4m3 have been developed in Phase 1, including calculations of required air pressure and heat inputs (calculations based on ref 14). Third and finally, the project will trial batch-drying in a commercial log drying kiln[,using an adapted drying crate with vent ducts laid through the heather brash. For each of these methods, detailed records will be maintained regarding drying times, ambient temperature and humidity, costs and efficacy.

3.4 Biomass Product Processing Options

Both heather and bracken have high lignin content (measured at 40.6% and 49.0% [17]). This makes both crops potentially suitable for processing into pellets or briquettes, where binding to form a solid mass is required.

Long transport distances between harvest and processing centres are unviable, and Phase 1 identified how local supply chains could distribute the resulting biomass product, with three potential end uses being identified; chopped heather (either pure or mixed with conventional woodchip) in large woodchip boilers; heather pellets in pellet stoves; heather briquettes for use in conventional stoves or log boilers.

In addition, most upland areas where heather moors are located are in areas without mains gas and where high emission heating fuels are common. In the Barningham area, previous work commissioned by the Barningham Net Zero CIC community group identified that the village consumed a total of 1,930MWh of heating oil (kerosene) annually, equivalent to 75% of the total village heat demand[18]. In common with other rural areas, a significant proportion of households in Barningham have multi-fuel stoves suitable for burning briquettes, with an increasing number of pellet and woodchip fired systems also being installed.

While particle size specifications for boiler feeds and pellet and briquette pressing machines vary, a harvested size of up to 50mm was found to have widespread potential across all three options. While the Loglogic Softrak and double chop D1700 cutter head has achieved a chop size of 40mm - 65mm in previous biomass trails (see ref. 12) the design of the cutter bar is such that additional pairs of blades can be added to achieve a smaller cut size. It is therefore anticipated that a lightly adapted DC 1700 Loglogic cutter will provide suitable material for all three solid biomass end uses without the need for additional milling.

Within the Phase 2 proposal it is intended to trial all three of these solid biomass options. Barningham Estates currently already operate two woodchip fired district heating systems, each powered by an auger fed ETA 200kW biomass boiler. The fuel storage and supply infrastructure for these boilers is already operational, with the boilers operating on G30 chip specification at 20% moisture content, although technically capable of accepting G50 grade chip. Trial firings will be undertaken to assess the effectiveness of heather chip and mixed heather and woodchip within the Phase 2 project as a direct replacement for woodchip. Subject to confirmation of the 10% - 15% moisture content of standing heather in winter from ref. 15, this raises the prospect that the Phase 2 project could consider a simple cut and deliver woodchip supply direct to woodchip end users without any post-harvest drying or processing required.

Alongside the local woodchip demand, the Phase 1 project identified an existing local demand for a sustainable solid fuel that would be suitable for wood burning stoves, with a more limited local demand for pellets. Although domestic pellet demand is likely to rise over time, most smaller pellet boilers require EnPlus A1 standard pellets or similar, while commercial pellets boilers can accept lower grades. However, the analysis in the Phase 1 project indicated that such a pelleting operation would need to be of reasonable scale to successfully access the commercial pellet market, whereas the distributed nature of the heather/bracken resource instead lends itself to a smaller scale operation with a more localised supply chain. Without confirmation that the A1 pellet standard would be achievable for the heather feedstock, it was unclear whether heather/bracken biomass would be suitable for the more local pellet market likely to develop in the coming years.

Given this, within Phase 2 a small scale pelleting trial is also envisaged, with off site pelleting of a sample batch by Condex Ltd. Discussions have also taken place with White Horse Energy Ltd regarding their mobile pelleting project. Should both applications be successful we envisage collaborating on larger scale trial pelleting of the heather crop. This would potentially enable heather/bracken derived pellets to enter the commercial biomass feedstock supply via a third party producer/wholesaler, who could be contracted to provide an on-site pelleting service as required while having the capacity to aggregate supply sufficiently to operate at the scale required for commercial pellet supply beyond Phase 2.

Within Phase 1 a test briquette pressing was undertaken by RUF UK Ltd. A total of 60kg of baled heather was processed and the resulting briquettes were classified as ‘Excellent’ by the production assessment process, with no adverse issues noted. The RUF test press report is attached as Annex 8 (separate document). See also images A1.5 and A1.6 in Annex 1.

