

# Greenprint Thought Leadership Report – A Vision for Tomorrow Appendix

A carbon negative systems model for green infrastructure management

South Gloucestershire Council & West Sussex County Council

27/03/2026



## Document Control Sheet

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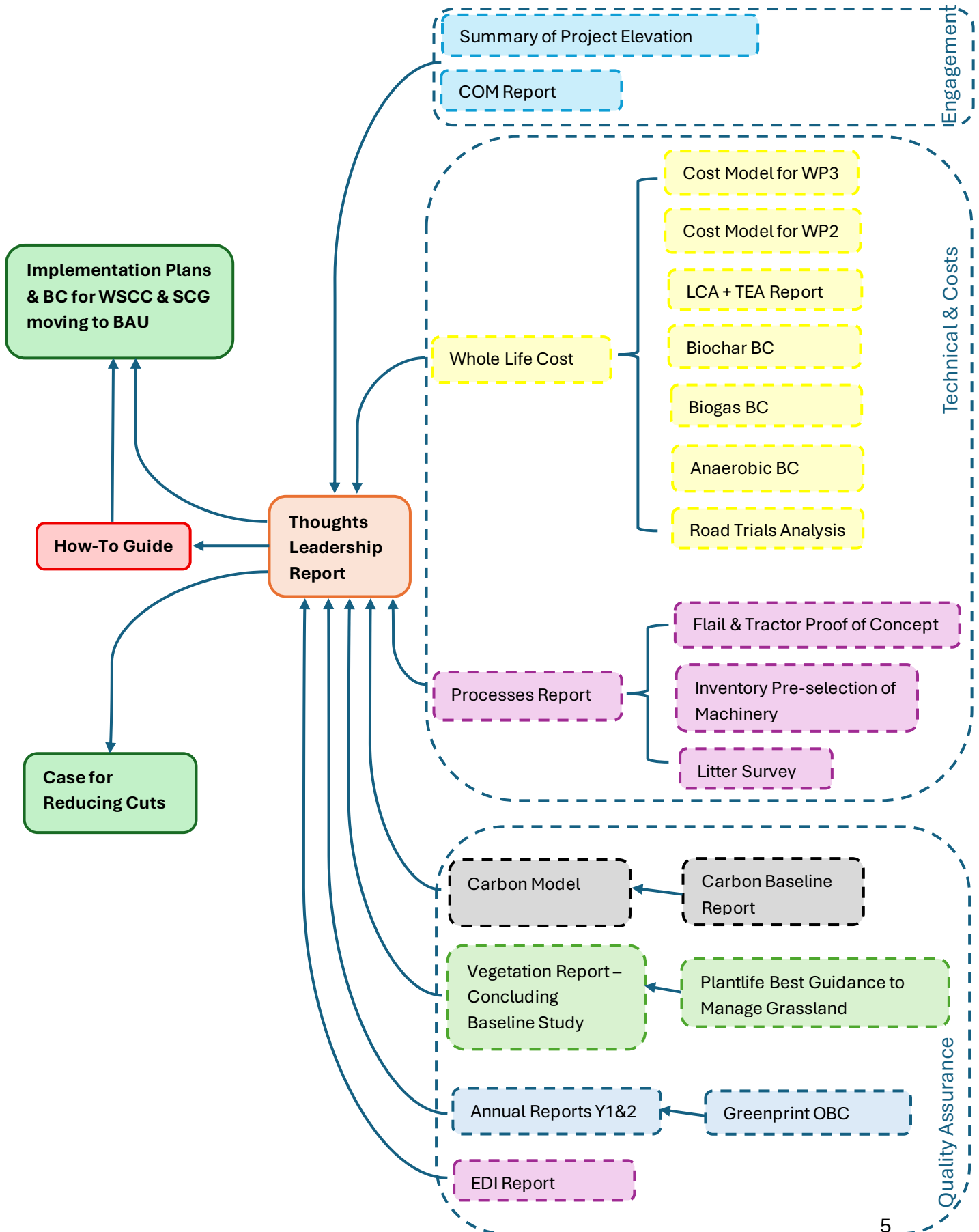


## References





1. Feasibility Of Grass-Based Biomethane As A Sustainable Fuel For South Gloucestershire's Mowing Fleet
2. ICan Greenprint Modelling
3. Adkins Greenprint Carbon Model



















## Appendix A - Greenprint: Documents Organisation and Inter Relation



## Appendix B – Machine Selection for WSCC & SGC

Model	Pros	Cons	Purchase Cost	Estimated Maintenance Cost	Operability	Staff Requirements	Previous Experiences	Relevant Information for Local Authority	In-situ demo possible	Preferential ranking
	The machine performs reliably in wet conditions, offers fast cutting speeds, handles dense vegetation with ease, and features a high-lift collecting box for efficient disposal. Its design also minimises blockages, ensuring smoother, uninterrupted operation.	Too large for current transport, struggles with tight access and tree canopies, risks contact with parked cars, needs extra ballast for stability, and has vulnerable rear wheels prone to curb damage.	10K	Unknown	Requires Compact Tractor	Trained operator	Ideal for large or damp sites, the machine cuts quickly, handles dense growth, tips high, and resists blockages—maximising efficiency with minimal downtime	Performs well in tough conditions but needs space, care, and transport adjustments	Farol	
	High-quality cutting and collection performance	Initial purchase cost may be higher compared to other models	High	Moderate to High	Requires a tractor or similar vehicle	Trained operator	Widely used and trusted by highway authorities	Well-suited for large-scale operations with a higher budget	Does not collect	
	Versatile, can operate on various terrains	May have limited capacity for larger biomass	Moderate to High	Moderate to High	Compact and manoeuvrable	Trained operator	Suitable for areas with uneven or challenging terrains	Ideal for smaller to medium-sized projects with specific terrain requirements	Contacted Jeremy Vincent 8 06/23, he is on leave and will contact me when he returns.	
	Wide cutting width for efficient verge clearance	Requires attachment to a compatible vehicle	Moderate to High	Moderate to High	Requires a tractor or similar vehicle	Trained operator	Proven track record in verge cutting and biomass collection	Suitable for large-scale verge clearing projects with a need for wider cutting widths	Not sure they produce equipment that collects, have submitted enquiry via web site	
	Excellent mulching capabilities for biomass processing	May have limited collection capacity compared to others	Moderate to High	Moderate to High	Requires a tractor or similar vehicle	Trained operator	Well-suited for mulching applications and processing biomass on-site	Ideal for projects where mulching and on-site processing are key requirements		
	Dual functionality for mulching and soil tilling	Initial purchase cost may be higher compared to other models	High	Moderate to High	Requires a tractor or similar vehicle	Trained operator	Suitable for projects requiring both mulching and soil tilling capabilities	Offers versatility for projects where soil preparation is a priority alongside biomass management	Contacted them 8/06/23, awaiting a reply	
	Litter being developed. Can cut 3 tonnes per hour, trailer holds 8t	Limited information available for maintenance costs. Only one demo unit has been built, not in commercial operation.	£100k + 1140k for tractor + £20k for litter picking head	Unknown	Item needs to be attached to a tractor. Large unit, not been proven on long term highway operations	Trained operator	Limited use, only been used for small scale trials and demos	so would be built to order lead time approx 6 months. Was designed to be used in Lincolnshire as part of a cut and collect project but project cancelled due to issues with grass cuttings being labelled by EA as contaminated so no AD plants able to process them.	Contacted Derek Scott, 13 June. They may be able to do some regional demos later in the year when they launch the litter collecting head	2
	Being used in UK	Initial purchase approx £300K	£300K	Unknown	Purchase price includes the unimog	Would need trained operator, although currently available as a contract operation including driver. Would need 1/4 crew	Widely used in Germany and has recently been used by National Highways, discussions ongoing regard to trial on M25	Can be used for litter collecting, normally this is done in Jan / Feb. Latest cutting head cuts grass to 12mm so does not collect litter when cutting grass.	Spoke to Tony Levitt on 13 June, indicated that a trial may be possible, he is going to contact the operator of the current machine working in the UK to see if something can be arranged.	1

Model	Pros	Cons	Purchase Cost	Estimated Maintenance Cost	Operability	Staff Requirements	Previous Experiences	Relevant Information for Local Authority	Fuel Consumption
 Amazona Profihopper 1500	High-output, versatile mower that handles mowing, mulching, and debris collection. Compact, eco-friendly, and ideal for large-area maintenance.	Unreliable, over complex electrical system		High	Requires trained tractor driver.	LANTRA Ride-on mower certification, drivers licence		Performs well in open areas with high output; limited manoeuvrability and urban suitability	- Heavy mowing or full load: ~5 L/hr
 Kubota FC4-501 2x	Appealing looks - Good access to engine	Heavy on the ground, weak build quality (lift arms break regularly), Mowing head is very wide, Parts backup is very poor, Poor operator visibility, even with a rear camera fitted, Poor reliability	£50,950 each	High, in excess of £8000 per machine	Not suitable for verge mowing, better suited to large open spaces	LANTRA Ride-on mower certification, drivers licence	None	Mower required a few modifications prior to deployment, experienced significant downtime, with mowers often out of service for weeks at a time	- Heavy mowing or full load: ~5 L/hr
 Ford Transit Leader 350 L2 EcoBlue (x4)	Drives and tows well	High purchase point compared to alternative manufacturers	£141,100 for all 4 units	Approx. £750 per unit per annum	No issues	Full UK driving licence with B&E entitlement	Not applicable	None specified	- 26 mpg
 Ifor Williams TT3621 Tipping Trailer (x4)	Well-built and tows well	Battery drain during electric tipping	£30,960 for all 4 units	Minimal, primarily tyres at approx. £100	Requires coupling and reversing experience	Driving licence	Prior use experience	None specified	N/A
 Stihl FS411 Strimmer 1x	Good build quality, reliable, easy to use	High purchase price	£774	£120	Easy to use	LANTRA Brushcutter certification	Stock machine on contract	None specified	N/A
 Kress battery equipment - Strimmer, Blower, Charging unit	Quiet operation, reduced lumes and vibrations, blower is as powerful as petrol equivalents	Strimmer struggles with long grass, unclear process for battery disposal once depleted, charging system limited to one vehicle, required for all-day usage	£14,000	Minimal	Easy to use	LANTRA strimmer certification	Not specified	None specified	N/A
 John Deere 2038R Compact Tractor 38 HP with Rytec M1600CH Flail Collector	Tractor can be used for other activities when not grass cutting. Cheaper than cut & collect mower. Simpler and less complicated flail with less to go wrong. Faster cutting speed.	Less manoeuvrable than mower, tractor wheels flatten grass prior to cutting. Not ideal for cutting small or narrow verges	38K	Minimal	Requires trained tractor driver.	Trained tractor driver		Versatile and cost-effective, the tractor with flail offers fast cutting and simpler maintenance. However, it's less manoeuvrable and unsuitable for tight verges due to grass flattening and size	- Average Rate: Approximately 0.66 gal/hr (2.5 L/hr)

Model		Pros	Cons	Purchase Cost	Operability	Staff Requirements	Relevant Information for Local Authority
Trailer Tandem Axle Hooklift Trailer with 3 Containers		Very good if you have a big enough area to leave the trailer, this has been invaluable to our side of the project.	Can be difficult to leave around urban areas. Where there are trees and street furniture.	£46,800	requires hitching and experience in reversing.	Fully trained operator	
Iseki SF5		Very good cutting finish with this machine, very rarely gets blockages.	Air intake pipes can be easily damaged. When parts need replacing, it can be a lengthy wait for replacements.	£50,820	can be difficult to manoeuvre on small verges.	Lantra Mowing training course	
KubotaFC4-501MOWER - NB: this mower was hired not purchased		Very modern and had a very comfortable cockpit.	far too many buttons and gadgets, was far too complicated for the operator. Machine would get easily blocked meaning the operator would spend most the time clearing the blockage.	£60,000	can be difficult to manoeuvre on small verges.	Lantra Mowing training course	I off hired this machine within 2 weeks as we deemed it not fit for purpose, this was due to everything stated in the cons column.
Mulching Flail kit for Iseki SF551 mower		Very good finish when cutting long, course grass. Cuts the verge with ease.	quite bulky when cutting around trees and street furniture.	11040 (inc VAT)	can be difficult to manoeuvre on small verges.	Lantra Mowing training course	
Case Maxxum 125 Tractor (WU71 TKA - asset number 43652		Very good for larger areas.	Not always needed when being used around urban areas.	£74,800	Better suited to larger area of grass.	Fully trained operator	
Husqvarna 520iRX Brushcutter trimmer		Reliable and easy to use.	Can be expensive to purchase, batteries are expensive and will only last 30 minutes.	£339	Easy to use	Lantra small tools training	
Major 2000 flail collector				£10,00 + VAT			Used on the A4174 Ring Road dual carriageway cut and collect trial summer 2025
Wiedemann Super 600 flail collector				£41,000 + VAT			

## Appendix C - Flail & Tractor Proof of Concept

Current methodology and machinery:

The use of two Kubota cut-and-collect mowers with two tipping trailers, two trailers for the mowers and four transit vans are currently used to deliver the cut-and-collect cuts across two specific areas within West Sussex.



