sofies

The Biochar Network - Demonstrating a Scalable GGR Solution

Final Report

Certified B Corporation

BLACK BULL BIOCHAR

Date Created: 14-12-2021

Disclaimer: This report (including any enclosures and attachments) has been prepared by BSW Timber Limited, Arla Foods Limited, R&S Biomass Equipment Limited, Biomacon GMBH, UK Centre for Ecology and Hydrology, Newcastle University, University of Edinburgh and Sofies UK. We do not accept any liability if this report is used for an alternative purpose from which it is intended, nor to any third party in respect of this report.

Authors:

Alex Clarke, Senior Consultant, Sofies UK
Hamish Creber, PhD Researcher, University of Edinburgh
Dr Saran Sohi, Senior Lecturer in Soil Science, University of Edinburgh
Dr Jeanette Whitaker, Principal Scientist at UKCEH

Contributors:

Thomas Hoffman, Head of Sales and Technical Assistance, Biomacon
Dominic Hafner, Consultant, Sofies Zurich
Benjamin Herbreteau, Senior Consultant, Sofies Geneva
Rowan Boardley, Innovation Coordinator, Arla Foods
Coline Ritz, Junior Consultant, Sofies UK
Prof. David Manning, Professor of Soil Science, Newcastle University
Hannes Zellweger, Managing Director, Sofies Zurich
Dr Ondřej Mašek, Reader in Engineering, University of Edinburgh
Peter Wejse, Head of University Collaboration, Arla Foods
Jo Lawrence, Senior Manager Agri Commercial Support, Arla Foods
Prof. Stuart Hazeldine, Professor of CCS, University of Edinburgh

1. Introduction

This consortium seeks to transform the greenhouse gas removal (GGR) market at pace by creating the first integrated biochar system in the world consisting of BSW, one of the largest forestry and sawmilling businesses in the UK and Arla Foods UK, a co-operative of c. 2200 dairy farms. Our mission for Phase 1 of the BEIS Direct Air Capture and other Greenhouse Gas Removal Technologies Competition was to test the concept of building a scalable business-to-business (B2B) platform that creates biochar at a low cost for the first time. This will enable farmers to trial and use biochar in slurry management and animal bedding without taking on significant capital or operational risk. Figure 1 provides a summary description of the pilot system, from the biochar production at the sawmill to the use of biochar on farm.

Our project – The Biochar Network – has outlined the science and engineering underpinning our scalable GGR solution, detailed how the GGR solution will be used in Phase 2 and assessed relevant information on how our pilot will be monitored. Our proposed application of biochar has numerous benefits for climate, soil, and livestock farming. Manure management systems, including farmyard manure (FYM) and slurry provide the ideal vehicle to deliver biochar to soil without the need for significant changes in on-farm infrastructure and management practices. This report proposes a system of biochar production and utilisation in the dairy value chain that represents the first step to create a fully-fledged commercial system that can deliver more than 50,000 t CO_2 yr^{-1} carbon storage by 2030, across 150 – 250 farms depending on farm size (accounting for 10% of Arla farms).

The structure of this report is based entirely on the BEIS deliverable requirements for the Final Report, as outlined in the Phase 1 DAC & GGR Competition Guidance.

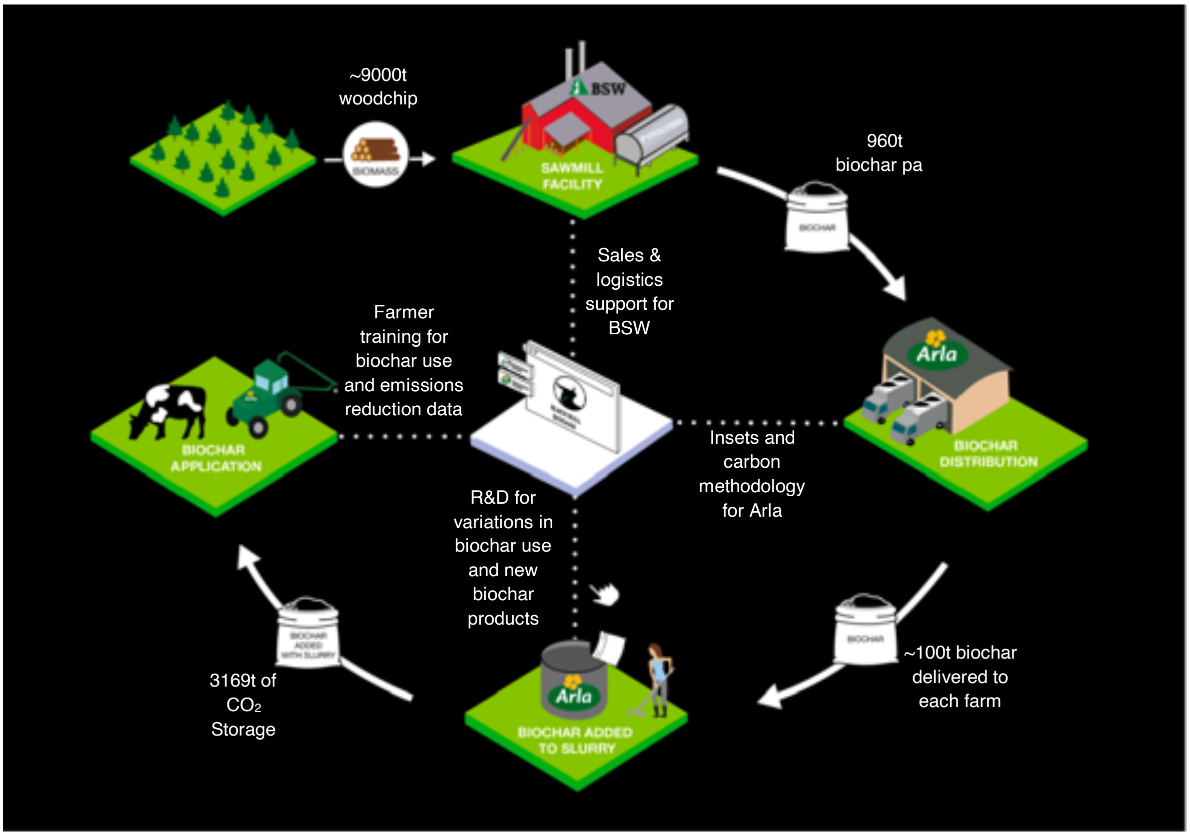


Figure 1 - Overview of biochar supply and use system with first of its kind B2B platform integration.

2. Science & Engineering

2.1. Chemical & physical processes

All chemical and physical processes used

Pyrolysis is the key chemical process used in the production of biochar. It is the process of thermal decomposition of materials at elevated temperatures in an inert atmosphere. Existing pyrolysis technology will be sourced from Biomacon without the need for any further technological developments. High temperature complete pyrolysis of woody feedstocks will deliver a highly stable biochar (see Figure 2). The process and feedstock type can be optimised for carbon longevity, which maximises GGR performance. Net energy production during pyrolysis will be utilised at the sawmill, reducing other energy inputs. The use of high-quality pyrolysis machinery and pyrolysis at high temperature will reduce the potential for biochar to oxidise, mitigating the risk of spontaneous combustion during storage.

Carbon stability

The extreme age (7000 years) of charcoal present in ancient terra preta soils (anthropogenic Amazonian soils) provide useful evidence for the potential longevity of carbon in biochar. Observational studies on biochar longevity extrapolating long-term persistence in laboratory soil incubations provide us with a further range of carbon longevity (100-10,000 years), with high confidence of at least 500 years storage for the majority of stable biochar carbon, when pyrolysis is conducted at >600°C.

This project will use the molar ratio of hydrogen to carbon (H:C ratio) to provide a simple index of aromaticity and carbon stability – the carbon in graphitic molecules containing no hydrogen (or oxygen) indicates biochar carbon stability and resistance to decomposition. When the H:C ratio is <0.4 it indicates high carbon stability. The pyrolysis conditions proposed in this project will produce biochar with an H:C ratio 0.2-0.3.