The trial harvesting and test pressing were not originally included within the Phase 1 work schedule, and are therefore added value elements of the delivery programme. Due to budget and time pressures, it was not possible to test the quality of the briquettes against Enplus standards, but informal burn tests have been undertaken in a domestic stove, which showed promising results, with a good burn and high heat output. Should the Phase 2 application be successful, a sample batch will be sent to AF Knights of Dundonald for full quality testing.

In Phase 2 it is proposed to contract RUF Ltd to conduct 4 weeks of test briquetting (up to 9 tonnes per week throughput) with the chopped heather being transported to their works for processing. In year 3 an additional week has been scheduled where an RUF Ltd press will be leased for a one week on-site trial.

Alongside the piloting of heather chip, briquettes and pellets feedstocks, the Phase 2 proposal will contract AH Knights Energy Services Ltd of Dundonnel to conduct quality tests of the resulting biomass products (woodchip, pellets and briquettes). This will inform decisions on product development and sales.

Work during Phase 1 also revealed a fourth opportunity for heather to supply the biomass feedstock sector, through the development of novel liquid biofuels. Discussions with Jeremy Oakley of Oakland Biofuels Ltd have led to the possibility of the Phase 2 project supplying a test batches of cut heather for the biofuel production process.

3.5 Assessment of Appropriate Scale and Model for Moorland Biomass Supply

With an abundant resource at Barningham, an appropriate harvesting method, and options for end use biomass production, the remaining determining factor defining the optimal operational model is one of the geographical scale. This is heavily influenced by the costs of bulk transport of the raw material. The Phase 1 project has determined that it is not viable to develop a model that requires unprocessed moorland biomass to be transported long distances (>20miles) to more centralized processing depots. Consideration was given to the use of compacting trailers to compress the harvest material to reduce the number of loads to enable longer transport distances, but the size of these make it difficult to integrate with the harvesting machinery, with the transfer ideally needing to take place on the moors very close to the harvested areas, and the Softrak unable to tip into high sided compacting trailers.

Given the likely yields available, and the observation that many estates either already have commercial biomass boilers or are suitable for the future development of these, the project has concluded that a smaller scale operation is most appropriate. The principle would be that the harvested material is dried and processed as close to the originating moors as possible, so the bulk is reduced and value enhanced prior to any transport to end use or market sale.

Early data from the TMB Calculator (discussed in detail in section 4.1 and available as Annex 5) suggests that Barningham Moor has sufficient available biomass to sustain a profitable biomass production operation, with significant free capacity to extend to other neighbouring estates via a production cluster model. In this model, the capital equipment is mobile and can be temporarily relocated to a different processing location, in a similar way that large agricultural equipment such as combine harvesters and grain dryers can work on a farm by farm contract basis. This model of single estate operation with additional production clustering is likely to be the predominant model of moorland biomass production, with either contracted harvesting and processing or shared equipment between cooperating estates.

The end use for the produced biomass may be combined into a single marketing operation on a cluster by cluster basis, but this may be more difficult to organise due to quality standards and the costs and difficulties of achieving accreditation on a multi-site operation. Instead, the project currently envisages a preference for self supply biomass production systems, with excess production sold into the local commercial biomass boiler market along with some domestic retail provision. The Phase 2 proposal will confirm these preliminary findings by adding more certainty to the yield and production costs, with product quality testing also confirming the most appropriate end users.

4 Contribution to Biomass Supply

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 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[19]) 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 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/ha/year. [Dry matter, above ground biomass only].

Biomass growth rates of bracken *Pteridium esculentum* have been observed at between 2,000 – 14,000kg/ ha/year^{-} dry matter (again excluding below ground rhizome biomass) subject to the density of fronds. Altitude and climatic region will again influence these values, but there is insufficient data available on regional variations. However, many landowners are seeking to control bracken, and while biomass harvesting may be one avenue, if the objective is the long term control of bracken, then naturally occurring yields should be expected to decline over time and should not be taken as a basis for long term viability projections.

The energy content of heather was measured by Worrall and Clay at 18MJ/kg, (5kWh/kg), suggesting a gross annual energy yield at the Barningham test site in the order of 1.75MWh/ha. The energy yield data may be a slight overestimate, as the energy content data is based on dry matter, rather than a normal moisture content typical of a biofuel. Data from ref. 7 shows test results from wood pellets produced from heather having a Net Calorific Value[20] (NCV) of 16.8MJ/kg (4.67kWh/kg), which provides a more relevant figure for comparative purposes but is consistent with the Worrall and Clay findings.

