Sponsored by: Department for Energy Security and Net Zero (DESNZ)

Conducted by:

Invica Industries & University of Nottingham, supported by Severn Trent Green Power

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DESNZ GGR Innovation Project: Phase 2 Bio-waste to biochar (B to B)

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Project Summary

Invica Industries successfully delivered a biocarbon demonstrator plant, proving that waste materials can be effectively converted into biochar for carbon sequestration. This project, supported by DESNZ through the Net Zero Innovation Portfolio (NZIP), Direct Air Capture and GGR Innovation Programme, demonstrated the viability of biochar as a scalable carbon removal solution whilst repurposing waste streams.

Key Achievements:

Technology, plant concept: The plant successfully produced biochar via pyrolysis from a range of feedstocks and validated biochar's ability to lock away carbon contributing to net-zero targets.

Effective Waste Utilisation: Organic waste, including AD screenings, verge cuttings, waste wood and oversized compost were successfully transformed into biochar, reducing landfill and emissions. Additionally other biomasses such as nut shells and olive stones were successfully converted into biochar.

Industry & Policy Impact: The project provided valuable data for future carbon removal methodologies, certification schemes, and market development.

Outcomes & Future Potential:

Carbon Footprint Reduction: Biochar's sequestration potential was demonstrated at scale.

Agricultural & Soil Benefits: The biochar produced enhanced soil health with composting trials.

Scalability Demonstration: The success of the plant paves the way for wider deployment across the UK with internet or external investment or joint ventures.

Stakeholder Engagement: Collaboration with waste processors, farmers, and carbon credit markets was strengthened.

Invica Industries' success with this demonstrator plant marks a significant milestone in integrating biochar into the UK's carbon management strategy while supporting circular economy principles.

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Output 1 Plant Design and Build

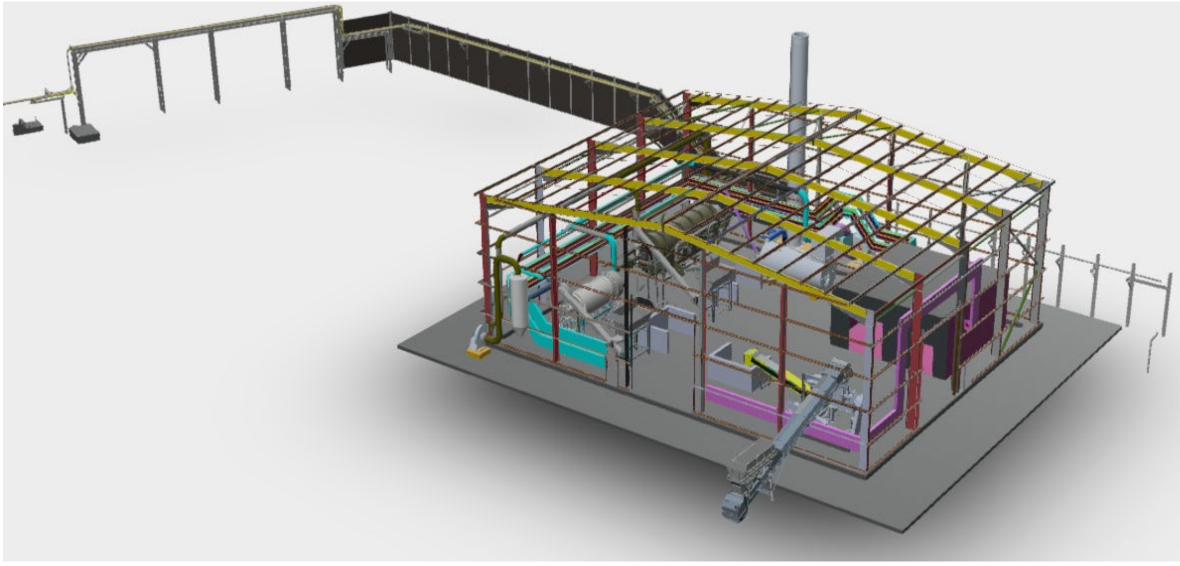


Figure 1.1 3D plant model

Figure 1.2 External plant image

Figure 1.3 Internal plant image

Figures 1.1,1.2 and 1.3 help to show how Invica collaborated closely with specialised subcontractors to design both the building and external/internal civil works required for the biochar plant, ensuring seamless integration of structural and operational requirements. By using both previously used and new sub-contractors. Invica developed a robust design that accommodated the plant's processing needs while meeting regulatory and environmental standards. The subcontractors were engaged early in the project to provide input on site preparation, foundation work, and an access road, ensuring efficient workflows and cost-effective solutions. The costs of the civil works were severely impacted by inflationary pressures experienced in 2022 due to multiple reasons, such as exiting covid restrictions, Russia’s invasion of Ukraine and concrete being used in HS2 implementation.

1.1 Rotary Kiln and Oxidiser

Figure 1.4 Rotary kiln and Oxidiser

The rotary kiln for the biochar plant was purchased from HeatSystems, as they offered the best value for money and have a proven track record with Invica on previous projects. This kiln features a unique design with efficient burner modifications, originally developed by Invica for another HeatSystems rotary kiln. These enhancements improve combustion efficiency and overall performance, making it well-suited for the plant's operational needs. Having successfully worked with HeatSystems before, Invica was confident in their ability to deliver a high-quality, reliable solution tailored to the project's requirements and this has proven to be the case with high quality performance during operation thus far.

The rotary kiln for this demonstration plant was designed to process an input of 500 kg per hour with AD screenings, with adjustable residence time controlled by the kiln's rotation speed, ranging from 10 minutes to 1 hour. It can operate at temperatures of up to 800°C, with an optimal range of 650–700°C. Previous R&D work has demonstrated that maintaining this temperature range effectively limits the presence of PAHs in the biochar, ensuring a high-quality, compliant biochar product. The federate has surpassed 500kg/hr for certain feedstock materials.

Figure 1.5 Oxidiser and heat recovery

Initially, the project explored Hydrothermal Carbonisation (HTC) as a method for processing anaerobic digestion (AD) screenings. HTC was first used back in phase 1 of the programme due to its ability to convert wet biomass into hydrochar under moderate temperatures and pressures. However, findings from Phase 1 and early Phase 2 indicated that unless the feedstock was a slurry with 80%+ moisture, the process was not as viable as anticipated. The high capital expenditure required for HTC systems, along with operational complexities, led to the reassessment of the overall approach.

With this new information, the project pivoted towards straight pyrolysis, which offered significantly lower CAPEX and greater operational simplicity. Pyrolysis was determined to be a more efficient method for handling AD screenings. To further enhance efficiency, a syngas scrubbing system was designed to clean the produced pyrolysis gases, enabling them to be directly fed into the kiln burners as a renewable energy source.

1.2 Heat recovery system

As the project progressed, inflationary pressures caused further design changes to manage rising costs and keep the project viable. The wet scrubber package that was initially included in the design was removed. The wet scrubbers were to be used to condense oils and tars from the pyrolysis syngas and allow the now cleaned syngas to be directly combusted in the rotary kiln burners.

This change meant the new focus was using waste heat recovery from the oxidiser. Instead of relying on additional energy inputs for drying, the system was redesigned to utilise waste heat from the oxidiser to directly pre-dry the incoming feed material to a moisture content of approximately 10-20%.

Any excess combustion gases are released via the stack, however for the commercial-scale plant (>10,000 tonnes feedstock input), a larger new rotary kiln can be designed with greater flexibility to optimise heat recovery and energy efficiency. One potential modification is to utilise waste heat from the oxidiser in a manner similar to the Pyreg pyrolysis system, redirecting the combusted syngas to heat the kiln up directly and improve overall thermal performance. Alternatively, a portion of this recovered heat can be used to preheat combustion gases, significantly reducing the need for additional fuel and lowering operational costs. However, if the feedstock has a high moisture content, the system can be configured to operate as it currently does, using all available heat from the oxidiser for drying. Then using natural gas to optimally control the pyrolysis process. Plant design all depends on the chosen feedstocks where for optimal processing the plant should be uniquely designed for that feedstock.

The Invica system offers multiple operational options depending on the feedstock being processed. For maximum thermal efficiency, the feedstock should be dried as much as possible before pyrolysis, as water evaporation is the most energy-intensive stage of the process. Any residual moisture is converted to steam, which is then heated to the final pyrolysis temperature before entering the oxidiser. Excessive steam can negatively impact the calorific value of the syngas, reducing overall efficiency. While some steam is inevitable due to water production during pyrolysis reactions, Invica recommends that feedstock moisture levels be kept below 10% before entering the kiln. Implementing an effective heat recovery system for drying is therefore particularly beneficial for processing high-moisture waste feedstocks, improving both energy efficiency and overall system performance.

1.3 Waste Heat Dryer

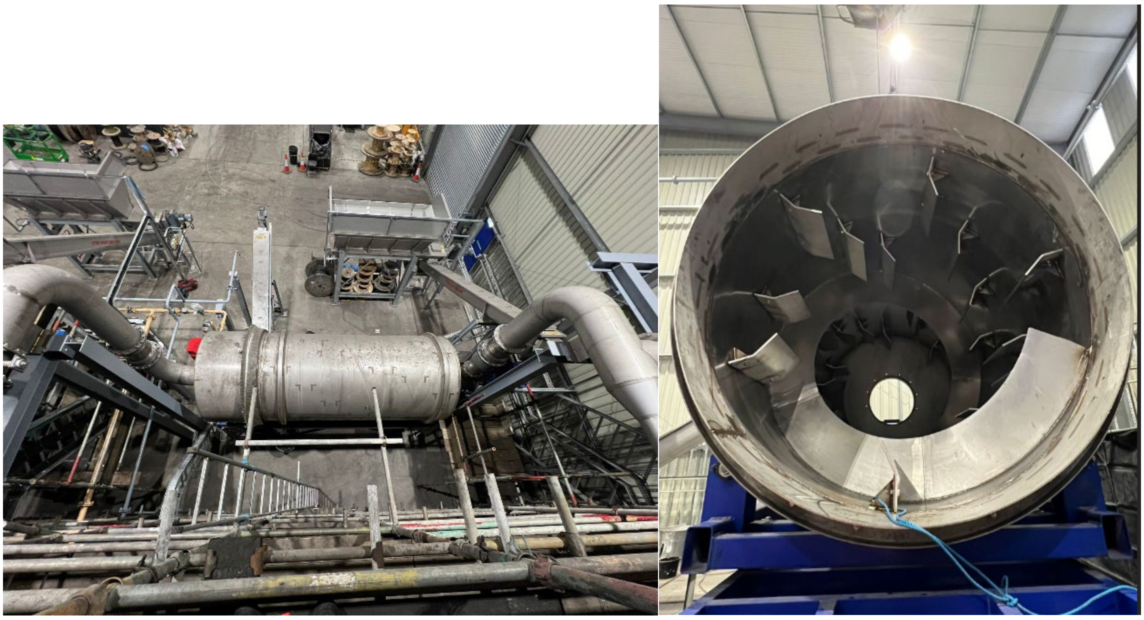


Figure 1.6 Waste heat dryer

The dryer is designed to process approximately 750 kg/hr of feedstock, reducing moisture content from 50% to 10%. It will be directly heated using a controlled mix of air and combustion gases from the oxidiser, with the gas temperature carefully regulated to 300°C safely below the material’s ignition point. This direct heating method eliminates the need for a heat exchanger, which could introduce potential maintenance issues and downtime. The waste heat dryer with direct drying is a key novelty part of the biochar plant.

1.4 MCC building

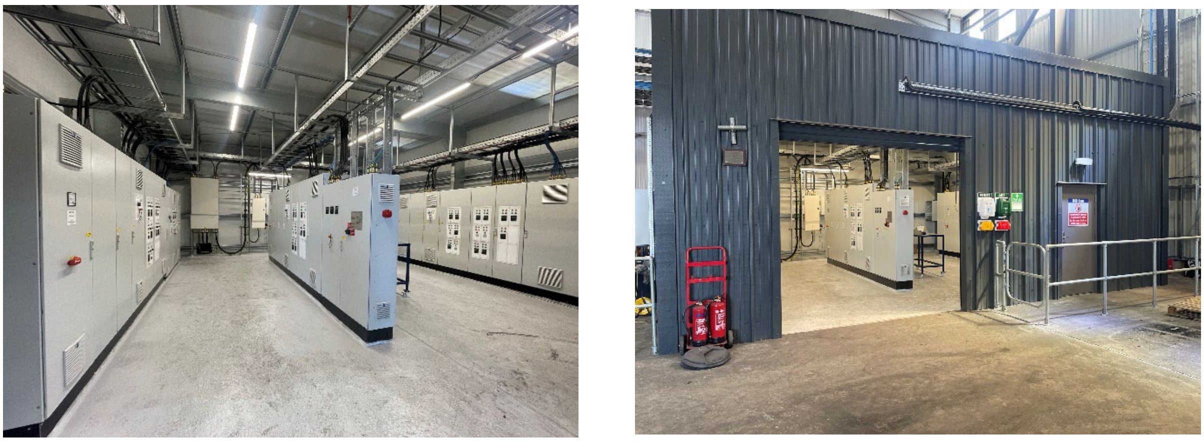


Figure 1.7 MCC building (internal and external)

The MCC building was built within the main building to reduce costs whilst meeting building regulations. This consists of 3 rows of panels with each one being for a different price of equipment (extruder, rotary kiln and dryer).

1.5 Extruder

Figure 1.8 Extruder

Invica's extruder is being used to pelletise waste materials such as AD screenings, either before drying or after drying and just before pyrolysis in the rotary kiln. However, inconsistent moisture levels have posed challenges, requiring both drying and the addition of a binder system for full operation to produce durable, high-quality pellets. Additionally, mechanical dewatering trials are currently underway for AD screenings to improve their suitability for processing. Certain waste streams like AD screenings must also be further milled to achieve the necessary particle size for effective pelletisation.

Invica has significant expertise in binder formulations and is actively testing the extruder to determine the best binder options for both feedstocks and biochar. Furthermore, there are opportunities to blend AD screenings directly with other materials, potentially bypassing the extruder altogether. This would allow the extruder to be prioritised for pelletising the final biochar product, enhancing its storage, transportation, and handling efficiency. By optimising both feedstock processing and biochar pelletisation, Invica is improving the overall efficiency and flexibility of the system.

Output 2: Environmental Permitting

One of the most significant challenges faced during the biochar demonstrator project was the environmental permitting process. This aspect of the project required careful attention and coordination with regulatory authorities to ensure compliance with both local and national environmental standards.

The permitting process with the Environment Agency (EA), proved challenging. The EA are working to their procedures, however, there is no middle ground between lab and commercial scale pyrolysis processes in the permitting procedure. This led to the permitting process being complex with the biochar production plant being a pilot demonstrator with many wastes to be tested. Any waste materials used in the process were required to go through Chapter 4 of the permitting process which involves waste incineration. This additional step introduced delays, as detailed information about the feedstocks being processed needed to be provided for evaluation before approvals could be granted.

Additionally, there were some contradictory interpretations in the regulatory framework. While Chapter 4 requirements applied to certain waste materials, other information suggested that processing under 3 tonnes per hour of non-hazardous waste may not require the full permitting procedure with local authority authorisation. Specifically, in these cases, the local authority would need to be notified, rather than undergoing the comprehensive permitting process through the EA. This added complexity in navigating the regulatory landscape, as Invica sought clarity on which rules would apply to the different waste streams used in biochar production.