Sourcing of materials

The proposed system starts with the use of woodchip and pinchip from FSC certified timber to create biochar (all timber sourced in the UK). These co-products provide an ideal feedstock for commercial biochar production, both in terms of biochar properties and availability. Biomass feedstock requirements can be fulfilled exclusively using this feedstock in scaling to greater than 50,000 CO_2 yr^{-1} carbon storage by 2030.

The production of sawmill co-products is forecast to remain stable over the timescale of Phase 2. Woodchip and pinchip have a relatively low price owing to lower demand from other processing industries, presenting opportunity for BSW to add value through conversion to biochar.

The biomass fresh mass requirement for the phase 2 pilot is ~9000 t yr^{-1}. BSW is currently optimising the outputs of the Fort William mill output, increasing woodchip production to 300,000 t yr^{-1}. Woodchip used for biochar production will divert less than 3% of this woodchip co-product (when including the reduction in required onsite use of woodchip for heat generation).

Based on the selected machine (Biomacon C500-I), the feedstock input will be around 350 kg pinchips h^{-1} per machine installed. To ensure optimal pyrolysis processing the pinchips will be pre-dried to under 30% moisture content. To limit the assurance testing required with variation of feedstock, input material consistency will be monitored and managed. The potential variation is low as >90% of timber processed at the Fort William mill is spruce (mainly Sitka spruce).

Materials and substances required

Biochar production for the designed system will utilise sawmill co-product derived from virgin woodchip. The two Biomacon C500-I pyrolysis units will require grid supplied electricity. Negligible water (~70 t per annum from Fort William's local water supply) will be required for the heat recovery system and biochar packaging. All pyrolysis co-products, bio-oils, liquids and gases will be burned, supplying heat, which will be utilised for the drying of sawn timber and to dry biochar feedstock. A small amount of combustion gases will be released as atmospheric emissions (detailed in Table 1), complying with Scottish air quality regulation and guidance. The pyrolysis unit is rated below the 20 - 50 MW bioenergy threshold that requires SEPA permitting and monitoring under The Pollution Prevention and Control (Scotland) Regulations 2012. SEPA will be informed of pyrolysis atmospheric emissions prior to production.

Table 1 – Exhaust gas emissions rates and composition for two Biomacon C-500I pyrolysis units operation at maximum capacity using woody biomass at 20% moisture content.

Gas Emission	Emission (kg hr^{-1})	Emission (m^3 hr^{-1})
All Gases	1440	1986
H_2O (steam)	1038	1760
CO_2	400	224
NO_2	1.55	0.42
CO	0.075	0.041
CH_4	0.002	0.004
SO_2	0.075	0.026

Minimal ash is produced as a pyrolysis waste product (0.5 t yr^{-1}) and will be disposed on land annually according to low-risk organic waste disposal (<1 t ha^{-1} yr^{-1}). Biochar will be packaged in polypropylene (PP) bulk bags, which will be collected from farmers and reused. Unserviceable bags will be recycled using commercial recycling firms.

Consumption of materials

Manure management systems, including farmyard manure (FYM) and slurry present the ideal conduit for applying biochar to soil. Biochar can be added directly to both FYM and slurry or as a component of animal bedding (see Figure 2). Biochar can then be evenly spread as a component of slurry or FYM to arable land or grassland, becoming incorporated into the soil, with a target application dose of 200 kg ha^{-1} yr^{-1}. Maximum potential biochar application dose for this system will not exceed 1 t ha^{-1} yr^{-1}. Biochar properties can be further altered to ensure compatibility with existing on-farm management and infrastructure systems.

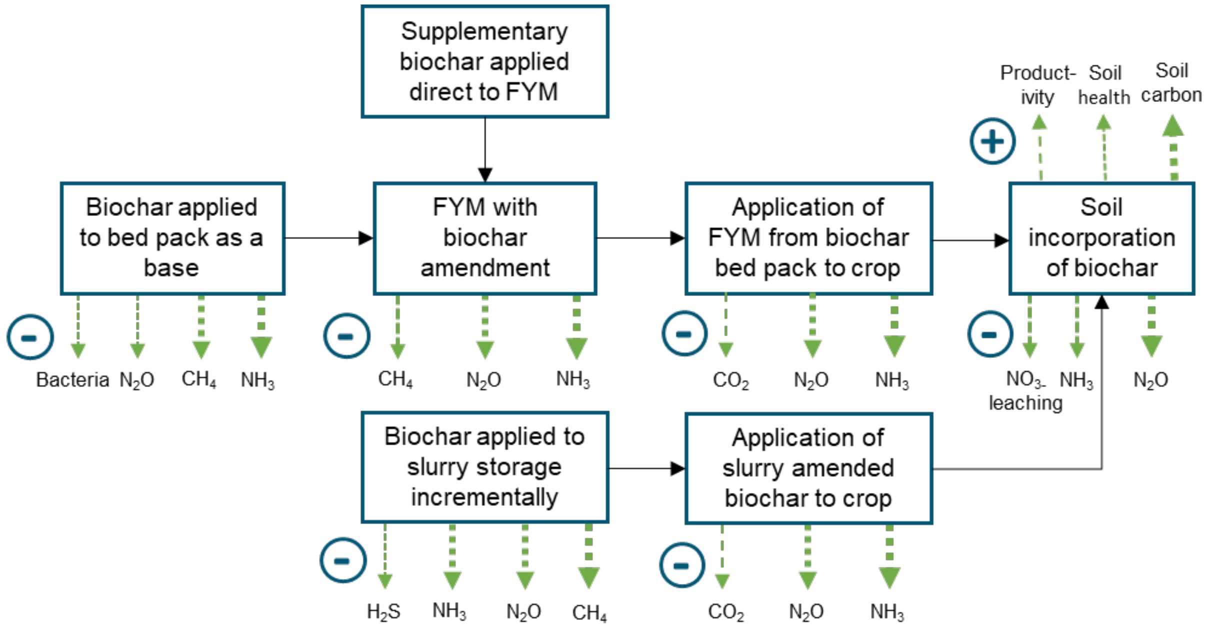


Figure 2 - Illustrative biochar scenario in manure management systems in dairy farming showing key stages in manure management systems (slurry and farmyard manure (FYM)), with point of application of biochar. Potential benefits of biochar compared with conventional manure management systems are outlined by green arrows (upward arrows showing an increase and downwards arrows a decrease, arrow thickness indicates relative extent of benefit at each stage).

2.2. Energy and fuel requirements

Table 2 - energy and fuel requirements for each process, sourcing process and selection rationale.

Stage	Energy requirements	Fuel requirements	Sourcing process & Rationale
Feedstock production	3 kWh electricity, 101 kWh heat	-	Electricity will be provided from the UK Grid to supply the supportive machinery including hammer mill and moving floor.
Pyrolysis	8 kWh (produces 1,004 kWh as heat)	9000 t woodchip	Electricity will be provided from the UK Grid UK Grid to operate the pyrolysis unit. Heat created through pyrolysis process will also be used for drying woodchip.
Biochar transport	-	7500 l diesel	Our goal is to piggy back on existing logistics, meaning bags will fit onto lorries already carrying other co-products to from Fort William to Carlisle. Therefore, we have assumed only part of the fuel required for transport is for the biochar alone.
Biochar use	-	250 l diesel	This is the estimate of fuel required on-farm for small vehicles (such as forklift trucks) moving the biochar.

2.3. Environmental Impacts

Biochar and Soil Improvement

Biochar affects soil physio-chemical properties such as soil pH, structure, porosity, nutrient cycling and moisture retention. The beneficial changes in these properties and the presence of biochar itself can positively influence the abundance, diversity and activity of soil biota. In addition to sequestering C, biochar can reduce soil N_2O emissions, nitrate leaching, and runoff; it can increase soil microbial biomass, plant available water, and crop yields. The benefits of biochar depend on the biochar design, which includes parameters such as feedstock type, pyrolysis temperature, application rate, biochar properties, soil properties, land management, climate, and other factors. Our biochar has been designed to maximise carbon storage and benefits such as N_2O emission reduction and nutrient retention.