While the 1.75MWh/ha/yr is low as an annualised figure compared to other dedicated biomass crops, the Worrall and Clay modelling suggests that due to the rotational cropping over an extended time period, a substantially higher energy value per ha. can be realised at the point of harvesting, thereby lifting production efficiency. In the case of the Barningham Phase 1 test plots, with an 8 year burn rotation, the modelled data suggest a yield of an encouraging 14MWh/ha.

For bracken, data supplied by Oakland Biofuel Ltd indicated test results from bracken of between 19-21MJ/kg (5.2 – 5.8kWh/kg). This suggests a wide range of possible annual energy yields, given the highly varied biomass production data, of between 10.4 – 81MWh/ha.

Overall the energy content values for heather and bracken both compare favourably to other conventional biofuel crops[21]. It is notable however, that the modelled overall energy yield per hectare for heather is somewhat lower than for most other biomass crops, entirely as a consequence of the slower growth conditions. Overall yields for bracken however, appear potentially comparable to short rotation coppice willow and wood fuels, subject to growing conditions.

The relatively low overall energy yield per hectare for heather is not seen as problematic for the principle of heather cropping for biomass, as the project is targeting marginal land where there is no competition with more productive crops, and where the current management practices effectively waste the biomass resource. A key innovative aspect of the Teesdale Moorland Biomass project is that any gains in terms of increased biomass feedstock come without any material change of land use or loss of productive land.

4.1 Contribution to Biomass Supply From the Project Site

There are strong indications from the Phase 1 project that yields may be substantially greater than the Worral and Clay theoretical estimate. Their study predicts an annual dry matter yield of c 350kg/ha at this site, or 2.8t/ha over an 8 year harvesting cycle, but our actual yield of 600kg from a 200m2 plot suggests a yield of 30t/ha. In part, this discrepancy could be explained by moisture content, with the harvested sample crop undried. However, if the moisture content at harvest is assumed to be 20%, as found in ref.7, this would still suggest a comparable trial crop of 24t/ha dry weight, falling to 21t/ha if the moisture content at harvest was assumed to be 30%. This raises considerable discrepancy between the theoretical yield data and the field trials, with a potential energy value at harvest of between 98-112MWh/ha at an annualised rate of between 12.25 – 14.0MWh/ha/yr from the harvested trial plot.

This significant divergence between theoretical and actual data could not be definitively resolved within the Phase 1 trial, and resolving this is a key feature of the Phase 2 proposals. Under the Phase 1 bid as submitted a sample harvest trial was not originally anticipated, so a full sampling program was not designed. This means the field trial is from a single small plot, which may be more or less representative. However, there are some tentative indications from additional Phase 1 work that the field trial data is more accurate at this location that the Worral and Clay theoretical model. Additional walkover surveys of other areas of Barningham Moor were undertaken to assess heather patches of similar age to the trial plot. The vegetation height and stem density (number of stems per m^2) of the trial plot (the remaining control plot) were measured, as a general proxy for crop density, and these were found to be broadly consistent with several other patches of aged heather across the moor, suggesting that the trial harvesting data has reasonable validity. However, our findings must remain provisional until we have conducted a formal randomised survey.

In terms of the contribution to biomass supply and the commercialization of the proposal, the Phase 1 project identified a total of 620ha of high density heather cover on the Barningham Moor (see ref. 1), with a target 8 – 10 year burning cycle indicating approximately 60ha/yr$^-$ are burned. If the yield at harvest was to be confirmed at 30t/ha/yr then that would provide a gross harvest (heather only) of c. 1,800t/yr. In reality, the harvest tonnage would be less than this due to parts of the moor being unavailable for harvesting through the presence of blanket bog, steep slopes, inaccessible location for machinery or the presence of significant obstacles. (See MTCS in Annex 4).

Within Phase 1 the TMB Calculator was developed to provide a methodology for assessing the available harvest, calculating the workload and input energy requirements for harvesting and transport to the processing unit, drying requirements and processing into end use biomass material, with the calculations providing a net energy yield for the harvested heather and a projected CO2e emissions calculation for the end use biomass. Much of the input data used within the TMB Calculator therefore remains provisional, and defining more accurate input data is a critical part of our Phase 2 proposal. However, current knowledge from Phase 1 enables a reasonable estimate to be made of the overall potential for biomass supply from the Barningham Moor site.