Invica will be processing feedstocks that are on the exemption list and seeking prior EA approval when they arrive under a waste code. This approach allows for certain materials to be handled under more flexible regulatory conditions. The permit also states that emission data must be collected and submitted at select intervals. Invica has already conducted the first emission analysis, which was well within the imposed limits, demonstrating the environmental compliance of the process.

Permitting is expected to be one of the biggest barriers to expansion and future investment in the biochar and waste-to-energy sectors. The pace at which permits are processed could impact the scalability of projects and slow down the implementation of innovative technologies.

It would be beneficial to develop a more streamlined pathway to obtain a permit for a demonstrator plant that is inherently going to experiment with a variety of feedstocks. Such projects are designed to explore different materials and optimise processes, but the permitting hurdles make it challenging to test new ideas efficiently. The need for approval every time a new feedstock is tested introduces delays that hinder the plant's ability to evolve and improve.

If emissions are within the prescribed limits and the biochar produced meets specific standards—such as those outlined by the European Biochar Certificate (EBC) or the UK Biochar Comparator Report—it should be acceptable under the environmental regulations. These standards ensure that the biochar is of high quality and safe for various applications, and it should provide a reliable foundation for future biochar projects.

Without the support of DESNZ, the permitting applications for this project would likely still be ongoing. Their help in navigating the complex permitting process was instrumental in advancing the project. Moving forward, creating clearer guidelines for pyrolysis would be beneficial to streamline the permitting process. This could help move projects forward more efficiently and ensure that the regulatory framework supports sustainable, scalable solutions.

Furthermore, to boost investor confidence, a clear guidebook outlining the permitting process for biochar and waste-to-energy projects could be helpful. This uncertainty creates significant risk for potential investors and companies considering entering the space. A more transparent and predictable permitting process would help mitigate these challenges and encourage further investment in biochar production.

A critical aspect is the need for a better understanding of the differences between waste incineration, gasification, and pyrolysis. Currently, under Chapter 4, these processes are grouped together, despite their significant differences. Each of these waste treatment technologies operates under different principles and has varying environmental impacts. A more differentiated approach to permitting, recognising these differences, would help ensure that each process is assessed appropriately and in line with its specific environmental profile.

Given these challenges, there is a clear need for a review of how the permitting process can be streamlined. A collaborative effort between the government, the EA, and industry stakeholders is crucial to identify and address inefficiencies in the current system. Aligning the permitting process with the specific requirements of biochar production by ensuring industry feedback is incorporated will aid market development. This collaboration would also help set clearer expectations for businesses, regulators, and investors.

Despite these challenges, Invica worked closely with the EA to ensure all necessary permits to run the plant were secured. This experience highlights the importance of early engagement with regulators and a thorough understanding of the relevant permitting procedures when scaling up.

Output 3: Biochar Production Operation

See plant drawings and process flow in Appendix 1.

During design and the build phases a HAZOP was run with an action plan shown in (Appendix 1). This HAZOP was essentially to systematically identify and evaluate potential hazards and operability problems in a process or system to ensure safety.

As part of the demonstrator project, Invica Industries successfully produced over 100 tonnes of biochar from a diverse range of feedstocks.

The project processed a variety of feedstocks, including:

- Anaerobic Digestion (AD) Screenings Blended with Waste Wood
- Waste Wood
- Oversized Compost
- Grass Cuttings
- Hazelnut Shells & Olive Stones
- Bagasse

3.1 Job creation

4 Operators

1 Project manager

1 Shift manager

3.2 Plant Performance & Engineering Adjustments

The plant has operated with good overall reliability, and Invica has seen very limited downtime due to plant issues other than feeding blockages with larger pieces of wood and oxidiser burner which at the start couldn't be turned off. Additionally, the plant has successfully met all environmental regulations required under the environmental permit, with regular monitoring ensuring compliance with emissions limits such as particulates, SO_x and NO_x.

One key observation during operation is that the syngas produced from the pyrolysis process has been so energy-dense that the oxidiser burner had to be completely turned off during steady-state operation to prevent the oxidiser going above the set temperature limit. Because of this the burner was always supplied with a small amount of natural gas when it wasn't needed.

Another issue that arose during operation involved the use of waste wood in the feed screws. The spacing between the plates of the screw was initially too narrow to accommodate larger pieces of wood, which led to blockages. These blockages were problematic as the wood would sometimes fit into the screw but then become lodged, causing interruptions in the flow. Invica modified the spacing of the feed screw plates, allowing for larger pieces of wood to pass through with less issues. Additionally, the large wood pieces caused issues with the double flap valves in the kiln, which were not designed to handle the size of the material. The double flap valves possible modifications are under investigation.

The energy use for the operation has been carefully monitored throughout the project. However more information is needed here with 24/7 hour running with no shutdowns. This information is crucial for understanding the plant's energy efficiency and environmental impact, providing transparency for future scaling and commercialisation.

An engineering challenge was identified in the ductwork supplying combustion gases to the dryer. Due to heat loss during transfer, it became necessary to apply lagging to the ductwork to maintain adequate temperatures for effective drying.

Additionally, the ID fan on the oxidiser that sends the gas to the dryer is limited to operating at 400°C. Combined with further heat loss along the ductwork, this resulted in the temperature reaching the dryer at only slightly over 60°C, reducing drying efficiency. With the application of thermal lagging, this issue has improved significantly and has increased the gas temperature to the original target of approximately 300 ^{o}C. This means the ID fan does not need to be upgraded. Insulation alone was enough to solve the problem.

Furthermore, space restrictions at the site meant that the dryer was positioned farther from the oxidiser than ideal. While this layout did not impact overall plant functionality, optimising future designs to reduce this distance would reduce heat loss through the ductwork.

For commercial-scale deployment, an ID fan capable of handling increased temperatures of over 600^{o}C can be used, allowing for the full utilisation of waste heat from the oxidizer. The heat from this could be enough to power two dryers.

3.3 Ongoing Operations & Knowledge Building

Invica Industries will continue to operate the plant beyond the project's official end. This ongoing operation will serve to further refine processes, gather additional data, and increase knowledge of biochar production from the waste streams cited above.

Invica carried out analysis of the feedstock and of the produced biochar (Appendix 1) with process log example also shown in Appendix 1.

3.4 Dryer and Rotary Kiln Integration

Currently, the dryer is a standalone unit in the plant design, separate from the rotary kiln to allow for flexibility in operation. This design ensures that individual parts of the plant can be operated independently, which is beneficial for system maintenance and troubleshooting. However, in future plant configurations, the dryer could be directly linked to the rotary kiln for greater operational efficiency.

3.5 Biochar Storage & Fire Safety

During operations, Invica has gained valuable insights into biochar storage, particularly regarding its flammability. Biochar can be prone to spontaneous combustion if not handled and stored correctly, especially when contaminants, such as larger debris or residual materials, make their way into the rotary kiln. If these contaminants are not sufficiently cooled during the cooling screw process, they can cause localised overheating, potentially leading to combustion within the biochar collection bags. This occurred during production where a large stone was in the feed material and came out very hot in the bag of biochar. The cooling screws did not cool down the stone enough and it was enough to ignite the biochar bag. This shows the importance of reducing large stones that could end up being heated in the rotary kiln.

To mitigate this, Invica has made operational adjustments to ensure that biochar is cooled more quickly and uniformly. Ongoing monitoring of biochar storage conditions and cooling rates will continue to be critical as Invica look towards commercial-scale operations.

3.6 Scaling up

Scaling up a biochar production plant requires a strategic approach to ensure efficiency, reliability, and economic viability. The demonstrator plant plays a crucial role in validating design parameters, optimising the process, and identifying potential bottlenecks. By proving the technology at a smaller scale, it builds confidence in the design and operational, minimising risks associated with large-scale deployment. Economies of scale are important for biochar production in terms of fixed operational expenditure costs. With the number of operators being relatively fixed despite increase in production. With a higher throughput more biochar is produced leading to higher revenues. However, storage space requirement for this biochar should be considered.

One of the key constraints in scaling up is the practical size of the rotary kiln. Invica believe to maintain control in relation to heat transfer through the material and being able to use the waste heat from the oxidiser to heat the kiln indirectly a kiln with a feed rate of approximately 1.5 tonnes an hour federate is best suited. Bigger rotary kilns exist but heat up time and flexibility should be considered. One of the key selling points to the Invica system is utilising off the shelf equipment and fast production. Larger kilns require longer design and build periods. Invica have also had experience of this in the activated carbon industry where suppliers have opted for a rotary kiln that is too big and have lost control of the process. This means that rather than increasing the size of an individual kiln, a multi-unit approach should be considered for higher throughput. They bring additional benefits such as maintaining production when one rotary kiln is down or undergoing maintenance.

To achieve greater production capacity, a modular and parallel processing design could be implemented. This involves running multiple kilns in tandem. This approach also enhances reliability by reducing downtime risks—if one kiln requires maintenance, the others can continue production uninterrupted. Additionally, modularity simplifies the scaling process, as proven units from the demonstrator plant can be replicated and optimised for full-scale operations.

Output 4. Biochar Characterization (University of Nottingham)

4.1 Scope

The characterization of biochar produced on a laboratory-scale at the University of Nottingham (UoN), the R&D kiln and the pilot plant at INVICA was conducted to assess its properties, with a focus on proximate and ultimate analysis, atomic H/C ratio, heavy metal content, and polycyclic aromatic hydrocarbon (PAH) levels to ensure compliance with the European Biochar Certificate (EBC) standards. The details of the methodology are provided in Appendix 2.

Table 4.1 summarizes the 17 biochar samples produced during this project. Sample 0 is a reference biochar sample produced from commercial pilot plant built and operated by Woodtek, using virgin wood at a temperature below 900°C.

Samples 1–3 are anaerobic digestion (AD) food waste biochars produced in the laboratory at UoN at temperatures of 550°C, 600°C, and 650°C, respectively. Samples 4–6 are AD biochars produced using the R&D kiln at INVICA, with production temperatures of 600°C, 650°C, and 700°C, to determine the optimal biochar production conditions for the pilot plant. Subsequently, two larger-scale (>10 kg) AD biochar samples (Samples 7 and 8) were produced using INVICA R&D kiln at 550°C and 650°C for initial screening prior to the pilot plant production.

Finally, Samples 9–17 were produced at the pilot plant at 650°C with a residence time of 30 minutes (Figure 4.1). Among these, Samples 9–11 (bagasse biochar, Bagasse & PKS mixed-biochar, and waste wood biochar[a]) were obtained during discontinuous pilot plant runs, while Samples 12–17 (hazelnut shell biochar, olive stone biochar, waste wood biochar[b], PKS biochar, Veolia whole tree shredded biochar, and the Veolia ARB (arboriculture) chip biochar) were produced from continuous pilot plant operations.

Table 4.1. Sample information

Sample No.	Sample name	Production conditions	Received Date	Scale
0	Virgin wood biochar (Woodtek)	<900°C		
1	Lab-AD biochar 550°C	550°C for 30mins	14/02/2023	lab
2	Lab-AD biochar 600°C	600°C for 30mins	14/02/2023	lab
3	Lab-AD biochar 650°C	650°C for 30mins	14/02/2023	lab
4	Kiln-AD biochar 600°C	550°C for 30mins	21/02/2023	kiln
5	Kiln-AD biochar 650°C	650°C for 30mins	21/02/2023	kiln
6	Kiln-AD biochar 700°C	650°C for 30mins	21/02/2023	kiln
7	Kiln screening-AD biochar 550°C	550°C for 30mins	02/02/2024	kiln big scale
8	Kiln screening-AD biochar 650°C	650°C for 30mins	02/02/2024	kiln big scale
9	Bagasse biochar	650°C for 30mins	13/06/2024	pilot
10	Bagasse & PKS mixed-biochar	650°C for 30mins	13/06/2024	pilot
11	Waste wood biochar[a]	650°C for 30mins	31/07/2024	pilot
12	Hazel nut shell biochar	650°C for 30mins	13/11/2024	pilot-continue run
13	Olive stone biochar	650°C for 30mins	13/11/2024	pilot-continue run
14	Waste wood biochar[b]	650°C for 30mins	13/11/2024	pilot-continue run
15	PKS-biochar	650°C for 30mins	13/11/2024	pilot-continue run
16	Veolia whole tree biochar	650°C for 30mins	11/12/2024	pilot
17	Veolia ARB chip biochar	650°C for 30mins	12/12/2024	pilot

Samples 11 and 14 were produced from the same feedstock—waste wood. [a] sample 11 was obtained during a discontinuous run, while [b] sample 14 was produced during a continuous run of the pilot plant.

Figure 4.1. Biochar produced from kiln and pilot-plants. A) Kiln screening-AD biochar 650°C, B) bagasses-biochar, C) mixture of bagasse and PKS-biochar, D) waste wood-biochar[a], E) Hazel nutshell biochar, F) olive stone biochar, G) waste wood biochar[b], H) PKS biochar, I) Veolia ARB chip biochar.

4.2. Proximate and Ultimate Analyses

To optimize the production conditions for the pilot plant, a range of production temperatures was tested in the UoN laboratory and the INVICA kiln scale. The proximate and ultimate analyses, along with the atomic H/C ratios of all AD biochar samples (Table 4.2), were used to guide the production optimization.

On a dry basis, the results show that the lab-produced AD biochar closely matches the kiln-produced AD biochar in terms of proximate analysis. Although production temperature impacts biochar composition, the contents of volatile matter, fixed carbon, and ash remain within relatively narrow ranges of 20–25%, 36–41%, and 31–42%, respectively.

The H/C ratio decreases with higher production temperatures in both lab and kiln experiments, dropping from 0.46 to 0.38 for the lab-produced AD biochar (550°C to 650°C) and from 0.47 to 0.33 for the kiln-produced AD biochar (600°C to 700°C). When scaling up production for the kiln screening, the H/C ratio decreases from 0.43 to 0.36 as the production temperature increases from 550°C to 650°C. This indicates that 650°C is the optimal production temperature, ensuring the biochar has an H/C ratio below 0.4, which meets the EBC biochar application standard.

In comparison, the commercially available virgin wood biochar produced by Woodtek—using wood as the feedstock and produced at a higher temperature (up to 900°C)—exhibits a higher fixed carbon content (64%) and lower ash content (16%) compared to the AD biochar due to differences in feedstock composition. Woodtek biochar's H/C ratio of 0.32 is similar to that of the AD biochar produced at 650°C (H/C = 0.36–0.40), with lower production temperatures being used in this project.

Table 4.2. Proximate analysis, Ultimate analysis, and H/C ratio of the AD biochars. The methods used are detailed in the experiment section.

