Direct Air Capture (DAC) & Greenhouse Gas Removal (GGR) Net Zero Innovation Programme (NZIP) Phase 2 Final Report

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BLACK BULL BIOCHAR

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Acronym & Abbreviation Glossary

API	Application Programming Interface
ARA	Ahlstrom Radcliffe Biochar Production Site
AWJ	A.W. Jenkinson
BBB	Black Bull Biochar
C500-I	Biomacon C500-I Decarbo Energy System
CDN	Content Delivery Network
CI/CD	Continuous Integration / Continuous Deployment
CMS	Content Management System
CORC	CO2 Removal Certificate
COSHH	Control of Substances Hazardous to Health
CRM	Customer Relationship Management
CSV	Comma-Separated Values
DAC & GGR	Direct Air Capture & Greenhouse Gas Removal
DESNZ	Department of Energy Security & Net Zero
dMRV	Digital Monitoring, Reporting and Verification
EBC	European Biochar Certificate
HAZOP	Hazard and Operability
JNR	Jenkinson Newton Rigg Biochar Production Site
JWT	JSON Web Token
LCA	Life Cycle Assessment
LRWP	Low Risk Waste Position
MC	Moisture Content
MCPD	Medium Combustion Plant Directive
MRV	Monitoring, Reporting and Verification
NZIP	Net Zero Innovation Portfolio
P&ID	Piping and Instrumentation Diagram
P500	PYREG P500 Carbonization Unit
PLC	Programmable logic Controller
PP	Polypropylene
SAT	Site Acceptance Test
UI	User Interface
URL	Uniform Resource Locator
UX	User Experience

Introduction

The application of biochar has a seemingly unlimited list of benefits for soil, climate and livestock, yet it has failed to scale commercially. BBB proposes that the reason for failure largely boils down to the business model, not the technology. Pyrolysis is a commercialised technology and the approach to biochar production in agriculture to date has been facilitated through two unscalable pathways: either an individual uses basic technology to create biochar in their backyard or a farmer buys a pyrolysis unit and tries to sell or use the biochar. BBB analysed these existing approaches in Phase 1 of the DAC & GGR NZIP programme and found the following commercial barriers:

1. High costs/expensive on-farm infrastructure
2. Lack of a scalable supply chain to produce biochar and market for biochar
3. Lack of knowledge within the agricultural sector of the benefits of using biochar

The Phase 2 Biochar Platform Pilot project seeks to overcome these barriers by transforming the greenhouse gas removal (GGR) market by creating a scalable integrated biochar system consisting of large forest products, paper production and farming organisations in the UK (Figure 1).

Diagram

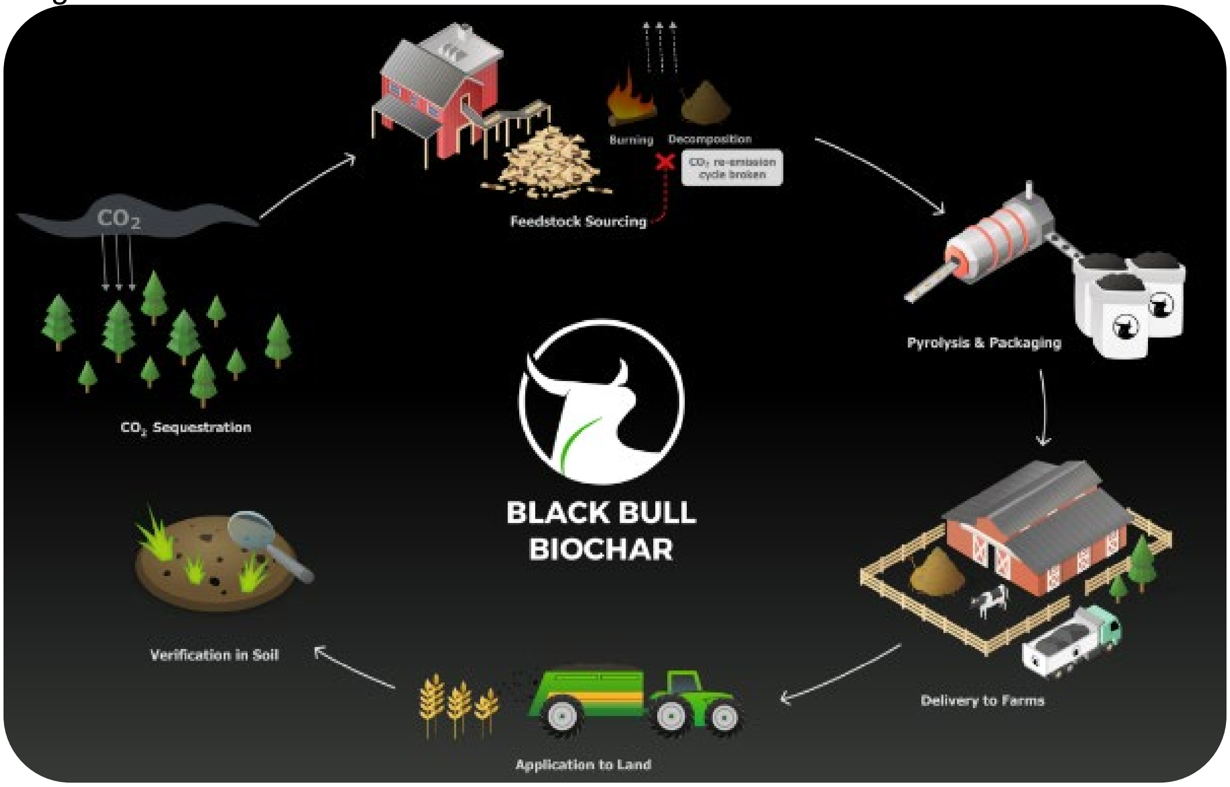

Figure 1 – The scalable integrated biochar system piloted during DAC & GGR Phase 2.

Our goal was to demonstrate the concept of building a scalable business-to-business (B2B) system. For industrial companies, this means an approach that provides economic, renewable heat. For farmers, this means cost-effective tailored biochar delivering maximum impact for an affordable total cost. For carbon credit customers, this means the highest quality biochar carbon credit possible. Once this system is established, this project lays the foundation to allow multiple companies to integrate themselves into an international B2B biochar network.

This report details the work completed by BBB in achieving the demonstration of the pilot system developed for the DAC and GGR Phase 2 Programme. This work was funded by the Department of Energy Security & Net Zero (DESNZ), through the Net Zero Innovation Portfolio (NZIP). The project commenced on the 17th May 2022 and concluded on the 31st March 2025. BBB would like to thank our numerous partners that came together to ensure this project was a success.

Partner Name	Description
Agrecalc	Farm carbon footprinting and impact modelling tool
Ahlstrom	Industrial partner
Arla	Dairy cooperative
AW Jenkinson Forest Products	Biomass supply & site partner
BIOMACON	Pyrolysis engineering and tech partner
dss+	Sustainability consultancy
EBC (European Biochar Certificate)	Biochar certification body
PYREG	Pyrolysis technology provider
Puro.earth	Carbon removal credit certification platform
Soil Association Organic	Organic farming certification and collaboration
SRUC (Scotland's Rural College)	Academic and trials partner
UK Centre for Ecology & Hydrology	Scientific research partner
University of Edinburgh	Research and academic partner

The Key impacts of DAC & GGR NZIP

The Phase 2 of the DAC & GGR NZIP programme has had a significant impact on the biochar industry, primarily through derisking the scale-up of biochar in the UK through a number of achievements:

- The establishment of Black Bull Biochar, founded in 2022
- First to bring a PYREG pyrolysis unit to the UK (>50 in mainland Europe)
- First to bring a Bimoacon pyrolysis unit to the UK (>30 in mainland Europe)
- Now the largest UK biochar producer in terms of biochar production capacity
- Scalable pathway of biochar carbon removal through 10,000 Arla dairy farms
- Scalable pathway of biochar carbon removal through 37 Ahlstrom industrial sites
- Scalable feedstock supply through AWJ (largest UK biomass supplier)
- One of three UK biochar companies to become certified by EBC
- Independent trials showing 16% increase in grassland yield

Biochar Production

With this project, BBB aimed to design, construct and operate 2 innovative biochar production plants, producing quality biochar at scale. The biochar production process is similar at both plants: Biomass is fed into the pyrolysis unit via the hopper and enters the reactor, where it undergoes pyrolysis. Once fully pyrolysed, biochar is discharged, quenched with water, and bulk bagged. The process produces heat that is collected by heat exchanger into a hot water system that can be used for many different applications in a manufacturing environment.

Ahlstrom Radcliffe Pyrolysis Site

Design & Development – Ahlstrom Radcliffe

The challenge was to investigate the different pyrolysis manufacturers and find the best machine, that had a proven history in reliability, performance and cost effectiveness. After reviewing numerous manufacturers, BBB decided on Biomacon. Locally sourced industry leaders in biomass handling were contracted to assist in design and manufacturing of the peripheral plant equipment. Augur-type conveyors were selected to be the handling system to move materials through the process.

In 2022, a supply chain crisis impacted manufacturing timelines for the planned pyrolysis technology (Biomacon). Meanwhile, an opportunity arose to source a readily available unit from industry leaders, PYREG. Consequently, a P500 unit was selected for the Ahlstrom site, capable of a maximum heat output of 150 kWh and production rate of 150 t p.a..

The infeed system was designed with 2 biomass containers, totalling 40 m^3 storage capacity, holding (~10 tonnes of woodchip). The containers are removed from site by a hooklift truck, taken to the offsite woodchip drier and filled from above. Bins are then mounted directly onto guide frames. Hydraulic driven walking floors and discharge sliding plates are built into each container, feeding biomass mechanically into the P500. The biomass is conveyed from the hopper into the pyrolysis reactors. To guarantee the correct particle size required for the process, a twin shaft 20 mm knife shredder was installed between the infeed incline auger conveyor chute and the P500 hopper. The reactors heat the biomass to ~650°C in a low oxygen environment releasing the pyrolysis gases. The gases and air are pulled by fans into the combustion chamber where ignition occurs in the presence of oxygen, the combustion gases are then pulled across the reactor jackets to heat the biomass in the reactors. This requires no additional fuel.

The outfeed 'delivery' system comprises of a long incline discharge auger conveyor and a horizontal auger conveyor fitted with four bagging chutes. Each chute is fitted with a sliding plate valve to control the biochar flow into bag, enabling biochar discharge manual diversion and isolation. In normal operations, the sliding valves are all open to allow natural shift along the auger conveyor once bags and chutes are filled.

Site installation – Ahlstrom Radcliffe
The installation process developed as follows:

JUL 23
- **Ground survey** – Trial pits dug to assess ground conditions

AUG 23
- **HAZOP final report**
- **Groundworks** – Surface upgraded to a concrete base
- **P500 installation** – Reactor and technological container delivered into position

SEP 23
- **Steel canopy** – Assembled in situ and bolted to the concrete
- **Utilities** – Water, mains power and gas connected to the P500
- **Peripherals** – Storage, infeed and bagging system were assembled

NOV 23
- **Health & Safety signage** – fully installed

DEC 23
- **Perimeter fencing** – With access gates to biomass containers and bagging

The pyrolysis heat is utilised by Ahlstrom to preheat the site steam boiler feedwater to reduce natural gas usage. Initially, the low-temperature heat system was installed in pilot form. The system was open loop, feeding hot water into the large brown water feed tank, used to preheat/clean the pulping kiers. The finalised system created a closed loop system that maintains an elevated temperature in the main boiler feed tank, reducing the required load on the steam boilers.

Plant Commissioning – Ahlstrom Radcliffe
The Site Acceptance Test (SAT) was agreed upon and signed on 23rd December. Training was provided to P500 operators, in preparation for post-commissioning operations. While plant optimisation was continued beyond this date, P500 commissioning was deemed complete.

In parallel with commissioning, the first European Biochar Certificate (EBC) pre-audit was undertaken. The inspection and sampling that followed in April, led to the successful accreditation of a EBC on the first biochar batch.

Operational Delivery – Ahlstrom Radcliffe
At Ahlstrom, BBB are responsible for operating the plant.

In January, daily operations were handed to operational subcontractors, with support from BBB and PYREG. COSHH, Risk Assessments and Operational Method

Statements were prepared and reviewed by the parties involved, including start-up and shutdown procedures. Feedback and operational ‘walk-throughs’ informed iterations of these documents. BBB produced several data logs for operators to capture critical information on machine operations, daily tasks, biochar production and EBC compliance.

It became clear that the plant required a dedicated local operator with the technical expertise to closely monitor and calibrate the unit instead of subcontractors. In March, a Pyrolysis Operations Manager was hired who had a background in steam production operations. The first full articulated lorry load was subsequently shipped to Arla farms on 28th March 2024.

As BBB’s operations experience grew, it became clear that runtime is closely correlated to the operators' capacity and skillset. In August, BBB hired a Plant Operator to improve operational capabilities. This role has been integral in streamlining day-to-day operations, such as P500 calibration, managing the supply of biomass and fuel, plant maintenance, quality testing, data collection, managing biochar production, etc. With a full-time operator onsite, BBB can be reactive to the changing demands of biochar production.

Installation of an office onsite provided the operations team onsite with a comfortable environment to work, space for biochar and biomass testing and improved storage. See Figure 2 for site image.

Figure 2 – Ahlstrom Radcliffe site showcasing BBB’s PYREG P500 pyrolysis unit, peripheral equipment, canopy and container office.

A. W. Jenkinson Newton Rigg Pyrolysis SITE

Design & Development – Newton Rigg

From the outset of the project, the intent was to deploy C500-I pyrolysis machines from Biomacon, which was successfully implemented at the site in Penrith. The Biomacon C500-I can deliver 450 t p/a of biochar and 500 kW of usable heat, according to the manufacturer's data.

The plant is situated on an A.W. Jenkinson's host site in Penrith (Newton Rigg), where a redundant boiler house and existing plot were reconfigured to accommodate the plant. This allowed a like-for-like replacement of a combustion biomass boiler with a similar equal-rated pyrolysis boiler. The design of the building layout, storage/infeed capacity and bagging area concrete has been completed by A.W. Jenkinson according to information and specifications provided by Biomacon and BBB.

At this plant, heat from pyrolysis is extracted for use in a surrounding heat network and biomass drying bins, reducing both cost and carbon footprint of the feedstock.

Site installation – Newton Rigg

The plant installation was led by a team at A. W. Jenkinson (AWJ), who managed all civil works and updated Black Bull Biochar with the following developments:

APRIL 24

- **Concrete works** – Ground and aggregated slab and wall panel installed
- **Internal reconfiguration** – Various bays and internal steelwork complete

MAY 24

- **Utilities (electrical, drainage and water)**
- **C500-I delivered**
- **Roof refitted** – altered post C500-I delivery
- **Green wood store** – Built to the side of building
- **HAZOP** – Hazard and Operability study completed by DSS+

JUL 24

- **Biomass handling equipment delivered**
- **Utilities** – heat sink works, pipework, heat exchanger and buffer tanks connected
- **Unit Installation** – PLC and control panel connected to power and internet

AUG 24

- **Fire Risk Assessment** – final report provided, and actions implemented

SEP 24

- **Bagging System Installed**

Plant Commissioning – Newton Rigg
Commissioning activities were separated into Pre-Biomacon and Biomacon commissioning phases. Pre-Biomacon commissioning encompassed works on the heat network, control systems and some unit hardware.