This methodology in principle works well but the Kubota mowers have been plagued with breakdowns and parts failures, along with their inability to deal with long wet grass. Kubota have said they are being used beyond their recommended application. The machines are not up to the job and are costing the project a significant amount of money and skewing the real costs for this type of methodology. The use of the vans and trailers is perfect for the current volumes and the methods of carrying the cut grass and machinery around the county. It is proposed that if this methodology was to continue then the vans and trailers format would continue, if the areas are the same as before, but these would have to be reviewed if this methodology was adopted across the whole county. A disposal/processing point within the county would also help reduce handling and costs which again are skewing the true costs for this service.

Therefore, a demonstration of an alternative cutting methodology is proposed in the autumn of 2025 using a compact tractor and mini cut-and-collect flail mower.

The rationale behind this concept is that a compact tractor is less technical and more reliable than the Kubota mowers in our experience and professional opinion, the mini flail cut-and-collect has less opportunity to fail and it's a more simplistic piece of equipment. The demonstration is also to ensure this equipment can work on the grass plots in the urban environment as these are normally full of street furniture and vary greatly in size and angle.

Currently not everywhere is able to be cut by the current machines, so areas have to be trimmed using a petrol/battery-powered strimmer similar to the BAU methodology.



Picture above shows the flail being proposed but the tractor shown is not the one we will be trialling. Details to follow.

The findings of the demonstration will be shared in time for the final report and costings made available of the alternative machinery.

Estimated costs:

- Compact tractor £30k each TBC after demo
- Flail cut-and-collect £10k each TBC after demo
- Vans and trailers already owned

## Appendix D - LCA and TEA for commercial-scale biochar production and deployment for WSCC

### Introduction

A life cycle assessment (LCA) and techno-economic analysis (TEA) have been conducted to evaluate the environmental and economic feasibility of producing biochar from grass cuttings and green waste.

### Methods

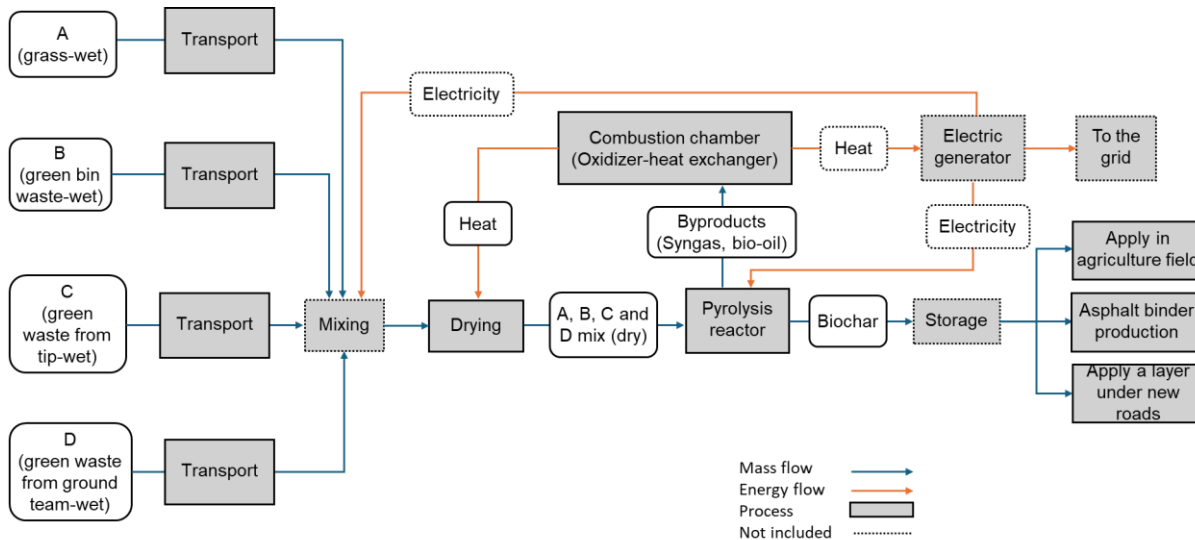
The study considers a commercial-scale biochar production facility with an annual processing capacity of 10,000 dry tonnes. The system boundary includes feedstock transportation, drying, and pyrolysis, as shown in Figure 1. Process units marked with dotted lines are excluded from this initial analysis. Two primary production scenarios and three biochar application scenarios are analysed:

- Scenario 1: Biochar production using only grass from WSCC
- Scenario 2: Biochar production using a feedstock mix of 10 wt% grass and 90 wt% green waste from WSCC
- Scenario 3: Scenario 2 + Biochar application in agriculture field
- Scenario 4: Scenario 2 + Biochar application as a road aggregate (asphalt-binder mix)
- Scenario 5: Scenario 2 + Biochar application as a layer beneath new roads

All the scenarios are assessed using LCA and TEA to determine their environmental impact and economic viability. For Scenario 1, an assumed transportation distance of 10 miles is considered for transporting grass cuttings to the biochar production facility. In Scenario 2, actual road transportation distances from existing grass-cutting collection depots and green waste composting sites are applied. The proposed biochar production facility location is Langhurstwood Road, Warnham (RH12 4QD). For Scenarios 3-5, the biochar transport distance of 10 miles is considered in each case.

This report also examines feedstock availability in WSCC to assess the feasibility of a grass-only biochar production approach. It explores viable biochar production options based on current feedstock availability and evaluates different biochar production pathways by considering greenhouse gas (GHG) emissions and cost implications.

Finally, the report summarises key findings, outlines future plans, and discusses potential revenue streams for the recommended biochar production routes in WSCC.



**Figure 1:** Biochar production system boundary

(\*Applying biochar in agricultural fields is not a straightforward process under the current regulatory framework)

## Results

### Feedstock availability in WSCC

To meet the 10,000 dry-tonnes per annum (tpa) feedstock requirement for Scenario 1 (100% grass-based biochar production), approximately 50,000 wet-tpa of grass (assuming 80% moisture content) is needed. However, this demand exceeds the maximum potential availability of grass cuttings in WSCC (Table 1).

In Scenario 2, where the feedstock mix consists of 10 wt% grass and 90 wt% green waste, the required input is 5,000 wet-tpa of grass (80% moisture content) and 18,000 wet-tpa of green waste (50% moisture constant). The grass requirement can be met by combining the maximum potential of urban and rural verge cuttings, while WSCC's green waste availability can fully satisfy the remaining 90 wt% feedstock requirement. This assessment confirms that a 1:9 weight ratio of grass to green waste presents a viable feedstock supply scenario for sustainable biochar production.

**Table 1:** Feedstock availability in WSCC

WSCC	Total (tpa)	Collection locations	
		Woodhorn	Olus
Grass-cuttings (current)	300		
Grass-cuttings (max potential)	3361		
Grass-cuttings (rural verge network)	2233		
Green waste	53860	19445	13337
Garden waste	12200		
Total-wet (current)	66360		

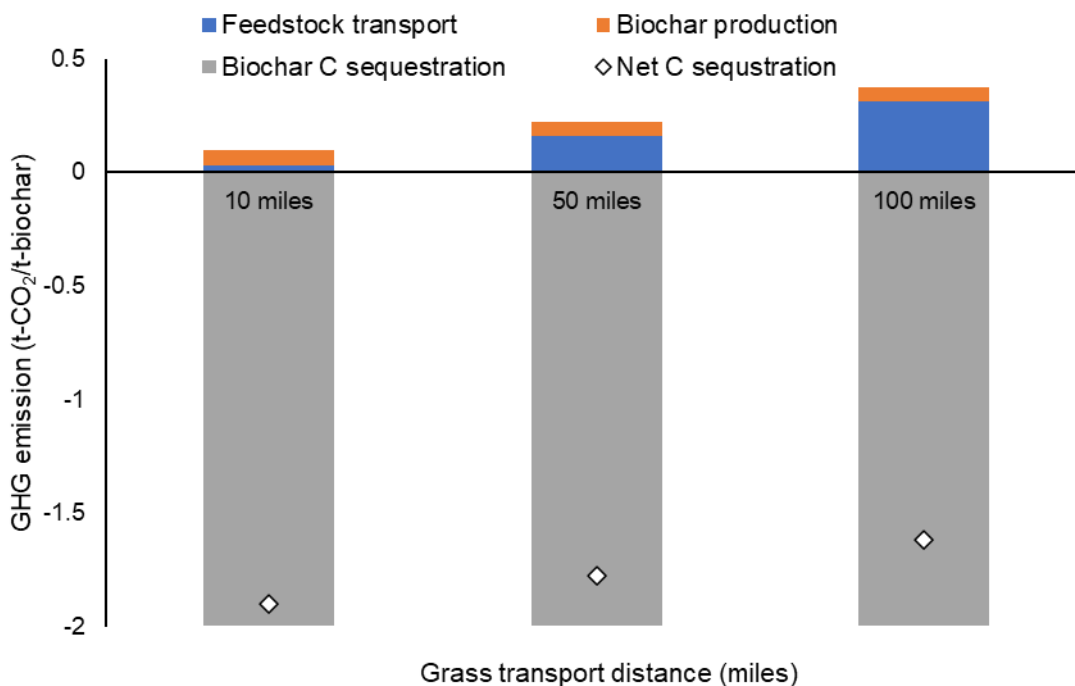
Total-wet (max potential)	71654	19445	13337
Total-dry (max potential)	34149	9723	6669
Moisture contents: grass: 80%, green waste: 50%			

### Grass based (100 wt%) biochar production: Scenario 1

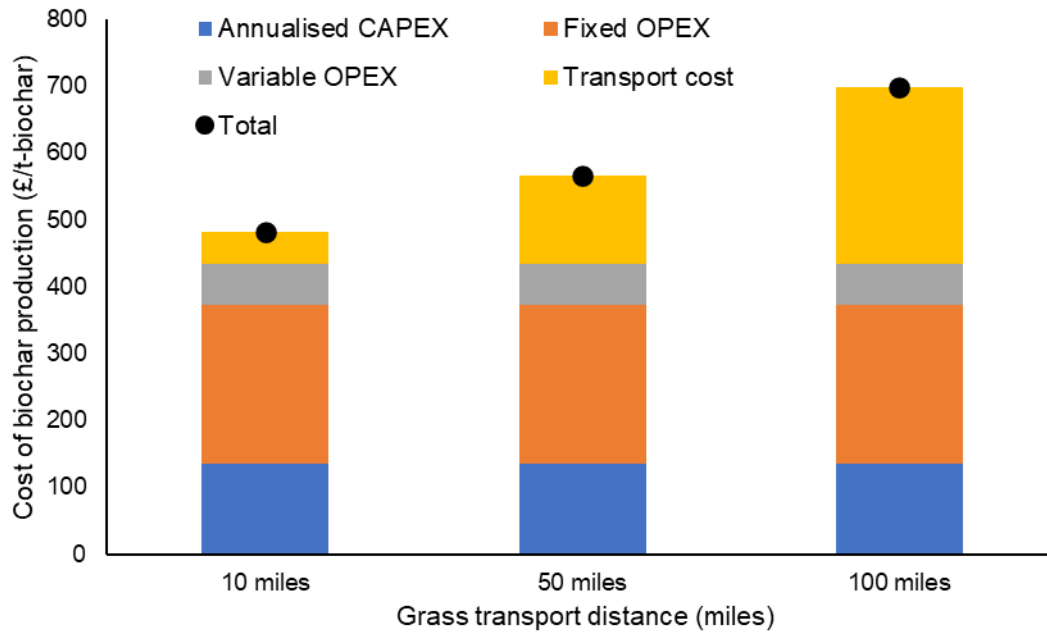
Since WSCC does not produce enough grass to fully meet the biochar plant's feedstock requirements, additional grass deliveries from outside regions would be necessary, resulting in longer transportation distances. To evaluate the impact of transport logistics, greenhouse gas (GHG) emissions and production costs were analysed for feedstock transport distances of 10, 50, and 100 miles.

A significant increase in emissions was observed as transportation distance increased (Figure 2). However, due to biochar's high carbon sequestration potential, net carbon removal remains positive. That said, longer transport distances significantly reduce net carbon removal efficiency. Feedstock transportation distance is a critical cost factor. Increasing the distance from 10 miles to 100 miles nearly doubled biochar production costs (Figure 3), making long-distance transport economically unfeasible.

Given these findings, long-distance transport of grass is not recommended due to its substantial impact on both cost and carbon removal potential. Instead, co-mingling grass with readily available green waste is the most practical approach for sustaining commercial-scale biochar production. As demonstrated in the feedstock availability assessment, the grass-green waste blend ensures a stable feedstock supply while maintaining economic and environmental feasibility.