Sample		Proximate analysis (Wt.%)				Ultimate Analysis (Wt.%)			H/C Ratio
		Moisture	Volatiles	Fixed carbon	Ash	Carbon	Hydrogen	Nitrogen	
Lab-AD Biochar 550 °C	wet basis	3.1±0.1	23.8±0.7	36.5±0.9	36.6±0.4	-	-	-	-
	dry basis	-	24.6±0.7	37.6±0.9	37.8±0.4	47.9	1.9	2.8	0.46
	daf basis	-	39.5±1.2	60.5±1.2	-	77	0.3	4.4	0.46
Lab-AD Biochar 600 °C	wet basis	3.3±0.4	22.7±1.9	34.6±2.1	39.3±2.9	-	-	-	-
	dry basis	-	23.5±2.1	35.8±2.3	40.6±2.8	47.3	1.5	2.6	0.37
	daf basis	-	39.6±2.7	60.4±2.7	-	79.8	2.5	4.4	0.37
Lab-AD Biochar 650 °C	wet basis	2.7±0.3	20.2±0.6	36.6±1.0	40.5±0.4	-	-	-	-
	dry basis	-	20.7±0.6	37.7±0.9	41.6±0.5	50.1	1.6	1.9	0.38
	daf basis	-	35.5±1.2	64.5±1.2	-	85.9	2.7	3.2	0.38
Kiln-AD Biochar 600 °C	wet basis	5.6±0.3	23.0±0.2	38.7±4.1	32.8±4.1	-	-	-	-
	dry basis	-	24.4±0.2	40.9±4.3	34.7±4.2	52.7	2.1	2.5	0.47
	daf basis	-	37.5±2.6	62.5±2.6	-	80.7	3.2	3.8	0.47
Kiln-AD Biochar 650 °C	wet basis	5.1±0.4	19.5±1.1	45.6±2.7	29.8±1.3	-	-	-	-
	dry basis	-	20.6±1.2	48.1±2.7	31.3±1.5	52.4	1.7	2.2	0.40
	daf basis	-	30.0±2.5	70.0±2.5	-	76.4	2.5	3.3	0.40
Kiln-AD Biochar 700 °C	wet basis	4.9±0.5	19.1±0.8	45.0±2.3	31.0±2.6	-	-	-	-
	dry basis	-	20.1±0.8	47.3±2.6	32.5±2.5	53.9	1.5	2.1	0.33
	daf basis	-	29.9±1.7	70.1±1.7	-	79.9	2.2	3.2	0.33
Kiln screening-AD biochar 550°C	wet basis	3.8±0.2	22.2±1.5	36.7±1.6	35.7±1.6	-	-	-	-
	dry basis	-	23.5±1.6	38.7±1.0	37.8±0.8	49.4	1.8	2.2	0.43
	daf basis	-	37.7±2.2	62.3±2.2	-	79.4	2.8	3.5	0.43
Kiln screening-AD biochar 650°C	wet basis	3.7±0.1	20.8±1.3	39.1±1.2	36.4±1.8	-	-	-	-
	dry basis	-	21.6±1.4	40.7±1.3	37.8±1.9	48.9	1.5	2	0.36
	daf basis	-	34.7±1.5	65.3±1.5	-	78.5	2.4	3.2	0.36
Virgin wood biochar (Woodtek) 900 °C	wet basis	5.8±1.2	19.0±0.8	60.8±2.6	14.7±1.4	-	-	-	-
	dry basis	-	20.1±0.8	64.3±2.3	15.6±1.6	71.5	1.9	0.8	0.32
	daf basis	-	23.9±1.4	76.1±1.4	-	84.6	2.2	0.9	0.32

Wet basis is as received, includes all moisture and ash. Dry basis excludes moisture content. Dry ash-free (daf) excludes both moisture and ash.

4.3. Heavy metal and PAH content

Eight pilot-produced biochars were analyzed, including samples from both discontinuous and continuous pilot plant runs. Bagasse and waste wood biochar (a) were produced during discontinuous runs, while hazelnut shell, olive stone, waste wood biochar (b), and palm kernel shell (PKS) biochar were produced during continuous runs. One AD biochar (screening-650°C) produced from the kiln was also analyzed. All these samples were sent to Eurofins for EBC-compliant analysis, with full reports available in Appendix 2. Table 4.3 summarizes the results.

As the results (Table 4.3) indicate that the H/C ratios of all the analyzed biochars are listed below 0.4, meeting the threshold set for all seven EBC applications.

Table 4.3. Heavy Metal and Polycyclic Aromatic Hydrocarbon (PAH) Concentrations in Biochar Compared to EBC Standard Limits.

Parameter	EBC standard limit values							Biochar-dry basis result							Unit
								R&D Kiln	Pilot plant						
	1) EBC-FeedPlus	2) EBC-Feed	3)EBC-Agro-Organic	4) EBC-Agro	5) EBC-Urban	6) EBC-Consumer-materials	7) EBC-Basic-Materials	AD	Bagasse	Waste wood[a]	Hazel nut shell	Olive stone	Waste wood[b]	PKS	
H/Corg ratio (molar)	<0.4	<0.4	<0.7	<0.7	<0.7	<0.7	<0.7	0.31	0.2	0.26	0.33	0.27	0.28	0.32	
Arsenic (As)			13	13	13	13		1.2	< 0.8	9.7	< 0.8	< 0.8	8.7	1.0	mg/kg
Lead (Pb)			45	120	120	120		14	< 2	38	5	< 2	29	4	mg/kg
Cadmium (Cd)			0.7	1.5	1.5	1.5		< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	mg/kg
Copper (Cu)	70	70	70	100	100	100		95±15	8.0±1.3	184±30	47±7.6	22±3.6	251±41	81±13	mg/kg
Nickel (Ni)	25	25	25	50	50	50		64±9.9	2.0±0.3	22±3.4	10±1.6	5±0.78	13±2	8±1.2	mg/kg
Mercury (Hg)			0.4	1	1	1		< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	mg/kg
Zinc (Zn)	200	200	200	400	400	400		703±190	50±14	316±87	91±25	31±8.6	196±54	41±11	mg/kg
Chromium (Cr)	70	70	70	90	90	90		85	8	66	24	36	74	98	mg/kg
Total 8 EFSA-PAH excl. LOQ	1	1	1	1	1	1	4	7.3	1	4.8	0.2	<0.8	0.2	0.1	mg/kg
Benzo(e)pyrene	<1	<1	<1	<1	<1	<1	<1	1	0.1	0.7	< 0.1	< 0.1	< 0.1	< 0.1	mg/kg
Benzo-(j)-fluoranthen	<1	<1	<1	<1	<1	<1	<1	<0.1.	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	mg/kg

Waste wood [a] was obtained during a discontinuous run, while [b] was produced during a continuous run of the pilot plant.

Heavy metals

The contents of arsenic (As), lead (Pb), cadmium (Cd), and mercury (Hg) in all samples comply with EBC standards. However, several biochars exhibited elevated levels of specific metals:

AD Biochar contain higher zinc (703 mg/kg) and nickel (64 mg/kg), exceeding the limits for EBC 1–6 but still meeting the EBC 7 standard. Copper content (95 mg/kg) exceeds the EBC 1–3 limit (70 mg/kg) but complies with EBC 4–7 (100mg/kg).

Waste Wood Biochar (a and b): Both samples show higher copper and zinc content. Copper exceeds the limit for EBC 1–6 (100 mg/kg) at 184 mg/kg (waste wood[a] biochar) and 251 mg/kg (waste wood[b] biochar). Zinc content in waste wood[a] biochar (316 mg/kg) surpasses the EBC 1–3 limit but remains within EBC 4–6; waste wood[b] biochar (196 mg/kg) is high but within all EBC standards.

PKS Biochar: Copper levels exceed the EBC 1–3 limit (<70 mg/kg) but remain within the EBC 4–7 thresholds. Chromium (98 mg/kg) surpasses the EBC 1–6 limit but meets the EBC 7 requirement.

Overall, bagasse, hazelnut shell, and olive stone biochars meet the heavy metal limits for all EBC standards. The AD biochar (Ni, Zn), waste wood biochar (Cu), and PKS biochar (Cr) exceed specific limits but remain suitable for EBC 7 applications.

PAH Content Table 4.3 also presents the polycyclic aromatic hydrocarbon (PAH) concentrations. Benzo(a)pyrene and benzo(j)fluoranthene levels are at or below the detection limit (<1 mg/kg) for all samples. The total 8 EFSA-PAH concentrations reveal differences based on production mode and feedstock: For the discontinuous runs resulting from the plant having to be repeatedly cooled and reheated since 24 hour operation was not possible, the total 8 EFSA-PAH concentrations of AD biochar (7.3 mg/kg) and waste wood biochar sample a (4.8 mg/kg) exceed EBC standards (maximum is 4 mg/kg), due to tar condensation making them unsuitable for all applications. Only bagasse biochar (1 mg/kg) just meets the EBC 1-6 requirements, and within the EBC 7 standard.

However, for the continuous runs, the total 8 EFSA-PAH concentrations of Hazel nut shell, olive stone, waste wood biochar sample b, and PKS biochars are all less than 1mg/kg, all meet PAH limits across EBC 1–7. Notably, the PAH content in waste wood[b] biochar dropped significantly from 4.8 mg/kg in the discontinuous run to 0.2 mg/kg in the continuous run, highlighting the positive impact of stable, continuous operation.

Therefore, considering both heavy metal and PAH concentrations, bagasse, hazelnut shell, and olive stone biochars are suitable for EBC 1–7 applications. Waste wood[b] biochar and PKS biochar are suitable only for EBC 7- Basic-Materials application. While AD biochar and waste wood[a] biochar due to excessive PAH levels are unsuitable for any EBC application.

These results demonstrate that the pilot plant is capable of producing high-quality biochar, though feedstock composition significantly influences the final product's compliance with EBC standards.

Output 5 Monitoring reporting and verification (MRV, University of Nottingham)

For biochar to be deployed for greenhouse gas removal (GGR), Invica Industries consider that firstly it should satisfy environmental standards, such as the voluntary European Biochar Certificate (EBC, https://www.european-biochar.org/media/doc/2/version_en_10_2.pdf,) in terms of low concentrations of heavy metals and organics, including polycyclic aromatic hydrocarbons (PAHs). The EBC heavy metal, PAH and other organic pollutant limits are graded according to application with building applications being less stringent than agricultural use with the highest specification being applied for incorporation into animal feed. Secondly, evidence should be obtained that the carbon will be stable over centennial timescales. Any biochar deployed to agricultural land will meet the European Biochar Certificate standard and, any biochar not meeting this specification, will be used in aggregates, where the permitted levels of heavy metals and toxic organic compounds are much higher.

Once applied to soil, biochar is exposed to biotic and abiotic factors that result in the oxidation of some of the carbon to CO_2. For the certification of carbon-sinks, it is of the utmost importance to predict as accurately as possible how much carbon in biochar will remain stored in the environment and for how long. The most common approach has been to use biochar in the environment or to incubate it under controlled conditions and measure the CO_2 released to calculate the mean residence time. However, realistic incubation periods (1-10 years) are not suitable to measure persistence in the range of centuries to millennia. The EBC have produced a draft paper on biochar as a carbon sink (https://www.european-biochar.org/media/doc/2/c_en_sink-value_2-1.pdf) and proposed an atomic H/C ratio below 0.5 as a measure of high stability. Invica Industries proposes using the stable polyaromatic carbon (SPAC) content as a considerably more sensitive measure of stability than atomic H/C ratio. SPAC has been developed by the University of Nottingham and is determined by hydropyrolysis, an analytical pyrolysis technique (Meredith et al. 2012. Geochim. Cosmochim. Acta, 97, 131) that eliminates all free and covalently bound non-aromatic species and all aromatic species consisting of up to seven fused rings.

Payments for biochar should be based on the SPAC content or other indicator as a reliable indicator of long-term stability, and this approach is currently being developed through the BBSRC Biochar Demonstrator led by the University of Nottingham with key stakeholders, including DESNZ and Defra, who both have representatives on the Expert Advisory Group for the Demonstrator. Although biochar can be traded in current markets, such as Puro Earth, protocols need to be in place concerning MRV, particularly compliance to providing valid records of all biochar deployed.

Figure 5.1 provides a plot of SPAC content vs atomic H/C ratio for a selection of biochars including AD fibre-derived samples from the Phase 1 and 2 projects. For the AD derived biochars, the SPAC content ranges from 60 to 95%. For the laboratory samples, the SPAC content increases with preparation temperature. The kiln samples, where temperature is less homogeneous than for the laboratory samples, have similar SPAC contents to the laboratory sample prepared at 600°C. These results confirm the extremely stable biochar will be produced from the pilot plant, especially if the kiln temperature can be maintained close or above 650°C.

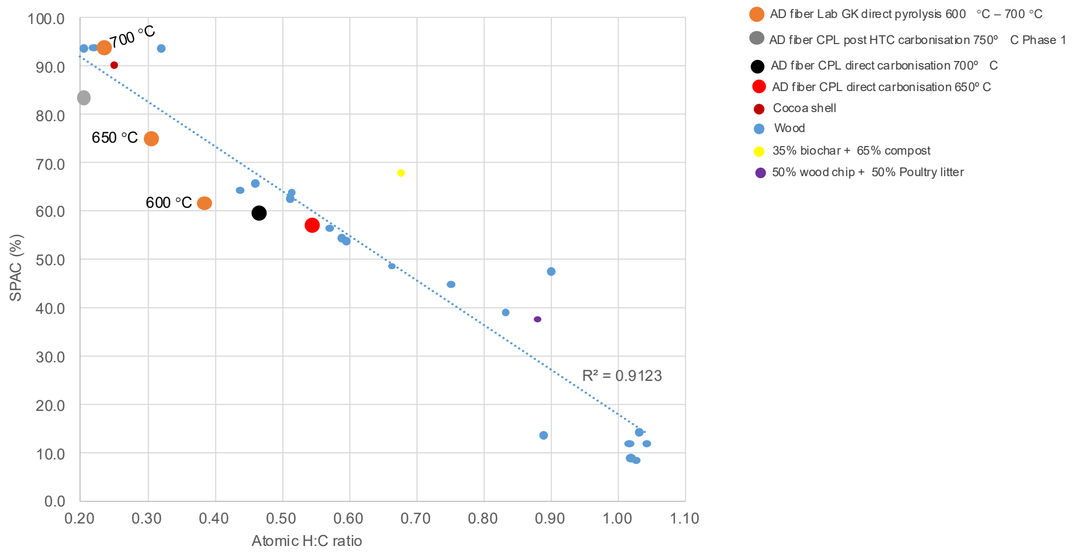


Figure 5.1 A plot of SPAC content vs. atomic H/C ratio for a selection of biochars. The larger circle points are samples from AD fibre either prepared on a lab-scale in a Gray-King retort and from the kg-scale rotary kiln at Invica Industries.

Clearly, once applied to agricultural, forestry and forestry/woodland systems, it is very difficult to monitor the biochar, both in terms of mass and composition. Therefore, it is important that the C content of all biochar being deployed is recorded regularly when feedstock composition may vary. We intend to transport biochar in a wet state, containing about 50% moisture to avoid any risk of spontaneous combustion during storage. Therefore, the moisture content needs to be determined on several sub-samples to know exactly the amount of C in biochar that has been deployed. Of course, the mass of wet biochar will be weighed before transportation in 2 m^3 bags. When biochar is spread on the surface where no till is used in regenerative agriculture, atmospheric sampling should be carried out at selected sites to monitor for possible loss of biochar as particulate matter.

The life cycle analysis in Section 6 indicates that the net greenhouse gas removal potential ranges from 1.83 to 2.25 tonnes CO_2 equiv. per tonne of biochar for AD screenings and over-sized compost, respectively. Therefore, taking an average value of close to 2.0 tonnes for a plant processing 10,000 tonnes dry feedstock of a blend comprising AD screenings and over-sized compost p.a. producing 3,700 tonnes of biochar, the plant would sequester 7,400 tonnes of CO_2 equiv. p.a.