In September 2024, the Biomacon commissioning engineer attended the site to complete the C500-I and the related peripheral equipment commissioning concurrently. C500-I Operator training was provided to BBB and A.W. Jenkinson staff. In the commissioning period, the EBC pre-audit for this second site was also completed. In October 2024, the Biomacon SAT was signed, with the full scope of aspects checked and approved.

Operational Delivery – AWJ Newton Rigg
At Newton Rigg, AWJ are responsible for operations. See Figure 3 for site image.

Figure 3 – A.W. Jenkinson Newton Rigg site showcasing BBB's Biomacon C500-I pyrolysis unit, peripheral equipment, pre-existing building and container dryers.

PILOT PLANT RESULTS

The following plant results provide a detailed overview of biochar output, heat production, feedstock consumption, and CO_2 removal. As demonstrated, the target of more than 100 tons of CO_2 removal is forecasted to be achieved three times over, at a total of 341 tons.

Table 1 – Total production from the 2 sites combined up to 28/02/25

	Units	ARA	JNR	Total
Biochar Bags[1] *End of project forecast*	2 m^3 bags	180 *200*	296 *361*	476 *561*
Dry Biochar	t DS	40.4 *44.9*	60.9 *74.3*	101.3 *119.2*
Carbon removed	t CO_2e	101.0 *112.2*	187.6 *228.8*	288.6 *341*
Heat	MWh	634 *671.5*	606.3 *705.9*	1240.3 *1377.4*
Feedstock Consumption Dry	t	279.2 *304*	247.3 *376.3*	526.5 *584.1*
Feedstock Consumption Wet	t	n/a n/a	367.5 *442.5*	367.5 *442.5*

[1]**Bag fill volume has been measured at 1.44 m3 per bag**

ARA emissions testing in April and October demonstrated overall consistent data and confirmed the plant performance was in line with the manufacturer-stated emission data and concentrations were below the emission limits. While some concentrations (e.g., CO) increased above the expected concentration from manufacturers' data, all emission concentrations were below emission limit values. See Table 2 for full results.

Table 2 - ARA flue stack emissions data with comparison to manufacturer-provided expectations.

ARA Plant Emissions

Parameter	**Units**	**APR result**	**Calculated Uncertainty (+/-)**	**OCT result**	**Calculated Uncertainty (+/-)**	**Manufacturer expected**
Total Volatile Organic Compounds	mg/m³	0.16	2.00	0.64	1.80	1.50
Total Volatile Organic Compounds Emission Rate	g/hr	n/a	n/a	0.36	0.98	<1
Oxides of Nitrogen (as NO_2)	mg/m³	140	4.20	97.00	2.80	264.00
Oxides of Nitrogen (as NO_2) Emission Rate	g/hr	n/a	n/a	54.00	1.50	66.00
Sulphur Dioxide	mg/m³	0.75	1.10	0.76	1.40	67.00
Sulphur Dioxide Emission Rate	g/hr			0.42	0.79	17.00
Carbon Monoxide	mg/m³	1.70	1.20	23.00	1.30	8.00

Carbon Monoxide Emission Rate	g/hr	n/a	n/a	13.00	0.74	2.00

AWJ emissions testing in February demonstrated overall consistent data and confirmed the plant performance was in line with the manufacturer-stated emission data and concentrations were below the emission limits. See Table 3 for full results.

Table 3 - JNR flue stack emissions data with comparison to manufacturer-provided examples.

JNR Plant Emissions

Parameter	**Units**	**FEB Result**	**Calculated Uncertainty (+/-)**	**Manufacturer Example**[1]
Methane	% v/v	0.39	-	n/a
Total Volatile Organic Compounds (VOC)	mg/m³	1.60	1.70	n/a
Oxides of Nitrogen (as NO2)	mg/m³	142.00	4.30	n/a
Sulphur Dioxide	mg/m³	0.77	2.00	n/a
Carbon Monoxide	mg/m³	5.20	1.30	7.00
Oxygen	% v/v	12.10	0.27	10.03
Stack Gas Temperature	°C	54.00	-	145.00

Biochar Quality and Feedstock Utilisation

The biochar produced at both sites used virgin sawmill woodchip from FSC certified sawmills and was found to be of a high quality, in terms of carbon stability, agronomic performance and contaminate content. The full chemical and physical analysis results for biochar produced at the two sites, ARA and JNR, can be found in Table 4.

Table 4 - Biochar quality analysis for Ahlsrtom Radcliffe (ARA) and Jenkinson Newton Rigg (JNR) production sites. Analysis completed by Eurofins Friebourg. EBC limit values are displayed for comparison, 1) EBC Agro-Organic, 2) EBC Agro and 3) EBC basic materials. Results are shown as AR (as received) and DB (dry basis).

		EBC Limit values			ARA		JNR	
Parameter	Unit	1)	2)	3)	AR	DB	AR	DB
Basic Physical and Chemical Properties								
Bulk density<3mm	kg/m³					133		207
Bulk density	kg/m³				236		187	
Specific surface(BET)	m²/g					471.06		434.27
Water holding capacity(WHC) <2mm	%					302.9		283.1
Moisture	%(w/w)				39.8		21.9	
Ash content(550°C)	%(w/w)				1.3	2.2	1.5	1.9

[1] Average of M1, M2, M3 full load examples provided from Biomacon

Total carbon	%(w/w)				55.0	91.4	74	93.7
Carbon(organic)	%(w/w)				55.0	91.4	73.6	93.2
Hydrogen	%(w/w)				1.0	1.7	1.1	1.4
Total nitrogen	%(w/w)				0.22	0.37	0.42	0.53
Total Sulphur	%(w/w)				<0.03	<0.03	0.03	0.04
Oxygen	%(w/w)				3.0	5.0	2.2	2.7
Total inorganic carbon(TIC)	%(w/w)				<0.1	<0.1	0.4	0.5
H/C ratio(molar)					0.23	0.22	0.18	1.9
H/C org ratio(molar)		<0.7	<0.7	<0.7	0.23	0.22	0.18	0.18
O/C ratio(molar)					0.041	0.041	0.022	0.022
Volatile Compounds	%(w/w)				4.4	7.2	3.5	4.4
Gross calorific value(Ho,V)	kJ/kg				20800	34500		34400
Net calorific value(Hu,p)	kJ/kg				19600	34100		34200
pH in CaCl2					8.7		8.3	
Salt content	g/kg				1.77		1.3	
Salt content	g/l				0.236		0.27	
Conductivity at 1,2 t pressure	mS/cm					1.0		150
Conductivity at 2 t pressure	mS/cm					1.4		200
Conductivity at 3 t pressure	mS/cm					2.0		280
Conductivity at 4 t pressure	mS/cm					2.2		290
Conductivity at 5 t pressure	mS/cm					2.6		350
Crude ash	%(w/w)				1.3	2.2	1.5	1.9
Heavy Metals and Contaminates								
Arsenic(As)	mg/kg	13	13			<0.8		< 0.8
Lead(Pb)	mg/kg	45	120			<2		< 2
Cadmium(Cd)	mg/kg	0.7	1.5			<0.2		< 0.2
Copper(Cu)	mg/kg	70	100			5		7
Nickel(Ni)	mg/kg	25	50			4		20
Mercury(Hg)	mg/kg	0.4	1			<0.07		< 0.07
Zinc(Zn)	mg/kg	200	400			57		19
Chromium(Cr)	mg/kg	70	90			21		51
Boron(B)	mg/kg					10		9
Manganese(Mn)	mg/kg					269		377
Silver(Ag)	mg/kg					<5		< 5
Total8EFSA-PAHexcl.LOQ	mg/kg	1	1	4		(n.c.)3)		(n. c.) 1)
Total16EPA-PAHexcl.LOQ	mg/kg	64)	64)			1.4		2.3
Benzo(e)pyrene	mg/kg	<1	<1	<1		<0.1		< 0.1
Benzo-(j)-fluoranthen	mg/kg	<1	<1	<1		<0.1		< 0.1
Nutrient Composition								
Phosphorus as P2O5	g/kg					0.8		0.7
Potassium as K2O	g/kg					1.5		2.6
Calcium as CaO	g/kg					6.5		4.8
Magnesium as MgO	g/kg					1.1		1.2

Sodium as Na2O	g/kg					0.8		0.2
Sulphur as SO3	g/kg					0.2		0.2
Iron	g/kg					0.5		0.5
Silicon	g/kg					1.9		1.5
Total nitrogen	g/kg				2.2	3.7	4.2	5.3

All biochars produced met the strictest EBC limit values for contaminates, with many below the detectable level. The PAH content was found to be exceptionally low, indicating efficient pyrolysis conditions. The H:C org ratio, often used as a proxy to indicate carbon permanence, was also considerably low, comparable to the most stable biochars produced from slow pyrolysis. The H:C org ratio was 0.22 and 0.18 for the ARA and JNR sites respectively. This minor difference may be due to the extended residency time used by the JNR Biomacon C500-I unit, compared with the ARA PYREG. All biochar was produced at a target pyrolysis temperature of 650℃.

Demonstrator Hub

Design & Development

For the pilot, a group of early-adopter farmers willing and motivated to trial biochar were selected 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. 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. Most of these farmers were from the Northwest of England and the Southwest of England. Due to the concentration of biomass, timber processing, and dairy farms near and within the region, Cumbria and Southwest Scotland emerged as a logical place to select 10 farms to form the Biochar Demonstrator Hub.

The purpose of the Demonstrator Hub was to trial BBB's biochar products through a number of different approaches, including applying biochar to slurry or farmyard manure (FYM), and bedding. These trials would serve to test the practicalities of biochar use on farm and gain qualitative feedback on the usability and on-farm impacts of the products. A biochar handbook (see handbook illustrations in Figure 4) was created to provide the farmers with guidance on biochar use. Farmer engagements, including online catch-ups, workshops, and farm visits were planned and held throughout the project. These served a variety of purposes, including knowledge dissemination, demonstrations, and user research.

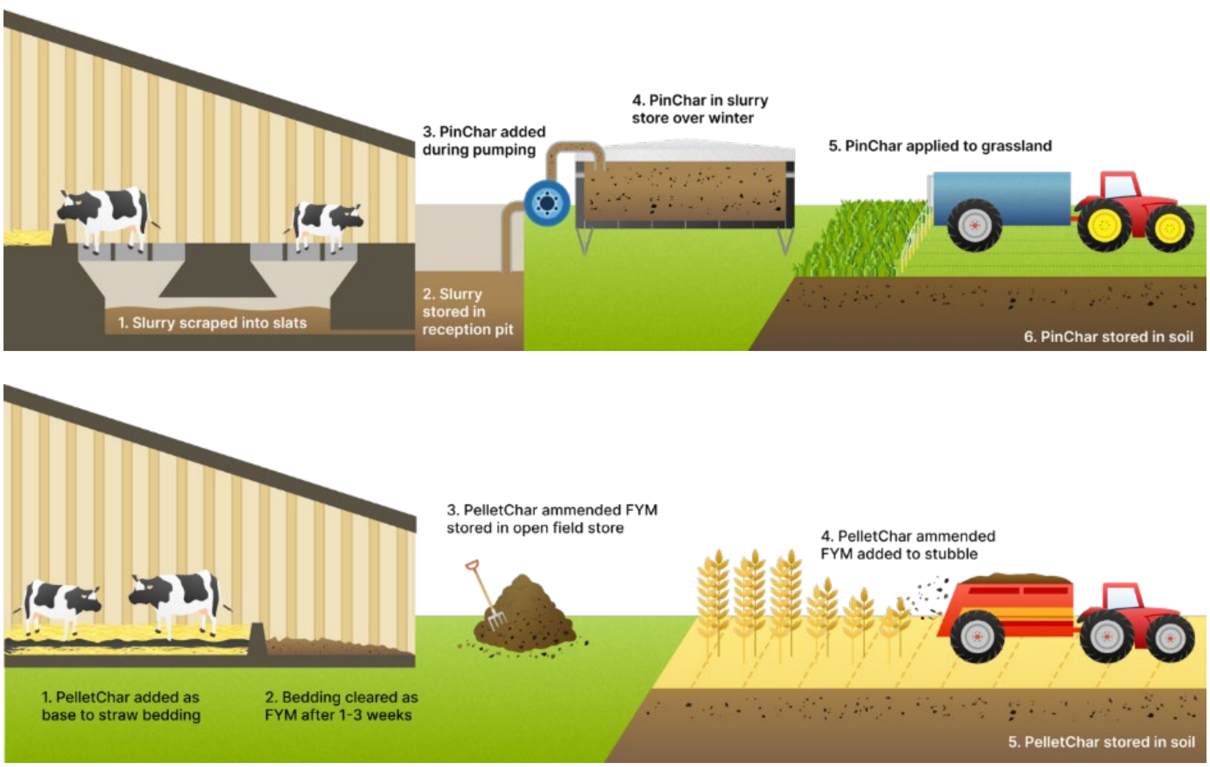

Figure 4 – Illustrations from the farmer guidebook, illustrating biochar use in housing and manure management systems on dairy farms.

Results

The farmers trialled biochar in a variety of application methods, depending on their preferences and farm systems. One of the selected Demonstrator Hub farms was the Arla research farm at SRUC Crichton, where the SRUC biochar trials were held. The remaining 9 farms were operational dairy farms, ranging from 220-1000 acres in size. The farms trialled application in slurry, farmyard manure, bedding, and direct-to-land. Throughout the project, a total of 8 engagement sessions were held with the farmers, summarised below (Table 5).

Table 5 – Farmer engagement sessions were held with demonstrator farms throughout the project.

Engagement	Date	Description
1-1 catch-ups (online)	January 2023	Conducted research to understand farmers' on-farm systems, including ideal logistics, delivery processes, and payment plans for future commercialisation.
In-person workshop	March 2023	Hosted the first in-person gathering of all participating farmers. Discussed the project plan, timelines, and farmers' intended uses for biochar. Visited the SRUC field trial site.
The science behind biochar benefits webinar	May 2023	Presented research on biochar benefits and explained the mechanisms behind them, helping farmers understand how to achieve desired outcomes with biochar use.
On-farm demonstration	June 2023	Provided biochar to one of the Demo Hub farmers, who applied it in trial tanks with slurry and calf bedding to demonstrate its practical on-farm applications.
Farm visits	September 2023	Conducted on-site visits to create tailored biochar use plans for each farm, set up farmer accounts on the BBB app, and shared first-year (2023) results from the SRUC field trials.
1-1 catch ups (online)	February 2024	Collected farmer feedback after the first biochar delivery in December. Updated each farmer's biochar use plan and explored farmer perceptions of biochar.
Farm visits	October 2024	Introduced farmers to Charcodes, BBB's biochar traceability system, and guided them through the onboarding process.
Biochar workshop and site visit	November 2024	Held a workshop to review feedback on Charcodes and large-scale biochar use, share second-year (2024) field trial results, and tour the Biomacon site.

Discussion

Biochar Application Practicalities

The pilot trials by the Demonstrator Hub revealed valuable insights on how to best use biochar effectively and practically. These covered a range of application methods with various organic fertilisers and direct applications to land. The results of the trials have informed the go-to-market strategy of BBB. BBB will now provide farmers with tailored biochar use advice as part of the "Biochar Plan" function of the app, which is in development. BBB also produced a farmer handbook for the demonstrator farms in this project to assist with biochar use on farm, but direct advice was also required to aid decision support.