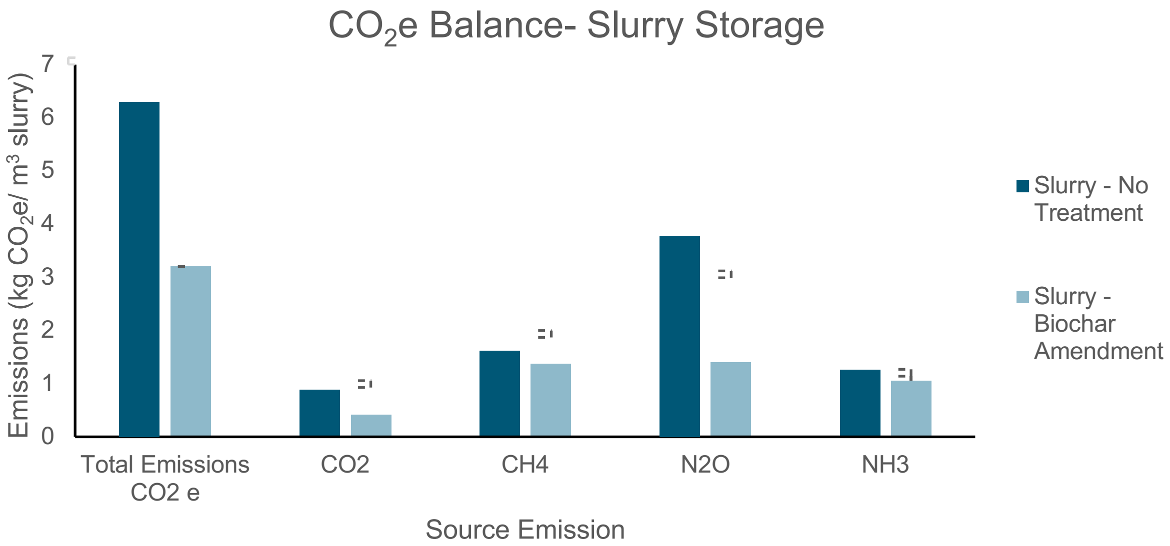
High single application doses (over 30 t ha^{-1}) of biochar have the potential to temporarily negatively impact soil. Certain feedstocks (particularly animal derived) can contain contaminants, such as heavy metals, which are concentrated during pyrolysis. Our proposed system and biochar specification removes the risk of these adverse impacts – biochar produced from virgin softwood applied at relatively low doses (under 1 t ha^{-1}) will mitigate any application risk of biochar to the plant and soil system.

Table 3 - Summary of impacts of biochar application on soil ecosystem services. Question marks indicate unclear impact. The number of tick marks indicates the extent of biochar impact.

Ecosystem service	Parameter	Biochar impact	Impact description
Carbon storage	Soil C	✓✓✓✓	Increases
Greenhouse gas fluxes	CO_2 N_2O	✓ ✓✓✓	Increase short-term, decrease long -term Decreases
Soil biology	Microbial biomass	✓✓	Increases
Water erosion	Runoff Nutrient loss	✓ ✓	Often decreases Reduces fertiliser nutrient loss
Nutrient leaching	Nitrates	✓✓	Reduces
Available water	Available water	✓✓✓	Increases
Soil fertility	Nutrients Acidity	✓✓✓ ✓	Improves nutrient use efficiency Reduces (liming effect)
Crop yields	Degraded or low fertility soils High fertility soils	✓✓ -	Increases Improved productivity

Manure and housing emissions reduction

The strength of available evidence in the scientific literature has been reviewed to assess confidence in the effect and impact of biochar in providing emission reduction of greenhouse gases and ammonia during the storage phase of manure management and in animal bedding. Specified biochar can effectively reduce NH_3 and N_2O, with the proportional reduction of these gases depending on the point of application in the bedding and manure management system. These reductions can have a significant beneficial impact on the net carbon footprint and air quality/livestock conditions on dairy farms (see Figure 3). From stakeholder research it has been found that these benefits are of value to farmers and key to the valorisation of biochar products, creating a financially viable solution than other GGR technologies.



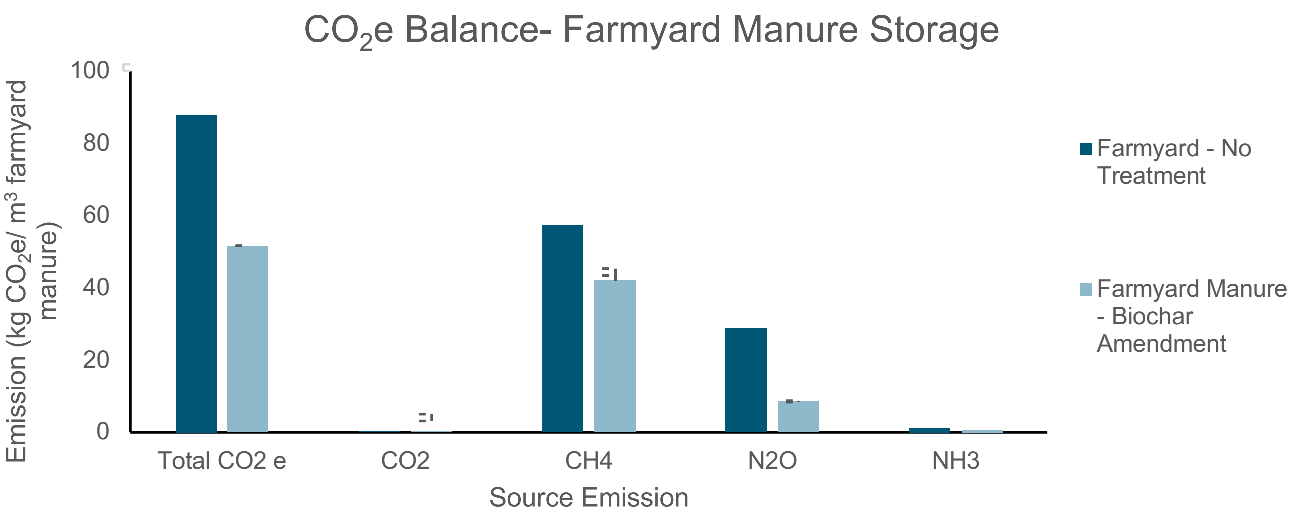


Figure 3 - Potential GHG and ammonia (NH3) emission reduction during slurry storage phase (above) with biochar application at 10% total volume (1.2% by wet weight) for a two-month storage time and during farmyard manure storage phase (below) with biochar application at 94 kg/m3 farmyard manure (10% by wet weight). All source emissions except ammonia (NH3) are expressed as kg CO2e/m3 ammonia (NH3) is expressed as kg/m3. The difference between farmyard manure and slurry storage in terms of emission reduction can be attributed to the difference in dose (8x higher per m3 in farmyard manure).

3. Pilot Design Plan

3.1. Credibility of the design

There are three key areas of design within our project: biochar, pyrolysis and the business-to-business (B2B) software platform. All three have been built with a farmer centred design approach from the outset.

Biochar design

The use of biochar on farm will be focused on separate biochar applications to slurry and to animal housing. The two biochar products will have one common property – Maximised carbon stabilisation and biochar longevity through pyrolysis at temperatures of 700-750°C, providing a high conversion of biomass to stable carbon and effective GGR. The remaining properties will be as follows for each biochar product:

PinChar - slurry and manure

- High nitrogen sorption – high biochar surface area and micro-porosity will maximise beneficial interactions with nutrient nitrogen in slurry and manure. This is achieved through processing that retains the physical micro-structure of wood (vessels, tracheids etc.).
- Low matrix density – compatibility with slurry storage requires low matrix density to limit sedimentation in the slurry tank and ensure even dispersion during mixing prior to field application.
- Particle size – here, the maximum solid size is consistent with slurry application method and slurry storage; the use of pinchips as a feedstock is ideally suited to provide biochar with a small particle size compatible with conventional slurry application methods.

PelletChar - animal bedding

Biochar will be produced from pelleted softwood (no bark) - slow pyrolysis at 700–750°C, with option of water addition during cooling to eliminate dust.