**Figure 2:** GHG emission in biochar production with respect to the feedstock transport distance

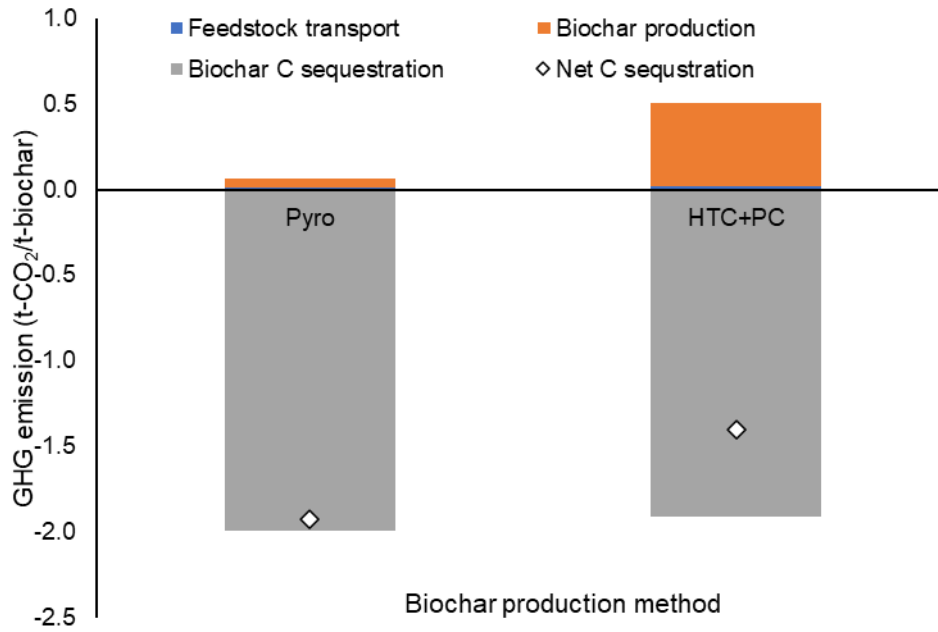


**Figure 3:** Biochar production cost at increasing feedstock transport distance

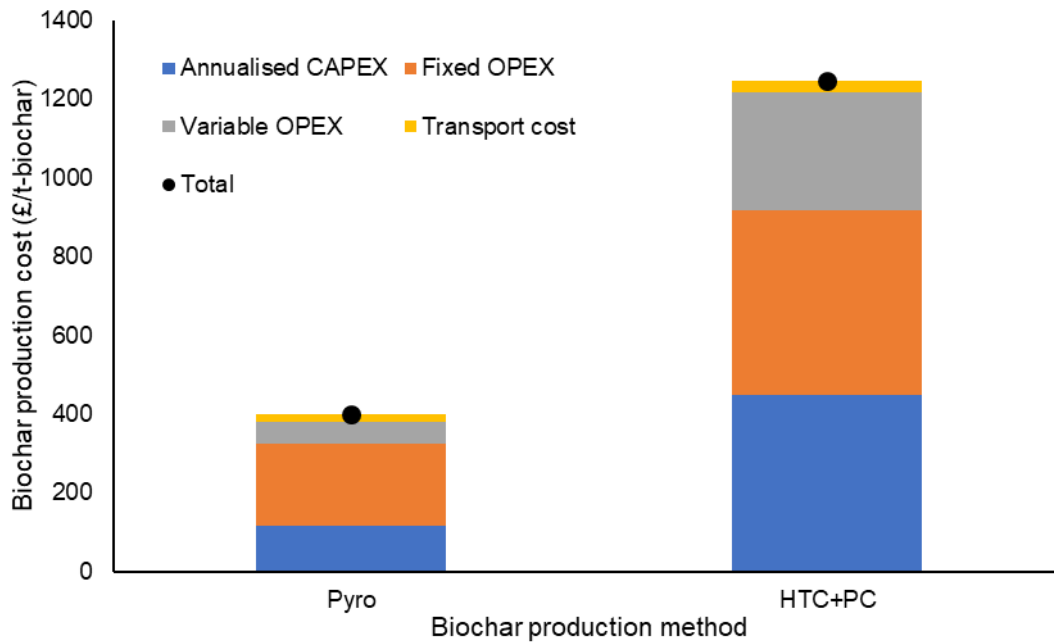
Grass (10 wt%) and green waste (90 wt%) based biochar production: Scenario 2

Following the recommendation of co-mingling grass and green waste for biochar production - based on feedstock availability and transport distance assessments - the next step is to identify the most suitable biochar production method. Biochar can be produced via two main routes: pyrolysis or hydrothermal carbonization (HTC). Pyrolysis involves feedstock drying followed by direct pyrolysis at 750°C, whereas HTC consists of hydrothermal carbonization at 200°C, followed by post-carbonization pyrolysis at 750°C. This study evaluates both production routes using a 1:9 mass ratio of grass to green waste to determine their feasibility in WSCC’s biochar production scheme.

To accurately represent WSCC’s feedstock supply chain, this work applies actual transportation distances for grass and green waste collection. Grass is assumed to be supplied equally from two depots: Drayton Lane Highway Depot (PO20 2BW) and Grasstex Depot (RH12 3AS). Green waste is assumed to be collected from Olus Composting Site (BN5 9BJ) and Woodhorn Composting Site (PO20 2FT). The potential biochar production facility location is considered to be Langhurstwood Road, Warnham (RH12 4QD). Actual road transportation distances from these supply locations to the biochar production facility are incorporated into the evaluation to reflect real-world conditions. All parameters and assumptions used in the analysis are detailed in Table 2.



**Figure 4:** GHG emissions for biochar production from the pyrolysis and HTC routes



**Figure 5:** Biochar production cost in pyrolysis and HTC routes

Pyrolysis resulted in a higher biochar yield, enhancing its carbon sequestration potential. In contrast, HTC exhibited significantly higher natural gas and electricity consumption, leading to increased GHG emissions. Despite these differences, both routes contributed to CO<sub>2</sub> removal, as biochar itself acts as a long-term carbon sequestration medium (Figure 4).

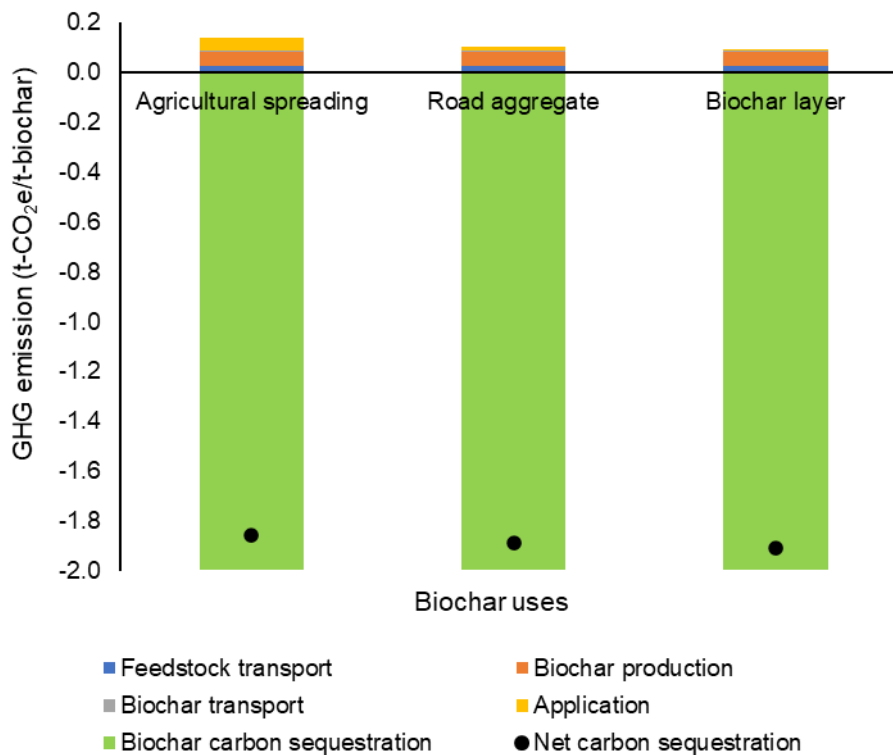
In terms of cost-effectiveness, pyrolysis was found to be the more economically favourable option, with a biochar production cost of nearly £400 per tonne (Figure 5). In contrast, HTC route reached a production cost of over £1200 per tonne, primarily due to high capital costs for the HTC reactor and increased operating costs associated with electricity and natural gas consumption.

The cost estimations in this study align with the values reported in the DESNZ Phase 2 report of the Biochar Demonstrator, ensuring consistency and relevance to industry benchmarks.

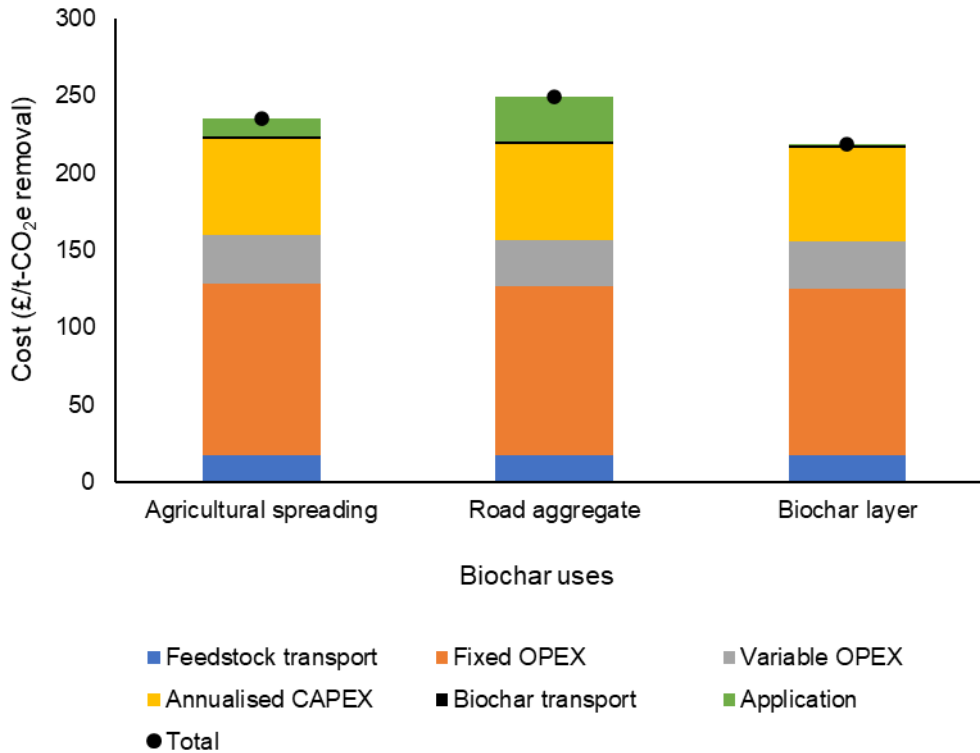
### Biochar applications: Scenarios 3-5

Building on the identification of pyrolysis as the environmentally and economically superior option in Scenario 2, the pyrolysis of co-mingled grass and green waste (mass ratio 1:9) is evaluated in Scenarios 3, 4, and 5. These scenarios explore three potential biochar use cases: (i) agricultural field application (Scenario 3), (ii) incorporation as a road aggregate in asphalt binder mix (Scenario 4), and (iii) application as a biochar layer beneath newly constructed roads (Scenario 5). The overall greenhouse gas (GHG) emissions and costs for each case, considering the entire supply chain, are shown in Figures 6 and 7. A transport distance of 10 miles is assumed for all scenarios, and the parameters and assumptions used are summarised in Table 2.

Biochar application options depend strongly on its quality or grade; however, for comparability across scenarios, a uniform biochar quality is assumed. A telehandler is used for loading biochar in all use cases. In Scenario 3, biochar is applied at a rate of 1 t/ha using a tractor equipped with a manure spreader. In Scenario 4, the dry process of biochar–asphalt binder production is modelled, involving biochar grinding in a ball mill, pelletising in a pellet mill, and mixing with heated aggregates and bitumen in a pug mill at a mixing ratio of 90% aggregates, 9.4% bitumen, and 0.6% biochar. In both road-related scenarios (4 and 5), spreading of the aggregate–bitumen–biochar mix or biochar layer is conducted using a paver machine.



**Figure 6:** GHG emission for whole life cycle considering different biochar uses



**Figure 7:** Cost of CO<sub>2</sub>e removal for each biochar use case

Results show that GHG emissions are highest for agricultural application compared to road-related uses. However, the higher energy demand for biochar–asphalt binder production leads to a greater cost per tonne of CO<sub>2</sub>e removed in the road aggregate scenario relative to agricultural spreading and the biochar layer scenario. Among the three options, the biochar layer beneath new roads achieves the lowest GHG emissions and removal cost. Nevertheless, the emissions and costs associated with all three use cases are relatively minor when assessed over the full life cycle.

**Summary, recommendations and future plans**

This study has evaluated the environmental and economic feasibility of biochar production in WSCC using grass and green waste as feedstock. The analysis demonstrates that a 100% grass-based biochar production approach (Scenario 1) is not viable due to insufficient local grass availability and the high cost and emissions associated with long-distance transportation. Instead, a co-mingling approach (Scenario 2), using a 10:90 mass ratio of grass to green waste, provides a sustainable and economically feasible solution.

Among the two biochar production methods assessed, pyrolysis is identified as the preferred route over hydrothermal carbonization (HTC). Pyrolysis results in higher biochar yield, lower greenhouse gas emissions, and significantly lower production costs - making it the most practical and scalable option for commercial biochar production in WSCC. In contrast, HTC is less favourable due to high capital and operational costs, primarily driven by increased electricity and natural gas consumption.