Application to bedding

Farmers who trialled biochar in bedding reported mixed outcomes, with some noting that cows turned dirty, while others reported that the herd remained clean. Some noted that their paper bedding lasted longer in the housing, as it was able to keep dry due to the biochar added. Cows appearing dirty was typically due to high levels of biochar application. However, due to the high water-holding capacity of biochar, it is effective in smaller amounts.

Application to slurry

Biochar application with slurry has shown positive crop impacts through the field trials conducted in this project, with the detailed results presented later in this report (see page 15). However, slurry stores on farm were typically >1 million gallons in capacity. This meant that a large amount of biochar (>50 t) per farm would be required to reach even a 1% concentration of biochar, making it highly impractical for a farmer. Additionally, as slurry stores are filled and emptied continuously, it would not be possible to trace which fields biochar has been applied to. Directly applying biochar to the desired field and then spreading slurry over top may be an effective method of co-application.

Application to farmyard manure

Farmers were able to mix biochar with their stored manure heap using a telehandler. The biochar-amended FYM was spread through standard muck spreaders. Overall, mixing biochar with FYM (directly or via bedding) emerged as an effective and practical method of biochar application.

Direct application to land

Biochar was shown be directly applied using a lime spreader, but its low density meant multiple loads were needed to apply over a full field. Followed by slurry application, this would allow farmers to gain the benefits of applying biochar amended slurry, with improved ease and precision compared to adding it to slurry stores directly.

Farmer App

BBB has developed a dedicated farmer app for farmers. Currently, the app enables farmers to place and track biochar orders and deliveries, providing a record of biochar received to date, as well as a ‘biochar plan’. Looking ahead, the app will be integrated with BBB's biochar traceability system. This integration will provide farmers with greater visibility into the origin, quality, and impact of the biochar they use, supporting data-driven decision-making and improved sustainability outcomes.

Overall, application to bedding, farmyard manure, and direct biochar application co-applied with slurry emerged as the most effective and practical use cases. Developing guidelines for biochar application and tracking with these methods will be key in the scale-up and wider adoption of biochar. An updated farmer handbook will be created incorporating findings from the pilot trials. Targeting application and keeping records of where biochar has been applied will ensure its effectiveness can be maximised.

Field Trial Summary

This section provides a short executive summary on the field trial work conducted by BBB, SRUC and UKCEH. The field trials were conducted to test the performance of the BBB biochar in the target use system and understand how the application method can alter soil properties over time. The aim of the trials was to;

1. Identify any effects of biochar on crop yield and quality in grassland and arable crops when biochar is co-applied with organic fertilisers at low application rates (<1 t/ha/yr).
2. Assess the extent and longevity of changes to soil nutrient and carbon content with a single low-dose biochar application on representative agricultural soils.
3. Investigate the longevity of any changes to crop yield with single and repeated biochar application across multiple growing seasons and crop cycles.

Design & Development

Biochar field trials were conducted at SRUC Crichton Farm, Dumfries, commencing in Spring 2023. These trials investigated the effects of biochar on soil properties and crop yield in both arable and grassland systems. Biochar was applied at low dose rates as an amendment to organic fertiliser.

Twenty experimental plots were established, each measuring 10m x 10m. The plots were separately established across two crop types: 10 grassland plots and 10 arable plots, planted with winter wheat, establishing both an arable and a grassland trial. For each trial, five plots were designated as control plots and five were treated with biochar-amended slurry (for grassland) or biochar-amended farmyard manure (for arable). Initial treatment application was as follows:

Grassland:

- **Grassland Control treatment**: Slurry application at 50 t ha^{-1} yr^{-1}, with no biochar (slurry April 2023 & slurry April 2024)
- **Grassland Biochar treatment**: Slurry application at 50 t ha^{-1} yr^{-1}, amended with biochar during the storage phase at 1% biochar dry matter (equivalent to 500 kg ha^{-1} yr^{-1}) (biochar/slurry April 2023 & slurry April 2024)

Arable:

- **Arable Control treatment**: Annual farmyard manure application at 10 t ha^{-1} yr^{-1}, with no biochar
- **Arable Biochar treatment**: Annual farmyard manure application at 10 t ha^{-1} yr^{-1}, amended with biochar during the storage phase at 10% biochar dry matter (equivalent to 1000 kg ha^{-1} yr^{-1})

To assess the residual effects of biochar and the efficacy of top-up biochar application, the five treatment plots for both arable and grassland field trials were split into **Biochar** and **Biochar+** plots (two and three plots respectively). Biochar+ plots had a second biochar application in spring 2024, using the same application methods and rates as Spring 2023. No additional biochar was applied during 2024 in **Biochar** plots.

Crop yield and quality were assessed during each growing season (2023 & 2024) by SRUC. Soil sampling and analysis was conducted by UKCEH at time points throughout the trials, including baseline sampling during March 2023.

Key Findings

Crop Yield and Quality

Grassland

Biochar application consistently increased total grassland yield in both 2023 and 2024. The 2023 biochar-treated plots produced a 16.1% higher yield than controls. In 2024, single biochar application plots maintained the highest percentage yield increase at 17.9%, while plots with repeated applications (Biochar+) exhibited a slightly lower increase of 10.3%. The total yield in 2024 was proportionately lower than 2023 across all treatments, reflecting the general trend in the region due to high rainfall. The annual results indicate a sustained yield benefit from biochar, with no benefit from repeated applications within the experimental timeframe. There was no significant difference in crop quality across the treatments.

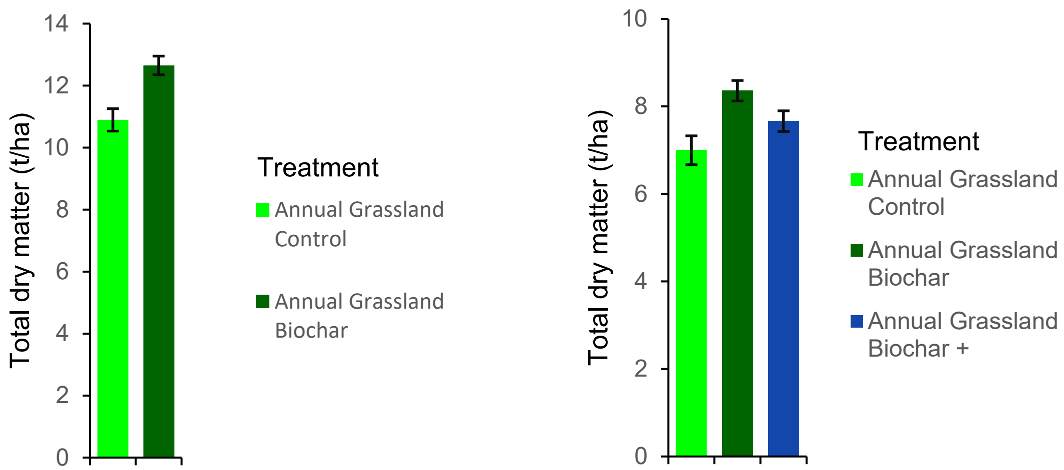

Figure 5 – Year 1 (2023) *left* and Year 2 (2024) *right* yield results for grassland plots.

Arable

In the 2024 arable trial, biochar application led to increased yields compared to the control plots, with the biochar treatments showing higher dry matter yields. Whole crop yield was 34% greater than the control plots. The results suggest that biochar may have the potential to enhance yield, however further investigation is required. Top-up biochar application did not increase yield compared to a single biochar application. Results indicate that a single biochar application at 1 t/ha/yr may increase crop yield for multiple years, despite ongoing soil cultivation altering biochar distribution in the soil. No yield results were achieved during 2023 due to the prevalence of weeds in the plots.

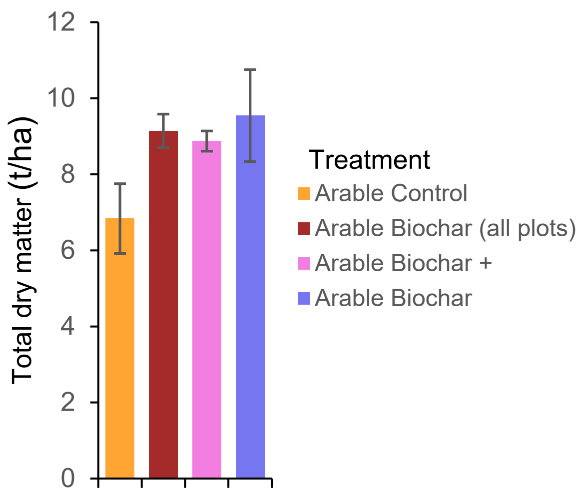

Figure 6 – Whole crop yield for arable plots in Year 2 (2024).

No differences were found in the crop quality across plots and treatments, suggesting that the biochar may increase yields without detrimentally effecting crop quality parameters.

Soil Properties

Low-dose biochar application was shown to alter certain soil properties for the duration of the trials. The key findings were;

1. Biochar addition to grassland plots was associated with increased pH, soil carbon and bulk density between March 2023 and January 2025.
2. Biochar added to arable plots correlated with short-term increased nitrogen over the same time frame.
3. There is a greater impact of biochar on the grassland plots than the arable plots, this may be due to how the different land types are managed, or biochar may have greater effects when mixed with slurry than farmyard manure.

Biochar Operations & dMRV Platform

The digital infrastructure of BBB was developed to support the end-to-end management of biochar production, distribution, and traceability. Its main objective was to create a streamlined, transparent, and efficient system to support BBB business operations, facilitate farmer engagement, and ensure rigorous tracking of biochar movement for carbon credit verification.

The software subcontractor, Webpanda, outlined a preliminary roadmap for the BBB platform, defining the key functionalities required to support biochar supply chain operations. This included the development of a secure, scalable, and user-friendly web-based application, incorporating best practices in software architecture and iterative development through CI/CD processes. While a significant portion of design and development work went towards website development and more general IT infrastructure work, this report will focus on the BBB web app and its components.

Purpose and Benefits of the Platform

BBB platform was designed to address key operational challenges in biochar production and distribution, providing a centralized system for tracking biochar from production to application. The software core purpose of the software was to:

- Enable traceability of biochar for compliance and carbon credit verification
- Provide farmers and BBB staff with a user-friendly interface to manage orders
- Support inventory management across multiple pyrolysis sites
- Automate workflows, such as farmer onboarding, invoicing and customer support

The application was built iteratively, ensuring that its functionality evolved in response to real-world requirements and user feedback, while maintaining a flexible and modular architecture to support future enhancements and scalability.

Refining the Digital Vision of BBB

The initial vision for the stack of technologies used to build out the digital ecosystem of BBB laid out a general direction and framework that would guide the development process. These suggestions were based upon industry-specific best practices and patterns (using a modern JavaScript framework with the appropriate tools) and early assumptions surrounding the future needs of various stakeholders of BBB.

As can be expected of a project of this scale, and especially given the somewhat uncharacteristic habits and profiles of its main users (farmers and biochar production ops), its end-to-end application capabilities and system requirements were adapted along the way to better accommodate the project, and especially users' needs.

Following the Agile approach (as opposed to a waterfall approach), development implemented general CI/CD guidelines and practices. While BBB envisioned a section of the app for B2B companies, the needs and usefulness of our initial 4 modes/sections of the web app evolved significantly. The project shifted its focus and priorities towards fulfilling core needs such as the requirements of the company operations, and dMRV (digital monitoring, reporting, and verification) practices within BBB. This process of restructuring and prioritising the sections of the BBB app was continuously guided by user-centric research and feedback, and a decision was eventually reached to completely remove 2 of the 4 "modes", and to add a new one (see change between Figure 7 and 8).

Flow

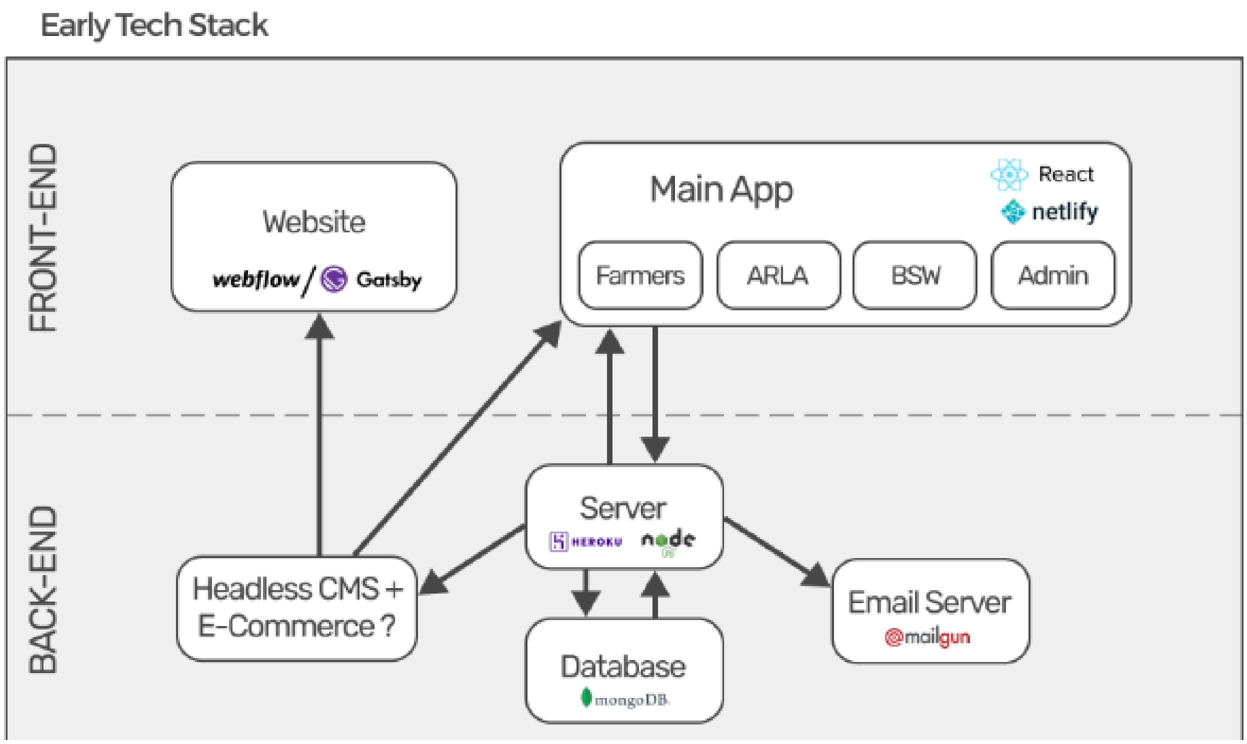

Figure 7 – Initial stack proposal for BBB app development

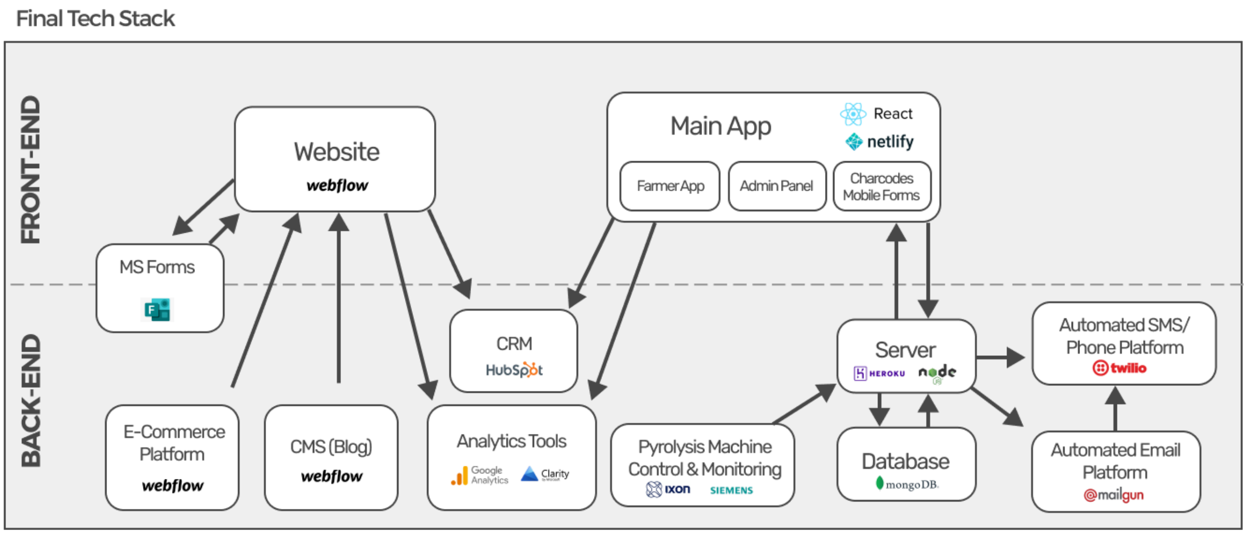

Figure 8 – Final Stack used for BBB app development

Technologies Overview

As outlined in the Tech Stack diagram (Figure 8), the project made use of many different technologies and 3rd party services that worked in unison to achieve the desired functionality from the BBB app. Below is a non-exhaustive list, along with a brief explanation.