Based on the measured heather cover and the anticipated burn interval, with deductions in respect of inaccessible areas and areas that cannot be harvested, (using the methodology employed in the MTCS in Annex 4) the TMB Calculator indicates an annual crop harvesting figure of 40.5ha for the Barningham site. Using the trial harvesting data of 30t/ha as the provisional harvest volume, the TMB Calculator projects a potential annual heather crop for the Barningham Estate of 1,200 tonnes, yielding a gross energy value of 3,850MWh once moisture content and process losses are accounted for. Once harvesting, transporting and processing the harvest material into final biomass products are accounted for the TMB Calculator indicates that the Barningham Moor site could produce an annual net yield of 3,780MWh with unit emissions of 0.0041kg/ CO_2e/kWh, around 27% of the current BEIS conversion factor for woodchip and wood pellets. If this was to replace kerosene heating oil, then net annual savings of approximately 1,000t/CO_2e could be achieved. [Using BEIS 2021 kerosene conversion factor of 0.25975kg/CO_2e/kWh].

4.2 The Potential Contribution from Moorland Vegetation to National Biomass Supply

This difference between theory and observation makes it somewhat difficult to assess at this early stage the significance of our innovation to UK biomass production. Worral and Clay estimate there is between 2,800km^2 – 7,000km^2 of heather across the UK, of which between 112km^2 and 875km^2 is burned annually. A 2005 research paper from Natural England, covering English uplands only, identified heather dominated vegetation in a total of 2,486km^2, but with only 725km^2 under active burn management and the area actually burned annually defined by a highly varied burn interval of between 6 – 20 years[22].

The Worral and Clay paper provides a calculated annual net potential energy yield (UK) from the currently burned heather of 0.025Mtoe or 290GWh (allowing for combustion efficiency losses and harvesting/processing energy inputs), rising to 0.119Mtoe/1,383GWh if all the available heather was harvested. In context, this would equate to between 1.1% and 5.1% of the amount of renewable heat derived from plant based biomass and domestic wood consumption from 2020[23]. No figures could be derived for the potential contribution from bracken to the total biomass feedstock supply, although it is clear that there is energy value within bracken and the same harvesting methodology as proposed here could enable further biomass gains from bracken crops.

While terrain will limit the area of heather that could be practically harvested, the divergence in yields in the Phase 1 field trial of >10 times the theoretical yield suggests that heather moors could provide a more substantial proportion of current and future biomass heat demand than previously estimated. A key aspect of the Phase 2 development will be to expand the harvesting trial and develop greater certainty regarding the anticipated yields.

During the Phase 1 programme, contact was made with representatives from Yorkshire Water PLC, who expressed an interest in the Teesdale Moorland Biomass project and its relevance to upland land management in the South Pennine area. The company is responsible for substantial areas of degraded uplands, dominates by *Molinia* grasslands, where coarse purple moor grass *Molinia caerulea* dominates. This is viewed negatively by both farmers and conservationists, as *Molinia* dominance leads to reduced nutritional values alongside poorer conservation outcomes. In the case of Yorkshire Water, there is a particular concern over the build up of fire hazards, with the dry spring vegetation typical of *Molinia* grasses creating a major uncontrolled fire hazard.

Preliminary discussions have focused on whether there is a possibility to identify a productive option for the periodic harvesting of *Molinia* grasses as a mechanism for reducing fuel loads and protecting against catastrophic wild fires. There will be energy value within the standing *Molinia* crop, although it is not yet clear whether this is in a suitable form for biomass production. However, some work to assess this is proposed within the Phase 2 program and the harvesting systems should have widespread applicability to other upland species beyond heather.

The Phase 1 project has confirmed that there is a significant biomass potential from upland areas, predominantly through the management of heather on grouse moors for biomass rather than open heather burning, and that there is an existing requirement for heather to be periodically managed. This confirms that moorland biomass can potentially provide a substantial national biomass resource without any additional demands on agricultural land, and with a positive ecological benefit.

5 Wider Environmental Benefits of Moorland Biomass Production

5.1 Comparative Impacts on Soil Quality From Heather Burning and Biomass Harvesting

To test whether cropping has an adverse impact on soil; health compared to burning, a soil testing program was developed by Dr John Bothwell of Durham University. Four plots were sampled (control, cropped, recently burned, old burned) over three months (Oct-Dec 2021), for a total of 48 samples from the

Barningham Estate (see images A1.7 and A1.8 in Annex 1). Another 48 samples from a range of other moorland locations in Yorkshire and Co. Durham were also collected to act as baselines and to allow translation of findings at Barningham to other patches of Moorland.