- Low dust – using pelleted biomass limits fragmentation of biochar and increases bulk density, which significantly lowers dust content. Water addition (~10% by mass) during biochar extraction after pyrolysis will also reduce dust distribution.
- Moderate alkalinity – feedstock with low ash content (wood without bark) and balanced pyrolysis temperatures will minimize pH increases and reduce ammonia emissions.
- Moderate nitrogen sorption – nitrogen sorption potential will be balanced with the requirement for low-dust. Pelletised feedstock from woody biomass will provide adequate sorption without detriment to essential physical properties.
- Blunt fragmentation and low sharpness – pelleting breaks down the primary cellular structure of wood before pyrolysis, which means the pellets fragment in a way that does not cause abrasion to the livestock in bedding.

Pyrolysis technology

Commercially available Biomacon pyrolysis technology will be used, without the need for any further technological development. Complete high temperature (700–750°C) pyrolysis of woody feedstocks will deliver a consistent, highly stable biochar. Net energy production during pyrolysis will be utilised on the sawmill site, reducing the demand for energy from other sources. Two Biomacon C500-I pyrolysis units will be needed to supply enough biochar to the farmers in Phase 2, enabling trials across a cross-section of different slurry systems. Each C500-I unit produces 500 kW of thermal energy when processing wood chip of 20% moisture content at 295 kg h^{-1}. At 20% moisture content the nominal processing capacity would be 263 kg h^{-1} to ensure a stable heat output. The output rate will be of 120 kg h^{-1} of biochar at Fort William for each of two units installed.

Software platform

To scale up the supply and use of biochar quickly and effectively, a B2B platform is required. At its core, this platform needs to enable suppliers and users of biochar to plug-in to a market that provides a consistent sales funnel for the supplier and a high quality low-value product for the user. It serves as a scale up mechanism to meet different customer needs in the system, including wood suppliers, farming co-operatives & individual farmers. Each user will therefore have a different online account facilitated by the super admin, run by the start-up Black Bull Biochar. The platform is designed to provide each user with a customer experience (see Figure 4) that enables understanding of biochar impacts, data on their farm's evolution in terms of emissions reduction and storage as well as lead in times to their sales/orders. It also allows Black Bull Biochar, the wood supplier and the co-op to have an overview of their progress and allocation of insets/offsets.

Web Panda will be sub-contracted during Phase 2 to build this software platform. The software construction will be divided into three separate parts: a website, an app composed of 4 different "modes", and a back-end that receives calls and feeds information to the app and website. Figure 4 shows the wireframe of the app including accounts for suppliers and users (co-op and individual farmer).

Figure 4 – Wireframe of stand-alone B2B platform from user experience point of view. Each user has a different account including suppliers, farmers (co-op and individual) and the super admin for Black Bull Biochar (BBB). The app is designed to provide each user with a positive experience that enables understanding of biochar impacts, data on their farm's evolution in terms of emissions reduction and storage as well as lead in times to their sales/orders. It also allows BBB, the wood supplier and the co-op to have an overview of their progress.

3.2. Cost of the design

Table 4 – Budget for Phase 2 pilot running between April 2022 and March 2025. At time of writing, €1 Euro = £0.85 GBP

1. People						
	Company/Person			**Cost**	**VAT**	**Total (inc. VAT)**
BBB Operational Costs	Staff & overheads for three years			£951,990	£180,878	£1,132,868
Sub-contractors	University of Edinburgh, UKCEH, SRUC, WebPanda, Sofies, Shoosmith & Eurofins			£266,421	£50,620	£317,041
Travel and farmer time costs	Arla			£44,485	£0	£44,485
Sub-total 1	£1,262,896					
Sub-total 1 (inc. VAT)	£1,494,394					
2. Product						
	Description			**Cost**	**VAT**	**Total (inc. VAT)**
Feedstock	Woodchip required for pyrolysis			£550,800	£104,652	£655,452
PP Bags	2m3 bags for biochar			£43,694	£8,302	£51,995
Biochar	Small trial of biochar from 3rd party			£10,000	£1,900	£11,900
Logistics	Haulage and distribution to Hub			£12,000	£2,280	£14,280
Certifications	EBC + Biomass boiler certificate			£16,000	£0	£16,000
Sub-total 2	**£632,494**					
Sub-total 2 (inc. VAT)	**£749,627**					
3. Machinery						
	Euro Price	**GBP Price inc. transfer fee**	**#**	**Cost**	**VAT**	**Total (inc. VAT)**
C500-I	€ 448,500	£382,750	2.00	£765,500	£145,445	£910,945
Discharge System	€ 10,000	£8,534	2.00	£17,068	£3,243	£20,311
Solid fuel storage (Moving floor)	€ 50,000	£42,670	2.00	£85,340	£16,215	£101,555
Intake system (Solid fuel storage - Pyrolysis)	€ 15,000	£12,801	2.00	£25,602	£4,864	£30,466
Hot water buffer tank (5,000 Litre)	€ 5,000	£4,267	6.00	£25,602	£4,864	£30,466
Machinery connecting sawmill to pyrolysis	€ 215,400	£183,822	1.00	£183,822	£34,926	£218,749
Sub-total 3	£1,102,934					
Sub-total 3 (inc. VAT)	£1,312,492					
Totals						
Total	£2,998,324					
Total (inc. VAT)	£3,556,513					

sofies

BLACK BULL BIOCHAR

3.3. Technical drawings of the pilot plant proposed

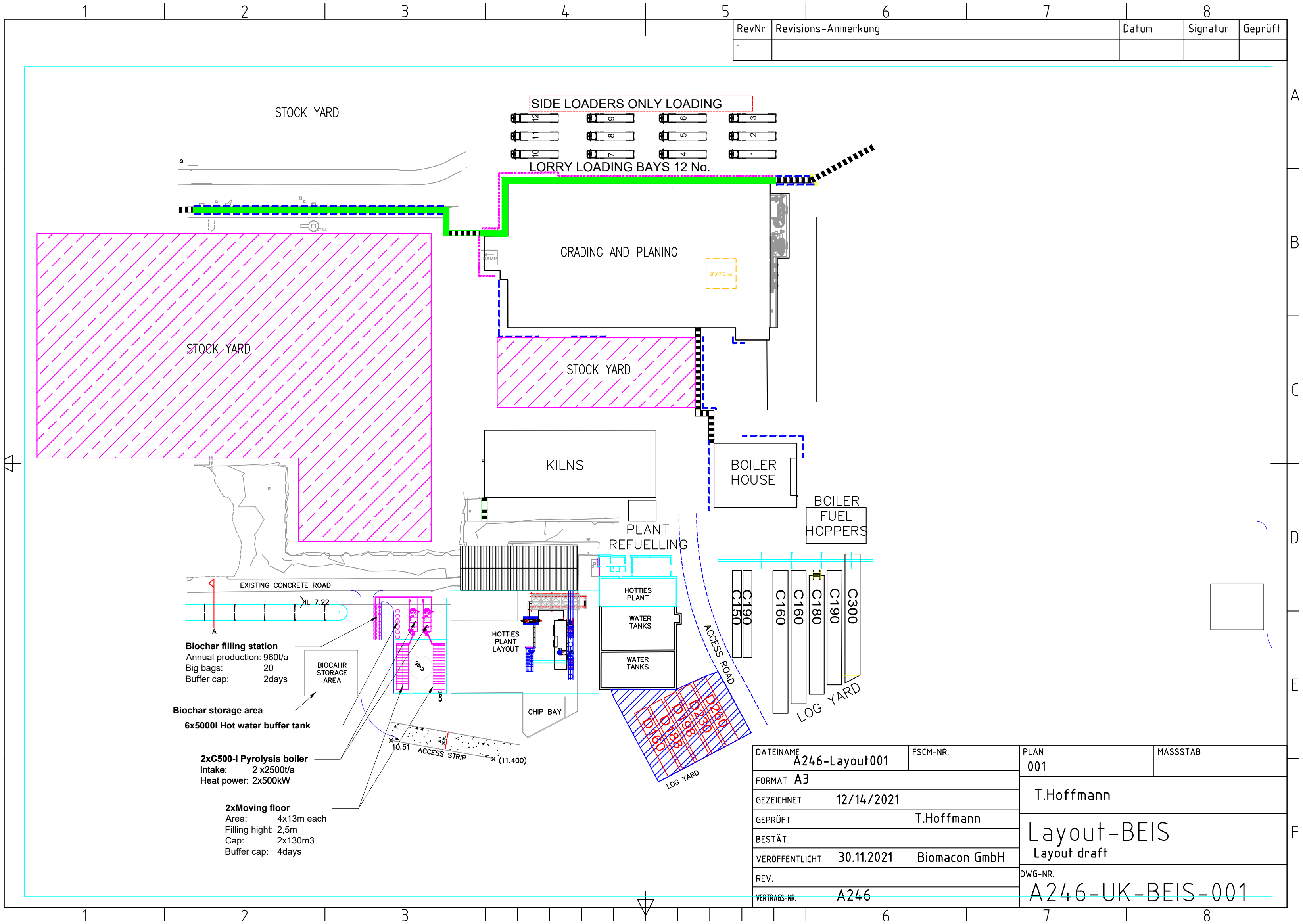


Figure 5 – Technical drawing displaying proposed Biomacon pyrolysis facility (labelled in bottom left) integrated with upgraded BSW "hotties" heatlog production line. Flecible biochar production facility comprises of two biomacon c-500l units and accompanying moving floor feed intake systems and extraction/packing systems.