Core Project Technologies

- React**:** JavaScript library for building the app dynamic and interactive frontend interface
- Netlify**:** Hosts the frontend, offering fast deployment and CDN (Content Delivery Network)
- Node.js**/**Express**:** A runtime environment used to build and run the app backend server, handling logic, APIs, and integrations
- Heroku **(Server):** A cloud platform used to deploy and manage the app backend infrastructure, providing hosting and scalability
- MongoDB**:** A NoSQL database used for storing and managing app data, such as user records and transactions. Our databases are currently hosted on Atlassian servers in Ireland

3rd Party Services/Platforms

- GitHub**:** A platform for version control and collaboration, used for managing and storing the source code of the project, as well as facilitating teamwork and code reviews
- Twilio **(Automated SMS/Phone Platform):** Sends automated SMS and phone notifications to users for communication workflows
- Mailgun **(Automated Email Platform):** Handles automated email delivery for notifications and updates within the app
- HubSpot **(CRM):** A customer relationship management platform integrated to track and manage user interactions and data
- Google Analytics**:** Provides insights into user behaviour and traffic patterns to improve the app performance and user experience
- Microsoft Clarity**:** A tool for tracking user sessions, heatmaps, and analytics to optimize user interactions and identify potential issues
- Siemens/IXON **(Pyrolysis Machine Control & Monitoring):** Enables integration for monitoring and managing external pyrolysis machines

Development Workflow

The development and deployment process for the BBB app adhered to an agile approach. This workflow focuses on smaller incremental releases, implementing frequent feedback and adaptability into the workflow.

Workflow Summary

Both the back-end and front-end followed a similar workflow:

1. New functionality is planned, designed, and coded. First, a flow is established outlining the functionality of each screen within the app. Then, a rough wireframe with basic UI elements is created, which serves as both a proof of concept and a guideline for the design.

2. For the back-end, the coding process is carried out on an integrated development environment (code editor) and tested locally on a laptop. The codebase is frequently pushed (stored/backed up) to a dev branch on GitHub. Each new push corresponds to a new functionality or version.

3. Following the end of the development phase, the codebase from the development branch is pushed onto the staging branch of the project. This automatically triggers an app build.

4. Qualitative and quantitative feedback is collected from users. New features and improvements are aggregated and added to the product backlog. User data can be collected directly from the app, as well as through focus groups or workshops. Feedback is aggregated and reviewed.

5. At this stage, if the project is deemed satisfactory, both from a functional and visual point of view, changes are pushed from the staging branch to the production branch, which triggers a build and deployment to production. If it is not, development goes back to step 1, integrating feedback and fixing issues.

Key Challenges

- **User Adoption Barriers:** Some farmers were hesitant to use digital tools, which required additional onboarding support
- **Integration:** Planned integrations with external platforms proved unfeasible due to limited external interest or precocious software

Key Achievements

- **Charcodes:** Successfully improved adoption of the Charcode tracking system, which ensures biochar traceability
- **Enhanced Inventory Management:** Improved the repertory system of the Admin App, enabling advanced search filters to browse through biochar bags
- **Expanded Testing Scope:** Began testing and collecting feedback from farmers and 2nd parties

App Features & Functionality

The following section will take a closer look at the core features and functionality of the BBB platform. For the sake of clarity, it will be divided into four sections: the back-end, the farmer app, the admin app, and Charcodes.

App Infrastructure & Functionality

Server Setup

The server functions as the backbone of all of BBB's digital infrastructure, acting as the central hub that connects to all of its separate parts. As it stands, the server handles the following tasks:

- Fetching data from the database, as well as writing to and deleting from it
- Serving API endpoints, both to the app users and any external parties
- Running jobs such as managing accounts ot sending email reminders
- Verifying user identities and managing session tokens for secure access control

Farmer App

The Farmer "mode" of the BBB app shares the same entry point as the Admin app through the login screen (dashboard.blackbullbiochar.com). It provides specific functions unique to the farmer:

- Create and set up an account after receiving an invite with a referral code
- Set up a biochar package (deliveries of biochar spread across the year)
- Browse through orders and invoices
- Set/update delivery and billing details
- Tracking bags delivered, and number of "charpoints"
- Customer support through the creation of a support ticket

Admin App

The Admin app is the internal hub of BBB for managing operations and tracking data, also acting as a decision support tool.. Here are the main features of the admin app:

- **Order & Delivery Management**: Admins can schedule and manage orders, track shipments, and allocate deliveries to multiple farms
- **Farmer Account Management:** The admin team can view and update farmer profiles, including contact details, allocated biochar quantities, and order history
- **Inventory:** The system tracks biochar bags across multiple production sites. Biochar bags/Charcodes can also be browsed and filtered
- **Charcode generator:** A dynamic Charcode generator, which creates new Charcodes in the database and outputs the A4 paper
- **Support:** Admins can view and respond to support tickets, ensuring timely resolution of any farmer issues or questions

Charcodes

The third "mode" of the BBB app is a mobile form that is connected to a "Charcode", a unique QR code with an embedded ID linked to one biochar bag. Each code redirects to the appropriate form based on its progress through the sequence of steps from bagging to application.

Scanning the Charcodes at each step ensures the integrity of the biochar carbon journey and guarantees that the carbon credits associated with the biochar are accurately tracked and verified. This process added transparency and reliability to the carbon credit system, which is crucial for both farmers and buyers of carbon credits. A timestamp with an associated geolocation (longitude and latitude coordinates) is captured at each step. All of the data captured through Charcodes is accessible from the admin app.

The Charcode system also helps track inventory across multiple pyrolysis sites, providing real-time data on biochar stock levels and ensuring that production and delivery schedules are aligned with farmer demand. The Charcodes are scanned at various stages throughout the supply chain:

- **Bagging:** New bags are scanned once they have been successfully bagged. They are associated to a pyrolysis site, and have their moisture content, internal bag temperature, weight, and production date recorded. After this stage, the bag is now logged into our database.
- **Pickup:** After an order has been scheduled from the admin app, operators on site/storage prepare and scan bags from our inventory as they are being loaded onto a lorry. As a safety precaution, form validation is enforced to ensure the appropriate number of bags are scanned.
- **Delivery:** When the order arrives on farm, the farmer verifies and approves of the contents of the order being handed over to them. For each bag successfully tracked, the farmer is rewarded with ten “Charpoints”, which they can use as a voucher on their next biochar purchase. Before completing this form, a signature is required, which acts as a digital proof the goods were handed over to the customer/biochar user.
- **Application:** When biochar is applied on farm (per bag), the farmer fills out the application form. Which tracks the date and end use of the biochar being applied. Just like the previous step, Charpoints are allocated to the farmer’s account for each bag successfully scanned.

Monitoring, Reporting, and Verification

Design & Development

Monitoring, Reporting, and Verification (MRV) is essential in quantifying the amount and permanence of carbon removals achieved by GGR activities,[2]. GHG removals are measured over a period of time and reported to an accredited third party. These third parties verify the reported carbon removal and certify, and issue, the associated carbon credits.[3] To be credibly net-negative, an activity must permanently remove more GHG than it creates.

The BEIS Task and Finish Group report on MRV[4] outline a generic approach to MRV:

- Up and down-stream life cycle analysis (LCA) to identify, and quantify, potential sources of carbon leakage across the GGR value chain,
- Baselining background carbon/carbon dioxide levels, and
- Developing project completion and abandonment protocols and an MRV plan

To accurately calculate the carbon removals resulting from a biochar project, existing biochar CDR accounting methodologies typically require three key pieces of information[5,6,7]:

1. The amount of carbon stored in the biochar
2. The carbon emissions and leakages from producing and using the biochar (Figure 9)
3. Validation of the final biochar carbon sink (i.e. ensuring it is stored in an appropriate sink and not burned)

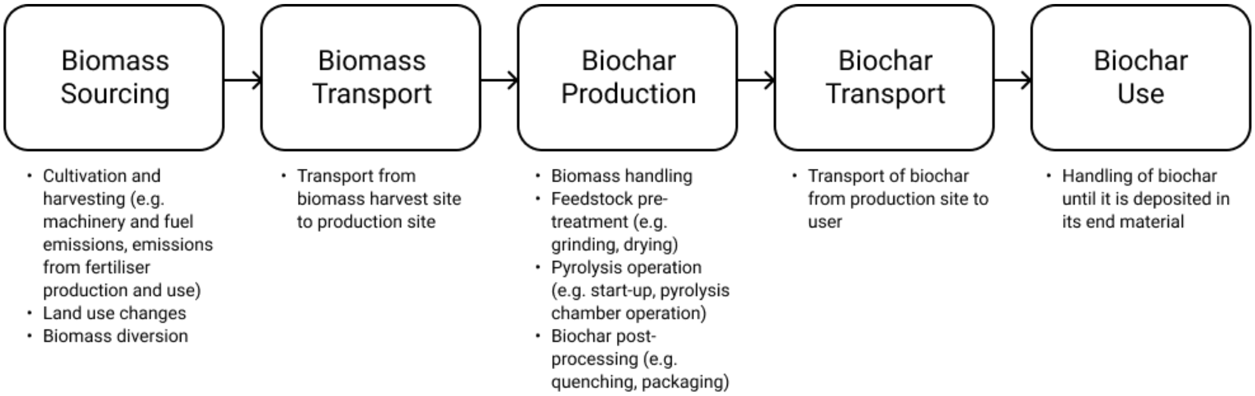

Figure 9 – Breakdown of emissions from different stages in the biochar value chain.

[2] BEIS 2021, Monitoring, Reporting and Verification of Greenhouse Gas Removals Task and Finish Group Report - LINK
[3] The World Bank 2022, What You Need to Know About the Measurement, Reporting, and Verification (MRV) of Carbon Credits - LINK
[4] BEIS 2021, Monitoring, Reporting and Verification of Greenhouse Gas Removals Task and Finish Group Report - LINK
[5] Puro.earth 2022, Biochar Methodology - LINK
[6] EBC 2020, Certification of the carbon sink potential of biochar - LINK
[7] VCS 2021, Methodology for biochar utilisation in soil and non-soil applications - LINK

At the start of Phase 2, BBB conducted a comparison of the leading biochar MRV and certification methodologies in the Voluntary Carbon Market (VCM). These included the European Biochar Certificate (EBC) C-Sink, Verra, and Puro.earth biochar methodologies. The analysis concluded that the Puro.earth standard was the most well-recognised in the market and suitable for BBB's production system. Following the existing standards to list BBB's carbon credits on a major registry is necessary to build trust and credibility in the carbon removal offset market.

BBB has undergone certification under the EBC-Agro and AgroOrganic labels and the Soil Association Approved Input Scheme (allowing the use of BBB biochar on organic certified farms). Maintaining both the EBC and Soil Association approval necessitates annual inspections to ensure compliance with the respective standards.

Results

BBB developed an MRV plan to ensure appropriate data collection measures are in place to facilitate verification and the certification of carbon credits. This involves a mixture of data collection procedures for operators on-site, maintaining production logs, and providing site documentation. The MRV plan is summarised below.

Monitoring & Measurement

Biomass Sourcing & Transport

The upstream monitoring of the MRV plan focuses on biomass sourcing, ensuring sustainable practices and accurate tracking of biomass production and supply. BBB sources all its biomass from A.W. Jenkinson (AWJ), the UK's largest biomass supplier. To verify sustainable sourcing, BBB utilises sawmill woodchip, a widely available co-product of the milling process (formerly classed as a waste product), ensuring no timber is felled specifically for its activities. A sustainable sourcing declaration has been obtained from AWJ, confirming that all feedstock supplied to BBB is sourced from UK forests under a valid felling licence, in accordance with the UK Forestry Standard (UKFS). This certification guarantees sustainable forest management and prevents land-use change. In addition to sustainable sourcing, BBB tracks biomass production and supply data. Information on energy use during chipping, drying, and other production processes is requested from AWJ. Biomass quantities supplied to BBB are recorded through delivery notes, which also provide data on transport distances, supporting the measurement of emissions from biomass transport.

Biochar Production

The biochar production phase involves extensive data collection on production inputs, emissions, operational activities, and production outputs. Embodied emissions from machinery and equipment are accounted for by obtaining material composition data from equipment suppliers. Energy use is tracked through propane consumption records, evidenced by delivery notes, and on-site electricity use is measured using installed electricity meters. Production emissions are monitored annually through flue gas analysis, conducted by an independent MCERTs-accredited vendor. This analysis measures key pollutants, including greenhouse gases (GHGs) like nitrous oxide and methane, as well as volatile organic compounds (VOCs). Operational data is recorded weekly, tracking machine operating hours and any production interruptions. Production outputs are also meticulously recorded through daily, and weekly, logs and tracked on the BBB operations dashboards. Biochar production is quantified using the Puro guidance for biochar suppliers, employing the dry bulk density method. Biochar samples are taken and oven-dried on-site to determine dry bulk density on a monthly basis. Bag weights and moisture content checks are also conducted to confirm biochar quality and ensure safe handling. Production of renewable heat, a co-product of the pyrolysis process, is measured using heat meters on-site.

To ensure the quality of the biochar, BBB follows EBC standards, which sets quality, sustainability, and safety criteria for biochar production. Each year, a representative batch of biochar, defined as biochar produced under similar production conditions over one year, is analysed at an EBC-accredited laboratory. The analysis measures key quality parameters, including carbon content, H/C ratio, calorific value, and concentrations of heavy metals and polycyclic aromatic hydrocarbons (PAHs) to ensure the biochar is safe for use in agriculture. In addition to batch analysis, daily retention samples are collected and stored for two years at each site. These samples serve as a physical record of biochar produced within a batch, providing traceability and the ability to verify biochar quality retrospectively if needed.