DNA was then extracted and sequenced from the 96 samples, using selected 16S, 18S and ITS primers: the 16S and 18S will give good coverage of the bacterial and microbial soil populations, while the ITS will allow resolution of the soil plant and fungal populations.

While the DNA extraction and sequencing is relatively routine, the DNA extraction was subject to significant delay, as the reagents employed are the same as required for Covid testing. The unexpected emergence of the Omicron variant led to a global shortage of reagents as the unprecedented demand for testing increased. This shortage has now been resolved, and the sequencing has now been completed, although the detailed analysis of the results has not been finalised.

A number of gasification tests have also been conducted on some heather samples, processing these thermochemically into biogas and biochar. In general, both of those components need to be sold if the process is to be economically viable.

These trials confirm hydrogen can be generated, with around 80% hydrogen and 20% methane, normal numbers from lignocellulosic biomass.

Given current energy prices, the biogas composition isn’t the limiting factor, with the key question being whether any profit can be made from the residue after gasification (ie the char or the effluent). One option is to convert the char into activated charcoal, which means that it has a high surface area to volume ratio. Results from gas adsorption measurements from the Durham University engineering department are currently awaited, which will give some idea of the untreated area-to-volume ratio: this will then inform any treatments that we need to convert the char into activated char during the gasification step. These gasification results are additional to the original project objectives, and will add to the available data on the potential for energy from heather.

Full results results from the soil analysis are attached as Annex 3.

5.2 Reduction of Pollution From Heather Burning

The impact of smoke on air quality and public health is well known. Public Health England (PHE) have calculated that over 1.3m new serious diseases were likely by 2035 due to existing $PM_{2.5}$ pollution at a projected total cost to the NHS and social care budgets of between £5.1 - £9.4bn[24]. There is also developing research suggesting that smoke particles from biomass wildfires can persist within the atmosphere over periods of several days or weeks, during which time they can chemically oxidize to become highly reactive ‘free radicals’, becoming up to four times more toxic over time[25]. There is also increasing evidence of public disquiet over the issue of smoke release from managed moorland fires[26].

Burning biomass on open moors is of particular concern, due to the lack of regulation of the combustion cycle that would normally be achieved within an enclosed boiler designed to maximise burn efficiency. Indeed, a target of managed fires is to burn off the top vegetation through low temperature burning, in order to avoid damaging the rootstock or peat surface (see ref. 6), which takes place in conditions of excess combustion air, whereas boilers are designed to operate at maximum burn efficiency and high temperatures. As a result, smoke released from upland fires tends to have particularly high levels of damaging $PM_{2.5}$ particulates[27]. Research into the accidental Saddleworth Moor fire of 2018 cited in ref.27 indicated that 28 premature deaths were likely to have resulted from the fire, with the majority of these arising as a consequence of persistent atmospheric pollution by $PM_{2.5}$ particulates.

Although the Saddleworth Moor fire is a particularly acute example of a very large accidental burn, covering approximately 800ha in an upland area relatively close to population centres, the burn area equates approximately the to total area of heather likely to be burned annually on managed grouse moors in England (from ref. 22) with perhaps three times this burned annually in Scotland.

While the management of heather is essential for biodiversity and to prevent catastrophic wildfire, managed burning inevitably contributes to $PM_{2.5}$ pollution, and while there are no accurate statistics to assess the quantities and temporal and geographic distribution of these, any initiative that can provide the same benefits as managed burning without the particulate release will have a beneficial impact on air quality and health outcomes.

5.3 Ecological and Conservation Benefits of Heather and other Moorland Vegetation Management

There is a continued debate around the issue of peatland management, and in particular the management activities of sporting estates on grouse moors. There is broad agreement that control of heather is required for a range of conservation objectives, alongside the provision of suitable habitat for commercial grouse shooting. If heather is allowed to grow too tall on blanket peat, it increasingly becomes a net CO_2 source[28]. Aged heather also provides reduced wildlife benefits, with significantly lower populations of ground nesting waders found on unmanaged heather[29].