Building on this finding, three potential biochar utilization pathways were evaluated: agricultural field application, incorporation into asphalt binder mix, and use as a road sub-layer. Results indicate that agricultural application generates the highest GHG emissions, whereas road-related applications achieve lower emissions overall. However, the energy-intensive nature of

biochar–asphalt binder production leads to a higher CO<sub>2</sub>e removal cost compared to agricultural spreading and road sub-layer application. Among the three pathways, using biochar as a road sub-layer yields the lowest emissions and removal cost. Nevertheless, emissions and costs from all three use cases remain minor relative to the overall system life cycle impacts.

Overall, this study highlights the potential of utilising WSCC’s available biomass resources for biochar production while emphasising the importance of feedstock selection, transportation logistics, and process optimisation in ensuring sustainability. Implementing a pyrolysis-based biochar facility with a grass and green waste co-mingling strategy would provide a cost-effective and environmentally beneficial pathway for carbon sequestration and circular economy development in WSCC. Further exploring of potential revenue streams, optimising plant operations, and assessing long-term policy incentives to further enhance the feasibility of biochar production in the region.

**Table 2:** Parameters applied for LCA and TEA

Biochar production route reaction conditions	HTC+PC	Pyrolysis
	HTC at 200 °C followed by pyrolysis (post-carbonisation) at 750 °C	Pyrolysis (direct carbonisation) at 750 °C
CAPEX (M£)	11	4
Biochar yield (wt% dry solids)	22 (grass only) 25 (co-mingling case)	30.30 (grass only), 35 (co-mingling case)
Natural gas usage (kwh/tn dry solids)	360	10
Electricity usage (kwh/tn dry solids)	145	65
Discount rate	8%	
Plant life	20 years	
Feedstock moisture	Grass: 80%, green waste: 50%	
Utility	Price	Emission factor
Natural gas (per kWh)	£0.07	0.23611 kg-CO <sub>2</sub> e
Grid electricity (per kWh)	£0.27	0.25692 kg-CO <sub>2</sub> e
Diesel (per L)	£1.29	3.28564 kg-CO <sub>2</sub> e
Transport staff salary	£90 per day	
Truck details	21 tonne full load truck, fuel consumption of 35 L/100 km and 0.25 L/100 km per tonne	
Plant worker details	£96/day, no. of shifts: 3/day, workers per shift: 2, supervisor for each 4 worker, 8000 operating hours per year (1 extra worker/day for HTC+PC route)	
Potential biochar plant location	Langhurstwood Road Warnham (RH12 4QD)	
Grass and green waste transport	Distance	Roundtrips per day
Grass from Drayton Lane Highway Depot (PO20 2BW)	31.1 miles	1
Grass from Grasstex Depot (RH12 3AS)	9.2 miles	2

Green waste from Olus composting site (BN5 9BJ)	16.3 miles	2
Green waste from Woodhorn composting site (PO20 2FT)	31.4 miles	1
Biochar transport distance	10 miles	
Telehandler	2500 kg (capacity), 2.5 L/h (Diesel)	
Diesel consumption of tractor, ploughing	15 L/ha	
Biochar application rate in soil	1 t/ha	
tractor speed	10 km/h	
Ball mill	30 t/h (input), 380 kW	
Disc pelletizer	149 kW	
Pug mill	140 t/h, 22.4 kW	

**Table 3:** Feedstock availability in SGC

SGC	Total	Collection locations			
		Yate	Mangotsfield	Stoke Gifford	Thornbury
Grass-cuttings (current)	367				
Grass-cuttings (max potential)	4762				
Grass-cuttings (rural verge network)	2265				
Food waste	8318	3974	4344		
Green waste	19269	10501	7123	609	1036
Total-wet (current)	30218				
Total-wet (max potential)	34613	14475	11467	609	1036
Total-dry (max potential), Moisture contents: grass: 80%, green waste: 50%, food waste:70%	13535	6443	4865	304	518

**Table 4 Detailed feedstock availability of WSCC**

	Collection locations																
	Woodhorn	Olus	Billingshurst	Bognor Regis	Hill	Burgess Hill	Chichester	Crawley	East Grinstead	Horsham	Littlehampton	Midhurst	Shoreham	Worthing	Selsey mobile	West Wittering mobile	
Grass-cuttings (current)																	
Grass-cuttings (max potential)																	
Grass-cuttings (rural verge network)																	
Green waste	19445	13337															
Garden waste			1028	748	1583	2398	1057	1172	542	1102	352	500	1564	83	71		
Total-wet (current)	66360																
Total-wet (max potential)	71654	19445	13337	1028	748	1583	2398	1057	1172	542	1102	352	500	1564	83	71	
Total-dry (max potential), Moisture contents: grass: 80%, green waste: 50%	34149	9723	6669	514	374	791	1199	529	586	271	551	176	250	782	41	36	

## Appendix E - Biomass Innovations Activities

We aimed to assess the performance of two technologies for converting verge biomass and anaerobic digestion residues: (i) hydrothermal carbonisation (HTC) and (ii) pyrolysis. The experiments were conducted to evaluate how the solid outputs, hydrochar and biochar, could create additional value and contribute to carbon savings locally.

Our duties consist of five tasks:

- **WP3.1:** Production of hydrochar and biochar in tonne quantities
- **WP3.2:** Characterisation of hydrochar and biochar
- **WP3.3:** Asphalt test programme (in Process 4)
- **WP3.4:** Evaluation of biochar for non-asphalt applications (in process 4)
- **WP3.5:** Contribution to techno-economic and life cycle analysis

This outlined report compares HTC and pyrolysis, details biomass conversion pathways, and presents selected process routes. It also summarises key test results, lifecycle and techno-economic assessments, and alternative applications for biochar. The plans for locking up' biochar in roads by incorporating it into asphalt or burying it beneath road surfaces is comprised in Process 4.

### Overview of Biomass Conversion Processes

#### Hydrothermal Carbonisation (HTC)

HTC uses heat and pressure to convert wet biomass into structured carbons, renewable fuels, and bio-fertilizers. The process operates at temperatures below 300°C for up to four hours in the presence of water. The primary product, hydrochar, serves as a soil ameliorant or feedstock for bio-products. Other outputs include process water and gas. HTC efficiently processes high-moisture feedstocks but faces challenges due to limited supply chain and high capital costs. Hydrochar can also be further carbonised into biochar via pyrolysis.

#### Pyrolysis

Pyrolysis thermochemically converts biomass into char, condensable liquid (bio-oil or tar), and non-condensable gas in an oxygen-free environment. The process requires pre-drying biomass to 10-20% moisture content to enhance biochar output and process efficiency. Biomass is then superheated at temperatures above 350°C in an inert atmosphere, producing biochar as a solid carbon-rich material. This technology enables energy recovery but necessitates precise control over drying and heating conditions for optimal output.

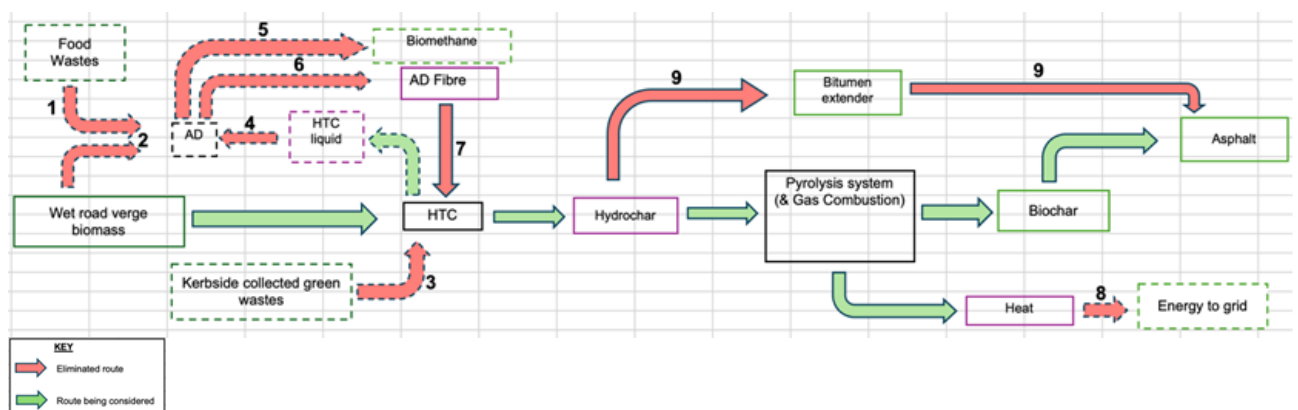
### Progress against project Deliverables

Year 2 Deliverables as stated in the Delivery Plan	Progress against deliverables and comments	Progress against schedule?
Develop plan and budget	Completed	
Plan preliminary tests	Completed	
AD biomass sourcing	Being handled by SGC Council (SGC)	

Initial aggregate material tests	Initial aggregate lab tests underway	
HTC and pyrolysis lab tests	Completed – full details of testing and results are given in	
Biochar characterisation	Characterisation is completed as/when biochar is produced	
Pilot tests	Pyrolysis pilot test with 100% grass cuttings completed and 50:50 mix of wood and grass cuttings. HTC pilot test with 100% grass completed	
Plan aggregate road testing	The overall plan is presented in section 6.	
Support Ricardo pyrolysis trials	Completed	
Techno-economics and lifecycle assessment	Work has been completed and approved by Simon Wilson. Aspects such as seasonality of biomass supply/storage to be discussed	

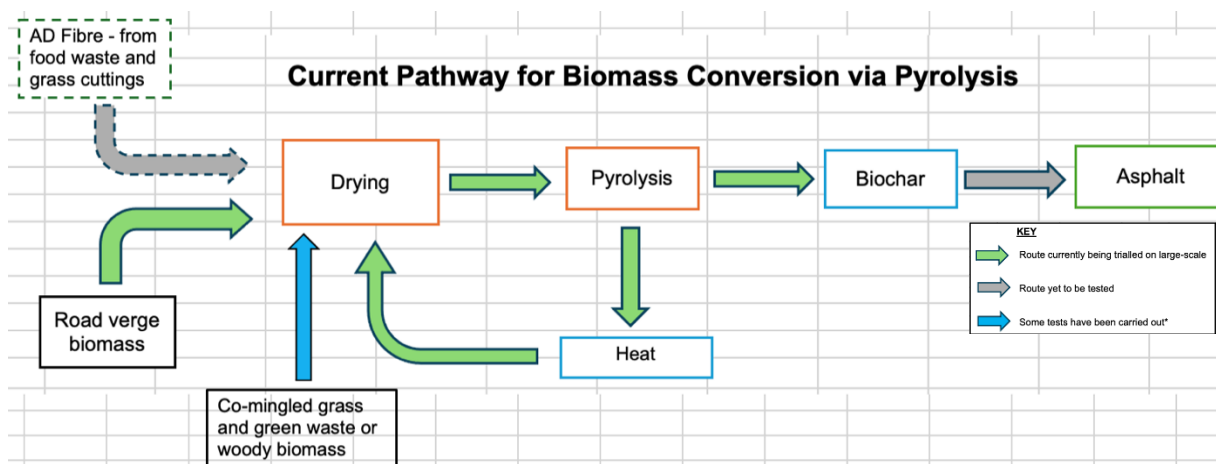
### Conclusions about HTC processing

The results obtained from processing food waste AD fibre as part of the DESNZ Phase 2 GGR project demonstrate that plastics degrade HTC performance causing too much moisture to remain after the filter press step. This negates the benefit of HTC in using lower energy consumption for water removal compared to drying (the first stage before pyrolysis). Co-mingling small proportions of grass cuttings with food waste does not change these results. Furthermore, the hydrochar obtained from the HTC process can only be considered as a solid biofuel since its stability is too poor for carbon sequestration owing to the low processing temperature of ca. 200C. As a result, post-pyrolysis would be needed to convert hydrochar into biochar. In addition, capital costs for HTC are high, therefore the process is only economically feasible if there are high gate fees, as for sewage sludge. Thus, although HTC can process verge biomass, the lack of a significant gate fee makes this process economically unattractive. For these reasons, only the initial pilot-scale HTC test is being carried out. HTC has been ruled out as a method for verge biomass processing in the Greenprint project.



## Conclusions on pyrolysis

Invica Industries has successfully processed solely grass cuttings but techno-economic analyses show that there is not enough grass available from WSCC for the economical operation of a locally located pyrolysis plant. Grass cuttings could be sourced from a wider area however, transport costs would be very high, making the process uneconomic. Furthermore, the seasonal availability of grass cuttings would mean that additional biomass would need to be considered for a facility (processing 10,000 tonnes of feedstock p.a.) to operate during winter. Data from WSCC show that there are large quantities of green waste available which would satisfy the additional biomass requirement. Therefore, pyrolysis of co-mingled grass and green waste/woody biomass has been deemed the most viable processing option going forward. Some of this testing has already been done at the Ricardo facility.



## Summary of Options Tested

The table below presents the evidence that co-mingled grass and green waste/woody biomass is the only viable option for the production of biochar.