Biochar Transport & Use

The downstream monitoring of the MRV plan focuses on the transport and application of biochar on farms. Biochar is transported to farms in articulated lorries, and the distances travelled are calculated using postcode information recorded on delivery notes. These records are used to calculate transport-related emissions. At the farm level, the primary use of biochar is in dairy farming, specifically for slurry or bedding applications. Since no additional farm infrastructure or fuel is required for the application process, no additional operational emissions are attributed to the biochar application. While biochar is known to reduce nitrous oxide emissions when applied to slurry, manure, or soil, these reductions are not included in the life cycle assessment (LCA) due to variability and uncertainty in quantification.

Reporting & verification

The Puro certification process consists of two types of audits conducted by third-party Validation/Verification Body (VVB), facility audits and output audits. A facility audit is a comprehensive review of the production site, equipment, processes, and documentation to confirm that the biochar production facility complies with Puro.earth's requirements. This verifies that the production setup aligns with the reported process data and sustainability claims. A Facility Audit Report is created by the VVB, and then reviewed by Puro.earth. If the facility audit review is successful, the production facility receives the status as certified as listed on the Puro.earth website. An output audit focuses on verifying the specific amount of carbon removal achieved by biochar production over a given reporting period. This audit confirms that the quantity, quality, and properties of biochar reported match the data used for calculating carbon (dioxide) removal credit (CORC) issuance.

For each of these audits, BBB must submit detailed documentation on biochar production, quality, and end use for the facility. Key reporting requirements include:

- Environmental and social safeguards
- Proof of sustainable biomass sourcing
- Documenting the biochar produced and methodology for calculating dry mass
- LCA data for the biochar production process
- Biochar properties determined by laboratory analysis
- Proof that biochar end-use confirms CO_2 does not return to the atmosphere
- Proof of no double counting of biochar carbon removal

Verification is conducted by the independent third-party VVBs, who reviews the submitted data, inspects production sites, and confirms that the biochar meets Puro.earth's criteria for carbon removal durability and quality through the aforementioned audits. The first date of the first monitoring period marks the beginning of a crediting period, which can last up to 5 years. The crediting period can be renewed twice by successfully undergoing a new production facility audit. Multiple output audits will be conducted for each production facility throughout the crediting period, typically once every 12 months.

The verified carbon removal credits (CORCs) are then issued, allowing for transparent tracking and trading of the environmental benefits achieved. This rigorous process ensures integrity, traceability, and confidence in the carbon removal claims associated with biochar production. BBB's first facility and output audits for both sites are planned for March 2025.

Shifting to Digital MRV: Biochar Traceability with Charcodes

A key part of BBB's mission is ensuring traceability and permanence monitoring of our biochar carbon removal credits, guaranteeing end-to-end supply chain integrity. Existing biochar standards drive the value of carbon credits and focus on total carbon accounting over the certification period. While crucial to quantifying the climate impact of biochar, this approach does not trace when and where the carbon moves along the value chain or ensure storage of the final carbon sink (i.e. recording location and application).

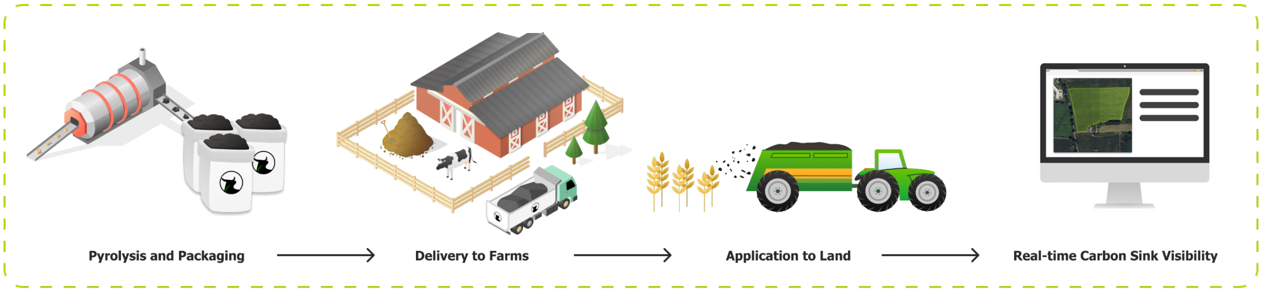

Figure 10 – Steps of the biochar value chain tracked through Charcodes

BBB is building Charcodes, a system to track key information for each bag of biochar, from production to application on farms (Figure 10). The Charcode on each bulk bag enables operators/customers to enter and track information relating to individual bags of biochar at each step of the supply chain, giving real-time visibility as the carbon moves and is stored. This includes bag-level data on:

- Biochar production – date, site
- Biochar properties – bag weight, moisture content, chemical properties
- Delivery to farms – quantity delivered, distance travelled
- Application on farms – application date, method

The bag-level traceability enabled with Charcodes is crucial to ensure each necessary step in biochar carbon removal has been completed. It also feeds into the admin app, supporting operations with inventory and logistics management. As carbon removal standards shift towards increasing traceability and digital MRV (dMRV), building and implementing Charcodes now enables BBB to future-proof and retain trust in all our carbon removal activities.

Discussion

BBB's MRV procedures ensure that key sustainability, production, and quality metrics are tracked and evidenced throughout the biochar carbon removal process. By developing an innovative system that overcomes previously identified challenges in collecting and utilising data, BBB can now quickly and efficiently collect comprehensive useable data at every stage—upstream, production, and downstream. BBB can now ensure compliance with sustainability standards, accurate carbon removal quantification, and traceability for all biochar produced.

Life Cycle Assessment

Design & Development

BBB has undergone carbon credit certification through Puro.Earth, a leading registry for engineered carbon removals which has been endorsed by the International Carbon Reduction and Offset Alliance (ICROA). A Life Cycle Analysis (LCA) was conducted as the base for the evaluation of the overall sustainability of the plant and the certification of CO_2 Removal certificates (CORCs).

The full project LCA is available as a standalone report. Two fundamental questions were addressed by the report:

- What is the potential in terms of carbon sequestration?
- What additional emissions are generated by the activity?

The system boundary was defined based on the Puro Biochar Methodology, and an attributional LCA approach is taken. Potential improvements or changes to the production process were considered through a sensitivity analysis.

Results

The results obtained from the study will serve both as environmental accounting against the funding obtained by DESNZ and as a basis for the generation of carbon credits through the Puro standard.

Ahlstrom, Radcliffe (ARA)

The Life chart (Figure 11) illustrates CO_2-equivalent emissions in kg CO_2-eq per tonne of biochar, categorised into Puro methodology stages of biochar production and use, all values are per dry tonne of biochar produced.

1. **$E_{biomass}$** - Represents emissions from biomass cultivation, drying, chipping, and transportation, contributing a value of 164.9 kg CO_2-eq.
2. **$E_{production}$** - Represents emissions from the production phase of biochar. This is a smaller value of 537.4 kg CO_2-eq that represent emissions from electricity consumption, propane use, packaging of biochar and equipment production.
3. **E_{use}** - Denotes emissions related to the use phase of biochar, with minimal impact of 48.9 kg CO_2-eq connected only to biochar transportation, since the handling on site is done manually. Note that E_{use} is scaled over the dry tonnes of biochar delivered, not produced.
4. **E_{stored}** - Represents the carbon storage capability of biochar, shown as a large negative (carbon-capturing) value of -3251.5 kg CO_2-eq per tonne.
   Net (CORC factor) - This represents the net GHG balance across all stages, showing a value of -2500.3 kg CO_2-eq, indicating a substantial net carbon capture per tonne of biochar.

Overall, while there are emissions from biomass sourcing and production, the large carbon capture in storage results in a significant net-negative impact, only partially limited by emission generated in the life cycle.

The LCA results for emissions only, categorized by level-2 categories, in terms of kg CO_2-eq per tonne of biochar are shown in Figure 12. Each component represents the emissions contribution from specific stages and equipment involved in biochar production and supply:

1. **Supply of biomass** – Accounts for 96 kg CO_2-eq per tonne. Standard average assumptions were made for laden and vehicle size, in accordance with what was indicated and the size of the loads recorded.
2. **Cultivation** – Contributes 41 kg CO_2-eq per tonne, representing emissions from cultivating the biomass feedstock. The emissions factor was selected based on the process for chip production at sawmills.
3. **Drying** – Accounts for 28 kg CO_2-eq per tonne, representing emissions from heat and electricity consumption in the drying of the biomass.
4. **Biochar Plant Operation** – Accounts for 336 kg CO_2-eq per tonne from plant operation activities due to energy consumption of the plant, peripheral equipment and propane for the start up, it is possible that with longer and optimized runtime this value could be reduced.
5. **Biochar Plant Emissions** – Direct emissions from the biochar plant, totalling 3 kg CO_2-eq per tonne.
6. **Biochar Plant Equipment** – Emissions associated with the equipment used in the biochar plant, contributing 52 kg CO_2-eq per tonne. The impact of plant production would be very high given the considerable quantity of materials used, but these are allocated over the long life of the plant. The lifetime represents an estimate given by the manufacturer and could be, especially for some components even much longer.
7. **Packaging** – Emissions from packaging processes, contributing 79 kg CO_2-eq per tonne are not insignificant, as they are consumed for every big bag produced by the plant, a reuse of the big bag or pallet could drastically lower this value. No reuse was considered at this stage.
8. **Peripheral Equipment** – A smaller emission source, showing 67 kg CO_2-eq per tonne. This value comprehends structural part of the plant (canopy, fence) that might have even longer life that the biochar equipment, a less conservative assumption of the lifespan should result in much lower value.
9. **Transport to the Farmers** – Contribute 49 kg CO_2-eq emissions per tonne.

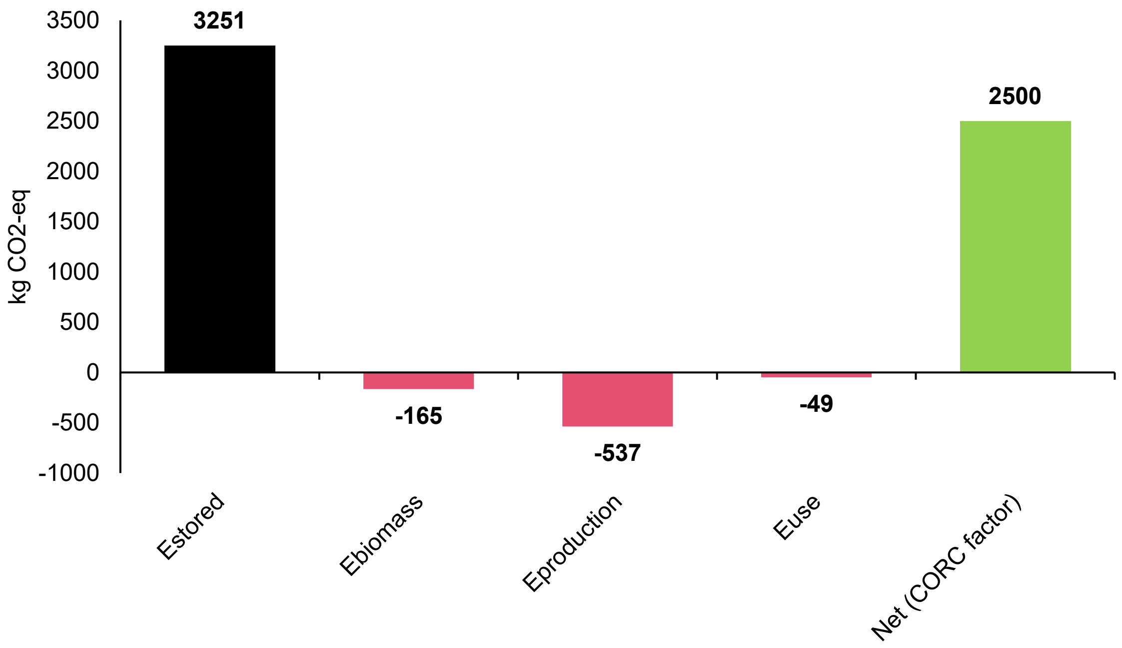

Figure 11 – The net climate impact in kg CO_2-eq for the ARA produced biochar.

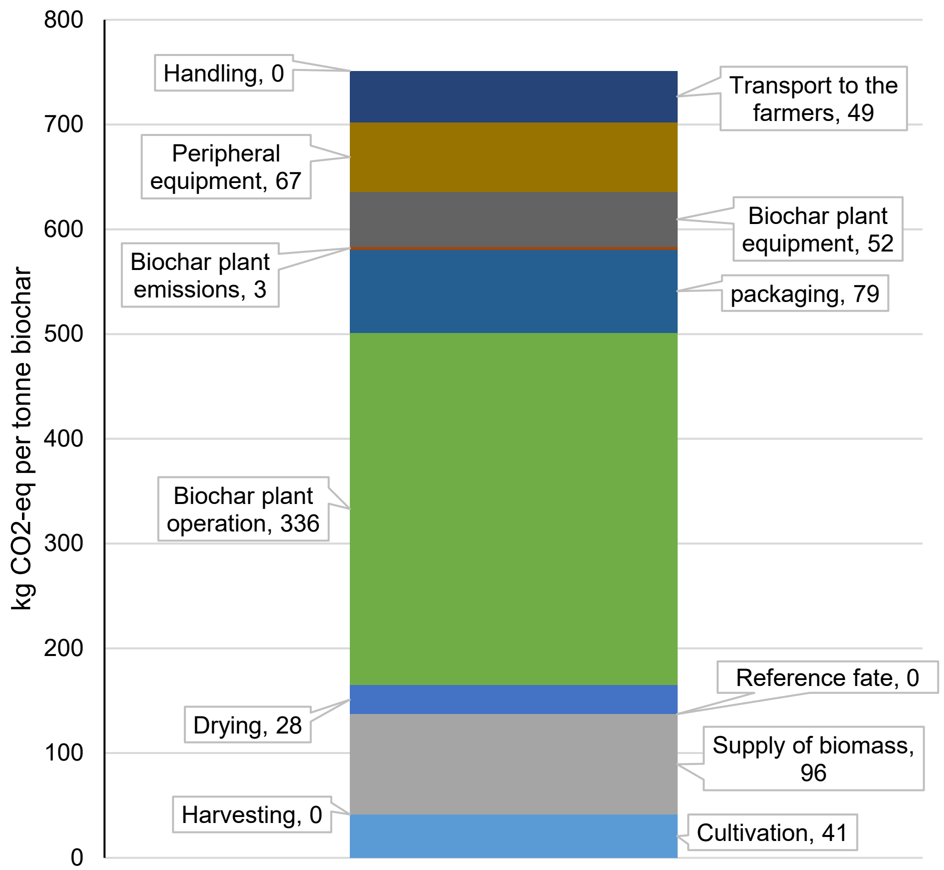

Figure 12 – LCA result for ARA produced biochar grouped by level-2 categories (emissions only).

AWJ, Newton Rigg (JNR)
The Life chart (Figure 13) illustrates CO_2-equivalent emissions in kg CO_2-eq per tonne of biochar, categorised into puro methodology stages of biochar production and use, all values are per dry tonne of biochar produced.