There is some disagreement over the most appropriate method of control however. Cutting acts as the main alternative to managed burning. However, there are concerns from moorland managers that cutting and leaving the resulting brash can both reduce regeneration of heather and allow sedges and grasses to become more prevalent. There is also some evidence suggesting that fertilization from nitrification arising from heather brash left *in situ* reduces the vigour of heather growth, particularly in acid soils, and that the build up of decaying cut heather can lead to the inhibition of growth over time (see ref. 17). These findings clearly favour a cutting regime that removes the cut material.

Various studies have found that regular burning restricts the development of peat forming sphagnum[30, 31], although the majority of this work is focused on blanket bog. Additionally, recent research has identified significant negative impacts of burning on the hydrology of moors[32]. Where cutting is proposed instead of burning, there have been some concerns over the impacts through compaction by heavy machinery and the removal of micro-topography as traditional cutting equipment can remove mossy hummocks[33]. However, this was again focused on wetter blanket bog areas, and such impacts from cutting were considered within the harvesting technology assessment, with the choice of the low ground pressure Softrak and the DC1700 cutter unit, which are designed to avoid damage to either soil density or micro-topography.

5.4 Wild Fire Mitigation by Management of Standing Biomass

With a significantly lower moisture content than live timber and other shrubby species, growing heather can provide a ready combustion fuel. In addition, the tendency of heather to rapidly dessicate under certain conditions can lead to significant fuel loading. (See ref. 16). The build up of high levels of combustible fuel is one of the key determinants to the severity of moorland fires[34], and accidental fires are becoming a more common problem as climate change affects weather patterns. There is widespread concern that moorland areas, including heather, bracken and *molinia* grassland areas are increasingly prone to such wildfires and that management operations to reduce the fuel load is a valid approach to reducing the risk of catastrophic fires. The proposal would achieve this additional benefit, which has relevance beyond existing grouse moors and may extend further the areas where biomass harvesting could become standard practice.

6 Phase 2 Project Plan

A detailed project timetable is set out in the attached Gantt chart (TMB Gantt Chart) which forms Appendix 6. This identifies the key work packages and deliverables, along with the timetable on a monthly basis, milestones and dependencies.

The project plan has been designed around the rationale of providing a real world field trial of a moorland to boiler production process of (principally) heather derived biomass products from a typical northern English upland estate, with the aim of demonstrating a more sustainable means to manage heather. The workflow includes the testing and refining of the Moorland Terrain Classification System (developed in Phase 1) as a means to assess the practical accessibility of heather moorland for harvesting, along with assessing the validity of the TMB Calculator, also developed in Phase 1, to provide a means of determining the viability of moorland sites for economic biomass production. The workflow therefore represents a staged testing of the various elements, refining and revising the findings as the trials progress.

A key aspect of the project is to assess whether cropping and removal of heather, as opposed to periodic burning, leads to any adverse impacts on soil health. Initial results from the Phase 1 sampling suggests that periodic cropping does not disadvantage soil elemental or metagenomic (bacterial) composition, but a longer time series of data is required to confirm this, and in Phase 2 a research programme of soil sampling and analysis across comparative sites under alternative management methods is proposed (workpackage 2).

Yield tests (deliverable 3.1) will commence in autumn each year to capture the full annual growth. This will continue throughout the full 3 year period in order to gather sufficient data to assess annualised yield figures and to allow comparison with other sites.

TMB Calculator Parameter testing (deliverable 3.2) will use map work (slope assessment and accessibility) and site surveys (heather cover, ground conditions and ground roughness) to gather data on suitability for harvesting and match these against the practical experience gained from the harvesting trials. This is scheduled for years 1 and 2 only, as this is judged sufficient for the parameter validation task. Standing crop moisture testing (deliverable 3.3) will continue throughout the project, as spatial and seasonal variations are anticipated, so the number of data points will be maximised in order to capture this variation.

Trial harvesting (workpackage 5) will be conducted by JW Baindridge and will commence with a single day in year 1, with three days each scheduled in years 2 and 3. The initial expectation is that harvesting of 1ha per day is possible. This will be accompanied by moisture testing of the harvested crop, with yields measured and compared against the TMB Calculator projections. Harvesting times will be varied as appropriate in response to the results from the standing crop moisture testing.