Testing Option	Process	Feedstock	Comments incl. any justification for ruling out the option
1	AD	Grass	Issue with Geneco
2	AD	Grass + food waste	
3	HTC	Digestate from 1	HTC not technically or economically feasible for this feedstock
4	HTC	Digestate from 2	
5	HTC	Grass	Technically feasible but uneconomical – high transport costs to source more grass
6	Pyrolysis	Grass	
7	Pyrolysis	Digestate from 1	Technically feasible but only economical if digestate contains plastic and doesn't meet requirements of PAS 110
8	Pyrolysis	Digestate from 2	
9	Pyrolysis	HTC hydrochar from 3	No hydrochar available as HTC is not technically or economically feasible
10	Pyrolysis	HTC hydrochar from 4	
11	Pyrolysis	HTC hydrochar from 5	Technically viable and some hydrochar will be produced but, uneconomical – high transport costs to source more grass

12	Pyrolysis	Co-mingled grass and green waste/woody biomass	Most viable option given the large quantities of green waste available in WSCC. Some testing has already been carried out at the Ricardo plant
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## Summary of Other Tests Carried Out

### A. Small-scale lab testing at the University of Nottingham

A summary of the tests conducted, and their findings is provided below. For a more detailed report, please refer to **Appendix 1** of the full report.

#### Brief description of tests

Urban grass from Horsham, WSCC– Cut 1 carried out March 2024 was collected and sent to the University of Nottingham (UoN) by Grasstex Ltd. At UoN the grass was stored in freezer to prevent further degradation. The grass was processed end June/early July 2024. Processing was as follows:

- i. HTC at 200C, residence time 1h. Followed by post-carbonisation at 650, 700 or 750C
- ii. Pyrolysis at 650, 700 or 750C

Each experiment carried out on 19 and 30g grass (ca. 80% moisture) for pyrolysis and HTC, respectively, followed by characterisation of the biochars.

#### Summary of findings

This project investigated the pyrolysis of grass cuttings under laboratory conditions to generate biochar. Two methods were investigated, direct carbonisation and hydrothermal carbonisation (HTC) combined with post-carbonisation at 650, 700 and 750°C. For direct carbonisation, the dry ash-free (daf) mass and carbon yields are 24 – 26 wt.% and 33.1–33.3 wt.%, respectively. Figure 3 shows images of the raw grass cuttings and hydrochar obtained at 200°C together with the liquid product and Figure 4 shows the biochar obtained from pyrolysis in a Gray-King report. The direct carbonisation of grass cuttings resulted in biochar with a grass-like structure compared to post-HTC biochar where the biochar was agglomerated.

The biochar yield was ca. 30% on a dry ash-free basis for the grass cuttings. However, when HTC was performed at 200°C before carbonisation, the biochar mass yield was reduced to ca. 24 – 26 wt.%. This is a common trend for all feedstocks and arises due to material being extracted as oil during the HTC stage.

### B. Pilot scale pyrolysis trial – Ricardo

A summary of the tests conducted and their findings is provided below.

#### Brief description of trial

WSCC delivered approximately 2.5 tonnes of grass to the BIOCCUS demonstrator plant on Monday, November 25<sup>th</sup>, 2024. This grass was cut on Wednesday, November 20<sup>th</sup>, 2024. The grass was mixed with ca. 1.5 tonnes of woodchip, dried and processed into biochar. Once dried to the target moisture content the mixture should have contained an approximate 50:50 mass ratio of grass to woodchip.

### Summary of findings

The plant was able to process the 50:50 feedstock and in total produced ~50 kg of biochar which is now undergoing laboratory analysis.

### **C. Pilot scale pyrolysis trial – Invica Industries**

A summary of the tests conducted and their findings is provided below.

#### Brief description of trial

Urban grass from WSCC – final cut carried out November 2024 with ~10 tonnes sent to Invica Industries pilot plant at Immingham by Grasstex Ltd.

Grass was processed December 2024/January 2025 in the pilot plant pyrolysis at 700°C. This temperature was chosen based on findings from the small-scale tests.

From 10 tonnes of wet grass (~80% moisture) 2 dry tonnes was processed, two-thirds of the dried grass was processed on its own and one-third was mixed with the same mass of wood before processing.

#### Summary of findings

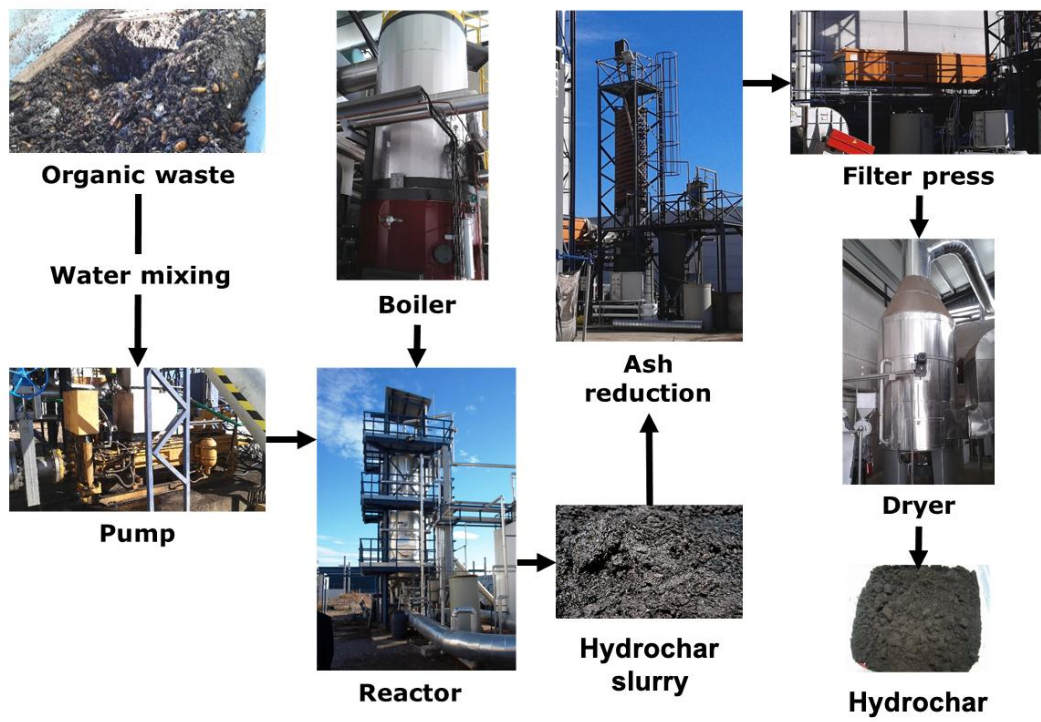
100% grass was successfully processed. ~1300 kg dry grass resulted in 162 kg of biochar (with 38.9% moisture). The ~700 kg 50/50 mix of dry grass and wood produced 225 kg of biochar (with 39.15% moisture). Full analysis according to the European Biochar certificate will be obtained on both the biochars produced.

### **D. Pilot scale HTC trial - Ingelia**

#### Brief description of trial

Urban grass from WSCC – Final cut carried out November 2024 ~10 tonnes sent to Ingelia HTC plant in Valencia, Spain (see Figure 6 for the HTC process steps at the Ingelia plant). Grass was processed to hydrochar during February 2025 .

Hydrochar pellets will be sent to the pilot plant at Immingham for further processing via pyrolysis to produce biochar. Further details on the trial and findings will be shared once the report from Ingelia is received.



*Figure 6 Hydrothermal carbonisation process steps at the Ingelia plant*

## Appendix F - Road Trials description

**1) Road Trial:** Using an aggregate material incorporated with biochar.

When: **September 20<sup>th</sup> and 21<sup>st</sup>, 2025**

Location: **Old Edinburgh Road (B7001), Bellshill, North Lanarkshire**

Total resurfacing area: 1420 – 2000m<sup>2</sup> across two carriageways. Thickness of binder course, 60mm. The road is 9m wide and 60 – 70m long.

Total trial area with biochar incorporated asphalt: **300m<sup>2</sup>** => 2 areas each measuring 50m x 3m = 150m<sup>2</sup>

Biochar incorporated asphalt requirement: **2 x 20 tonne lorry loads** (1 lorry load covers 150m<sup>2</sup>)

Percentage biochar incorporation: 1 x 20 tonne lorry load with **1% biochar** and 1 x 20 tonne lorry load with **2% biochar**

Total biochar requirement: **700kg** => 200kg (1% biochar incorporation) + 400kg (2% biochar incorporation) + 100kg (for contingencies)

The biochar used in the road trial was produced by pyrolysing a feedstock mixture consisting of 10% grass cuttings and 90% green waste, followed by pelletisation. The biochar specifications required for use in hot-mixed aggregates are highly specific. Preliminary testing conducted at Holcim indicated that the biochar pellets did not disintegrate rapidly enough during the hot-mixing process. Subsequent trials led to the development of a granular biochar, also derived from green waste, which was successfully incorporated into the hot-mixed aggregate. The final mixture contained 1% biochar; attempts to increase the incorporation level to 2% were unsuccessful. Biochar produced entirely from grass cuttings was unsuitable, as its fine structure posed a combustion risk during hot-mixing.

The biochar trial had to be postponed due to Holcim's Duntilland plant breaking down just prior to the trial. A suitable alternative has been sought, and the biochar trial is now scheduled to take place w/c October 13<sup>th</sup> as part of a scheme on Crofthead Crescent, Bellshill, north Lanarkshire.

**2) Biochar Burial:** Biochar patching application trial

Biochar burial has a greater magnitude of carbon sequestration than the incorporation of biochar in aggregate mixes. Therefore, a burial trial in WSCC is being explored.

When: **TBC**

Location: **Drayton Depot, Drayton Lane, Chichester, PO20 2AJ**

Four locations for patching within the initial section of access road into Drayton Depot have been identified. They are all on the same stretch of carriageway, meaning each patch will be exposed to all traffic entering Drayton, with the same level of axle load/stress.

The application and methodology have been discussed, and it has been decided that compaction of the biochar in its pure form is not possible. Instead, a mixture of biochar with

Type 1 has been suggested. This mixture will be utilised in the sub-base construction layer, at a ratio of 1 tonne of Type 1 to 1 hippo bag of biochar. This will be mixed by machine in a material bay in a large quantity and used as set out below.

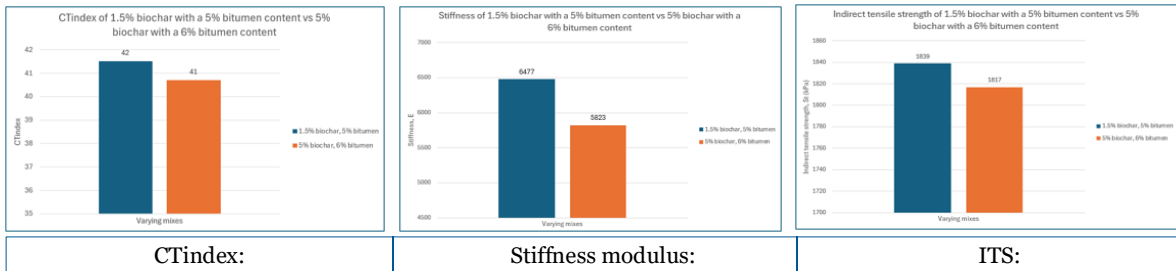
- 4 individual patches at 15 m<sup>2</sup> each, 60 m<sup>2</sup> in total
- Each patch will have the same surface course (40mm depth), binder (60mm) and base course (100mm)
- Patch 1 will have a 300mm excavation depth, with 100mm of compacted Biochar/Type 1 sub-base
- Patch 2 will have a 280mm excavation depth, with 80mm of compacted Biochar/Type 1 sub-base
- Patch 3 will have a 250mm excavation depth, with 50mm of compacted Biochar/Type 1 sub-base
- Patch 4 will have a 220mm excavation depth, with 20mm of compacted Biochar/Type 1 sub-base

**The Use of Biochar as a Fine Aggregate Replacement in Asphalt Mixtures and as a Filler in Mastics: Lab-scale tests**  
**1. Fine Aggregate Replacement**

- Two different types of biochar were used (whole tree wood biochar and ARB Wood chips biochar.)
- Two different particle sizes used, 0.5mm and 1mm.
- Five percentages of biochar were used to replace the fine aggregates in asphalt mixtures (1%, 1.5%, 2%, 2.5%, 5%.)