1. $E_{biomass}$ - Represents emissions from biomass cultivation, chipping, and transportation, contributing a value of 145.8 kg CO_2-eq.
2. $E_{production}$ - Represents emissions from the production phase of biochar. This is a smaller value of 161.1 kg CO_2-eq that represent emissions from electricity consumption, packaging of biochar and equipment production.
3. E_{use} - Denotes emissions related to the use phase of biochar, with minimal impact of 10.6 kg CO_2-eq connected only to biochar transportation, since the handling on site is done manually. Note that E_{use} is scaled over the dry tonnes of biochar delivered, not produced.
4. E_{stored} - Represents the carbon storage capability of biochar, shown as a large negative (carbon-capturing) value of -3396.1 kg CO_2-eq per tonne.
5. **Net (CORC factor)** - This represents the net GHG balance across all stages, showing a value of -3078.7 kg CO_2-eq, indicating a substantial net carbon capture per tonne of biochar.

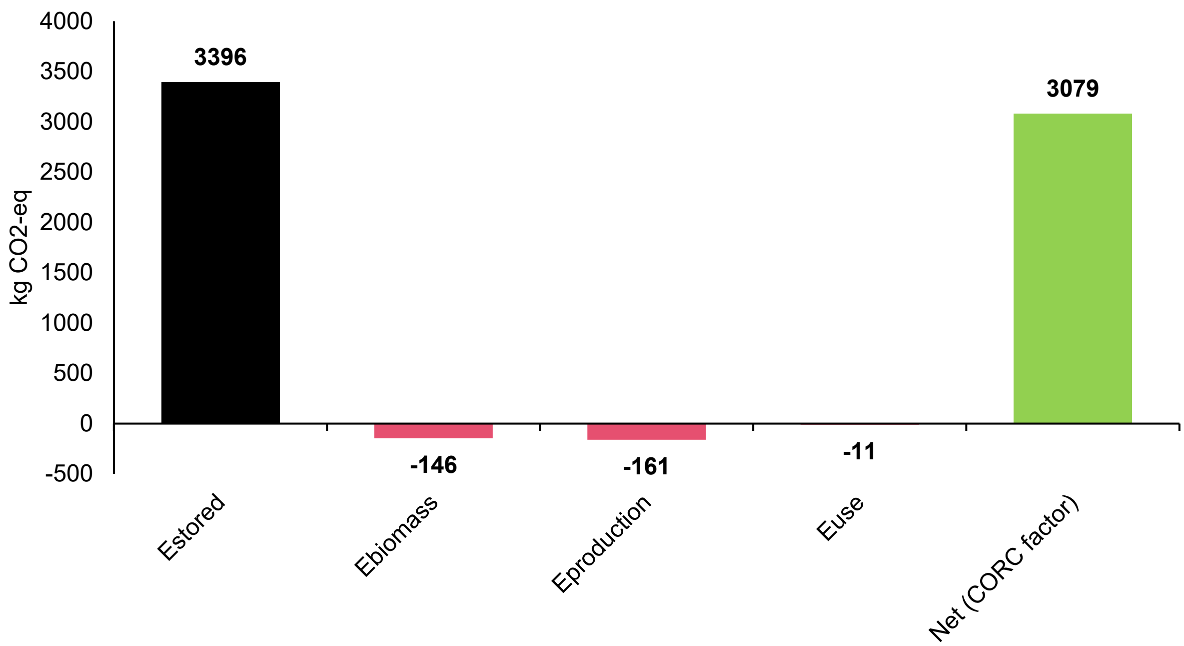

Figure 13 – The net climate impact in kg CO_2-eq for the JNR produced biochar.

The LCA results for emissions only, categorized by level-2 categories, in terms of kg CO_2-eq per tonne of biochar are shown in Figure 14. Each component represents the emissions contribution from specific stages and equipment involved in biochar production and supply:

1. **Supply of biomass** – Accounts for 39 kg CO_2-eq per tonne. Standard average assumptions were made for laden and vehicle size, in accordance with what was indicated and the size of the loads recorded.
2. **Cultivation** – Contributes 61 kg CO_2-eq per tonne, representing emissions from cultivating the biomass feedstock. The emissions factor was selected based on the process for chip production at sawmills.
3. **Drying** – Accounts for 46 kg CO_2-eq per tonne, representing emissions from heat and electricity consumption in the drying of the biomass.
4. **Biochar Plant Operation** – Accounts for 41 kg CO_2-eq per tonne from plant operation activities due only to energy consumption.
5. **Biochar Plant Emissions** – Direct emissions from the biochar plant, totalling 1 kg CO_2-eq per tonne.
6. **Biochar Plant Equipment** – Emissions associated with the equipment used in the biochar plant, contributing 25 kg CO_2-eq per tonne. The impact of plant production would be very high given the considerable quantity of materials used, but these are allocated over the long life of the plant. The lifetime represents an estimate given by the manufacturer and could be, especially for some components even much longer.
7. **Packaging** – Emissions from packaging processes, contributing 88 kg CO_2-eq per tonne are not insignificant, due to the fact that they are consumed for every big bag produced by the plant, a reuse of the big bag or pallet could drastically lower this value. No reuse was considered at this stage.
8. **Peripheral Equipment** – A smaller emission source, showing 6 kg CO_2-eq per tonne. This lower value is due to the smaller plant and the fact that there was no requirement to build a canopy or building for this reactor.
9. **Transport to the farmers** – Transport to farms emissions total at 11 kg CO_2-eq.

Discussion

Overall, while there are emissions from biomass sourcing and production, the large carbon capture in storage results in a net-negative impact, only partially limited by emissions generated in the life cycle.

A sensitivity analysis was conducted for both sites to assess the potential impacts on the Net CORC factor from modifications to the production process. For Newton Rigg, total emissions are low compared to the carbon storage potential per tonne of biochar (~10%). Sensitivity to changing production parameters was low, with a maximum increase to the CORC factor of only 1% from switching all electricity supply to hydroelectricity (which is not available near the site). For Ahlstrom, the results indicate that changes in the quantities of propane, electricity, and transport each have a marginal influence on the total carbon sequestration potential. However, renewable electricity sourcing could significantly reduce emissions from biochar production here. Switching to solar energy would reduce the emissions factor of electricity 59%, reducing the emissions from biochar plant operation by 17%. This would improve the Net CORC factor by 2%. This highlights the importance of prioritising renewable energy sources in reducing emissions and improving the sustainability of biochar production on this site.

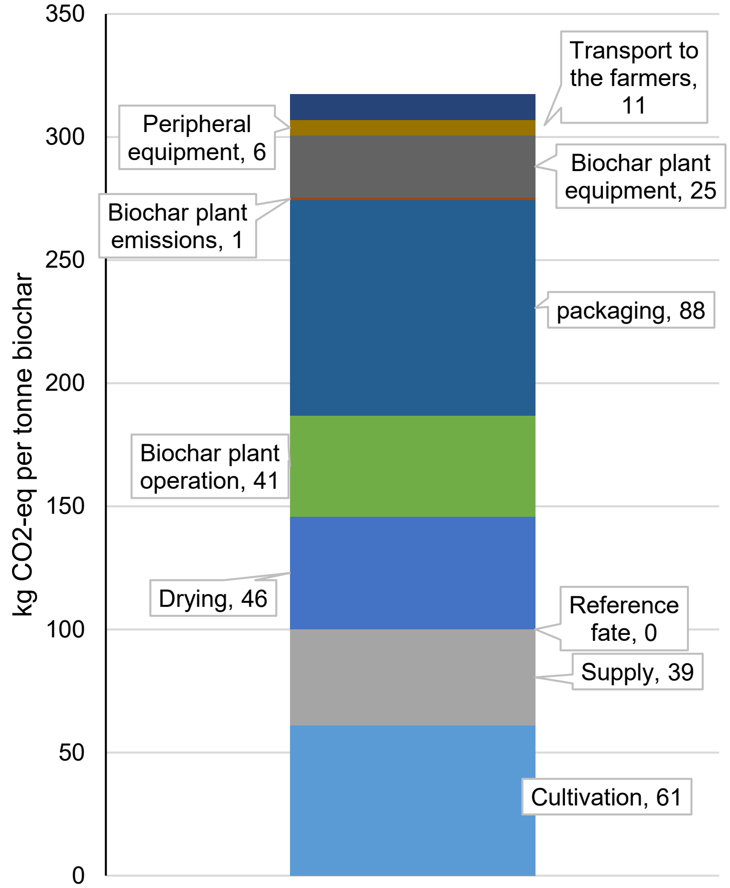

Figure 14 – LCA result for JNR produced biochar grouped by level-2 categories (emissions only).

The Newton Rigg site has a significantly greater CORC factor compared to the Ahlstrom Radcliffe site. The primary differences in CORC factors of biochar produced at both sites can be attributed to the greater transport distances of biomass to site and biochar to farms, and the use of propane to start up the PYREG unit. Overall, both sites still produce biochar with high CORC factors, removing over 2.5 t of CO_2-eq per tonne of biochar produced.

Carbon Removal & Carbon Modelling

Approach & Methodology

Biochar permanence carbon is critical to the technology efficacy as a GGR method. Puro.earth methodologies have been used to quantify net CO_2-eq removal, this removal is based on carbon removal durability of 100 years+, generally considered a conservatively short durability. The University of Edinburgh worked with BBB to better understand the permanence and carbon stability of the biochars produced in this pilot. To evaluate the carbon stability of the BBB product, a rigorous framework was developed, incorporating advanced modelling techniques and laboratory-based experimental validation. The RothC soil carbon model was adapted to integrate biochar carbon into three pools with distinct levels of reactivity and mean residence times (MRTs):

- **Labile Carbon Pool:** the most reactive carbon fraction of biochar that can be decomposed and released by microbial activity within approximately one month, under typical UK soil conditions.
- **Stable Carbon Pool:** the biochar carbon fraction with moderate reactivity, this carbon pool aligns with the humus pool in the RothC model, with MRTs of decades, and is susceptible to altered degradation rates with disturbance or changes to soil properties.
- **Inert Carbon Pool:** the least reactive and recalcitrant biochar carbon fraction, this pool was redefined to include extremely low reactivity, previously approximated as inert. MRTs for this pool extend to thousands or even tens of thousands of years and can be considered as permanent irreversible carbon removal in relation to human timescales.

Accelerated Ageing Protocol

The reactivity profile for each BBB-produced biochar was characterised using a controlled oxidative ageing method. Samples were exposed to increasing concentrations of hydrogen peroxide under standardised conditions, simulating degradation over extended timescales. Carbon loss and compositional changes were measured to fit a sigmoidal reactivity curve to the data, reflecting the progressive decomposition of the various biochar carbon fractions. This work was separately completed for ten reference biochars, produced at the University of Edinburgh from a range of feedstocks at pyrolysis temperatures of 550°C and 700°C, creating suitable reference data for a spectrum of carbon content and H:C ratio biochars.

Comparison to Reference Biochars

To contextualise the findings, the reactivity profiles of biochar produced by BBB at Ahlstrom Radcliffe and A.W. Jenkinson Newton Rigg, respectively, were directly compared to the reference biochars. This identified the relative stability of the pilot biochars. The reference biochars provided the baseline data for calibrating the RothC model and refining predictions of biochar behaviour under diverse environmental contexts. The updated model was then used to assess the longevity and permanence of the pilot biochars.

Results

ARA Results

Reactivity Profiles

The Radcliffe biochar displayed a sigmoidal carbon loss curve comparable to the most stable reference biochars (oilseed rape straw pellet (OSR) 700°C and miscanthus straw pellet (MSP) 700°C), with considerable resistance to oxidation under all but the most extreme conditions (≤0.08 mol. H_2O_2) (Figure 15 and 16). A substantial proportion of its carbon could be allocated to the inert pool, demonstrating biochar MRTs ranging from centuries to tens of thousands of years. This highlights the exceptional stability and suitability of the biochar produced in the project for long-term carbon storage and effective greenhouse gas removal. It further identifies the underestimation of carbon permanence used in the Puro.earth methodology for stable biochars (with an H:C ratio <0.3). Reactivity analysis has not yet been completed for biochar produced at Newton Rigg.

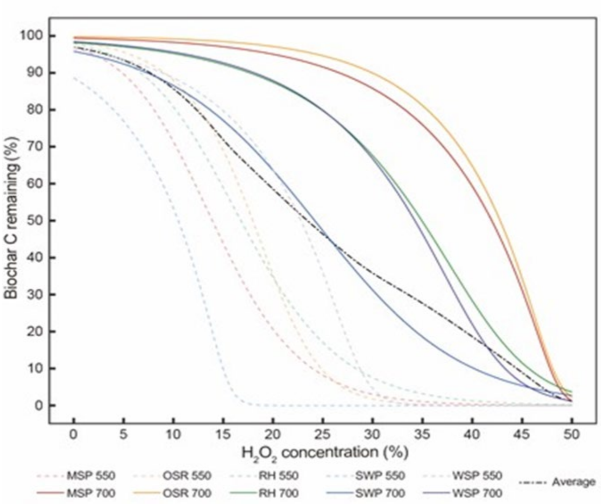

Figure 15 – Carbon reactivity curves for reference biochar

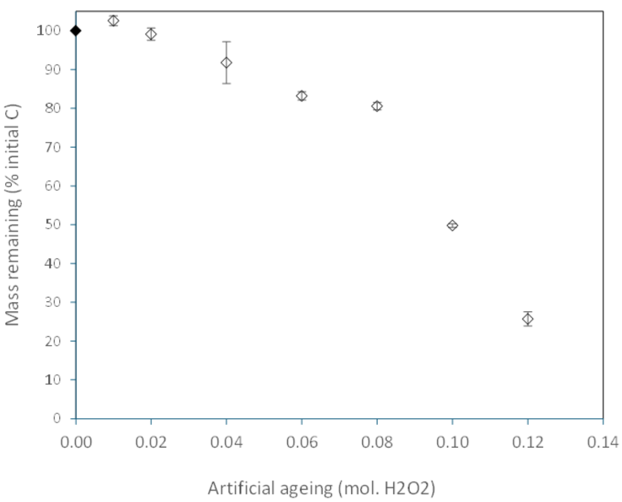

Figure 16 - Carbon reactivity curves for Radcliffe biochar

H:C Ratio Trends

Consistent with its high aromaticity, the Radcliffe biochar exhibited a gradual decline in H:C ratio as oxidative pressures increased (Figure 17). Biochars with a high initial H:C ratio exhibit a less stable H:C ratio with oxidation agent application and exhibit a rapid decline in H:C ratio. As reactive carbon is oxidised, the proportion of carbon to hydrogen decreases, thus the H:C ratio increases. This trend underscores the progressive loss of labile and stable fractions, leaving the highly recalcitrant inert carbon intact until high H_2O_2 concentrations are applied (>0.08 mol. H_2O_2). These findings suggest that biochar with an initial H:C ratio of ~0.2 has a higher proportion of carbon (up to 80%) that is in the inert carbon pool.