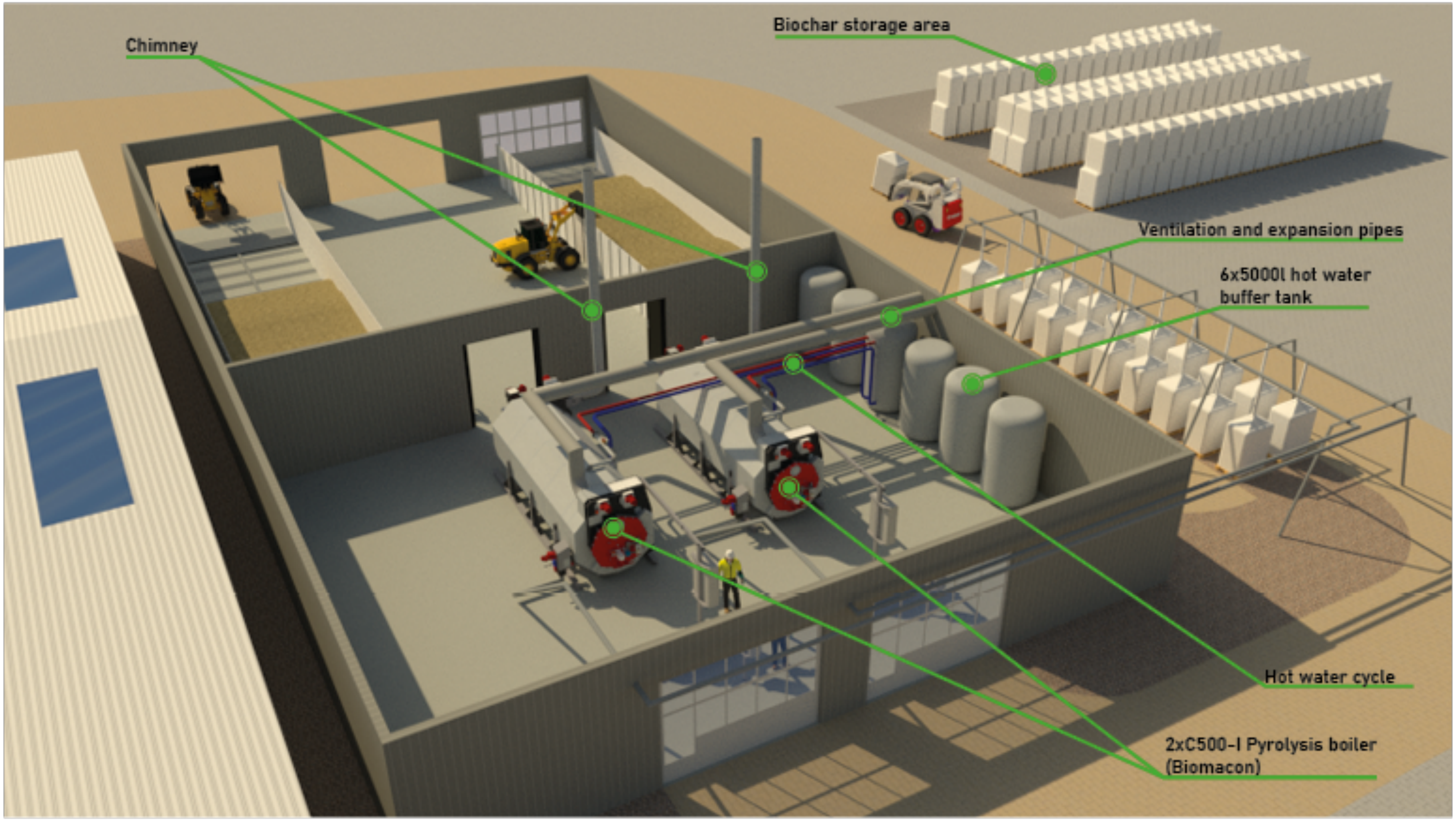


Figure 6 – 3D rendered visulisation of two side by side Biomacon C500I units at BSW Fort William. Heat will be transferred from hot water buffer tanks to BSW heat sinks (both in woodchip and timber drying processes).

3.4. Modelling

An LCA was completed for the biochar production and use system. System boundaries and processes are shown in Figure 7. Multiple datasets and sources were utilised to produce robust net carbon storage values for both PelletChar and PinChar. Results show that PinChar delivers net 2.95 t CO_2e t $biochar^{-1}$ carbon storage. PelletChar delivers net 3.10 t CO_2e t $biochar^{-1}$ carbon storage. These values include all allocated biochar and feedstock production and transport costs. Net carbon storage is at 500 years, based on the target stability and decay rate.

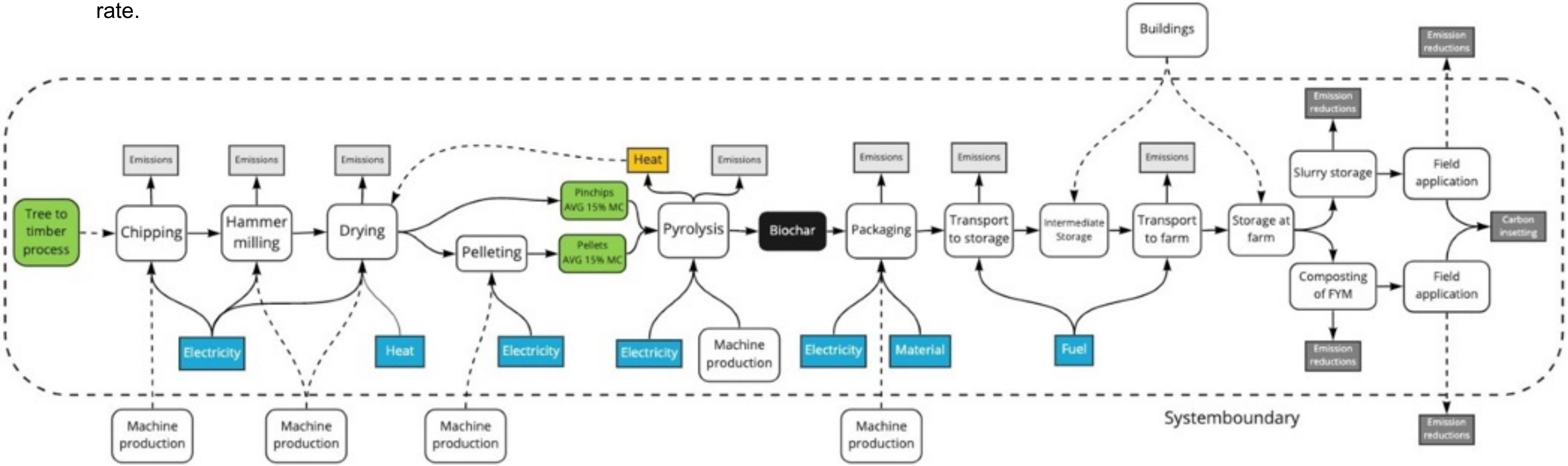


Figure 7 - Simplified representation of the LCA for the use of biochar on farms. As a co-product of timber production is used some simplifications are made in the upstream process. Timber is harvested and transported directly to the sawmill. At the sawmill the first process, after the excluded timber sawing system, is the chipping. The woodchips are then dried and crushed (hammer milling). Some of the pinchips are processed into pellets to be used as bedding material. During biochar production the emissions from the machinery production and transport to FW are taken into account. A proportion of pyrolysis heat is used for drying. The two different types of biochar are packed and delivered to the farms. Direct use in slurry storage with subsequent spreading in the field or as pellets in the bedding and then in farmyard manure storage are the assessed uses. For both applications, only the GHG emission reduction during the manure storage phase was considered. For all the processes included the electricity, fuel and heat required are included in the LCA, also the corresponding emissions.