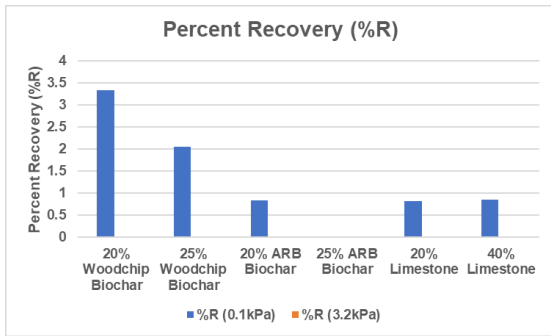
**Comparison between 1.5% and 5% Biochar Contents**

- Although the use of 5% whole tree biochar and 6% bitumen improves the mechanical properties overall, the samples containing 1.5% whole tree biochar is still the favourable choice

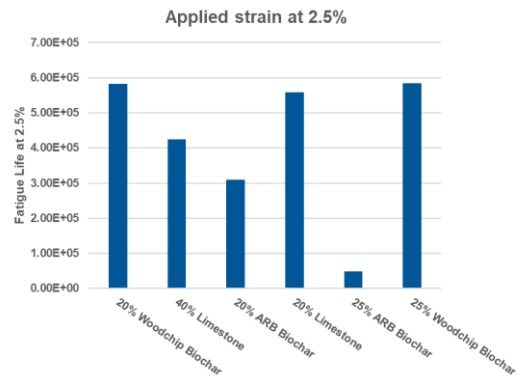


## The Use of Biochar in Mastics compared to Limestone

**Percent Recovery (%R)**



**Fatigue Life**



- The fatigue life results indicate that incorporating 20% and 25% woodchip biochar performs comparably to 20% limestone and significantly better than 40% limestone, with the biochar-modified samples exhibit higher fatigue life.
- In terms of elevated temperatures and rutting resistance, the percentage recovery (%R) values at (0.1kPa) for both 20% and 25% woodchip biochar show markedly superior performance compared to limestone and the other type of biochar.
- This suggests that the type of biochar used has a distinct influence on the behaviour of the modified bitumen

## Appendix G – Greenprint Cost Analysis

### Cut and Collect

Category	Comments
C&C (OPEX)	<p>This value was taken from data record for total cut and collect costs for 25 including disposal costs and maintenance costs</p> <p>Total cost were comprised of labour, transportation fuel costs, Sum of Strimmer Fuel Card (Unleaded) (£), Strimmer and Blower Fuel cost (£) and Mower Fuel Cost (£).</p> <p>Maintenance costs: were recorded in monthly charges to and were then added to the operational costs recorded.</p>
C&C (OPEX) without disposal	This value is the total cost for the project in 2025 minus disposal charges.
C&C (CAPEX)	<p>CAPEX costs were calculated using the purchase price of the equipment and its expected service life expectancy to show an annual cost on the project.</p> <p>Purchase costs were taken from the grounds team when the equipment was bought.</p> <p>Expected life expectancy was determined by the grounds team after using the equipment and estimating its expected service life based on usage</p>
C&C (TOTEX)	This is the total combined CAPEX and OPEX costs for 2025

Category	Comments
Total Grass Collected (wet)	This is the total amount of grass collected to date in 2025 that has been recorded. This has been calculated based on the total weight of grass disposed of by South Gloucestershire Council during 2025, at AD plants, (as these had weighbridge facilities to record each load deposited), by the total number of mower collection boxes required to generate the total tonnage disposed
Total Grass Collected (dry)	It is assumed that 80% of grass is moisture, and only 20% is useable for biochar production. This is 20% of the total weight of grass collected.

Category	Comments
Cost of C&C / dry tonne	<p>This is the cost to collect a useable tonne of biochar with current methods.</p> <p>This is calculated using the TOTEX cost and dividing it by the total dry grass collected</p>
AD Wet Tonne Cost	<p>This is the cost to collect a useable tonne of grass for AD with current methods.</p> <p>This is calculated using the TOTEX cost and dividing it by the total grass collected as all grass is able to be used in the AD process</p>

Category	Comments
Total Area Cut	Total area cut was calculated using the square metres for each site that was visited and multiplying that by the number of cuts to get the total area covered to date in 2025

Category	Comments
C&C cost / sqm	The recorded cost to cut 1 sqm under experimental conditions and was calculated by dividing the TOTEX cost by the total area cut in 2025

Category	Comments
Wet tonne	The recorded sqm that is required to collect 1 tonne of grass. This is calculated by dividing the total area cut by the total grass collected (wet tonnes)
Dry tonne	The recorded sqm that is required to collect 1 tonne of grass. This is calculated by dividing the total area cut by estimated total dry tonnes of grass collected

### Cut and Leave

Category	Comments
BAU (OPEX)	This value was taken from data record for total cut and leave costs for 25 including maintenance costs. Maintenance costs: were calculated as 18% of total costs based on the percentage maintenance costs represented for the total costs for cut and collect
BAU (CAPEX)	CAPEX costs were calculated using the original purchase price of the equipment and its expected service life expectancy to show an annual cost on the project. Purchase costs were taken from the grounds team when the equipment was bought. Expected life expectancy was determined by the grounds team after using the equipment and estimating its expected service life based on usage
BAU (TOTEX)	This is the total combined CAPEX and OPEX costs for 2025

Category	Comments
Total Area Cut	Total area cut was calculated using the square metres for each site that was visited and multiplying that by the number of cuts to get the total area covered to date in 2025

Category	Comments
BAU cost / sqm	The recorded cost to cut 1 sqm under experimental conditions and was calculated by dividing the TOTEX cost by the total area cut in 2025

## Appendix H – Project KPI's

To determine the success of the project, the following KPIs have been established. These have been broken into three stages. The following key is used to determine the status against these KPIs:

Achieved
In Progress
Not being achieved / concerns
Will not be achieved

Stage one is focused on testing the project. This is looking at whether the experiment presented in the outline business case has been trialled. These are as follows:

KPI Category	KPI – Stage 1 (Process Focused)	Achievements / Comments
Biodiversity Sampling	Soil and vegetation sampling will be undertaken	Vegetation sampling has been done. Need results from soil sampling required. New innovation required as well
Energy Supplies	Conversion of at least one waste into an energy source	Have produced biochar
Innovation Management	This project will seek to test at least 1 innovative process	Change to cut-and-collect regime
Biochar Production	Biochar will be created for asphalt and carbon trading from the grass clippings on WSCC and/or SGC	Have produced biochar
Hydrothermal Carbonisation	To trial and record tests with Hydrothermal Carbonisation (HTC) within the project	Have produced hydrochar
Anaerobic Digestion	To trial and record tests with Anaerobic Digester (AD) within the project	AD has now been secured as a way to process grass. Trials with AD will be done early 2025
Thermal Drying and Direct Carbonisation	To trial and record tests with Thermal Drying and Direct Carbonisation within the project	Have used thermal drying and direct carbonisation within the project to produce biochar
Cut Reductions	To trial and record tests with reduced cutting within the project	Have trialled and recorded the outcomes of parishes across both SGC and WSCC, adding up to a total of 83.3ha
Cut-and-collect	To trial and record tests with cut-and-collect within the project	We have conducted cut-and-collect operations and recorded financial and carbon quantities attached to these
Carbon	Carbon profile has been calculated for the whole system and the component parts of that system	Carbon profile has been created for the project. Will verify with data collected in 2025
Cost	Cost has been calculated for the whole system and the component parts of the system	Cost has been determined for verge management and pyrolysis. This will be verified with data collected in 2025

Overall Stage 1 KPIs have almost been completed. This shows that the project has stayed on track in setting up the experiment and the processes it was required to test. The only outstanding item is Anaerobic Digestion, which is looking to start soon given that commercial discussions with facilities are now looking promising.

The second set of KPIs is focused around ensuring that the project can be implemented successfully and can provide a valuable output. In this regard, these KPIs are output focused. Whilst achieving these KPIs aren't necessary for achieving the requirements of the project, they provide a focus for the project to achieve something that is practical and valuable to implement. Not achieving stage 2 KPIs are useful in understanding if the design of the system has the capability to provide societal value. Where the project cannot meet these KPIs, it will be made clear which factors are preventing this.

KPI Category	KPI – Stage 2 (Output Focused)	Achievements / Comments
CO2e	The project can show a system-level carbon reduction associated with processes in the project after 5 years.	Operationally, the processes are producing more carbon. However, there has been a large degree of carbon removed through biogenic removal. This currently is showing a negative carbon factor; however, it will require the implementation of biochar.
Cost	The project will provide a model that can demonstrate cost neutrality over 3 years	Currently, the process is not looking cost-effective. Work in 2025 will consider operational efficiency to reduce the cost as well as sourcing revenue for the production of resources from grass.
Biodiversity Net Gain (BNG)	BNG will increase by at least 10% in at least 80% of areas where the experiment is taking place over a period of 5 years.	Whilst in theory, the process is removing grass and reducing cuts increases biodiversity, this hasn't been measured long enough to give a result.
Job Creation	At least 1 new job created	WSSC - a Junior Management Consultant apprenticeship, has been employed and working on the project.
EDI	At least 1 event hosted encouraging individuals of varying backgrounds to contribute.	EDI event occurred March 2024 with 15 individuals from varying backgrounds.
Better communication within councils	There will be a forum established to allow the councils and different elements of each council to collaborate on the Greenprint initiative. There will also be written agreement between councils of the partnership.	There are weekly meetings ensuring alignment between SGC and WSSC. This ensures that any disagreements are discussed and solutions can be found collaboratively
Innovation Management	1 new process created and evidenced in running innovations in projects	The process of collecting grass and converting that into biochar and hydrochar has not been done elsewhere, and is an innovative approach to converting grass into a resource
Community Engagement	Number of visitors to knowledge-sharing platforms exceeds 10:1	Visitors to sharing platforms such as websites and social media has far exceeded 10 views per platform.

Overall, there are concerns about the cost of the process. This is likely the biggest factor that will determine the success of the project. Currently the cost to collect and process grass is looking expensive. For the project to have an output that is useful, consideration on how to reduce cost will be considered. From a carbon perspective, the process shows that it is reducing carbon because of the large amounts of biogenic carbon that is being sequestered with the grass. Biodiversity continues to be difficult to assess due to it being a slower metric to change and dependant on many ecological factors and dependencies on weather.

Stage 3 KPIs have been developed to ensure that the experiment can be read, understood and adapted by other parties. This will ensure that a successful project can be scaled up and require a lower level of effort from external parties to implement. It will also ensure that even if the experiment doesn't achieve stage 2 KPIs, that there will be appropriate documentation in place demonstrating the decision-making made in the project and showing the various angles that other parties can explore.

<b>KPI Category</b>	<b>KPI – Stage 3 (Scaling and Embedment Focused)</b>	<b>Achievement / Comments</b>
Carbon	Carbon impact is built in systematically to processes within the Highways sector of at least one council	WSCC has / is in the process of fully embedding carbon measurement across the Highways, Transport and Planning (HTP) function. Collecting data and measuring emissions on a yearly basis (using the FHRG approach)
Behaviour	X % increase in employee satisfaction	There was a behavioural survey done middle of 2024. There hasn't been any done since then.
Behaviour	Local Authorities' attitudes towards innovation and risk	There has been support from local members expressing interest in the project and the benefits that it provides
Behaviour of counties	Local communities' attitudes towards a change in verge management to support core challenges faced by the sector including decarbonisation and biodiversity	SROs within the councils are engaged in regular meetings. Events that have been hosted embed the idea within the council that reduction of carbon and increasing biodiversity is of benefit to them. This has not been quantified at this stage.
Knowledge Sharing	Documents produced which present the learnings from Greenprint trials at a level deemed sufficient to ADEPT	Documents in production. Will be finalised end of 2025
Council Engagement	At least one Local Authority signed up to a knowledge-sharing communication platform developed from Greenprint	Whilst little engagement through knowledge-sharing platforms, engagement is being made with North Lanarkshire and Shrewsbury
Private Sector	At least one private sector has provided considerable interest in Greenprint	There is interest from Invica industries who we are using for biochar production. We have not yet got interest from private parties looking to purchase biochar, however, it is likely this will be achieved before middle 2025. Other SMEs engaging with Greenprint include Cage Technologies and The Small Robot Company.



Survey	Both authorities have directly engaged with programme outputs through the industry survey	Local Authorities have continued to engage with industry surveys provided by Arup and other groups. There will be continuation of this until the end of the project
Toolkit	At least one Local Authority has adopted the Greenprint methodology and toolkit	Not yet developed

## Appendix I – Biochar Business Case

Business Case for Biochar Production and Deployment in West Sussex: General Framework

### Summary

This document provides the general framework for assessing the economic and carbon sequestration of biochar produced in West Sussex from predominately green waste but with some co-mingled grass cuttings. The plant will be capable of processing 10,000 tonnes of dry feedstock per annum producing ca. 3000 tonnes of biochar which has a carbon sequestration potential of 1.9 tonnes net CO<sub>2</sub> equivalent per tonne of biochar, after life cycle emissions of greenhouse gases have been considered. The key points are:

1. A 100% grass-based biochar production approach (Scenario 1) is not viable due to insufficient local grass availability and the high cost and emissions associated with long-distance transportation.
2. A co-mingling approach (Scenario 2), using a 10:90 dry mass ratio of grass to green waste, provides a potentially sustainable feasible solution. If required, other wood feedstocks can be used, including arboreal waste and oversized compost. A 10% addition was based on the maximum amount of grass cuttings that could be collected in West Sussex. However, the data provided by WSCC on the cost of cut-and-collect indicates there would only be 275 tonnes of dry grass cuttings available p.a. for two cuts at a cost of £383 per dry tonne. At this level of incorporation where grass cuttings only represent 2.75% of the total feedstock by mass, this would increase the cost of biochar production from £409 to £440 per tonne of biochar
3. Income from selling the carbon credits, if these are sold, is estimated as £237.5 per tonne of biochar compared. This remaining cost difference of £171.5 is covered by the avoided gate fee for windrow costing equating to £180 per tonne of biochar produced. For WSCC to keep the carbon credits, a minimum income of ca. £229 per tonne of biochar would be required that would need to be generated through biochar sales. These estimates are based on a moisture content of 50% w/w and, clearly, the actual contents should be determined for representative green waste samples to provide more precise estimates.
4. The high moisture content of green waste is likely to limit the amount of income that could be obtained from exporting surplus heat and power. If the biochar does not meet agricultural grade specification, then aggregates represent the major deployment route for the biochar.
5. Regarding agriculture, biochar has already been marketed blended with compost for horticultural use but the size of this market, and also for animal feed, are relatively small.
6. Applications were income close to £229 (WSCC keeping the carbon credits) per tonne of biochar would be obtained include pollution control in incinerators, exporting the biochar to the Middle East as a component for synthetic soils.