Output 6 Techno-economic analysis and LCA

The updated LCA/TEA reported here is based on the experience gained from constructing and operating the pilot plant and the latest information presented here has also been used in the Commercial Report. A commercial plant will need to be constructed and operated to ascertain any further improvements that could be made. The plan below is based on a biochar production facility with a CAPEX cost of £4m (including groundworks) to process 10,000 tonnes feedstock (dry basis) per annum. The three options considered are:

1. AD Digestate Screenings at Immingham or Severn Trent Green Power site (delivery will still be required)
2. Cleaned and sized oversized compost
3. Blend of AD screenings and oversized compost

The second and third options with oversized compost are included to demonstrate cases where there the quantities of AD digestate screenings are below the required amount of 10,000 tonnes p.a. (dry basis) to operate a plant without any other feedstocks. The cost of transport of feedstock is included in the analysis, but not biochar since it will be deployed close to the point of production, and it has a considerably higher bulk density than the feedstocks considered here. A feedstock transportation distance of 10 miles is considered in every case, with a cost per mile of £0.36 for each tonne.

6.1 AD Digestate Screenings

To recap, the project has shown the HTC followed by Pyrolysis (Route 1) can be ruled out with the added CAPEX removing any energy benefit of going through HTC rather than using waste heat to dry the feedstock. The comparison in Figure 6.1 indicates Route 1 is now even less attractive due to the increasing capital costs for HTC and Route 2 is profitable solely on the gate fee received (Table 6.1), without considering the income from carbon trading and commercial applications of the biochar. This has arisen through the reduced capital costs operating at a scale of 10kt/y dry feedstock, using the maximum size of kiln available. Further, the net CO_2 equivalent sequestered is greater for route 2 (Figure 6.2), at 1.83 tonnes per tonne of biochar.

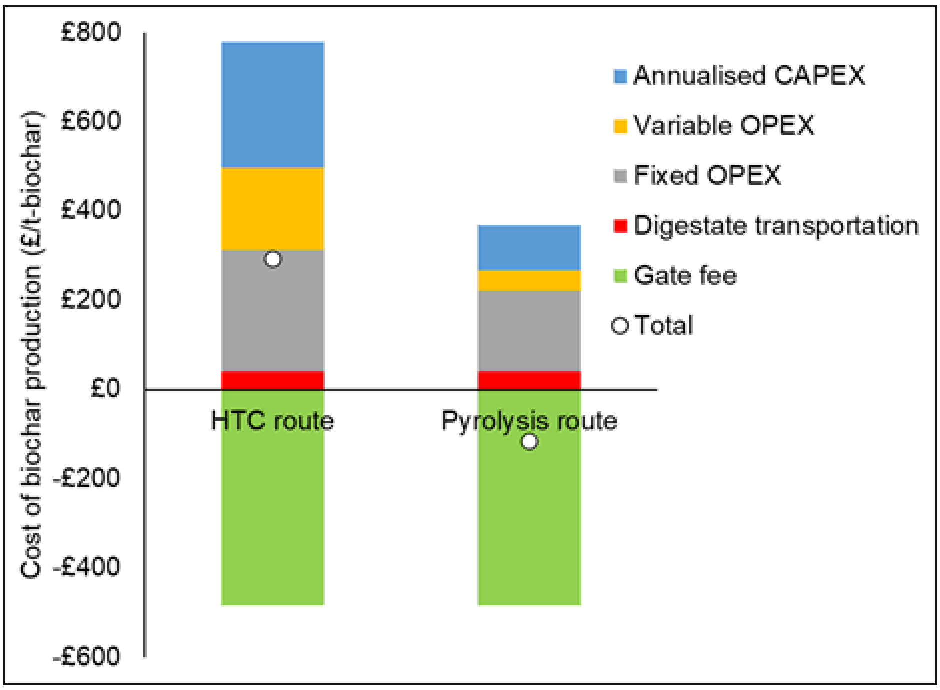


Figure 6.1 Comparison of biochar production costs for AD digestate screenings from HTC + pyrolysis and only pyrolysis.

Table 6.1 Costs for processing AD screenings where the only income is from the gate fee

Pyrolysis		
Gate fee	-£483.33	£/t-biochar
Digestate transportation	£40.00	£/t-biochar
Fixed OPEX	£180.82	£/t-biochar
Variable OPEX	£45.80	£/t-biochar
Annualised CAPEX (20 years)	£101.85	£/t-biochar
Total	**-£114.86**	£/t-biochar

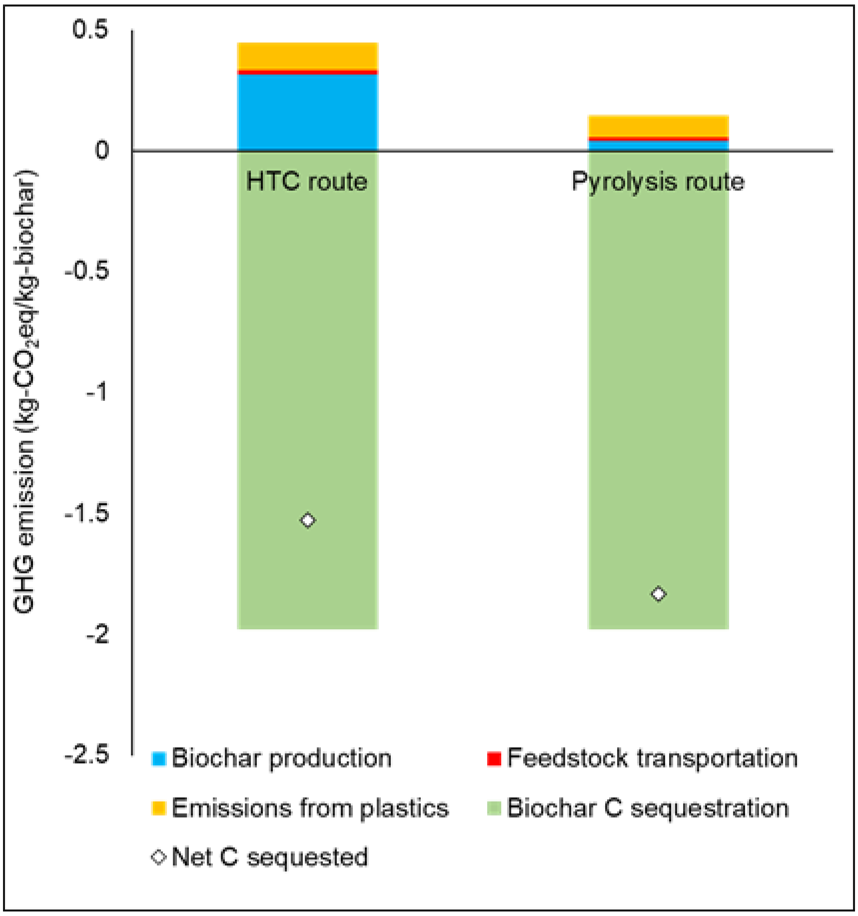


Figure 6.2 GHG emissions for the AD digestate screenings biochar from HTC + pyrolysis and only pyrolysis

AD screenings can produce biochar at low cost, making it an attractive option. However, this cost-effectiveness comes with a trade-off: the resulting biochar often contains higher levels of ash. This increased ash content can limit the biochar's application potential, as it may not meet the quality standards required for certain commercial uses for example in ecoke, filtration or may contain too many metals for soil enhancement. This can be negated by co-feeding the AD screenings with another feedstock, as demonstrated here with oversized compost. Additionally, feeding AD screenings into the plant on its own can present challenges due to low density causing issues with feeding screws.

Despite these challenges, the economic benefits of using AD screenings for biochar production make it a viable option (Table 6.2 and Figure 6.4). The process is cost-negative due to an estimated gate fee of £58 per wet tonne of digestate. However, gate fees aren’t always stable and this needs to be taken into consideration. Income from carbon trading has not been considered which would make the process more profitable. Trials are currently underway to densify the AD screenings further to reduce moisture content, which could enhance the efficiency and quality of the resulting biochar. With around 12,000 wet tonnes of AD screenings available from Severn Trent Green Power now, and this amount set to double by 2030, the potential for biochar production from AD screenings is significant.

6.2 Oversized Compost

Invica Industries is exploring the use of oversized compost as an alternative feedstock for biochar production. This approach leverages the availability of oversized compost, which can be delivered to Invica at a low cost. The estimated production cost for biochar using oversized compost is just over £500 including the purchase price and transportation (Table 6.2 and Figure 6.3), making it a possibility solution for sustainable biochar production. This is because the ash in oversized biochar is much lower and can be used for higher value applications such as in ecoke. The oversized feedstock once shredded can be fed into the plant relatively easily. The level of carbon sequestration achieved for the oversized compost is higher than for the digestate (2.25 tonnes CO_2 equiv. (Figure 6.4) due to its higher carbon content.

Table 6.2 Costs for processing oversized compost

Pyrolysis		
Oversized fee	£40.00	£/t-biochar
Oversized transportation	£32.01	£/t-biochar
Fixed OPEX	£241.09	£/t-biochar
Variable OPEX	£61.07	£/t-biochar
Annualised CAPEX	£135.80	£/t-biochar
Total	**£509.97**	£/t-biochar

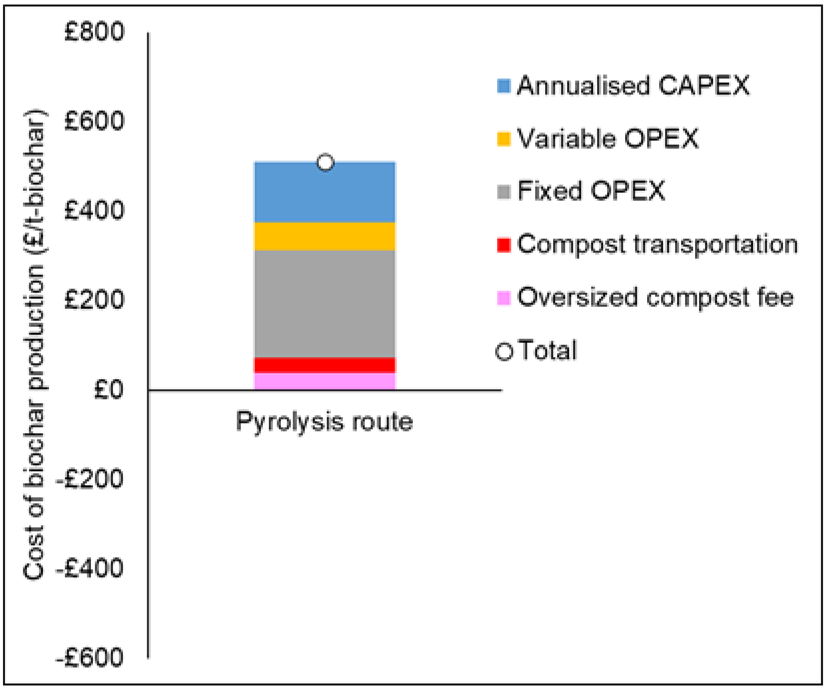


Figure 6.3 Cost of biochar production from pyrolysis of oversized compost.

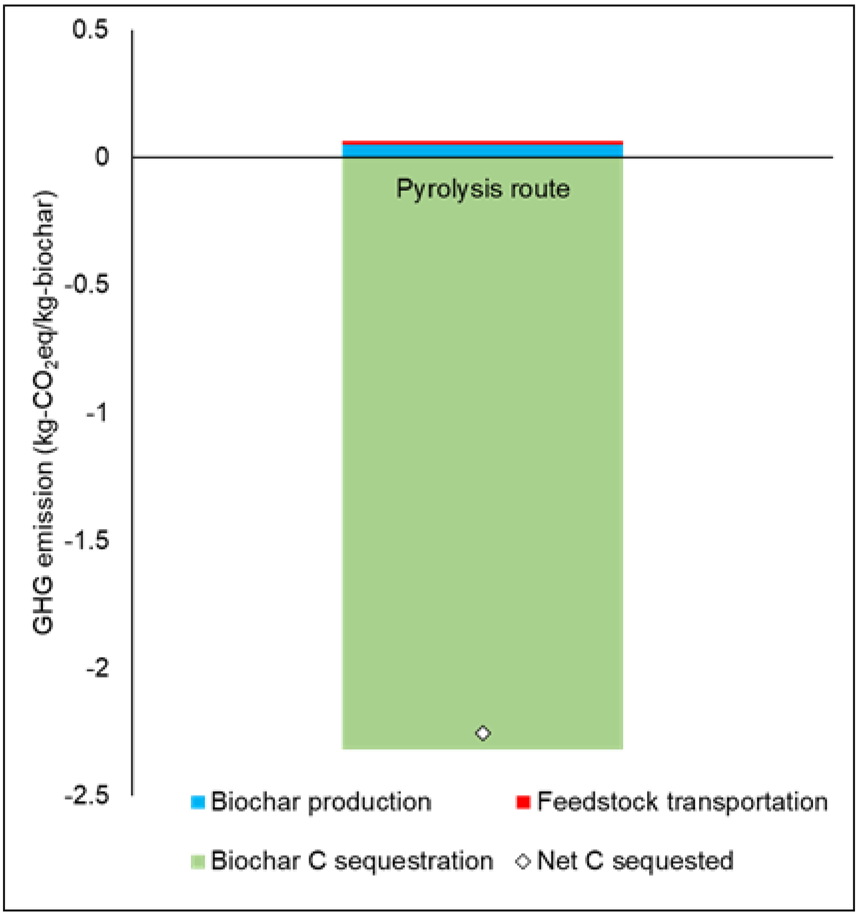


Figure 6.4 GHG emissions for biochar produced from oversized compost

6.3 Digestate Screenings: Oversized Compost (70:30)

Blending AD screenings and oversized compost in a 70:30 ratio could be an ideal solution for biochar production. This combination leverages the strengths of both materials, with AD screenings providing a cost-effective feedstock and oversized compost contributing to lower ash content. By mixing these materials, the resulting biochar can achieve a balance of quality and cost-efficiency. The blend can be fed into the waste heat dryer and then into the rotary kiln, optimising the production process. The production cost of biochar can be brought down to £30 per tonne (Table 6.3 and Figure 6.5), excluding potential income from flue gas treatment and carbon credits. While ash content will still need to be considered, for certain applications, a higher ash content is acceptable in others such as flue gas treatment. As expected, the level of carbon sequestration is close to 2 tonnes CO_2 equivalent per tonne of biochar (Figure 6.6).