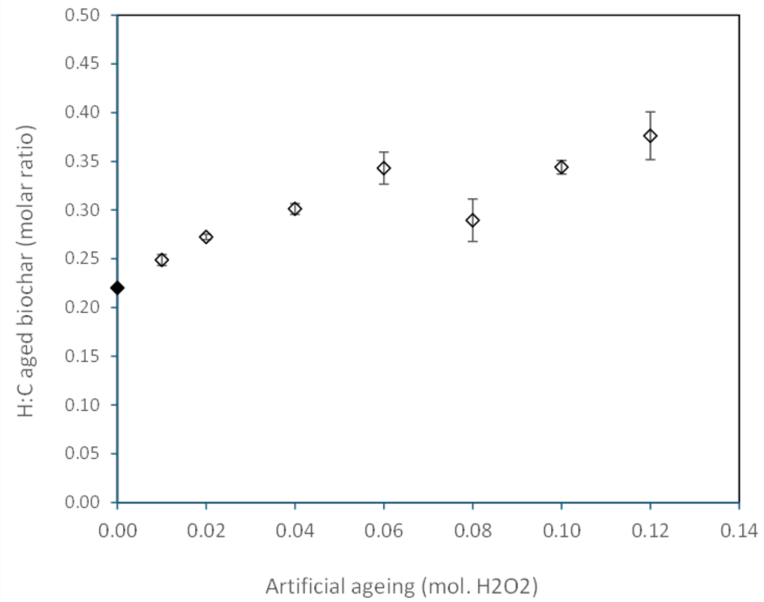

Figure 17 – H:C ratio change for Radcliffe biochar at increasing H_2O_2 concentrations

Integration with Soil Carbon Dynamics
The Radcliffe biochar reactivity data demonstrated compatibility with the calibrated RothC model. The pilot biochars will be used in the parameterised model to provide accurate simulations of the carbon behaviour and losses under the specific climatic and soil conditions of the Cumbrian farms where it has been applied. This will enable the permanence of the biochar and carbon loss dynamics to be assessed.

ARA & JNR Product Comparison
The graph in Figure 18 shows a comparison of the mass loss on ageing for biochar from the Penrith (JNR) and Radcliffe (ARA) sites. The Penrith samples contains negligible ash, yet the mass loss is dramatically lower than for Radcliffe. This indicates a biochar with carbon that is even more resistant to oxidation than the biochar from the PYREG plant.

We are halfway through re-analysing the aged Penrith biochar samples for carbon content, owing to inconsistencies in the weighing of microsamples for carbon analysis. However, the pattern in carbon loss so far appears to follow the mass loss curve quite precisely. This is unsurprising as the main reason for some mass loss curves appearing asymptotic above the X-axis is the presence of residual mass attributable to thermally stable ash. The Penrith biochar sample was already found to contain almost no measurable ash. Consequently, the amount of biochar material decreases with oxidant concentration, but the carbon concentration less so.

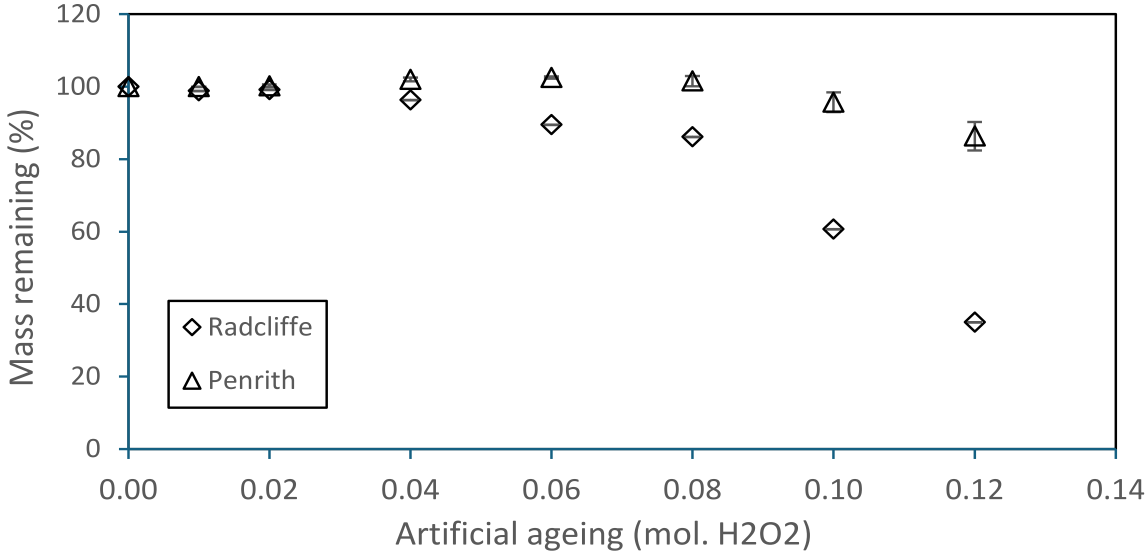

Figure 18 – Mass loss with oxidative ageing, compared for Radcliffe and Penrith biochars. Results are mean values with standard error (n=3), except the separately determined first data point.

In the last graph (Figure 19), the effect of accelerated ageing on the H:C ratio of the Penrith and Radcliffe biochars is shown. The Penrith biochars decrease in H:C ratio very slowly, reflecting a particularly slow change in susceptibility to oxidation. The common discontinuity in the curves at 0.08 mol. H_2O_2 will be investigated further. The common anomaly for both biochars indicates a possible change around this stage in the ageing process, that may provide further mechanistic insight into biochar ageing or potentially a basis for a standalone predictor to accompany modelling.

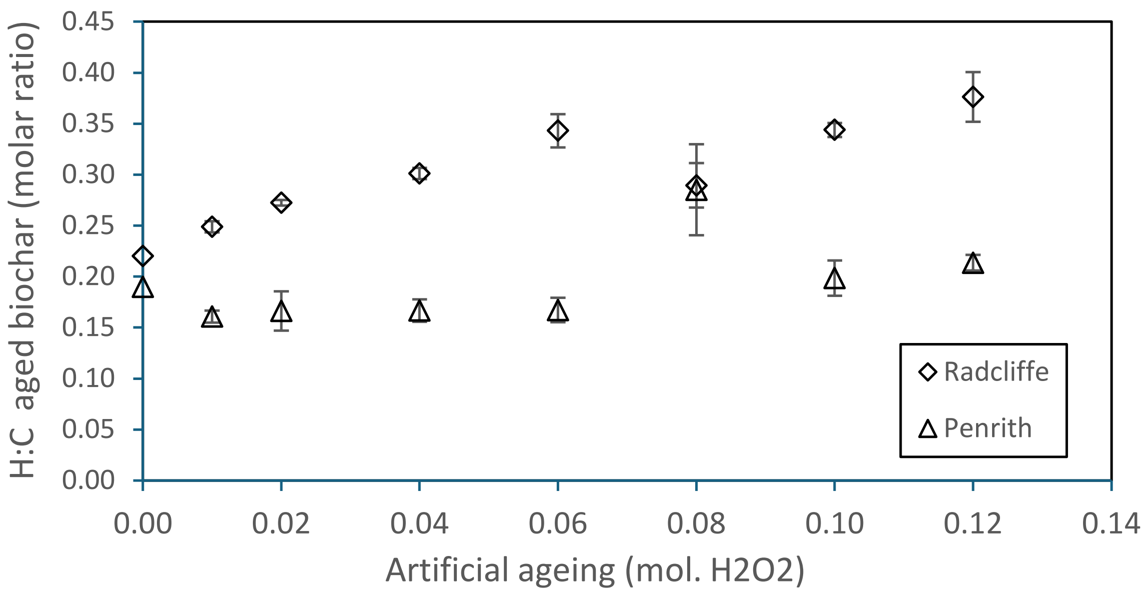

Figure 19 – Comparison of changes in H:C ratio with increasing levels of oxidation for the Radcliffe and Penrith Biochars**.** Results are mean values with standard error (n=3), except the separately determined first data point.

Finance

Budget Overview

Total project spend was £2,997,620; £2 under the originally contracted amount. As the project progressed, there was variation in the work package totals where underspends in certain areas were reallocated to areas needing more funds.

As shown in Table 6, the largest variances can be seen in the spend across work packages 2, 4 & 1. The PYREG plant was commissioned by the end of Dec-23 and the Biomacon plant was commissioned by Oct-24. Consequently, there was less demand for biochar production materials such as feedstock and other site consumables than originally planned. It became apparent as the project progressed that the planned team of 4 was too few for the project demands. Hires were made throughout the project including a Finance Manager, Operations Associate, Full-stack Developer & Plant Operator, bringing the team up to 8 full-time employees.

Table 6 – Project Spend by Work Package

ID	Work Package	Original Budget	Actuals	Var
1	Biochar Production	£1,112,933	£1,189,800	£76,867
2	B2B Preparation and Demonstrator Hub	£610,814	£286,542	-£324,272
3	Platform Development	£59,790	£47,719	-£12,071
4	Management	£816,401	£974,098	£157,697
5	Monitoring Reporting and Verification	£151,595	£150,495	-£1,100
6	Legal	£55,250	£55,674	£424
7	Stage Gate Reviews	£119,234	£159,733	£40,499
8	Report on MRV Methodology	£14,488	£21,732	£7,244
9	Report on Barriers and Risks to Commercialisation	£14,488	£21,732	£7,244
10	Phase 2 Final Report	£42,629	£90,094	£47,465
		£2,997,622	**£2,997,620**	**-£2**

Payment timelines were affected by the addition of another pyrolysis manufacturer. Now that units were being sourced from two different manufacturers there were two different payment schedules for the units as opposed to one. This shifted a large portion of the costs to later in the project. As shown in Figure 20, actual spend began to converge with budgeted spent in the middle of the final project year, when all large CAPEX had been procured.

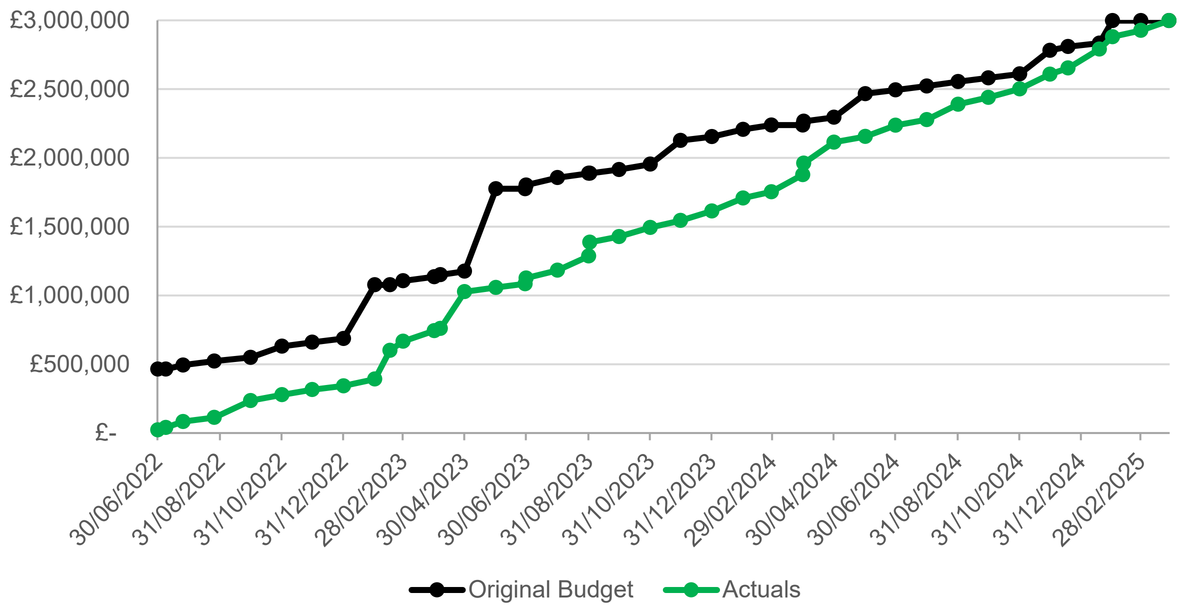

Figure 20 – Cumulative project spend across the project timeline

Cost Breakdown

Table 7 – Project costs by cost centre

Cost Centre	WP	Costs
Capital Expenditure - PYREG	1 & 2	£620,193
Capital Expenditure - Biomacon	1 & 2	£604,912
Direct Production	2	£250,528
Subcontractor & Legal	5 & 6	£205,929
Software Development	3	£47,719
Staff Costs	4, 7, 8, 9 & 10	£965,762
Overhead	4, 7, 8, 9 & 10	£154,522
Travel & Subsistence	4, 7, 8, 9 & 10	£124,555
Unit Servicing	4	£23,500
		£2,997,620

- The total spend on capital expenditure was £1,225,105. This was made up of design, machinery and peripheral equipment costs for the 2 plants.
- Direct production costs involved in the production and delivery of biochar totalled £250,528. This included biomass, logistics, packaging, PPE, and general site consumables.
- Subcontractor and legal included work done by third parties relating to the biochar field trials, carbon modelling, product certifications, and the LCA and all legal work required for the project. This came to £205,929.
- Software development costs were £47,719 which included the web application work done by Webpanda at the beginning of the project. The software developer from WebPanda then joined BBB as a full-time employee in February 2024 to continue work on this area.
- Staff costs, business overheads, unit servicing and travel costs totalled £1,268,338.

Benefits & Challenges

Challenges

Risks

The main residual risks BBB believe to be most critical to future performance are summarised below, using the risk scoring in Table 8.

Table 8 – Risk scoring matrix (risk rating=probability score x impact score)

Probability Scoring			Impact Scoring		Risk Rating	
Certain	>90%	5	Very high	5	Very high	21-25
Likely	50-90%	4	High	4	High	16-20
Moderate	10-50%	3	Medium	3	Medium	11-15
Unlikely	3-10%	2	Low	2	Low	5-10
Rare	<3%	1	Insignificant	1	Insignificant	0-4

Feedstock Variation

- Risk: Variations in feedstock size and moisture content can impact the performance of both the PYREG and Biomacon units. Larger woodchips may not fully pyrolyse, increasing the risk of smouldering, while moisture levels above 25–30% can lead to incomplete carbonisation or system blockages.
- Mitigating action: BBB explored feedstock screening options and installed a shredder and misting system at the Ahlstrom plant to minimise the risk of large woodchips. Additional quenching was considered, and metal sheeting was added to the bagging system to prevent smouldering. To control moisture content, all biomass was collected directly from the dryer, and deliveries were inspected upon receipt.
- Residual Probability = 2, Residual Impact = 3, Final Risk Rating = 6

Lack of permanent skilled on-site operations

- Risk: Using subcontractors to operate the plants proved difficult during the pilot project due to lack of specific skills and the alignment of goals and motivations.
- Mitigating action: BBB brought operations in-house at Ahlstrom, significantly improving production and onsite operations. BBB concluded that for sites to be successful, operations should be managed by a dedicated BBB workforce. Future resources to train future teams will be crucial to run successful additional pyrolysis plants.
- Residual Probability = 3, Residual Impact = 4, Final Risk Rating = 12

Price too high for farmers

- Risk: Farmers might be interested in the project but find the price is too high for implementation at the end of the project

- Mitigating action: BBB engaged directly with demonstrator farmers to highlight the long-term value of biochar. Potential inclusion in Arla's Sustainable Incentive Scheme was explored to further reduce costs, with the expectation that the final price would demonstrate a strong ROI for future customers.
- Residual Probability = 2, Residual Impact = 4, Final Risk Rating = 8

Monitoring and Data Collection

Production

A key challenge in production was quantifying the dry mass of biochar. Two industry-standard methods exist for this: calculating dry mass based on the wet weight and moisture content or using volume and dry bulk density. Given that biochar was packaged in fixed-volume bulk bags, the latter method was applied. However, to avoid overestimating carbon removal, it was necessary to establish the actual volume of biochar within each bag. This was achieved through wet weight and moisture content data collected from a large sample of produced bags.