### 1. Introduction/Scope

This document provides the general framework for assessing the economic and carbon sequestration of biochar produced in West Sussex from predominately green waste but with some co-mingled grass cuttings. The plant will be capable of processing 10,000 tonnes of dry feedstock per annum producing ca. 3000 tonnes of biochar which has a carbon sequestration

potential of 1.8 tonnes net CO<sub>2</sub> equivalent per tonne of biochar, after life cycle emissions of greenhouse gases have been considered. The techno-economic and life cycle analysis behind these figures in the Appendix was also reported in the Greenprint Second Year Annual Report. The key points are:

- i. A 100% grass-based biochar production approach (Scenario 1) is not viable due to insufficient local grass availability and the high cost and emissions associated with long-distance transportation.
- ii. A co-mingling approach (Scenario 2), using a 10:90 dry mass ratio of grass to green waste, provides a potentially sustainable feasible solution. If required, other wood feedstocks can be used, including arboreal waste and oversized compost. A 10% addition was based on the maximum amount of grass cuttings that could be collected in West Sussex. However, the latest data provided by WSCC on the cost of cut-and-collect indicates there would only be 275 tonnes of dry grass cuttings available p.a. for two cuts at a cost of £383 per dry tonne. At this level of incorporation where grass cuttings only represent 2.75% of the total feedstock by mass, this would increase the cost of biochar production from £409 to £440 per tonne of biochar (Figure 1). However, in practice, it is realistic to use other much lower cost feedstocks with the green waste, such as arboreal waste and oversized compost.
- iii. Pyrolysis with thermal drying is identified as the preferred route over the alternative approach of hydrothermal carbonisation due to the prohibitive cost of this approach.
- iv. There is sufficient green and garden waste available in West Sussex to sustain a plant processing 10,000 tonnes dry mass to produce ca. 3,000 tonnes of biochar per annum (p.a.).

This report builds upon this analysis (Appendix 1) to provide general framework for assessing a business case for biochar production and deployment, which describes the key factors that must be taken into consideration. Some possible applications for biochar are outlined but, to date, no large-scale established markets exist in the UK, making economic forecasting uncertain.

## 2. Analysis

### 2.1 CAPEX/OPEX

The combined figure of ca. £409 per tonne for biochar produced from green waste (Figure 1) benefits from the operating scale of the plant where CAPEX (depreciated over 20 years, Appendix 1) increases significantly as the scale is reduced. Note that the capital costs also include estimates for groundwork to prepare the production site with the required facilities, a topic often overlooked. Due to the highly variable moisture content of green waste, surplus energy available for export as heat and power have not been considered. This will be negligible for 80% moisture but will start to be significant for less than 50% moisture.

**Figure 1.** Comparison of the cost of biochar produced from (a) 100% green waste and (b) green waste containing 2.75% grass cuttings. Only the direct pyrolysis route is viable. The net carbon sequestration in both cases is 1.9 tonnes of CO<sub>2</sub> equiv. per tonne of biochar.

## 2.2 Feedstock costs

The cost of grass cuttings from cut-and-collect has already been addressed where only a small level of incorporation into the feedstock increases the cost of biochar production significantly (Figure 1). The fee paid for the disposal of green waste for windrow composting will be avoided if green waste is diverted to biochar production. However, the same front-end separation for pyrolysis is required as for windrow composting to remove extraneous material, such as stones and plastic items. Information is received on the fee that will be avoided for disposing green waste for windrow composting. It is assumed that the avoided disposal fee will be *ca.* £30 per tonne and that the front-end separation cost will be £10 per tonne, based on oversized compost, the net cost avoided equals £20 per tonne. Assuming a relatively low moisture content of 50% and a biochar yield of 30% on a dry basis, this equates to **£180 per tonne of biochar produced**, representing a potential saving to **WSCC of £400k p.a.**

Other feedstocks can be considered, such as arboreal waste from tree surgeons and over-sized compost. However, wood from tree surgeons is likely to bear a cost since it could be diverted from combustion, but the likely cost is low compared to grass cuttings (*ca.* £50-100 per tonne). Although over-sized compost is relatively low cost, it will still require a similar front-end treatment to green waste prior to pyrolysis to remove extraneous constituents.

## 2.3 Transport costs

The additional cost for transporting green waste to the processing site are relatively small for distances used in Appendix 1. The biochar production cost per tonne increases by £20 and £47 for transport distances of 50 and 100 miles, respectively.

The costs for transporting biochar per unit distance are less than for the green waste due to the higher bulk density. When accounting for biochar soil applications, transporting biochar over 100 miles increases the total cost by only £6.75 per tonne in Scenario 2 due to its relatively high bulk density. A transport distance of more than 275 miles is required to raise the total cost by £20 per tonne.

## 2.4 Carbon trading income

Assuming a net carbon sequestration potential of 1.9 tonnes of CO<sub>2</sub> per tonne of biochar as for the biochars being considered (Appendix 1) and a price of £125 per tonne of net CO<sub>2</sub> sequestered in carbon trading platforms, such as Puro Earth (<https://puro.earth/>), this would generate potential income of £237.5 per tonne of biochar compared to the production cost of £409. If the carbon credits are sold on the voluntary market, then WSCC would not be able to use to the biochar sequestered to offset their overall emissions of CO<sub>2</sub>. However, the avoided gate fee income of at least £180 per tonne would offset the remaining production cost of £171.5 after the income from carbon trading has been subtracted. For WSCC to keep the carbon credits, a minimum income of *ca.* £229 per tonne of biochar would be required that would need to be generated through biochar sales.

## 2.5 Export of heat and power

Given the high moisture content of green waste and grass cuttings, it is assumed that virtually all the surplus heat produced by combustion of the volatile species released during pyrolysis will be required for the dryer leaving little for export to be used locally of conversion to power. However, if the mean moisture content of green waste is known, then the surplus heat and the income from a relatively small amount of power generation from any surplus energy not required for drying can be estimated and this would provide an additional, albeit small, income stream.

## **3.1 Biochar markets**

### 3.1 Introduction

The key factor to consider is that biochar used for applications involving pollution control will still need to be buried after use, if income from carbon trading is received. Further, markets need to be guaranteed for several years, or the overall economics would be adversely affected. For the business model outlined with the carbon credits sold in the voluntary market, the income for biochar, no income is required from biochar sales for this scenario. As already described, for the carbon credits to be retained by WSCC, income from biochar sales would need to be at least ca. £229 per tonne of biochar would be required that would need to be generated through biochar sales. Markets where biochar would need to sell at ca. £250 per tonne would make this scenario profitable.

All the possible applications of biochar are summarised in Appendix 2 and Table S4 (Appendix 1) considers the potential market size for the different applications of which the most relevant will be addressed here where it is considered that biochar can attract value and there is a potential demand for several thousand tonnes of biochar p.a., although these do critically depend upon the grade of biochar produced which is addressed in voluntary standards, such as European and World Biochar Certificate.

As well as being sequestered to achieve greenhouse gas removal, biochar can be used as a fuel to displace coal as a renewable in the iron and steel industry. This would not attract carbon credits as the biochar is combusted but a sales price of over £250 per tonne is potentially attractive if the biochar meets specifications in not having too high an ash content.

### 3.2 Agricultural and horticultural use

As Table S4 (Appendix 1) and Appendix 2 indicate, the applications are numerous ranging from animal feed and a compost additive to slurry treatment. However, biochar needs to meet the agricultural grade specification in the European/World Biochar Certificate (EBC/WBC). Adding biochar to animal feed is a niche market demanding the highest purity biochar in terms of pollutant levels, such as heavy metals, as defined by the EBC/WBC.

One major application is the prevention of run-off from digestate, chicken litter, biosolids and other material that might be spread to land, but more demonstration activities are needed to ascertain the effectiveness of the biochar, and so markets are yet to be established. However, biochar as an additive for compost is already sold commercially in the UK by more than one company

(<https://onnubiochar.com/?srsltid=AfmBOopQuF4wqzb0k2cxSggdDvMlhOAvhUzfpQuEBlgNacdJjFhQ3qIt> ; <https://www.brodiebiomass.co.uk/brodie-biomass-acquires-soilfixer-expanding-its-biochar-and-soil-improvement-offerings/>).

Trials have shown that biochar can have a beneficial effect on both composting and anaerobic digestion. Adding biochar initially means the added benefits are obtained and the biochar is present for land-spreading, giving the knock-on benefits of reducing nutrient run-off. Markets for these applications have not yet emerged since the economic and environmental benefits still need to be quantitatively assessed.

### 3.3 Uses in aggregates for construction, roads and other applications

If the biochar does not meet the specification (EBC/WBC) required for agricultural use, then aggregates will be the main application with a lower specification that allow greater levels of pollutants, including heavy metals. There is already a vast literature on biochar addition to concrete to abate CO<sub>2</sub> emissions where typically levels of 5% w/w addition of biochar can be tolerated. The Greenprint and other Live Labs projects are investigating the scope incorporating biochar into road aggregates. To be economically viable where aggregates represent a means of low-term carbon sequestration, the biochar will first need to find an application with respect to pollutant control before being incorporated into aggregates. Further, information of the end-of-life fate of aggregates will be needed to demonstrate the permanence of carbon sequestration by this route.

Emerging applications include the use of biochar in plaster boards (<https://adaptavate.com/products/breathaboard>) and insulation foam (<https://www.carboncell.co/uk>) (Table S4, Appendix1) and the University of Nottingham is working with both the companies involved in these developments. The same arguments regarding end-of-life of these materials applies as for aggregates but these markets could potentially be lucrative if the cost of biochar is small in relation to the sale price for plaster board and insulation foam.

There is a market in the Middle East for biochar being used as a component in artificial soils. This would attract income of £220 per tonne in addition to that from carbon trading.

### 3.4 Fuel gas treatment

Regarding pollution control, Invica Industries is exploring the use of biochar as an activated carbon replacement for flue gas treatment where it is mixed with lime, calcium oxide. This approach values the biochar at a base value of ca. £200 per tonne, with the additional revenue from carbon credits, would be highly profitable (given the avoided gate fee for windrow composting and the income from carbon credits covers the production cost) making it an attractive and environmentally beneficial option. After use, the mixture of lime and biochar would be spread to land, as is currently practised with activated carbon/lime blends.

### 3.5 Offsetting greenhouse gas emissions in heavy industry

Currently, Invica Industries market a biocoke for use in iron and steel production where it can displace the use of anthracite in electric arc furnaces. Provided the green waste-derived biochar

meets the required specification, the only guaranteed application where income of over £200 would be received would be as a biofuel to displace fossil fuels in heavy industry, particularly iron and steel production. However, this is offsetting emissions rather than permanent greenhouse gas removal and, consequently, WSCC would not gain any carbon credits and would need to use the avoided gate fee for green waste disposal to be profitable.

### 3. Conclusions

1. An overall framework is presented for assessing the economic feasibility of biochar production and deployment in West Sussex. There is sufficient feedstock, predominately green waste, to sustain a plant production 3,000 tonnes of biochar p.a. but there is some uncertainty around the likely markets for the biochar produced and the income they would generate to ensure profitability.
2. Grass cuttings would only comprise a maximum of ca. 3% of the feedstock adding an additional cost of £31 to the capital; and operating costs of £409 per tonne of biochar.
3. The minimum income received will need to be greater than ca. £200 per tonne of biochar, the difference between production costs and the income from carbon trading. For WSCC to keep the carbon credits, a minimum income of ca. £400 per tonne of biochar would be required. However, if the income from avoiding the gate fee for green waste going to windrow composting is used to offset this, biochar would need to sell at ca. £250 per tonne. These estimates are based on a moisture content of 50% w/w and the actual contents should be determined for representative green waste samples to provide more precise estimates.
4. The high moisture content of green waste is likely to limit the amount of income that could be obtained from exporting surplus heat and power. If the biochar does not meet agricultural grade specification, then aggregates represent the major deployment route for the biochar.
5. Regarding agriculture, biochar has already been marketed blended with compost for horticultural use but the size of this market, and also for animal feed, are relatively small.
6. Applications where income close to £225 per tonne of biochar would be obtained include pollution control in incinerators, exporting the biochar to the Middle East as a component for synthetic soils.