3.5. Relevant data

Table 5 shows some of the key data that underpin the design of the system, particularly in relation to the economic and environmental aspects of the system. The data represented here was used to calculate the LCA, build the Design Plan and write the Business Plan.

Table 5 – Key data used in biochar production and use calculations. Values also have been used in the LCA to provide net CO_2e storage for both PelletChar and PinChar. Data has underpinned feedstock requirement calculations and pyrolysis heat production and utilisation.

Parameter	Amount	Unit
Max. feedstock moisture content	30	%
Max. feedstock axis size	60	mm
Nominal heat power range per pyrolysis unit	250-500	kW per pyrolysis unit
Feedstock intake rate	295	kg/h per pyrolysis unit
Biochar production rate	58	kg/h per pyrolysis unit
Ash production rate	0.03	kg/h per pyrolysis unit
Thermal efficiency at nominal heat power	0.85	-
Electrical power consumption at nominal heat power	4	kW per pyrolysis unit
Electrical connection Voltage/Frequency	400	V/50 Hz per pyrolysis unit
Electrical connection fuse	32	A per pyrolysis unit
Electricity, Medium voltage	0.212	kg CO_2/kWh
Electricity, Low voltage	0.212	kg CO_2/kWh
Pyrolysis, conversion rate	5	t green woodchips/t biochar
Density of biochar - PinChar	0.13	t/m^3
Density of biochar - PelletChar	0.31	t/m^3
Woodchip production	16.6	kg CO_2/t of wood chipped
Drying, Heat consumption	495	kWth/t of green woodchips
Drying, Electricity consumption	22.5	kWh/t of green woodchips
Amount of water to dry	0.45	t of water/t green woodchips
Hammer mill, Electricity consumption	45	kWh/t of green woodchips
Pellet production, Electricity	96	kWh/t of pellet produced
Pellet production, Heat	31	kWth/t of pellet produced
Pyrolysis, electricity consumption	4	kWh
Heat produced by pyrolysis unit	0.54	MW/0.068 t biochar
Heat produced	9.41	MW/t of biochar
Pyrolysis, run time	8000	h/year
Expected lifetime of Biomacon unit	15	y
Transport distance (GER-UK)	1476	km
Distance Ft. W to Carlisle	331	km
Distance Carlisle to Farms	50	km (average)

Dose range of biochar application to slurry and bedding

Weekly biochar application rates (kg per cow) have been calculated for various slurry Dry Matter (DM %) contents and slurry application methods. These rates apply to slurry production of a medium output dairy cow (6000-9000 l yr^{-1}) which produces 0.37 m^3 of slurry at 6% DM per week (corrected for typical winter rainfall). At the lowest dose rate (representing a 1% dry matter addition) a typical dairy farm with a 350 milking cow herd size would require 68 t PinChar yr^{-1}. In area of high precipitation more water enters the slurry system and higher doses of biochar can be applied, maintaining a constant biochar slurry ratio. Biochar will be applied as a component of slurry, with spatial rates varying according to slurry application rates and biochar doses. Biochar will be applied to land at a target dose of 200 kg ha^{-1} yr^{-1} and will not exceed 1 t ha^{-1} yr^{-1}.

Table 6- Biochar application dose rate according to DM % and application method (kg biochar cow^{-1} wk^{-1})

	DM 2 %		DM 4 %		DM 6 %		DM 8 %	
	Target	Max	Target	Max	Target	Max	Target	Max
Splash Plate	29.6	37.0	22.2	29.6	14.8	22.2	7.4	14.8
Trailing Shoe	7.4	14.8	3.7	7.4	0.0	0.0	0.0	0.0
Band Spreader	18.5	25.9	11.1	18.5	3.7	11.1	0.0	3.7

Table 7 - Biochar application dose range (% total weight addition) according to DM % and application method.

	DM 2 %		DM 4 %		DM 6 %		DM 8 %	
	Target	Max	Target	Max	Target	Max	Target	Max
Splash Plate	8	10	6	8	4	6	2	4
Trailing Shoe	2	4	1	2	0	0	0	0
Band Spreader	5	7	3	5	1	3	0	1

PelletChar added as a 1 cm depth base t straw bedding would require 1.5 kg of biochar per m2, with 50% of the volume attributed to air spaces between biochar particles. With 10.5 m^2 required in straw systems per cow, 16 kg of biochar would be required for each bedding cycle per cow. A typical dairy farm with a 350-milking cow herd, which has calf and drystock housing, size would require 30 t PelletChar yr^{-1}.

3.6. Cost savings compared with exclusive development contracts

Table 4 shows the lowest possible costs for this pilot and offers the best possible price reduction compared to the price applicable in the case of an exclusive development (as outlined by BEIS in their Phase 1 Guidance Notes). As the budget currently stands, 59% will be spent in the UK and 41% will be spent abroad on sub-contractors working in Switzerland and pyrolysis machinery from Germany. Black Bull Biochar will not make profit on this project. In the case of a commercial client as opposed to an SBRI contract, the price of this project would likely be in the region of 25-50% higher, factoring in profit made for developing the intellectual property.

4. Project plan

4.1. Site selection

To build a revolutionary business-to-business (B2B) platform that delivers Greenhouse Gas Removal (GGR) through an integrated biochar system consisting of sawmills and farms, we need to create a hub of farms using biochar and select a BSW sawmill mill to use for the Phase 2 pyrolysis units.

Sawmill Selection

The BSW Fort William sawmill was identified as ideal for producing biochar. It produces the highest output of woodchip per year of all the BSW sawmills (150,000 t yr^{-1} currently with plans to double this output by 2025) and has sufficient floor space to build the pyrolysis units and store the biochar safely and securely. 9000 t of woodchip is required each year to produce 960 t biochar per year. The only drawback for using Fort William is its lack of proximity to dairy farms. However, the BSW sawmill site in Carlisle, Cumbria is close to a large network of dairy farms and could be used as a logistics centre. 30-40 trucks currently leave the Fort William sawmill for Carlisle each day. Biochar can easily piggy-back on this logistics route with low carbon and economic costs, given that less than 35 curtain sided trucks are needed per year to transport biochar to Carlisle. From here biochar can be delivered on farm through a hub and spoke model.

The BSW site addresses

BSW Timber, K2 Sawmill, Corpach, Fort William, PH33 7NJ

BSW Timber, Carlisle Sawmills, Cargo, Carlisle, CA6 4BA

Biochar Demonstrator Hub

For a successful pilot, a group of early-adopter farmers willing and motivated to trial biochar are needed to set up a Biochar Demonstrator Hub. To discover these optimal people and places, a high-level assessment of regions based on carbon and economic cost of logistics and interest in biochar from dairy farmers was undertaken. The analysis found that dairy farming in the UK is concentrated in six main regions along the west coast, from Ayrshire to Devon, with a total of 1.85 million milking cows (2020[1]). To gauge nationwide interest in biochar, a survey was sent out to over 100 Arla farmers. 79 farms from the survey applied to become part of the Biochar Demonstrator Hub. The majority of these farmers were from the Northwest of England and the Southwest of England. Owing to the proximity of the BSW sawmills to Cumbria, Cumbria and Southwest Scotland emerged as a logical place to pick 10 farms to form the Biochar Demonstrator Hub.