Electricity and heat meters were installed on-site to measure energy consumption and renewable heat output. Prior to establishing an in-house operations team, obtaining consistent and high-quality production data was challenging. With the expansion of the operations team, data input became more reliable and was recorded with minimal errors.

Downstream

Ensuring that biochar was applied to its final material matrix—such as animal bedding, manure, or soil—was previously a challenge. However, with the development of Charcodes, application tracking became possible. For this system to be fully effective, high levels of engagement and buy-in from farmers were required. To address this, application tracking is being integrated into a biochar management feature within the app, providing incentives for farmers to contribute data. Biochar deliveries to farms were tracked through delivery notes and Charcodes, simplifying the calculation of transport emissions.

Reporting

The implementation of rigorous monitoring and data collection facilitated an efficient data compilation process in preparation for auditing by Puro.earth. However, as multiple types of reports are required by Puro, any discovered data errors necessitated updates across all reports, which was time-consuming. Transitioning to digital Monitoring, Reporting, and Verification (dMRV) for all operational data could streamline this process and reduce inefficiencies.

Verification

Certification processes were found to be effective for larger sites, such as the Newton Rigg facility. However, new rules introduced in January 2025 placed smaller sites, particularly those producing fewer than 1,000 CORCs per year, at a disadvantage. Under the new rules, an auditing fee of €12,000 will be required for certification of these smaller sites, increasing the financial burden.

Audits were typically conducted on an annual basis, meaning that carbon credits could only be issued and sold once per year. A transition to dMRV for all production data could enable monthly credit issuances, which would provide a more consistent revenue stream.

Environmental Impacts

As part of the Puro.earth certification process, an Environmental Impact Evaluation report was completed for both the Ahlstrom and Newton Rigg production sites. As the sites were designed with high-end pyrolysis units and similar production systems, many of the impacts and relevant mitigations are similar across both facilities. The environmental impacts identified and mitigations are shown in Table 9, specifying where mitigations differ between sites.

Table 9 - Environmental impacts identified and mitigations summary

Impact Category	Impact	Mitigations
Emissions to air	Small quantities of NOx, SOx, CO and organic compounds are emitted to atmosphere.	Emissions are regularly monitored (at least annually) in order to ensure that levels remain consistent. The unit is operated within "normal" design parameters, ensuring that oxygen levels remain correct and complete combustion of pyrolysis gases occurs.
Emissions to air	Wind deposition of highly mobile biochar dust or accumulation of biochar dust in enclosed spaces.	Biochar quenching, and operator training to meet health and safety requirements when handling loose biochar.
Emissions to water	Waste liquids generated onsite.	ARA Waste liquids treated through the wider site's effluent treatment system. JNR All waste liquid is not contaminated and can be disposed to drain.
Emissions to water	Rain runoff from the site structures and slab.	Site kept clean and all biochar spills immediately cleaned.
Emissions to soil	Disposal of waste to land	No wastes are disposed to land, excluding 'waste biochar'. Biochar collected during start-up and when pyrolysis temperatures are out with the acceptable temperature bracket is separated and disposed by applying to land at rates >1t/ha to grassland.
Emissions to soil	Contaminants from poor quality biochar.	By utilising virgin woody biomass and monitoring pyrolysis conditions the risk of biochar contamination is mitigated. BBB is EBC certified under the Agro and AgroOrganic labels, verifying the biochar is safe for agricultural application.

		Biochar produced outside of the acceptable EBC thresholds is discarded.
Generation of solid waste	A small volume of solid waste produced during regular cleaning.	Ash is collected and kept in sealed vacuum bags during disposal, mitigating the risk of material escaping into the wider environment before disposal to a permitted landfill.
Generation of liquid waste	Liquid waste produced from water condensing at the heat exchanger and/or in the flue stack.	ARA Waste liquid collected into a sealed ibc container, pumped into a transportable ibc, and emptied into the Ahlstrom site's effluent treatment system. JNR Pipe work fitted to ensure waste liquids are transferred directly to drain.
Accumulation of materials in stock at the facility	Hot product increasing the risk of fire.	Biochar kept away from the plant and shipped >5 days after production. Biochar adequately quenched to ~30% MC.
Accumulation of materials in stock at the facility	Release of dust into air.	Biochar adequately quenched to ~30% MC and stored in sealed 2m³ bags.

Social Impacts

Biochar production necessitates a skilled workforce to operate pyrolysis machinery, and oversee the overall production process. This creates direct employment opportunities for local residents, including technicians, engineers, and administrators. Since setting up the site, BBB has hired a Head of Pyrolysis Operations and Pyrolysis Plant Operator based in Radcliffe, and we plan to expand our operations team in the area.

BBB is also working to engage local communities, and have a close relationship with the local forest school near Radcliffe, who we have previously donated surplus woodchip to.

The environmental protection impacts of biochar, including reducing on-farm emissions, principally ammonia (NH_3) and nitrous oxide (N_2O), and limiting nutrient leaching and runoff, have positive social implications. Particularly, in catchment sensitive regions, biochar could play a role in keeping waterways clean and preserving ecological spaces for recreation and educational activities for local communities.

As biochar is not commonly used in UK agriculture, a key aspect of the project has been to build educational resources and engage with farmers across the country, to introduce them to biochar and demonstrate how it can be integrated to benefit their farming practice. So far, seven detailed blog posts have been uploaded to the BBB website as a resource for farmers to effectively use biochar for their desired benefits.

These activities will promote environmental resilience and foster community awareness about sustainable land management practices. The widespread adoption of biochar holds promise for education, environmental stewardship, and sustainable development opportunities.

Legislation and Regulation

There is a lack of specific legislation covering biochar use in the UK. Biochar production and use falls under the Environment Agency's Low Risk Waste Position (LRWP) 60. LRWP 60 only applies to biochar made from waste feedstocks. As BBB uses virgin sawmill co-products as feedstock, biochar production at Ahlstrom and Newton Rigg is exempt from this.

The only legislation for biochar application in England is LRWP 61. BBBs products are made with virgin woody feedstocks which are not classed as waste products. Our products are designed to be used without requiring an environmental permit for waste operations.

BBB provides users of our biochar with resources to achieve their desired agronomic impacts from biochar, whilst adhering to environmental regulations. Our products and suggested use systems mitigate the potential negative impacts of biochar on soil, sometimes associated with extremely high-dose blanket applications and certain biochar properties.

Benefits

Scalability

This project has proven that a system of biochar production and utilisation in the dairy value chain can create a fully-fledged commercial system that will deliver more than 50,000 t CO2 yr-1 carbon storage by 2030 following scale up. Research conducted in Phase 1 showed that if biochar used for farmer consumption is 96 t biochar yr-1 per farm (delivering 317 t of carbon storage), then just 158 Arla farms would achieve 50,000 t CO2 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 BBB to convert this interest into new biochar farms after the project. BBB already has 50 farmers on its waitlist, which it has accrued throughout the project. As revenues commence in April 2025, BBB will look to divert more resources towards marketing and sales in an effort to ensure demand matches supply.

To reach a balance where there is enough supply for a nationwide dairy market, biochar production will need to scale in tandem with demand. A national 50,000 t biochar carbon removal system can be achieved through the construction of 37 more Biomacon C500-I pyrolysis machines. This will allow biochar to reach a sufficient scale where it is a well-known product in the farming industry, shifting the market from 'early adopters' towards the 'early majority'. BBB will also start to explore other uses for biochar to ensure the suppliers are receiving the best price for their co-products.

Business Plan

Summary

Black Bull Biochar aims to scale its production of biochar, carbon credits and renewable heat (see Figure 21) through strategic commercial partnerships. This plan outlines the steps to leverage these partnerships to enhance market reach, improve production efficiency, and drive sustainable growth. Our mission is to rapidly remove carbon and create the highest quality biochar and carbon removal credits in the world.

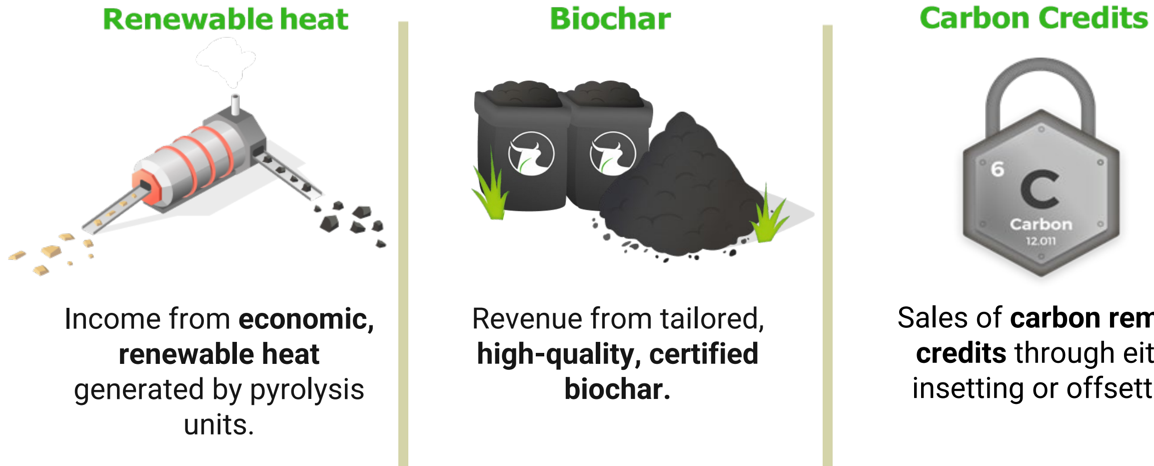

Figure 21 – The three potential revenue streams for BBB as demonstrated in the pilot system.

Market Analysis

The biochar carbon removal market is a critical tool for delivering Net Zero. Currently, around 2 billion tonnes of carbon are removed from the atmosphere each year, mainly through afforestation, according to the State of Carbon Dioxide Removal Report 2024 by the University of Oxford. The durability of afforestation carbon removal is hard to predict, which makes biochar a promising option for carbon removal, especially due to its relatively unique status of being able to deliver carbon removal at a significant scale now. The key to delivering that scale is partnerships with large organisations that can either supply, use or facilitate an advanced biochar system.

Finance, Marketing & Sales Plan

BBB will leverage multiple financing solutions to ensure its scale up plans are sustainable. It is worth mentioning that the cost / tCO_2e will range significantly depending on site requirements.

Debt Financing

Debt financing involves borrowing money to be repaid over time with interest. Asset financing involves using the company's assets as collateral to secure funding. Both could be flexible ways to finance specific equipment and infrastructure needed for biochar production. BBB has engaged with Siemens Financial Services, Kumo.Earth and Lombard (part of the NatWest group) to discuss scale-up options. This could be a great way for BBB to grow however, debt lenders tend to be risk averse when it comes to working with early-stage technologies.

Equity Financing

Equity financing involves raising capital by selling shares of the company. This can be a useful way to fund large-scale projects while bringing in investors who are aligned with the company's sustainability goals. BBB has engaged with ~20 venture capitalists (VC) throughout the project and now has a strong shortlist of eager investors that it plans to scale with. However, it is worth noting that for many VC's find biochar companies intellectual property light, too CAPEX heavy or too early stage / not enough revenue. This is why grant funding is so important from the government as, when designed effectively, can plug gaps in the private financing ecosystem.

Marketing & Sales Strategy

Demonstration Projects

BBB will look to collaborate with large agri-food organisations to expand into new markets and implement replica pilot projects on their farms, using biochar to improve soil health and increase crop yields. This will allow BBB to drive adoption at home and abroad. The results of demonstration projects will be documented and analysed, creating detailed case studies that demonstrate the effectiveness of biochar in agricultural applications and use these case studies in marketing materials to attract other agricultural businesses and stakeholders.

Digital Marketing

As of April 2025, BBB will develop a comprehensive digital marketing strategy, including Search Engine Optimisation (SEO), content marketing, and social media campaigns, to increase brand visibility and attract potential customers. BBB will continue to create informative and engaging content, such as blog posts, videos, and infographics, to educate the audience about the benefits of biochar and its applications. Leveraging social media platforms will be essential to share success stories, case studies, and updates on partnerships and projects, fostering a community around sustainable agriculture and carbon removal. Implementing targeted online advertising campaigns to reach specific demographics and regions will also drive traffic to the website and generate leads.

Route to Market Assessment

Dependencies

There are risks and dependencies for the next steps to commercialisation, depending on market conditions and regulatory environments, as well as the uncertainties related to revenue streams, customer validation, and policy support. The top five dependencies / risks to commercialisation can be summarised as follows:

1. **Customer Validation: Failure to Secure Customers**
   Dependency: Positive engagement with farmers and corporates.
   Uncertainty: Proving the value of biochar and securing long-term customers.
2. **Financials: Inconsistent Revenue Streams**

Dependency: Revenue from heat, biochar sales, and carbon credits.
Uncertainty: Market regulation and pricing for carbon credits vary significantly, impacting revenue stability.

3. **Insurance: Pyrolysis Assets are Challenging to Insure**
Dependency: Availability of suitable insurance products for relatively unknown technology.
Uncertainty: High premiums for low-value assets and the need for comprehensive company insurance.
4. **Policy & Regulation: UK Regulatory Environment**
Dependency: Alignment with UK and EU biochar regulations.
Uncertainty: The nature of biochar inclusion in national greenhouse gas inventories and policy frameworks such as the Emissions Trading Scheme.
5. **Feedstock Supply: Sourcing**
Dependency: Sustainable biomass supply.
Uncertainty: Long-term availability and partnerships with major biomass suppliers.

Route to Market Assessment

Key Steps to Commercialisation

Regulatory Approvals and Policymakers

BBB will work closely with regulators to obtain necessary certifications and approvals for biochar products from relevant agricultural and environmental authorities and ensure compliance with local and international standards for biochar use in agriculture.

Production Scaling

BBB will continue to invest in pyrolysis technology to increase production capacity and establish efficient supply chains for raw materials and distribution networks.

MRV Deployment

Monitoring, Reporting, and Verification (MRV) is crucial for biochar projects as it ensures the accuracy, transparency, and credibility of carbon sequestration claims. BBB plans to build its own MRV system, through the BBB app and a suite of new hardware tools, to provide a standardised process of measuring and validating the amount of carbon sequestered through biochar production.

Wider Benefits

Job Creation

BBB plans to hire an additional 100 people by 2030, through its scale up plans. The expansion of biochar production facilities will create 51 jobs in operations and logistics., mainly for plant operators of pyrolysis units. Increased demand for biochar products will generate 16 employment opportunities in sales, marketing, and distribution. 13 more jobs will be required in innovation and R&D, which will be funded through grants, revenue and R&D tax credits. The BBB software and MRV system will also require a further 18 people, if BBB is successful in licensing out its software and scaling it. It should be noted that this job creation assessment is just for BBB's scale up plans. The wider industry could require considerably more human resources.