Table 6.3 Costs for processing digestate screenings: oversized compost (70:30)

Pyrolysis		
Gate fee	-£365.77	£/t-biochar
Oversized compost fee	£9.73	£/t-biochar
Digestate/ Oversized transportation	£30.27	£/t-biochar
Fixed OPEX	£195.48	£/t-biochar
Variable OPEX	£49.51	£/t-biochar
Annualised CAPEX	£110.11	£/t-biochar
Total	**£29.34**	£/t-biochar

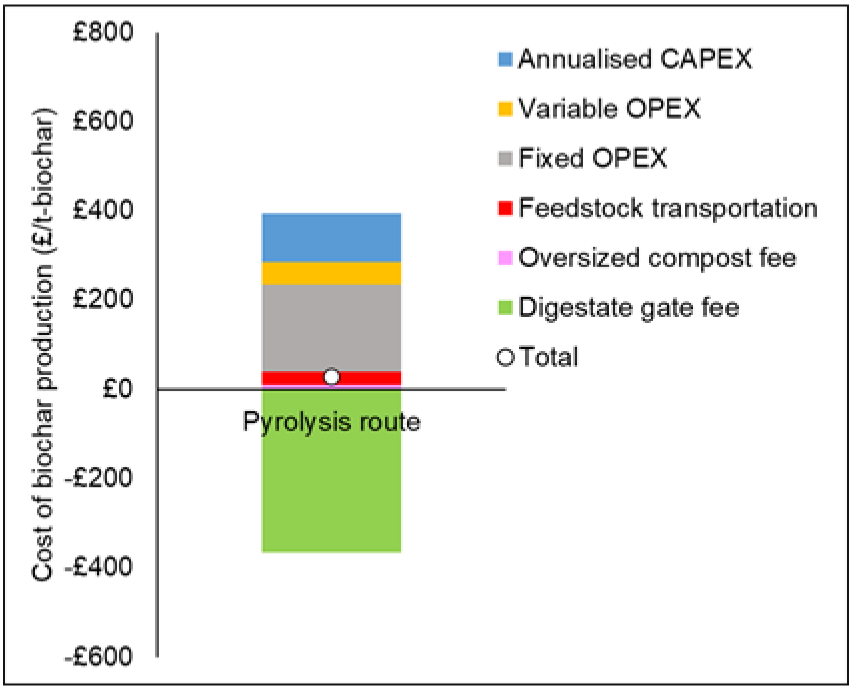


Figure 6.5 Cost of biochar production from pyrolysis of AD screenings (70%) and oversized compost blend (30%)

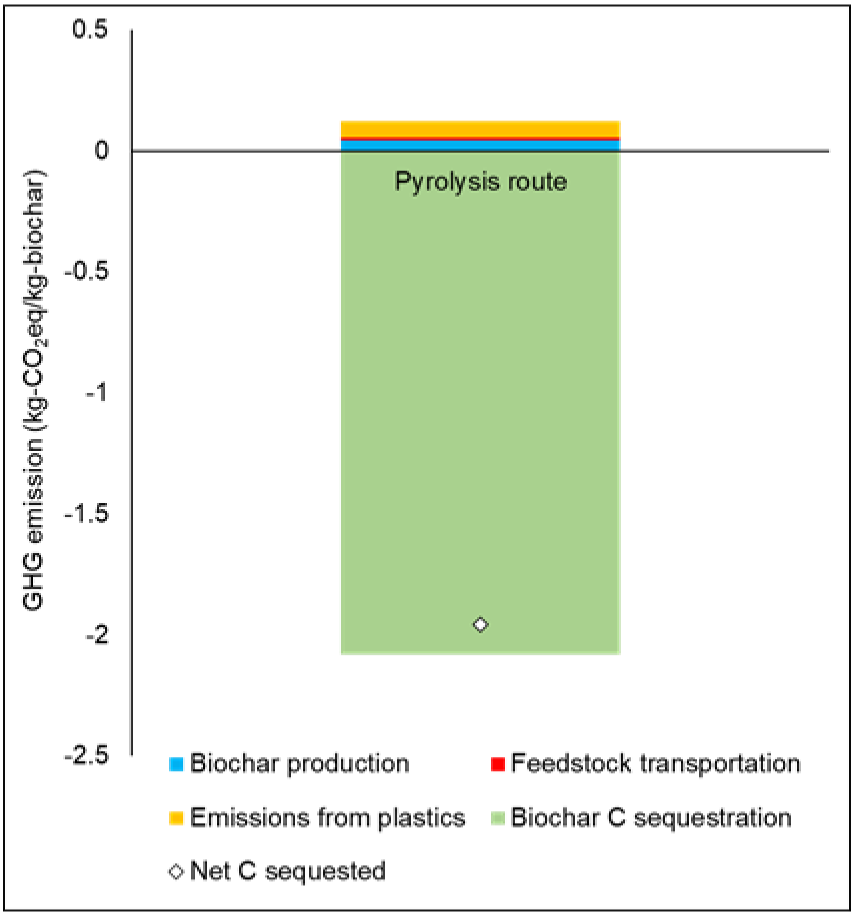


Figure 6.6 GHG emission in pyrolyzing AD screenings (70%) and oversized compost blend (30%)

6.4 Biochar value

Invica Industries is exploring the use of digestate biochar combined with oversized compost as an activated carbon filler for flue gas treatment. This pathway represents the highest value for Invica, aside from using the biochar in ecoke. However, in ecoke applications, the biochar is combusted, whereas in flue gas treatment, the biochar is eventually sequestered, providing a more sustainable solution and can gain further income through access to carbon credits.

Table 5 Costs and income for processing digestate screenings: oversized compost (70:30)

AD Screenings 70%, Oversized Compost 30%	10,000 (tonnes pa, db)
Biochar plant CAPEX + 20% contingency	£4,000,000
Biochar production net cost/t	-£59.71
Biochar Production tonnes	3700
Total cost	-£220,927
Carbon content of biochar wt%	56.65%
Carbon credits £100/t CO2eq	£207.72
Revenue Carbon Credit potential	£768,551.67

Output 7 Biochar Deployment (University of Nottingham)

This activity has involved the following:

1. Mesocosm experiments

2. Small plot experiments (12 m x 12 m) were established at two sites on the University of Nottingham farm.

3. Windrow and small-scale composting experiments

4. Large-scale trials on arable land and forestry and possible use in solar cells

The outputs for each of these are now summarised indicating what additional data is still to be obtained for the large-scale trials.

7.1 Mesocosm Experiments

Initial work was conducted on the effects of biochar on herbicide efficacy, on enhancement of indigenous soil nitrogen fixing bacteria (*Rhizobium*) and the development of standardised protocols for testing the effects of biochar on plant growth.

Further work has since been undertaken to evaluate the effects of biochar derived from woody feedstock on the growth of strawberries, tomatoes and kale. Strawberries and tomatoes are high value cash crops and can be grown in the field or under cover. Kale was investigated because of growing interest in it as a 'superfood' for humans and its value as a forage crop for livestock. In contrast to the other two crops, kale was grown on relatively alkaline soil. It is known that biochar often increases soil pH and its greatest benefit is observed in acidic soils. However, many soils in the UK and other temperate regions are neutral-alkaline and it is important to determine the effects of biochar when applied to such a soil. Therefore, alkaline soil was used as the substrate for the kale mesocosm experiments.

Irrespective of the experiment and soil used, commonalities were observed across the systems. For example, with increasing concentration of biochar amendment, an increase in soil pH and water holding capacity was consistently observed, and a decrease in bulk density (i.e. mass of soil per unit volume) (e.g. Figure 7.1; data from a strawberry trial). In this case, the 2.5% amendment was the lowest, and higher concentrations were used in line with other mesocosm investigations and to ‘push the system’. The 2.5% amendment is the most realistic in terms of field application. Increasing pH of acidic soils is beneficial for plant growth and nutrient mobility, improved water holding capacity is beneficial in areas prone to drought and a lowered bulk density is advantageous in heavy soils where compaction might impede root growth, aeration and water infiltration.

For the trials undertaken, plant growth (yield), plant chemistry (nutrient status) and soil chemistry were evaluated. Key findings from trials conducted with strawberry, tomato and kale are presented in Appendix 3 and summarised in Figure 7.1.

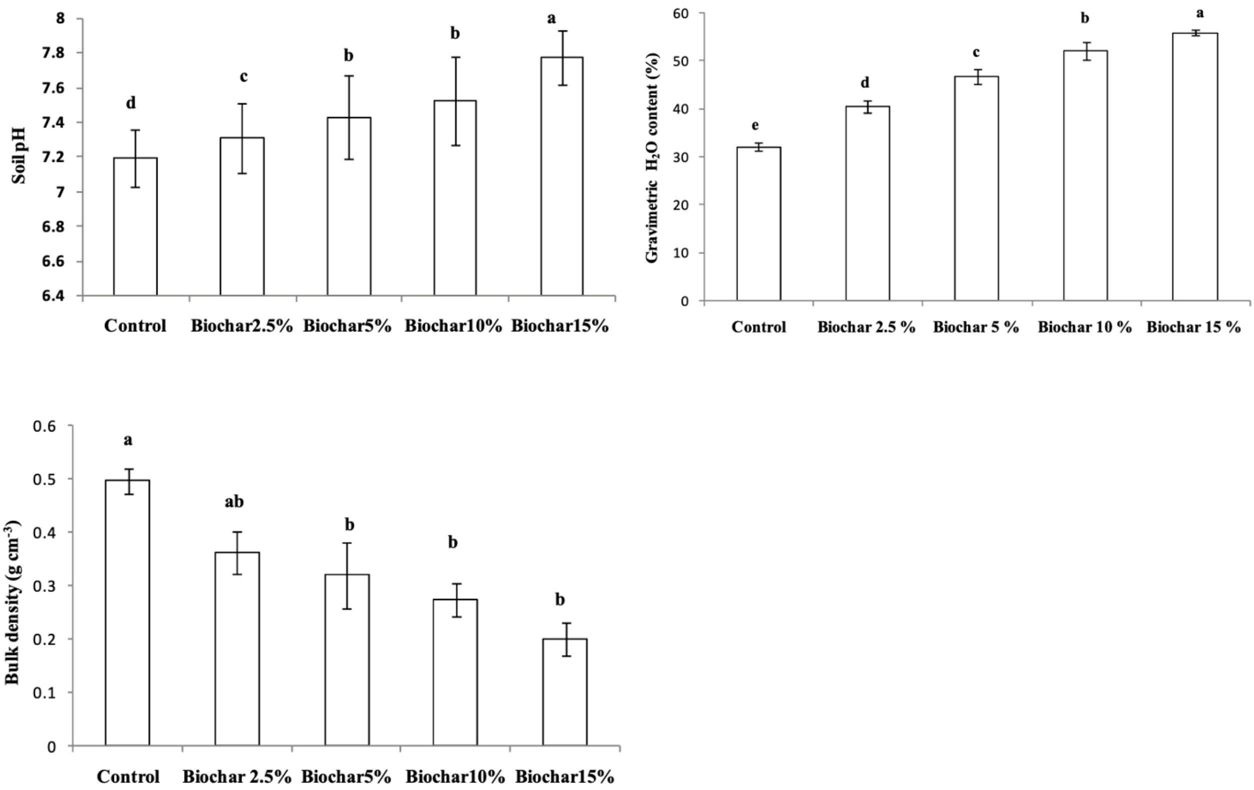


Figure 7.1 Increased soil pH and soil water content and decreased bulk density were generally observed with increasing biochar concentrations up to 15% by weight across the studies undertaken. This illustrates for soil taken from at the end of the strawberry growing trial, the superscripted columns are not significantly different.

7.2 Small Plot Experiments

Small plot experiments (12 m × 12 m) were established at two sites on the University of Nottingham farm. The sites differ in soil texture, with one being a sandy loam (at Sutton Bonington) and the other a heavier clay (at Clifton). The trials were embedded into the commercial part of the farm and are subject to normal agronomic practices. To date, there are a total of 32 plots at each site and so far, treatments mainly consist of two wood-based biochars (designated Wood A and Wood B) and a woody/brash-based compost which was applied as a single treatment, or in combination with the Wood B biochar. However, cocoa husk biochar was also applied a year later (2023), and this is included in the 2024 yield data reflecting the expansion of the trials as new biochars are produced. The Wood B biochar was applied as either a single application (Wood B1 or B2 depending on timing of application, 2021 and 2022 respectively, both at 10 t ha^{-1}) or as a repeated application (Wood B1&B2 giving a combined concentration of 20 t ha^{-1}). Wood A was applied only once at 10 t ha^{-1} (2021) and was a commercial biochar bought in for comparison. In 2023, a new biochar (cocoa husk) was deployed, both as a single application and as an amendment to one of the Wood B2 treatments; the aim was to evaluate not just repeated applications, but also the effects of combining biochars from different feedstocks.

Table 7.1 Outline of biochar deployment at the small plot field sites.

Treatment	Year of Application
Control (no amendments)	2021
Wood A	2021
Wood B1 and B2	2021 & 2022 (respectively)
Compost (wood/brash)	2022
Compost + Wood B2	2022
Wood B2	2022
Wood B2 + Cocoa Husk	2022 & 2023 (respectively)
Cocoa Husk	2023

The higher application rate does not exceed the Environment Agency’s stipulated concentration because of the size of the plots versus the total area of the field. It is anticipated that the trials will run for at least a further three years and the aim is to deploy new biochars as they become available, where the monitoring will be completed as part of the Biochar Demonstrator project. This will enable us to quantify short- and long-term changes to the soils across wood-based biochars deployed at different time scales and also encompass a full range of cropping cycles. Applications of biochar type and date are summarised in Table 7.1.

Data are summarised in Appendix 3 for cereal crops (wheat, oats and barley). Yields of a range of combinable cereal crops grown in two contrasting soils were unaffected by the three types of biochar used to date. Furthermore, applying 'raw' biochar to the fields was not detrimental which is an important observation in terms of the practicalities of deploying the product. Applying biochar with a compost was neither beneficial nor detrimental to plant yields; the lack of benefit from the compost is likely a reflection of the nutrient status of the soil which would have been sufficient for the crops grown since the plots are situated within a commercial part of the farm. They were given farmyard manure and Nitram as part of normal agronomic practice. Nevertheless, it does address the question often posed about the need to apply biochar with additional nutrients and/or 'prime' it prior to deployment. Whilst this may be beneficial on poor soils, it seems unnecessary in an agronomic setting on fertile soil. Time since deployment did not affect yields and nor did repeated applications (over two years) of the same biochar, or of two biochars derived from different feedstocks. The altered available nutrient profiles at the Clifton site are likely to be a result of the biochar-related increase in soil pH. This was not evident at the Sutton Bonington site, nor were any altered nutrient profiles. The clay soil at Clifton is likely to have a higher cation exchange capacity than the sandy loam at Sutton Bonington. Therefore, altered pH and possibly increased microbial activity may have released elements already present, rather than amendments adding new nutrients per se, but this needs further investigation as does the long-term effect of biochar additions. We are currently building a profile of the sites both spatially and temporally and aim to deploy further biochars as they become available. This facility is growing in importance and will enable further detailed analyses.

7.3 Composting

After extensive discussions with Veolia, it was decided to conduct a large-scale windrow composting trial at their Oxton site. The main concern was that the biochar used would carry the waste code based on the feedstock used. For this reason, virgin wood had to be used with Veolia supplying whole tree and Arb chip feedstock. The large-scale composting trial began in December 2024. A 200-tonne windrow of municipal green waste shredded to a maximum particle size of 300 mm was mixed with 12,679 tonnes of biochar, also produced from a feedstock of green waste. The concentration of biochar in the green waste is 6% when a moisture content of 50% for both elements is factored in. A second 200 tonne control windrow has also been established with green waste and no addition of biochar.

Windrow procedure The windrow composting procedure at Oxton spread over six weeks is summarised below.