The drying trials (workpackage 6) will follow the harvesting pattern, with the design and build of the drying floor commencing in Q1 and Q2. The trials are expected to be iterative, with alterations of methodology as the data is gathered and assessed. The self-built dryer option was deemed to be the most cost effective approach as this is relatively common among self-suppliers of woodchip, and the drying principles are well established. Consideration was given to leasing or purchasing a purpose built drying system, but the capital costs were too great for the partnerships budgets for Phase 2 and no suitable lease options could be identified for the scale of production anticipated in Phase 2.

End use testing (workpackage 7) will follow harvesting and drying, and will focus primarily on briquette production. A test burn in the woodchip boilers will take place in Year 1 Q3, but this will be limited for two reasons. Firstly, RHI accreditation rules mean that using non-approved fuels is administratively problematic, and secondly, the Phase 1 analysis has identified that the replacement of woodchip (in this case self-supplied and sourced from the estate) has less economic potential than the development of a new heather biomass resource for selling on. (On other estates this may be a more cost effective option, which is why this is being tested in Phase 2).

Deliverable 7.1 allows for the hire for one week of an RUF Ltd briquette press in years 1-2 and 2 weeks in year 3, with the material being transported to RUF where they will conduct the pressing. This builds on the successful Phase 1 test pressing of a small sample batch. In year 3, an additional week on-site press hire is included, which will involve shipping the press to Barningham for *in situ* testing. This is a more expensive option, but is designed to ensure that any practical issues can be resolved as part of the development of the commercialisation plan.

Market testing (workpackage 8) will include technical quality testing by an accredited body (AK Knights) with a view to Enplus standard accreditation, as well as consumer testing. Following quality testing, briquettes will be given away free of charge to local end users, in exchange for a commitment to provide a detailed user feedback survey.

Project management (deliverable 1.1) will cover the ongoing management requirements including regular BEIS monthly meetings. A commencement period is scheduled for Q1 (deliverable 1.2) which will finalise contracts, protocols and the detailed project plan. Quarterly reporting (1.3) is included as a separate deliverable. An annual internal project review (workpackage 9) has been included at the end of each year, which will involve a formal review by all the project partners and reassessment and confirmation/revision of the subsequent planned activities. A separate risk assessment table has been attached (see Annex 9 TMB Phase 2 Risk Assessment Table).

Written protocols have been drafted for the field survey work, while detailed protocols for the drying trials will be drafted as part of the dryer construction work package once the design and operation details are finalised. Any results not accompanied by a completed methodological checklist and with contemporaneous field notes and recording will be rejected, and all notes and records will be retained in original form and available for independent inspection. All survey equipment, data loggers and recorders will be independently calibrated.

Laboratory testing of the soil samples will be undertaken independently of the project team on a contract basis as per Durham University operational protocols. All lab equipment is professionally maintained and calibrated as standard. Independent accredited contractors will be used for product testing, with multiple samples used to ensure any natural variances are captured and recorded. All test results will be reported to the BEIS project team.

Consumer product test records will be anonymised and collated in such a manner that they can be shared with BEIS and/or independent project assessors within GDPR regulations. The questionnaires will be drafted to include open questions in order to capture the full range of consumer views, independent of any bias from the project team.

The project lead will sign off all payments only after the satisfactory conclusion of the work and the provision of the agreed outputs. Wherever feasible, outputs have been correlated with reporting milestones which will ensure that BEIS project staff will also have to see acceptable evidence before work is formally signed off. Payments will be withheld for any deliverables deemed not to meet the relevant standards, or if evidence of adherence to operational protocols is not provided. Where the Project Lead is responsible for deliverables, these will be counter checked by Edward Milbank.

All reports and results arising from survey work and activity on the Barningham Estate will be liable to independent review by the Barningham Estate trustees, the body ultimately responsible for the management of the estate, and legally separate from the project team members.

Any data and evidence required for the oversight and governance decisions will be made available to BEIS for inspection, if required, including any drafts, statements or communications received, alongside the formal reports. All such material will be archived for a minimum of six years in accordance with existing TEC Ltd policies.

The Project Manager will oversee the reporting schedule, as was the case in Phase 1. A verbal report and update is proposed for the monthly monitoring meetings, with a written report supplied for the quarterly briefings, along with a RAG status analysis based on the deliverables as detailed within the attached Gantt chart. The proposed milestones have been largely coordinated to reflect the bi-annual stage-gate reviews, and the reporting will reflect BEIS requirements. Written reports will be drafted in consultation with the full project team and BEIS comments and responses fed back where project team members are not present at the briefings and meetings.