4.2. Site interaction

The pilot phase draws on a small fraction of the co-product stream. BSW already has a production line to produce woodchips and existing infrastructure will be used for drying and hammer milling. Once dried, the woodchips will be shredded with a hammer mill at the same place to obtain particles of around 25 mm long and between 1 and 3.5 mm wide. The

[1] https://www.statista.com/statistics/616188/dairy-cow-numbers-united-kingdom-uk/

pinchips are dried to 12-15% moisture content for the existing production of ‘Hottie Heat Logs’.

The heat produced by the pyrolysis will contribute to the wider site requirement for drying processes. In an exemplary scenario the wood dryer will have a thermal efficiency of 70%. Therefore, if all heat from the pyrolysis system (500 kW nominal heat power) is used for drying, 350 kW is the efficient drying heat load. It is assumed that that the dry mass of the incoming wood is 50% and that the target thermal stability (TS) is 85%. With an annual operation time of 8000 h, 15,000 t of fresh wood chips can be dried to 11,500 t of dried wood chips with a TS of 85% annually.

Biochar is continuously transported from the pyrolysis kiln via conveyor screws and deposited in bulk bags. PP bulk bags will be used of 2 m^3 volume, and for both types of biochar (PinChar and PelletChar for slurry and bedding applications respectively (0.5 t per bag for PelletChar) and 0.24 t per bag for PinChar).

The biochar is transported outside the building by the discharge system and filled into bulk bags. The filling station of the bulk bags should have a distance of at least 5 m from the building where the pyrolysis boiler is installed and from other combustible materials.

Pinchips will be stored in a dry environment close to the pyrolysis units so that automated continuous feed is possible. The storage capacity for feedstock will be sufficient for a week’s production of biochar (60 t per machine). Safe storage of feedstock is already in place at the production site. Figure 8 shows a material flow diagram through the Fort William sawmill.

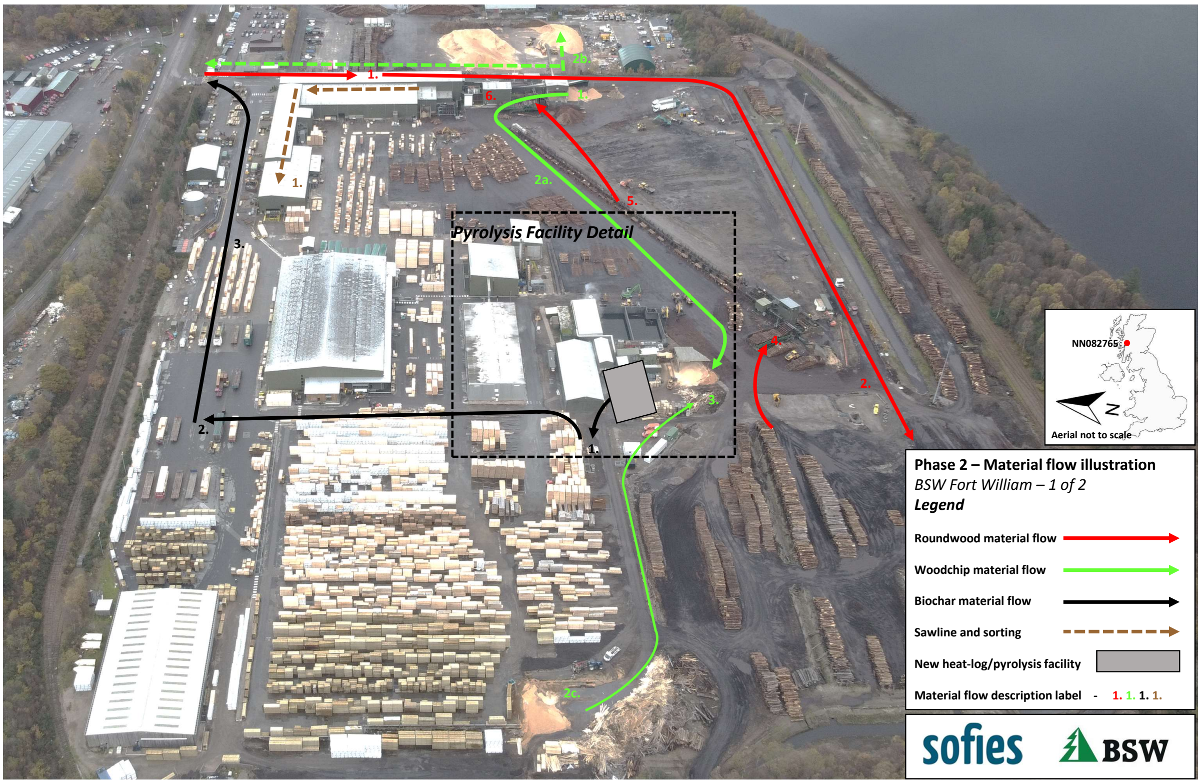


Figure 8 - Material flow diagram of the Fort William sawmill with biochar production

sofies

BLACK BULL BIOCHAR

4.3. Gantt chart

	2022									2023												2024												2025		
TASK	Apr 22	May 22	Jun 22	Jul 22	Aug 22	Sep 22	Oct 22	Nov 22	Dec 22	Jan 23	Feb 23	Mar 23	Apr 23	May 23	Jun 23	Jul 23	Aug 23	Sep 23	Oct 23	Nov 23	Dec 23	Jan 24	Feb 24	Mar 24	Apr 24	May 24	Jun 24	Jul 24	Aug 24	Sep 24	Oct 24	Nov 24	Dec 24	Jan 25	Feb 25	Mar 25
Platform Development																																				
Software development	■	■	■	■	■	■	■	■	■																											
Trial software with farmers										■	■	■																								
Iterate on software													■	■	■																					
Run software with live biochar deliveries and usage																■	■	■	■	■	■															
Iterate on software with stakeholder feedback																						■	■	■	■	■	■	■	■	■	■	■	■			
Pyrolysis Installment																																				
Purchase pyrolysis machinery	■																																			
Pyrolysis manufacturing	■	■	■	■	■	■	■	■	■	■	■	■																								
Supportive machinery procurement		■	■	■	■	■																														
Site preparation						■	■	■	■	■	■	■																								
Install pyrolysis machinery									■	■	■	■																								
Training of BSW operational staff											■	■	■	■																						
Biochar production														■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Biochar Demonstrator Hub																																				
Farmer guidebook preparation			■	■	■	■																														
Farm emission reduction and storage potential reports						■	■	■	■	■	■	■																								
Planning of Climate Check integration with biochar farmers			■	■	■	■	■																													
Small trial of biochar on farm / compatibility testing								■	■	■																										
Training of farmers for biochar use								■	■	■																										
Farmer guidebook iteration											■	■	■	■	■																					
Focus Group with farmers				■			■			■			■			■			■			■			■			■			■			■		
Categorisation of biochar use in systems													■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Integration of biochar into Climate Check																																■	■	■	■	■
Monitoring & Evaluation																																				
Field trial planning and setup						■	■	■	■	■	■	■																								
Field trial sampling												■		■							■				■		■						■				■
Annual treatment application												■													■								■				
Biochar testing & quality control													■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

5. Business Plan

5.1. Next stage development

Our strategy is to trial two C500-I pyrolysis machines at BSW's Fort William site with a network of 10 neighbouring Arla farms in 2023-2025 (Phase 2 of the project). This will provide an MVP (Minimum Viable Product) and the necessary information to incorporate the system into commercial roll-out (TRL 8) and facilitate the construction of 6 more pyrolysis machines at BSW sites in Dalbeattie, Newbridge and Southampton (TRL 9). As demand grows for biochar, the business-to-business (B2B) platform will allow more biochar suppliers to integrate into the biochar network, enabling scale up towards the equivalent of 33 Biomacon C500-I pyrolysis units to be deployed across the UK, reaching 50,000 t CO_2e per year by 2030.

Scaling up supply

To meet target CO_2 storage of 50,000 t CO_2 yr^{-1}, 115,000 t feedstock at 20% moisture content will be needed to supply the pyrolysis units (See Figure 9). This represents a pyrolysis woodchip intake at 14.4 t h^{-1} on an 8000 h pa basis. The model C-500I from Biomacon would enable the production of 500 kW of thermal energy based on the pyrolysis of 295 kg/h. To achieve the target of 50,000 t of CO_2 per year, 32 C500-I Biomacon machines would be needed, which would provide 16,000 kW of thermal energy. Large sawmills in the UK produce more than the required feedstock, meaning full scale-up feedstock requirements could be achieved from a single site.