- Material is split up as it arrives: Peak intake is 500 t/day, 40 lorries.
    a. Contaminated material (that with plastics) is quarantined spread out and the material picked out.
    b. Clean (and cleaned material) go into the shredder.
    c. Material is <5% soil.
- Shredder – normally on day of arrival
    a. 250 mm sieve so there will be larger chunks of wood in the material.
    b. Up to 40 lorries a day, especially on their busiest periods (April – September/October).
    c. Shredded material is around 40-50% moisture.
- First 3 weeks:
    a. Forced aeration (from bottom) – not that intense.
    b. Aeration means no turning (otherwise would be turned twice)
    c. Windrows are open air.
    d. Windrows are about **400 t** – circa 8 x 4 x 40 m in size.
- Second 3 weeks:
    a. Windrows are moved onto another pad.
    b. No aeration and are turned two-three times in the final weeks.
- After six weeks composting material is split:

a. Aim is to remove any plastic, metal and oversize material.
b. Screws remove anything >300 mm.
c. Next step – removes material 30-300 mm.
d. Blower – strips out plastics.
e. Final clean material is then split into:
    i. 0 – 10 mm for horticulture (has value and is sold).
    ii. 10 -30 mm for agriculture (is given away to farmers).

- Compost quality is tested using a standard self-heating stability test and CO_2 emission.
- Monitoring of the composting process included daily temperature measurements.
- Leachate was captured throughout off the pads and sent to water-treatment plant. There is no way to capture leachate off each pile as it all collates in tanks. The windrow test started in December 2024 and ran to early February 2025.

Small-scale composting

(i) Oxton green waste The same green waste as used in the windrow trial at Oxton is being used in laboratory-scale composting experiments with the following procedure being used. Following on from the previous report in which we outlined the results of a small-scale composting trial with poultry manure and the positive effects that biochar has on the composting process, we are currently conducting two further trials with municipal green waste. These are a commercial-scale composting trial and a parallel mesocosm-scale experiment to enable greater manipulation of biochar concentrations and more continuous data collection.

On the day the biochar was combined with the green waste, approximately 10 kg of the mix was collected from site and returned to the University of Nottingham. Approximately 25 kg of green waste from the control windrow was also collected (Figure 7.2). This was used to set up the parallel laboratory-scale investigation and for chemical and biological analysis of the starting material.

Figure 7.2 Left: Biochar made from green waste layered onto fresh green waste ready for incorporation and composting. Right: Incorporated biochar and green waste mix built into windrow ready for compositing to begin.

Experiments are in progress in tandem with the commercial trial. Green waste removed from the commercial site was amended with biochar at concentrations of 0, 5%, 10%, and 20% biochar with five replicates per treatment. Two litre mesocosms made from polypropylene containing the green waste and biochar mix are maintained in an incubator. The temperature was being incrementally increased to exceed the critical limit of 65° C for seven consecutive days when it will be gradually stepped down and held above 45° C for the remainder of the experiment (Figure 7.3). This mimics the temperature profile of the windrow, prevents heat shock of the microbial community and satisfies the PAS100 requirements. Temperature reports from the commercial trial are regularly obtained from composting facility and the same schedule maintained in the laboratory experiment. The duration of this experiment was ninety-days. This exceeded the windrow experiment timeframe (42-days). but measurements and samples were taken from the mesocosms at time points that match those of the large-scale trial for direct comparisons.

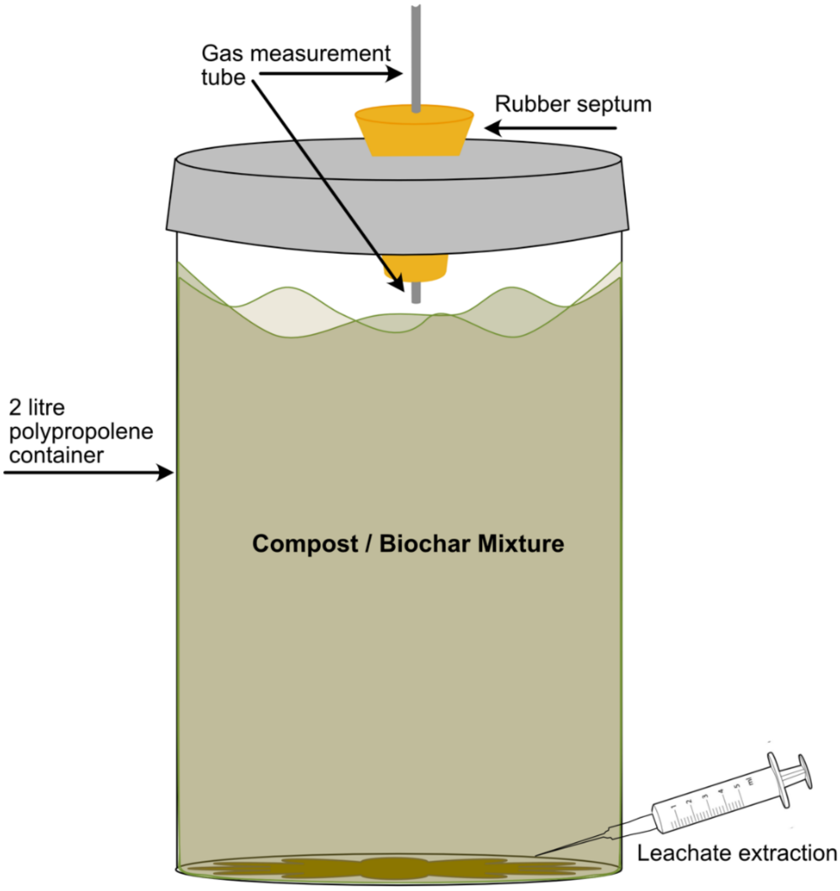


Figure 7.3. Diagram of mesocosm containing green waste with biochar treatments undergoing composting process at temperatures ranging from +45 to +65° C for a period of ninety-days.

Parameters being measured from each mesocosm are carbon dioxide flux, extractable carbon and nitrogen and carbon profiling from the compost/biochar mix, total nitrogen content of the leachate to account for nitrogen losses during the process and seed germination testing of the final composted product. Furthermore, DNA was and will be extracted at the beginning, middle and end of the experiment and analysis of fungal communities implemented. Pathogenic species will be identified at each stage and changes in relative abundance compared. Samples of the composting mix will be extracted at each monitoring stage, cultured for *Aspergillus* sp. fungal growth and tested for resistance against tebuconazole, a commonly used azole fungicide in gardening and horticulture. Tebuconazole can induce triazole resistance in *Aspergillus fumigatus*, the leading cause of invasive aspergillosis and listed by the World Health Organisation as a priority pathogen of concern. Determining whether municipal garden waste and commercial composting is a potential reservoir for fungal resistance is novel and important

<u>(ii) Variable feedstocks</u> A series of small-scale composting trials were undertaken during which green waste (garden clippings and vegetable peelings) or farmyard manure were composted with and without biochar in replicate 30 L barrels and a further smaller-scale trial was undertaken with poultry litter in smaller Duran bottles. Composts were sampled throughout the process. Data are too numerous to include here, but key observations included less ammonia released into the atmosphere and more efficient composting in treatments with biochar within the timescale of each trial biochar

Figure 7.4 Top left: View into 30 L barrels containing green waste and vegetable peelings (with or without 10% biochar) and top right shown two of the barrels after a period of composting. Bottom left: Duran bottles containing poultry litter with or without biochar. Bottom right: Farmyard manure with or without biochar immediately after application and prior to incubation.

In addition to the changes in chemistry of the composts, an interesting finding was the biochar-related change in composition at the end of the composting period. In this case, poultry litter taken from a small-holding was composted for 84 days and the FTIR (Fourier Transform Infrared) spectra generated showed that the signatures from the biochar-amended compost were different from those of the control, because fewer peaks were identified in the zones normally associated with carboxylic acids (Figure 7.4). Also, the limited peaks in the biochar-amended samples where lignocellulose should be, suggests that the maize straw used as bedding for the hens, was less well degraded in the control samples. Absorbance values falling into the ranges expected for carboxylic acids were subjected to discriminant analysis which separated the treatments, thereby showing that biochar amendment enhanced the composting process and produced more ‘mature’ compost.

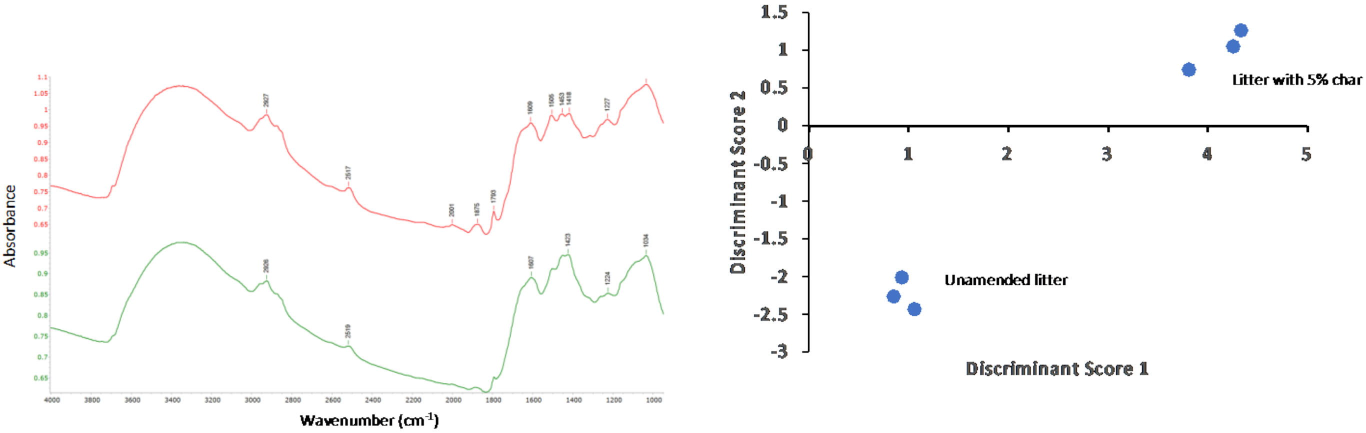


Figure 7.4 Left: FTIR spectra for samples of composted poultry litter containing biochar (bottom spectrum) or not (top spectrum). Right: Discriminant Scores for FTIR generated absorbance values associated with carboxylic acids of composted poultry litter.

Biochar produced from the pilot plant has already been delivered to three sites: Lancashire (agricultural trial), CNRS-Université de Lorraine France (forestry), Veolia UK at Oxton for a windrow composting trial. Further, regarding non-agricultural use, biochar has been supplied to Newcastle University to investigate the incorporation into solar cells.

Lancashire County Council (LCC)

On September 16, 2024, 5.5 tonnes of a wood-derived biochar (on 22 pallets) prepared from Grade A recycled wood were dispatched from Invica Industries to John Cooper Recycling Ltd, Farington Moss Recycling Centre, Leyland, for biochar spreading later in the autumn. Lancashire County Council (LCC) are investigating how the public sector can learn from regenerative agricultural practices, and how these can be applied to public land to enable councils to utilise their land holdings to help address net-zero objectives. LCC is looking at biochar specifically, and how it's ability to sequester carbon in the soil can contribute to offsetting residual emissions. LCC are currently in their third year of biochar application across two agricultural sites, measuring a total of 6 hectares. The biochar from Invica Industries is being applied to one of the sites in conjunction with biochar sourced elsewhere at a rate of 10 tonnes per hectare per year.

Forestry trial in France

On November 2, 2024, 160 kg of wood-derived biochar was dispatched from Invica Industries to CNRS-Université de Lorraine in France. The first deployment is planned between December 2024 and Spring 2025 at a forest site in Poule-les-Echarmeaux. This trial aims to investigate the impact of biochar on newly planted trees in forested land to extend the extensive trials already underway with the National Forest as part of the UKRI GGR Biochar Demonstrator Project.

The planted trees will include a mix of pine (Pinus nigra var. corsicana), chestnut (Castanea sativa Mill.), red oak (Quercus rubra L., syn. Quercus borealis Duroi), and Douglas fir. During tree planting, planting holes will be dug, and two handfuls of biochar will be added to the bottom of each hole before being covered with soil to avoid direct contact with tree roots. The remaining biochar will also be applied to the soil around trees that were planted 1–2 years ago.

Tree growth will be monitored by comparing trees planted with biochar and those planted without biochar, using paired intervals for comparison. The first batch of biochar deployment will cover approximately 1 hectare, with a density of 1,000 trees/ha, where 300–500 trees will be treated with biochar and the remainder left as "blank" reference trees.

Newcastle University

Up to seven different types of biochar—derived from bagasse, waste wood, AD food waste (produced in the INVICA industry pilot plant), macadamia nut, olive stone biochar from INVICA, and two additional types from Pyrocore — have been dispatched from the University of Nottingham to the Energy Materials Laboratory at Newcastle University. Each type of biochar, supplied in quantities of less than 500 g, is being utilized to optimize biochar for the development of solar power cells, highlighting the innovative application of biochar.

Output 8 Project Budget

The budget was £4,997,822.04 with Invica industries being the lead partner utilising £4,561675.42 of this budget with STGP and UoN giving up a portion of their budget to aid with inflationary pressure during the plant build. Additionally, due to this unforeseen inflation Invica committed an extra £1.06m of their own funds, across years 2 and 3 of the project showing Invica's commitment and how much they believe in biochar being a commercially viable solution for carbon sequestration. This brings the total project costs to £6,057,822. During 2022 during the project build there was unprecedented inflation globally with steel and concrete price doubling and general inflation in double digits. Invica underwent value engineering to try and keep the plant in scope as much possible but simultaneously reduce costs. The wet scrubber package was chosen to be removed from the plant. The wet scrubber package design centred around condensing oils and tars from the syngas. This cleaned syngas would then be fed directly to the kiln burners for combustion. However, the wet scrubber package would have brought significant risk to the project through many operational unknowns. For cost mitigation purposes and operational risk the wet scrubber package was therefore cut from the project scope.

With the design works now completed with this project it is envisaged a commercial scale biochar production plant with a feed capacity of 10,000 tonnes dry feedstock per annum would cost approximately £4 million would include £1 million allocated for off-the-shelf equipment, such as pyrolysis rotary kiln, dryer, oxidiser and feedstock handling systems. Another £1 million would cover installation costs, including system integration, electrical work, and commissioning. The remaining £2 million would be invested in groundworks and building construction, ensuring a robust facility with appropriate foundations, storage areas, and operational infrastructure

Output 9 Environmental and social impacts

During the project over 120 tonnes of biochar have been produced. This is around 250 tonnes CO_2/e. The feed rate when operational was around 500 kg/hr resulting in approximately 150 to 200 kg/hr biochar. If the plant was operational for a full year this would equate to around 2,500 tonnes CO2/e assuming the biochar meets specifications and is successfully sequestered. Deploying 40,000 t of biochar from the B to B Technology using the demonstration plant developed here by 2030 would represent an industry with a turnover of *ca*. £20M p.a. employing over 50 personnel, operating 10 facilities at a scale of 10,000 tonnes dry feedstock p.a., together with further numbers in the supply chain for the kiln and other components needed to construct the pyrolysis plants sourced in the UK.

Regarding the plant, five operators have been employed by Invica Industries for the operation of the pilot-plant, together with a project administrator to oversee the procurement and installation of the pilot facility. Dedicated research personnel at the University of Nottingham were employed to cover various aspects of characterising the biochar from the pilot plant and the deployment trials on the biochar produced, which included the large windrow composting trial with Veolia. The total effort at the University of Nottingham, including the dedicated researchers, technical support and project supervision amounted to 4 person years.