7 Future Commercialisation Plan

The Phase 1 project findings highlighted that a localised biomass production system located close to the origins of the biomass crop inputs was required to maximise production efficiency, with the end use either within the estate/farm where possible (particularly in the case of woodchip) or through ideally local or regional supply chains for finish briquettes. The opportunity for aggregate pellet production through a third party mobile pelleting operation is also viewed as a potential route to commercialisation. However, the current Phase 2 commercialisation plan has been developed on the assumption that the plan has to be internally valid without relying on other projects within the Biomass Feedstocks programme.

The TMB Calculator (see Annex 5) indicates a gross annual income of approximately [redacted] based on the current assumptions (see the 'Financial Projections' tab on the yield calculator), a raw harvest yield of 30t/ha (as per the small scale trial harvest) and based on current market prices for woodchip and biomass briquettes of similar energy content. Even given the uncertainties of the harvest yield, this suggests a substantial business opportunity.

The initial draft includes a first estimate of revenue costs, including labour, input energy and overheads. This should be viewed as an indicative projection only at this stage, and will be refined as part of the Phase 2 work as more data becomes available. For example, in the current TMB Calculator version, the heat source for crop drying is assumed to be mains electricity, as for the proposed Phase 2 trials, whereas for a full commercial operation any heat input, if required, will come from the biomass crop itself and therefore be much lower cost.

Within the Phase 1 programme an outline capital equipment budget has been developed, based on the purchase of the full requirements for a commercial biomass supply operation. (See Annex 7 for details). This includes the purchase of a Softrak 140 and DC1700 cutter and was developed on the assumption that full woodchip drying facilities would be required, including a dedicated biomass boiler to serve as the heat source. If the moisture content at harvest is lower, as with the 10% - 15% values found in ref. 15, heated drying may not be necessary, although the drying equipment has been included here to generate a more robust financial model. A containerized woodchip drying system has also been included, which provides for two hookbin containers plus hooklift trailer with drying floors that can double as a dedicated transport system from the moor to the processing facility as well as the drying facility. The draft commercialisation plan has been developed on the basis of a high equipment specification, so all equipment is priced as new.

Given these factors, the initial iteration of the TMB Calculator indicates a substantial net annual return on investment (ROI) of [redacted](excluding finance costs), with the return remaining positive even if the yield was reduced by 50%. These figures are based solely on the biomass production operation on Barningham Moor itself. There is significant opportunity to expand the operation and the commercialisation plan has been developed on the basis that it is transferable to other estates.

The projected utilisation rate of the equipment is low, if Barningham Moor is the sole harvested area. The Softrack would be engaged on Barningham Estates for under 50 days per annum, while the briquette press would be required for around 70 days and the dryer around 160 days, (although this is on the basis of a somewhat pessimistic 30% moisture content at harvest). For all the equipment, there would be ample scope for extended cropping and processing on other sites, providing a significantly enhanced income generating potential. For example, the hiring out of the Softrak (plus driver) on a contract basis could yield a net [redacted]per day surplus after costs at current local market rates.

To avoid the inefficiencies of transporting bulk moorland crops long distances for processing, the drying facility has been selected to be capable of regular relocation, with ambient air drying possible at any location and heated air drying where there is an appropriate heat source already available or capable of being installed. Depending on the end use processing, this could produce dried heather chip or utilise the mobile pelleting option, or the briquette press could be temporarily relocated.

The Teesdale Moorland Biomass proposal is therefore capable of providing a cost effective local enterprise in its own right, based on the model of a localised harvest and biomass supply operation, with the potential for the widening of the operation to neighbouring estates under a cluster model, maximising the utilisation rate of the supply infrastructure and the consequent business turnover. The cluster model could operate as a contract operation, providing a service to harvest and process moorland biomass for third parties to consume or sell on, or it could develop as a dedicated biomass supplier, harvesting on third party moorland but retaining control of the resulting biomass product. The precise pattern of these commercial relationships is one of the key questions to be answered in Phase 2.

In addition to the further development of the Barningham biomass harvesting cluster, the Phase 2 project envisages developing the TMB Calculator as a commercial asset. Following testing and validating in Phase 2, this would be available for TEC Ltd to provide consultancy services to moorland owners seeking to develop their own biomass supply operations, forming the basis of financial planning for new developments and identification of market opportunities.

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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.

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24th February 2022

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