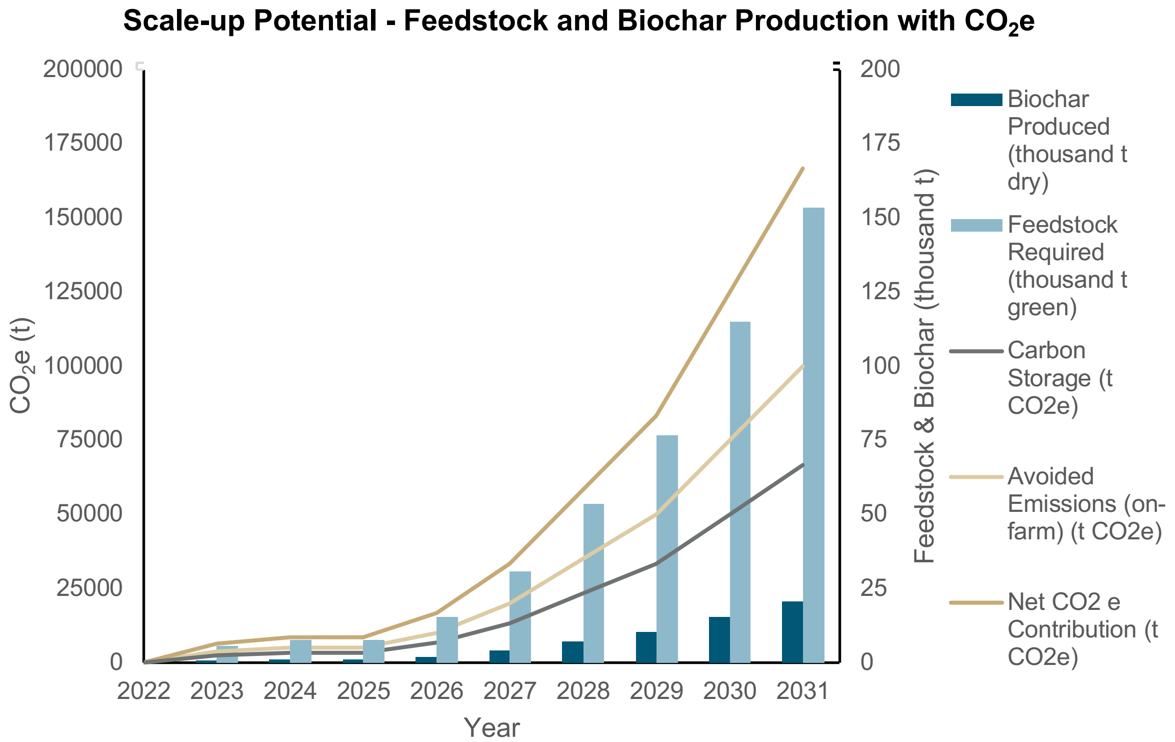


Figure 9 – Biochar production and feedstock requirement scale-up to target carbon storage of 50 thousand t CO2e yr-1 by 2030 and beyond. Avoided emissions through manure GHG emission reduction due to biochar application are displayed.

Given the number of pyrolysis units required (if Biomacon C500-I machines are to be used), larger models of pyrolysis units are likely to be needed. This requires a steeper capex, which requires investors who are keen to invest in a proven market with a scalable pathway. The B2B platform being constructed by Black Bull Biochar provides this pathway through the Phase 2 pilot. At the end of the pilot, an accurate value can be placed on the biochar by Arla and Arla's farmer owners. This value can be known because, for the first time, farmers have been allowed to experiment with biochar in their slurry management systems at a meaningful scale, so they can see the range of benefits biochar can provide through this system.

Energy production

A key element of ensuring sustainability of pyrolysis derives from the use of heat from pyrolysis units. Several options exist for energy valorisation in the scale up strategy.

1. The heat produced by the pyrolysis is used for drying purposes – Here, the priority will be to use the heat produced to pre-dry the pinchips used for biochar and also the existing heatlogs production. Considering a heat transfer efficiency of 90%, the total heat produced by the pyrolysis could provide a drying capacity of 13.9 t/h, i.e. slightly superior to the heat needed for the biochar production system.
2. The heat produced by the pyrolysis is use for cogeneration – Considering a CHP engine with 32% efficiency (e.g. Jenbacher technology), 7.6 MWe of electricity could be produced or 3.8 MWe with 6 machines equally distributed among 3 BSW sites. The remaining heat could be valorized for drying providing 57% of the demand of the pinchips pre-drying for biochar production. This solution will require larger investments but provides a highly valuable electricity production pathway, if valorised by the UK Grid.
3. The heat produced by the pyrolysis is sent to a district heating system. This solution adds complexity but could be interesting in terms of environmental impact. There are no district heating system in the close vicinity of BSW sites so this option is only preferable in a scenario where other sawmills companies are involved from 2025-2030.

Scaling up demand

This report proposes a system of biochar production and utilisation in the dairy value chain that creates the first step to create a fully-fledged commercial system that can deliver more than 50,000 t CO_2 yr^{-1} carbon storage by 2030. If we are to assume that the amount of biochar used in Phase 2 is correct for farmer consumption (96 t biochar yr^{-1} per farm delivering 317 t of carbon storage), then we would need to scale to 158 Arla farms to achieve 50,000 t CO_2 yr^{-1} carbon storage by 2030 (150-250 farms range if we are to consider smaller farms). 79 Arla farms signed up to join the Biochar Demonstrator Hub showing significant interest. It will be the role of the start-up, Black Bull Biochar to convert this interest into new biochar farms, which will be achieved through the Biochar Network, an online service, linked to the B2B platform that informs and engages potential biochar farmers, creating a waiting list for joining the Biochar Demonstrator Hub and scaling up the use of biochar as and when the supply can match the demand. Black Bull Biochar will also approach other dairy co-operatives if uptake is lower than expected from Arla farmers.

5.2. Dependencies

Our plan is compliant with the requirements of the current Environment Agency (EA) and Scottish Environment Protection Agency (SEPA) regulatory frameworks. It is anticipated that the biochar forum established as part of Phase 1 will lead to development of the regulatory frameworks applying to biochar during Phase 2. Planning for the Phase 2 pilot is compliant with the current regulatory position defined by the Environment Agency. Under these arrangements biochar remains regulated as a waste (regardless of feedstock) but can be produced and used freely in accordance with low-risk waste protocols (LRWP 60-61). For our system:

- Biochar is being produced from sawmill products that are not classified as a waste
- Application of biochar will not exceed 1 t ha^{-1} yr^{-1}.
- The primary purpose of pyrolysis is to produce a specified biochar product, rather than energy generation. Whilst the energy produced during pyrolysis will be utilised it is not the primary purpose (this is highlight by the fact that there are existing bioenergy generation facilities onsite which have unused capacity).
- Biochar has been specified to address key environmental issues in manure management and grassland systems.
- Biochar is performing valuable functions during the intended use and has a value above carbon storage only.
- Biochar will be added to slurry at ~1% by weight and will typically equate to annual applications to grassland of 200 kg ha^{-1} yr^{-1}, at least an order of magnitude lower than experimental doses used in research work.

Currently, the specific system proposed meets the requirements in the current EA regulatory framework (LRWP 60 & LRWP 61). Corresponding regulation in Scotland is under SEPA WST-PS-031. The application activity requests SEPA registration under Paragraph 7 Exception - 02 01 03 (activity application of material to treat land for benefit to agriculture or ecological improvement).

Other key dependencies

- Biomacon machinery arriving on time, running at full capacity without mechanical failure.
- No extreme currency fluctuations or recessions.
- Key B2B partners maintain full commitment to the pilot for duration of Phase 2.
- No severe regulatory changes.
- This project is not dependant on the BSW heat log project going ahead. If the ‘Hotties’ project does not go ahead, there is space for the pyrolysis units to operate in existing BSW buildings at the Fort William sawmill.