Invica Industries have taken a highly responsible attitude to the social and environmental acceptability of the demonstration plant developed. Working closely with the University of Nottingham and the Biochar Demonstrator who have organised specific stakeholder events for farmers and to discuss the policy and regulatory framework, Invica Industries are aware of the limits on biochar deployment on agricultural land and the permitting that need to be obtained, together with the need to cover transportation and spreading costs for farmers using biochar.

Regarding environmental concerns, there are no emissions to land of water from the plant and, as has already been described, the flue gas, including NO_x emissions, meets regulatory standards. A key aspect of the overall environmental assessment are the situation of plants and any impact that the biochar might have, in addition to long-terms carbon sequestration. The footprint of a unit processing 10,000 tonnes of

AD fibre p.a. is less than 30 x 30 m and these will be co-located at either AD plants or other industrial facilities rather than on green field sites to minimise issues with planning. As also discussed under MRV, any biochar deployed to agricultural land will meet the European Biochar Certificate standard and, any biochar not meeting this specification, will be used in aggregates, where the permitted levels of heavy metals and toxic organic compounds are much higher.

Knowledge was shared through social media posts and conferences (see ecoke LinkedIn profile for multiple examples).

Output 10 Key Successes and Outcomes

The successful construction and operation of the biochar plant marks a significant milestone, with **1**20 tonnes of biochar produced to date. The production in the given timeframe and operational hours available helps to show the plants design works and offers a good foundation to scale up production with a bigger plant either at Immingham or elsewhere.

Feedstock Variability & System Design: The importance of feedstock consistency has been highlighted as a crucial factor in process efficiency. Developing robust feedstock handling systems has proven essential to maintaining steady operations.

Production Conditions: Operational experience has refined our understanding of the optimal production conditions for achieving high-quality biochar while maintaining process stability and emissions control. Regular maintenance will be key to limit downtime. The ducting from the kiln to the oxidiser must be kept above 400 ^{o}C.

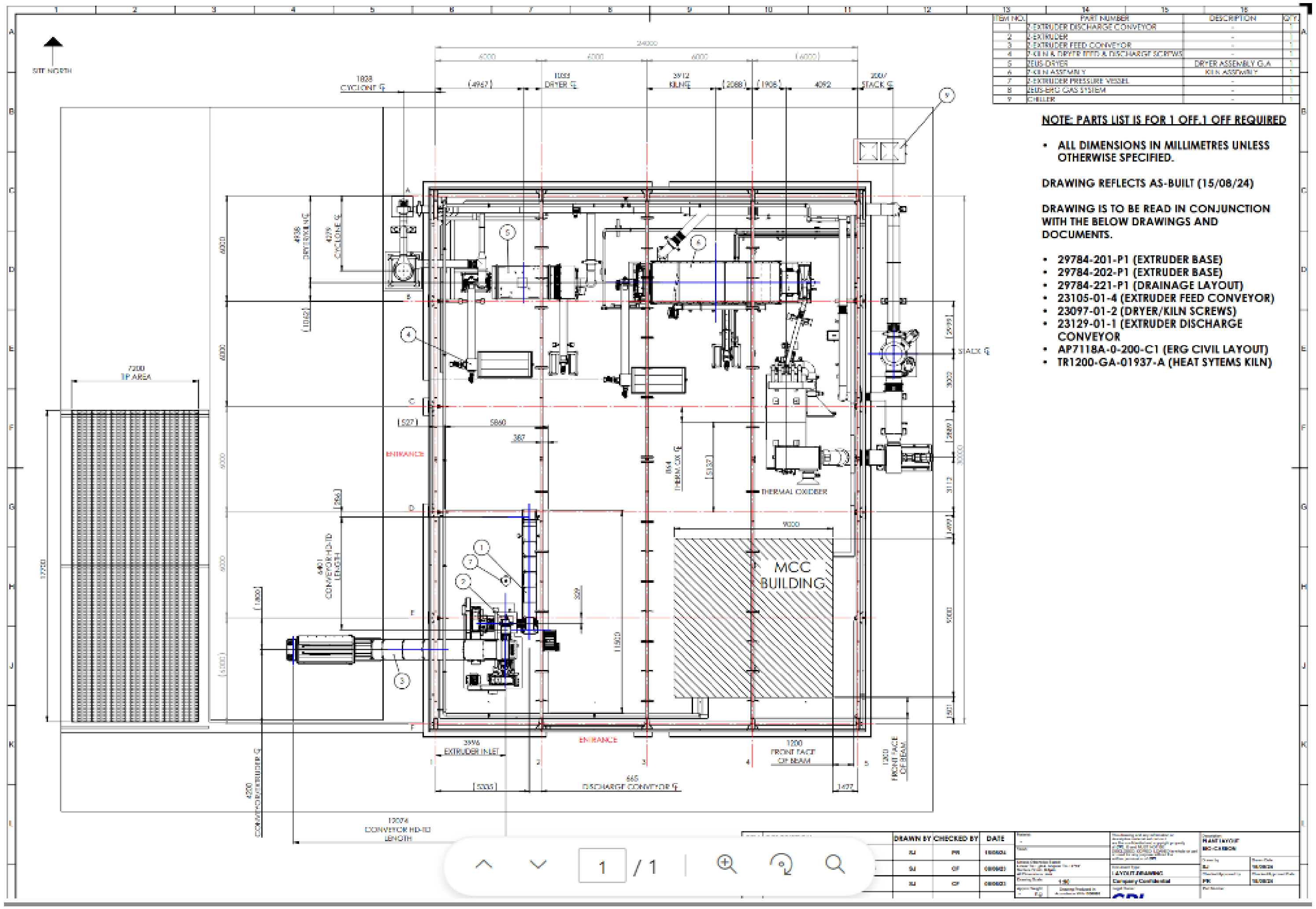
Scalability & Commercial Viability: With initial production success, the next step involves exploring more commercial opportunities for biochar applications, including carbon sequestration, and industrial uses.

Partnerships & Collaborations: Discussions with potential commercial partners and industry stakeholders have highlighted potential strategic collaborations.

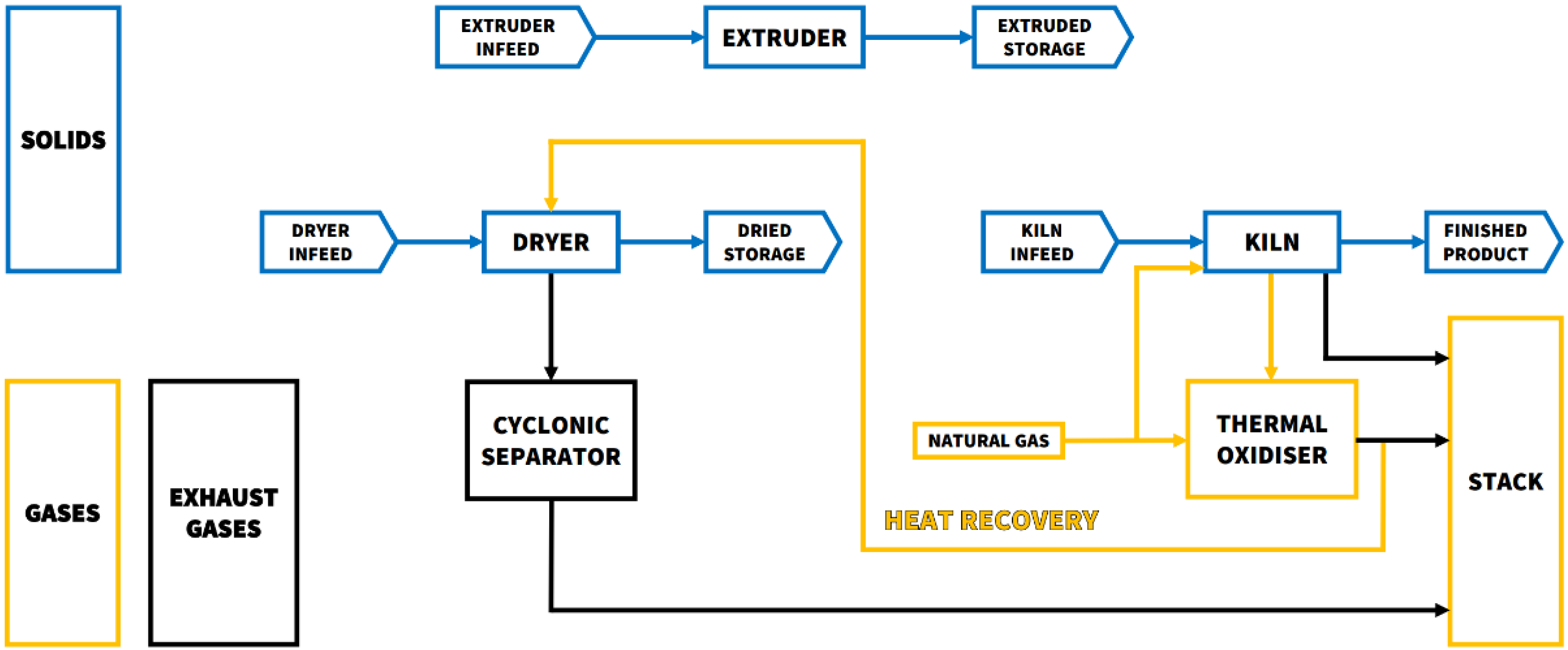
The commercial report (Appendix 4) highlights the commercial viability of biochar production. The report demonstrates how a feedstock blend could be the best suited for biochar production in terms of the feasibility of processing, in this case being able to feed the material into the plant but also providing a strong commercial case for investment. Biochar plants being located close to the feedstock is an important factor to reduce transportation costs and emissions. Furthermore, having a use for the biochar before, or whilst being sequestered opens the possibilities of additional revenue streams alongside carbon credits and can be a determining factor is a project is viable or not.

Appendix 1 Output 3 Biochar Production

3.1 Plant Drawings



3.2 Process Flow



3.3 Biochar production data

PKS - Palm Kernal Shell

Date	ID	Supplier	Tare (kg)	Gross Weight (kg)	Material Weight (Wet)	Moisture (%)	Dry Weight (kg)	Volume (ltr)	Bulk Density (m3)	Dry Bulk Density (m3)	Average Bulk Density (m3)
07/08/2024	Trial	CPL	1.1	12.3	11.2	25.0%	8.40	24	0.47	0.35	0.47

Wood Chip - 30mm

Date	ID	Supplier	Tare (kg)	Gross Weight (kg)	Material Weight (Wet)	Moisture (%)	Dry Weight (kg)	Volume (ltr)	Bulk Density (m3)	Dry Bulk Density (m3)	Average Bulk Density (m3)
08/08/2024	BCP-2024-W001	Down to Earth	1.1	4.9	3.8	11.8%	3.35	24	0.16	0.14	0.13
04/02/2025	BCP-2025-W001	Down to Earth	1.1	5.1	4	21.0%	3.16	24	0.17	0.13	
04/02/2025	BCP-2025-W002	Down to Earth	1.1	5	3.9	25.2%	2.92	24	0.16	0.12	
21/02/2025	BCP-2025-W003	Down to Earth	1.1	5	3.9	22.8%	3.01	24	0.16	0.13	
21/02/2025	BCP-2025-W004	Down to Earth	1.1	5	3.9	22.0%	3.04	24	0.16	0.13	
26/02/2025	BCP-2025-W005	Down to Earth	1.1	5	3.9	21.1%	3.08	24	0.16	0.13	

Full trea Chip - 50mm

Date	ID	Supplier	Tare (kg)	Gross Weight (kg)	Material Weight (Wet)	Moisture (%)	Dry Weight (kg)	Volume (ltr)	Bulk Density (m3)	Dry Bulk Density (m3)	Average Bulk Density
01/11/2024	BCP-2024-W004	Veolia	1.1	9.4	8.3	44%	4.65	24	0.35	0.19	0.18
05/03/2025	BCP-2025-W006	Sustainable Woodchip	1.1	9	7.9	49%	4.03	24	0.33	0.17	
06/03/2025	BCP-2025-W007	Sustainable Woodchip	1.1	9	7.9	50%	3.99	25	0.32	0.16	

Arb Chip - 50mm

Date	ID	Supplier	Tare (kg)	Gross Weight (kg)	Material Weight (Wet)	Moisture (%)	Dry Weight (kg)	Volume (ltr)	Bulk Density (m3)	Dry Bulk Density (m3)	Average Bulk Density
01/11/2024	BCP-2024-W003	Veolia	1.1	7.5	6.4	24%	4.86	24	0.27	0.20	0.20

Food Waste Getstate

Date	ID	Supplier	Tare (kg)	Gross Weight (kg)	Material Weight (Wet)	Moisture (%)	Dry Weight (kg)	Volume (ltr)	Bulk Density (m3)	Dry Bulk Density (m3)	Average Bulk Density
		Severn Trent	1.1		-1.1		-1.10	24	-0.05	-0.05	-0.05

Olive Stone

Date	ID	Supplier	Tare (kg)	Gross Weight (kg)	Material Weight (Wet)	Moisture (%)	Dry Weight (kg)	Volume (ltr)	Bulk Density (m3)	Dry Bulk Density (m3)	Average Bulk Density
01/11/2024	Trial	CPL	1.1	17.9	16.8	14%	14.51	24	0.70	0.60	0.60

S&B Gestate (Dry)

Date	ID	Supplier	Tare (kg)	Gross Weight (kg)	Material Weight (Wet)	Moisture (%)	Dry Weight (kg)	Volume (ltr)	Bulk Density (m3)	Dry Bulk Density (m3)	Average Bulk Density
16/12/2024	BCP-2024-DG001	Singleton and Birch	1.1	8.9	7.8	49%	4.02	24	0.33	0.17	0.17

S&B Gestate (Wet)

Date	ID	Supplier	Tare (kg)	Gross Weight (kg)	Material Weight (Wet)	Moisture (%)	Dry Weight (kg)	Volume (ltr)	Bulk Density (m3)	Dry Bulk Density (m3)	Average Bulk Density
16/12/2024	Trial	Singleton and Birch	1.1	13	11.9	80%	2.38	24	0.50	0.10	0.10

Oversized Compost 20mm

Date	ID	Supplier	Tare (kg)	Gross Weight (kg)	Material Weight (Wet)	Moisture (%)	Dry Weight (kg)	Volume (ltr)	Bulk Density (m3)	Dry Bulk Density (m3)	Average Bulk Density
05/12/2024	Trial	Ryedale Organics	1.1	7.7	6.6	24%	5.00	24	0.28	0.21	0.21

Oversized Compost 40mm

Date	ID	Supplier	Tare (kg)	Gross Weight (kg)	Material Weight (Wet)	Moisture (%)	Dry Weight (kg)	Volume (ltr)	Bulk Density (m3)	Dry Bulk Density (m3)	Average Bulk Density
05/12/2024	Trial	Ryedale Organics	1.1	6.7	5.6	25%	4.20	24	0.23	0.17	0.17

Oversized Compost (In house Shredding)

Date	ID	Supplier	Tare (kg)	Gross Weight (kg)	Material Weight (Wet)	Moisture (%)	Dry Weight (kg)	Volume (ltr)	Bulk Density (m3)	Dry Bulk Density (m3)	Average Bulk Density
05/12/2024	Trial	Ryedale Organics	1.1	6	4.9	22%	3.82	24	0.20	0.16	0.16