**Table S4: Potential applications of biochar**

Application	Benefits	Market / Potential	Commercial Value / Scalability
Soil amendment	Improves fertility, structure, water retention	Agriculture, horticulture	High – widely used, scalable in large agricultural markets
Compost blends	Enhances nutrient retention, reduces leaching	Niche horticultural markets, organic farming	Medium – niche markets, premium pricing

Livestock feed additive	Improves digestion, reduces methane emissions	Livestock farming (where permitted)	Medium – regulatory constraints, limited scalability
Aggregates and fillers	Reduces density, improves insulation	Construction industry, lightweight concrete, bricks	High – growing green construction market
Insulation foams	Enhances thermal insulation, carbon storage	Building materials, green construction	Medium – emerging market, requires R&D
Plaster boards	Improves thermal/acoustic properties	Construction, interior design	Medium – emerging niche, moderate scalability
Concrete and asphalt additives	Increases strength and durability	Infrastructure projects, sustainable construction	High – large-scale construction market
Bricks and tiles	Improves durability, carbon sequestration	Construction and building materials	Medium – potential for niche green construction projects
Water and wastewater treatment	Adsorbs nutrients, heavy metals, pollutants	Environmental engineering, wastewater plants	Medium – specialized industrial applications
Air filtration and odour control	Captures particulate matter and odours	Industrial, agricultural, municipal applications	Medium – moderate scalability, niche adoption
Soil remediation	Reduces pollutant bioavailability	Contaminated land restoration	Medium – high-value, project-specific market
Catalyst or catalyst support	Supports chemical reactions	Chemical industry	Low – specialised applications, small-scale
Polymer and composite additive	Improves mechanical/thermal properties	Plastics, composites	Medium – industrial niche, requires partnerships
Energy storage materials	High surface area, conductivity	Batteries, supercapacitors	High – growing clean-tech and energy storage market
Fuel pellets / briquettes	Renewable solid fuel	Energy sector, biomass power plants	High – scalable, existing bioenergy infrastructure
Biogas upgrading /	Improves gas quality	Bioenergy, biogas plants	Medium – limited to bioenergy facilities

syngas cleaning			
Cosmetics and personal care	Activated carbon substitute	Skincare, cosmetics industry	Medium – niche, premium market
Animal bedding	Absorbs moisture and odours	Livestock housing, pet care	Medium – small-scale but steady market

## Appendix 2

### The many uses of biochar (<https://www.biochar-journal.org/en/ct/2>)

#### The many uses of biochar

Biochar is much too valuable for it to be just added to soil without using it at least once for other beneficial purposes. Basic uses include drinking water filtration, sanitation of human and kitchen wastes, and as a composting agent. All of these uses have been documented in many different pre-industrial cultures. In the modern world, the uses multiply: adsorber in functional clothing, insulation in the building industry, as carbon electrodes in super-capacitors for energy storage, food packaging, waste water treatment, air cleaning, silage agent or feed supplement. All those uses could be part of more complex cascades when, after extended up- and down cycling, biochar can be used in a farmer’s manure slurry pit or in a sewage treatment plant, before being composted and thus finally becoming a soil amendment. Biochar should only be worked into the soil at the end of such “cascades,” keeping in mind that some biochar uses – for cleaning up metal or chemical contamination – would render the biochar unsuitable for agricultural soils and need different recycling pathways.

The following list of 55 possible uses of biochar is by no means complete. In fact it has only just been started. We will initially just comment shortly on a few applications in this list. The Biochar Journal (formerly known as Ithaka Journal) is publishing a series of in-depth articles on many of these uses, highlighting in particular the cascading benefits of biochar in agriculture and livestock farming. Biochar is without doubt one of this century’s most exciting new fields of research, with findings and their practical implementation increasing exponentially from year to year. Nevertheless, however much we enthuse over our field of research and the importance of our findings, it’s the real world that decides about its success.

#### The cascaded use of biochar in animal farming

*1. Silage agent, 2. Feed additive / supplement, 3. Litter additive, 4. Slurry treatment, 5. Manure composting, 6. Water treatment in fish farming*

At present some 90% of the biochar used in Europe goes into animal farming. Different to its application to fields, a farmer will notice its effects within a few days. Whether used in feeding, litter or in slurry treatment, a farmer will quickly notice less smell. Used as a feed supplement, the incidence of diarrhoea rapidly decreases, feed intake is improved, allergies disappear, and the animals become calmer. In Germany, researchers conducted a controlled experiment in a dairy that was experiencing a number of common health problems: reduced performance,

movement disorder, fertility disorders, inflammation of the urinary bladder, viscous salivas, and diarrhoea. Animals were fed different combinations of charcoal, sauerkraut juice or humic acids over periods of 4 to 6 weeks. Experimenters found that oral application of charcoal (from 200 to 400 g/day), sauerkraut juice and humic acids influenced the antibody levels to *C. botulinum*, indicating reduced gastrointestinal neurotoxin burden. They found that when the feed supplements were ended, antibody levels increased, indicating that regular feeding of charcoal and other supplements had a tonic effect on cow health. Visit the Ithaka Journal online (<http://www.ithaka-journal.net>) for in-depth articles on the use of biochar in cattle and poultry farming, as well as many of the other uses described below.

### **Use as a soil conditioner**

*7. Carbon fertiliser, 8. Compost additive, 9. Substitute for peat in potting soil, 10. Plant protection, 11. Compensatory fertiliser for trace elements*

In certain poor soils (mainly in the tropics), positive effects on soil fertility were seen when applying untreated biochar. These include the higher capacity of the soil to store water, aeration of the soil and the release of nutrients through raising the soil's pH-value. In temperate climates, soils tend to have humus content of over 1.5%, meaning that such effects only play a secondary role. Indeed, fresh biochar may adsorb nutrients in the soil, causing - at least in the short and medium term - a negative effect on plant growth. These are the reasons why in temperate climates biochar should only be used when first loaded with nutrients and when the char surfaces have been activated through microbial oxidation. The best method of loading nutrients is to co-compost the char. This involves adding 10–30% biochar (by volume) to the biomass to be composted. Co-composting improves both the biochar and the compost. The resulting compost can be used as a highly efficient substitute for peat in potting soil, greenhouses, nurseries and other special cultures.

Because biochar serves as a carrier for plant nutrients, you can produce organic carbon-based fertilisers by mixing biochar with such organic waste as wool, molasses, ash, slurry and pomace. These are at least as efficient as conventional fertilisers and have the advantage of not having the well-known adverse effects on the ecosystem. Such fertilisers prevent the leaching of nutrients, a negative aspect of conventional fertilisers. The nutrients are available as and when the plants need them. Through the stimulation of microbial symbiosis, the plant takes up the nutrients stored in the porous carbon structure and on its surfaces.

The thermal process that produces biochar is called pyrolysis (from the Greek, “pyro,” meaning fire and “lysis,” meaning separation). During pyrolysis, the crucial trace elements found in plants (over 50 metals) become part of the carbon structure, thereby preventing them from being leached out while making them available to plants via root exudates and microbial symbiosis. This feature can be used specifically when certain trace elements are missing in a certain regional soil or in soil-free intensive cultures such as “Dutch tomatoes”.

A range of organic chemicals are produced during pyrolysis. Some of these remain stuck to the pores and surfaces of the biochar and may have a role in stimulating a plant's internal immune system, thereby increasing its resistance to pathogens. The effect on plant defence mechanisms was mainly observed when using low temperature biochars (pyrolysed at 350° to

450°C). This potential use is, however, only just now being developed and still requires a lot of research effort.

### **Use in the building sector**

*12. Insulation, 13. Air decontamination, 14. Decontamination of earth foundations, 15. Humidity regulation, 16. Protection against electromagnetic radiation (“electrosmog”)*

Two of biochar’s properties are its extremely low thermal conductivity and its ability to absorb water up to 6 times its weight. These properties mean that biochar is just the right material for insulating buildings and regulating humidity. In combination with clay, but also with lime and cement mortar, biochar can be added to clay at a ratio of up to 50% and replace sand in lime and cement mortars. This creates indoor plasters with excellent insulation and breathing properties, able to maintain humidity levels in a room at 45–70% in both summer and winter. This in turn prevents not just dry air, which can lead to respiratory disorders and allergies, but also dampness and air condensing on the walls, which can lead to mould developing. You can read about the Ithaka Institute’s biochar-plaster wine cellar and seminar rooms in the Ithaka Journal. Such biochar-mud plaster absorbs smells and toxins, a property not just benefiting smokers. Biochar-mud plasters can improve working conditions in libraries, schools, warehouses, factories and agricultural buildings.

Biochar is an efficient adsorber of electromagnetic radiation, meaning that biochar-mud plaster can prevent “electrosmog”.

Biochar can also be applied to the outside walls of a building by jet-spray technique mixing it with lime. Applied at thicknesses of up to 20cm, it is a substitute for Styrofoam insulation. Houses insulated this way become carbon sinks, while at the same time having a more healthy indoor climate. Should such a house be demolished at a later date, the biochar-mud or biochar-lime plaster can be recycled as a valuable compost additive.

### **Decontamination**

17. Soil additive for soil remediation – for use in particular on former mine-works, military bases and landfill sites.

18. Soil substrates – Highly adsorbing, plantable soil substrates for use in cleaning wastewater; in particular urban wastewater contaminated by heavy metals.

19. A barrier preventing pesticides getting into surface water – berms around fields and ponds can be equipped with 30-50cm deep barriers made of biochar for filtering out pesticides.

20. Treating pond and lake water – biochar is good for adsorbing pesticides and fertilisers, as well as for improving water aeration.

### **Biogas production**

*21. Biomass additive, 22. Biogas slurry treatment*

Initial tests show that, through adding biochar to a fermenter’s biomass (especially heterogeneous biomasses), the methane and hydrogen yield is increased, while at the same time decreasing CO<sub>2</sub> and ammonia emissions. Through treating biogas slurry with lacto-ferments and biochar, nutrients are better stored and emissions prevented.

**The treatment of wastewater**

23. Active carbon filter, 24. Pre-rinsing additive, 25. Soil substrate for organic plant beds, 26. Composting toilets

**The treatment of drinking water**

27. Micro-filters, 28. Macro-filters in developing countries

**Other industrial uses**

Exhaust filters (29. Controlling emissions, 30. Room air filters)

Industrial materials (31. carbon fibers, 32. plastics)

Electronics (33. semiconductors, 34. batteries)

Metallurgy (35. metal reduction)

Cosmetics (36. soaps, 37. skin-cream, 38. therapeutic bath additives)

Paints and coloring (39. food colorants, 40. industrial paints)

Energy production (41. pellets, 42. substitute for lignite)

**Medicines**

(43. detoxification, 44. carrier for active pharmaceutical ingredients, 45. Cataplasm for insect bites, abscesses, eczema...)

There are several hundred other medical uses proven in its efficiency for many centuries. Somewhat forgotten during the last 40 years, more and more people and doctors rediscover its efficiency to treat a whole range of symptoms. Have a look at [www.CharcoalRemedies.com](http://www.CharcoalRemedies.com).

**Textiles**

46. Fabric additive for functional underwear, 47. Thermal insulation for functional clothing, 48. Deodorant for shoe soles

In Japan and China bamboo-based biochars are already being woven into textiles to gain better thermal and breathing properties and to reduce the development of odours through sweat. The same aim is pursued through the inclusion of biochar in shoe soles and socks.

**Wellness**

49. Filling for mattresses, 50. filling for pillows

Biochar adsorbs perspiration and odours, shields against electromagnetic radiation (electrosmog), and removes negative ions from the skin. Moreover, it acts as a thermal insulator reflecting heat, thereby enabling comfortable sleep without any heat build-up in summer. In Japan, pillows have been filled with biochar for a long time. This is supposed to prevent insomnia and neck tension.

51. Shield against electromagnetic radiation

Biochar can be used in microwave ovens, television sets, power supplies, computers, power sockets, etc. to shield against electromagnetic radiation. This property can also be used in functional clothing as protection for parts of the body particularly sensitive to radiation.

52. Food Conservation

Put a small bowl of biochar into the fridge (or small linen bags with biochar) and it will not only absorb bad odours but also Ethylen which will retard the post-ripening of fruits and vegetables

thus prolonging their conservation time. As the biochar takes-up humidity, the risk of mould is diminished. In food packaging the conservation time can be increased through the addition of biochar either in the packaging material or as an additive in small tea bags. For the long-term storage of potatoes, carrots, cabbage, apples, and other winter vegetables and fruits, to dig them into biochar can increase storage time for several months.

All of the proposed biochar uses except nos. 35, 41, 42 are carbon sinks. After its initial or cascading use, the biochar can be recycled as a soil conditioner. Fully depreciated when finally returned to the soil, the black carbon will slowly build up in the soil – and over a few generations the soil's biochar content could easily reach 50 to 100 tonnes per hectare, as is the case in the ancient Terra Preta soils.

*We have listed 52 possible uses of biochar. But the title refers to 55 uses... This is to be seen as an indication of our intention to keep on adding to the list over the coming years, as experience builds up. We can also be sure that the author has missed out a number of uses already available today (the first version of this article published in the Ithaka Journal only contained 44 possible uses). However, new uses of biochar will most certainly be published first in the form of an article in [The Biochar Journal](#), just check it regularly.*