3.4 Biochar Analysis

Sample Name	Sample type	Date received	Sample Date	Feedstock Supply Source	Sample Information	R&D SF #	Link to Sample Image	Moisture (AR)	Moisture (Inherent)	Volatiles (DB)	Ash (DB)	Fixed Carbon
PKS Biocarbon	char	17.12.24	13.12.24		Given by DC	165		39.2	0.938	14	16.6	69.40
Wood	char	17.12.24	13.12.24		Given by DC	168		66.5	1.79	14.4	6.74	78.86
Hazelnut	char	17.12.24	13.12.24		Given by SP	169		50.3	1.35	17.9	12.9	69.20
Feedstock Oversized Compost	Raw feedstock	22.01.25	20.01.25		Given by AA- 2 medium sized sample bags	171		34.7	0.797	74.5	3.7	21.80
Feetstock Dried Gestate	Raw feedstock	22.01.25	06.01.25		1 bag	172		23.4	0.346	61	24.3	14.70
Biocarbon Dried Gestate	char	22.01.25	06.01.25		BCP-2024.sB001 (3 large sized sample bags) Given by AA	173		54.2	0.52	18	46.7	35.30
Biocarbon 20mm Over	Char	22.01.25	20.01.25		Given by AA	174		32.6	0.944	14.8	12.6	72.60
Biocarbon 40mm Over	Char	22.01.25	20.01.25		Given by AA	175		22.1	0.894	14.1	17.2	68.70
Feedstock Grass	Raw feedstock	22.01.25	20.01.25		Given by AA- 2 medium sized sample bags	176		68.6	0.575	58.5	23.8	17.70
Biocarbon Grass	char	22.01.25	16.01.25		Given by AA (3 medium sized sample bags)	177		18.5	0.223	15.6	74.6	9.80
50% Wood, 50% Grass Feedstock	Raw feedstock					183		41	1.67	63.4	18.5	18.10
30mm Grade A Wood BCP-2025-W001/2	Raw feedstock	04.02.25	04.02.25		Given by AA (1 medium sized sample bag)	184		23.1	0.907	80.9	1.44	17.66
Wet Gestate Biocarbon	char	04.02.25	04.02.25		Given by AA (1 medium sized sample bag)	185		5.7	0.377	10.7	75.5	13.80
50% Wood, 50% Grass Biocarbon	char	04.02.25	04.02.25		Given by AA (1 medium sized sample bag)	186		43.7	0.891	10.3	31.6	58.10
Oversized Compost Biocarbon (20mm)	char	11.02.25	11.02.25		Given by AA (1 medium sized sample bag)	187		30.6	1.07	13.6	20.8	65.60
Oversized Compost Biocarbon (20mm) A	char	17.02.25	17.02.25		1 Medium Sized Sample Bag	187		30.4	0.875	17.2	23.7	59.10
Oversized Compost Biocarbon (20mm) B	char	17.02.25	17.02.25		1 Medium Sized Sample Bag	187		29.2	0.913	16.7	28	55.30
Oversized Compost Biocarbon (20mm) C	char	17.02.25	17.02.25		1 Medium Sized Sample Bag	187		32.7	0.847	17	15.7	67.30
Oversized Compost Biocarbon (40mm)	char	17.02.25	17.02.25		1 Medium Sized Sample Bag	192		20	0.845	15	20.2	64.80
BCP-2025-WOO1 30mm Wood	Raw Feedstock	04.03.25	11.02.25		Given by AA (1 medium sized sample bag)	196		29.8	1.27	79.6	1.42	18.98
BCP-2025-WOO2 30mm Wood	Raw Feedstock	04.03.25	11.02.25		Given by AA (1 medium sized sample bag)	198		35	1.33	80.6	1.77	17.63
BCP-2025-WOO3 30mm Wood	Raw Feedstock	04.03.25			Given by DL (1 medium sized sample bag)	199.00		25	1.43	79.7	1.51	18.79
BCP-2025-WOO4 30mm Wood	Raw Feedstock	04.03.25			Given by DL (1 medium sized sample bag)	200		23.2	1.37	80.6	1.31	18.09
BCP-2025-WOO5 30mm Wood	Raw Feedstock	04.03.25			Given by DL (1 medium sized sample bag)	201		25.5	1.57	80.5	2.15	17.35

3.5 Production log example

Date Started	Time Started	Date Finished	Time Finished	Down Time (hr)	% Running against Availablity	Batch Total (Days)	Batch Total (hr)	Days Run	Hours Run	Weight Delivered (Kg)	Moisture (%)	Dry Weight (kg)	Bulk Density	Biocarbon Weight (kg)	Moisture (%)	Bicoarbon Dry Weight (kg)
03/02/2025	15:00:00	13/02/2025	16:00:00	150.00	37.76%	10.04	241.00	3.79	91.00	17700	23.50%	13540.50	0.13	4899	32.33%	3315.15
24/02/2025	11:25:00	27/02/2025	15:48:00	7.75	89.85%	3.18	76.38	2.86	68.63	22960	22.0%	17908.80	0.13	5582.5	31.72%	3811.73
10/03/2025	12:30:00	14/03/2025	03:00:00	17.00	80.35%	3.60	86.50	2.90	69.50	53240	49.00%	27152.40	0.13	14156	40.83%	8172.46

3.6 HAZOP

Project Title:	CPL BEIS Biochar Plant, Immingham		Node:	X	Node Description:		ACTION LOG									
Guideword	**Cause**	**Consequence**	**Hazard / risk category**	**Unmitigated Severity**	**Unmitigated Frequency**	**Unmitigated Risk Ranking**	**Safeguards (Engineering Controls, e.g. BPCS)**	**Safeguards (Administrative Controls, e.g. Alarms, Human Response)**	**Conditional Modifiers**	**Mitigated Frequency**	**Mitigated Risk Ranking**	**Recommendation**	**Recommendation To**	**Recommendation Number**	**Action Response**	**Mitigated Frequency (with action complete)**	**Mitigated Risk Ranking (Action complete)**
Flow More	Extruder ZM1101 running faster than expected.	1. Potential for build up of material on the discharge belt which may overflow resulting in clean up. Process delays only. No hazardous consequenses identified. 2. If additive system is running, potential for quality issues but no hazardous consequences identified.										Review control system to ensure that the INFEED Convoyer ZH1001, Extruder ZM1101 and discharge belt ZH1201 are speed matched and synchronised to prevent potential blockages or loss of containment of material from the belts.	PR	1	Control procedure for infeed Work instructions available		
Flow More	Discharge Belt ZH1201 running faster than expected.	No hazardous consequenses identified.										Provide deflector on the end of discharge belt ZH1201 to ensure material feeds into the storage PEN without loss of containment.	SJ	2	Conveyor Design Changed no longer a Risk.	F0	
Flow Reverse	Conveyor belts running in reverse.	Potential for mechanical damage and spillage.										Ensure that ZH1001/ZH1201 conveyors and belts are not able to run in reverse.	PR	3	Conveyors fitted with Anti-runback		
Flow Reverse	Conveyor belts running in reverse.	Potential for mechanical damage and spillage.										Confirm if Extruder ZM1101 can be run in reverse. If Extruder can run if reverse eliminate this from the design if this is not required.	PR	4	Only available for controlled maintenance.		
Temperature Low	Low ambient temperature.	Potential freezing of process water lines resulting in blockage, no additio of water and product quality issues. No hazardous consequenses identified.										Update P&ID to show insulation and heat tracing on process water lines.	MM	5	Node 1 complete. No requirement for cooling sprays trace heating.		
Level High	Operator error adding more raw material to INFEED Hopper ZB1001.	Overfilling of INFEED Hopper ZB1001 which will overflow to the floor. No Hazardous consequences identified.										Provide mirror at the top of storage Hopper ZB1001 so that diver can see internal contents.	SJ	6	installed		
Level High	Operator error failing to empty storage PEN.	Increased Level in the storage PEN which will overflow and require clean-up. No Hazardous consequences identified.										Consider requirement to trip extruder system on High-Level in open storage PEN.	PR	7	Written in FDS Housekeeping guidance exists, discharge procedure to be part of extruder guidance BCP-WI-004		
Concentration Contaminents	Product change-over.	Potential for cross-contamination and product quality issues.										Review and prepare product changeover procedures to minimise cross-contamination between products.	PR	8	Procedure written BCP-WI-005		
Start Up	Requirement to start-up.											Ensure that start-up is configured such that ZH1201 starts first followed by ZM1101 and ZH1001. This order should be reversed in shut-down.	MS	9	Written in FDS		
Emergency Shutdown	Requirement to shut-down Extruder ZM1101.	Potential for INFEEDs to continue to Extruder ZM1101 resulting in process upset.										Emergency shut-down of Extruder should also stop all upstream and downstream equipment.	MS	10	Capture in emergency shutdown scenarios		

Flow No / Less	Bridging in Storage Hopper ZB2001.	No flow of material into the dryer resulting in overheating and increased product temperatures within dryer. This can lead to minor internal damage on localised hot-spots. Potential for overdried material to exit the dryer above its auto ignition temperature (AIT) leading to a fire over the open storage PEN, resulting in equipment damage. Potential for secondary fires due to poor housekeeping which may result in potential injury to operator.	1	S2	F3		1. TT2101 - High-High Trip (Product Discharge) (RRF = 10) 2. TT2103 - High-High Trip (Gas Discharge). (RRF = 0)	1. TT2101 - High-Alarm (Product Discharge) (RRF = 10) 2. TT2103 - High-Alarm (Gas Discharge). (RRF = 0) 3. Building Fire Alarm. (RRF = 10 - see comments)		F1		Provide firefighting water spray to open storage PEN.	CF	11	Fire suppression system designed and planned to be installed as requirement.
Flow No / Less	Bridging in Storage Hopper ZB2001.	No flow of material into the dryer resulting in overheating and increased product temperatures within dryer. This can lead to minor internal damage on localised hot-spots. Potential for overdried material to exit the dryer above its auto ignition temperature (AIT) leading to a fire over the open storage PEN, resulting in equipment damage. Potential for secondary fires due to poor housekeeping which may result in potential injury to operator.	1	S2	F3		1. TT2101 - High-High Trip (Product Discharge) (RRF = 10) 2. TT2103 - High-High Trip (Gas Discharge). (RRF = 0)	1. TT2101 - High-Alarm (Product Discharge) (RRF = 10) 2. TT2103 - High-Alarm (Gas Discharge). (RRF = 0) 3. Building Fire Alarm. (RRF = 10 - see comments)		F1		Review additional temperature sensors as part of fire risk assessment.	CF	12	Not practical to install sensors as current controls are sufficient.
Flow No / Less	LT2001 BPCS Failure Reading High.	No flow of material into the dryer resulting in overheating and increased product temperatures within dryer. This can lead to minor internal damage on localised hot-spots. Potential for overdried material to exit the dryer above its auto ignition temperature (AIT) leading to a fire over the open storage PEN, resulting in equipment damage. Potential for secondary fires due to poor housekeeping which may result in potential injury to operator.	1	S2	F3		1. TT2101 - High-High Trip (Product Discharge) (RRF = 10) 2. TT2103 - High-High Trip (Gas Discharge). (RRF = 0)	1. TT2101 - High-Alarm (Product Discharge) (RRF = 10) 2. TT2103 - High-Alarm (Gas Discharge). (RRF = 0) 3. Building Fire Alarm. (RRF = 10 - see comments)		F1		Provide mirror at the top of storage Hopper ZB2001 so that diver can see internal contents.	SJ	13	installed
Flow No / Less	ZVV2001 fails closed due to mechanical or electrical failure.	1. No flow of material into the dryer resulting in overheating and increased product temperatures within dryer. This can lead to minor internal damage on localised hot-spots. Potential for overdried material to exit the dryer above its auto ignition temperature (AIT) leading to a fire over the open storage PEN, resulting in equipment damage. Potential for secondary fires due to poor housekeeping which may result in potential injury to operator. 2. ZH2001/ZH2002 will continue to run which will block and jam resulting to mechanical damage to Screw Feeder. No Hazardous consequenses identified.	1	S2	F3		1. TT2101 - High-High Trip (Product Discharge) (RRF = 10) 2. TT2103 - High-High Trip (Gas Discharge). (RRF = 0) 3. LS2001 - High-High Level Trip will stop screw feeders. (RRF = 0)	1. TT2101 - High-Alarm (Product Discharge) (RRF = 10) 2. TT2103 - High-Alarm (Gas Discharge). (RRF = 0) 3. Building Fire Alarm. (RRF = 10 - see comments) 4. ZVV2001 Limit Switches indicate valve out of position. (RRF = 0)		F1		Activation of LS2001 dryer should be configured to carry out a controlled shut-down.	PR	14	Ensure full shut-down sequence for dryer.

Flow No / Less	Rotary dryer ZD2101 stops rotating due to mechanical or electrical failure.	Loss of movement inside rotary dryer resulting in a blockage in inlet w hich w ill back up into Screw Feeder and can also block the Gas Flow back to the Cyclonic Seperator. Increased pressure inside ZD2101 resulting in loss of primary containment from the seals, loss of hot non-flammable gasses resulting in a serious injury.	1	S2	F3		1. LS2101 - High-High Level Trip carries out controlled shut-dow n. (RRF = 10)	1. Rotation sensor XS2101. 2. PT2101 - High Pressure Alarm (RRF=10)	1. Occupancy assumed to be 10%. Operator w ould have to be adjecant to seal at the time of release. (RRF = 10)	F0		Review position of PT2101 to ensure that sensor is able to pick up blockage in Gas Outlet from ratary dryer.	MM	15	Covered by PIC120.
Flow No / Less	ZVV2201 fails closed due to mechai	Build up of material at the burner end w hich could ignite resulting in a fire in rotary dryer and significant equipment damage.	4	S2	F3		1. LS2102 - High-High Level Trip carries out controlled shut-	1. PT2101 - High Pressure Alarm. 2. ZVV2201 limit sw itches. (RRF = 0)		F1		Provide dryer controlled shutdow n in the event of ZVV2201 failing closed.	PR	16	Written in FDS
Start Up	Requirement to purge rotary dryer and cnnecting piew ork prior to start-up.	If the dryer is started up w ithout an adequete purge sequence w hen the burner starts it could ignite flammable gasses inside the dryer resulting in internal detonation, any overpressure w ill escape through the seals. Loss of primary containment of hot gasses and/or small flash fire around the seals esulting in an injury if an operator is nearby.	1	S2	F4		1. Engineering controls BCU w ill prevent burner start-up w ithout sufficient purge. (RRF = 100)	1. Guarding w ill be installed on the rollers adjecant to the seals to prevent access (RRF = 10).	1. Occupancy assumed to be 10%. Operator w ould have to be adjecant to seal at the time of release. (RRF = 10)	F0		Calculate the total volume of the rotary dryer ZD2101 and associated pipew ork and determine the running time of ZV2101 to achieve a minimum of 5 air changes.	MM	17	Burner not currently in operation
Start Up	Requirement to start screw feeders in correct order.											Ensure that start-up is configured such that ZH2201 starts first follow ed by ZVV2201, ZD2101, ZH2101, ZVV2001, ZH2002 and ZH2001. This order should be reversed in shut-dow n.	PR	18	Written in FDS
Emergency Shutdown	No hazardous causes identified.											Ensure that emergency shutdow n of the rotary dryer ZD2101 also shuts dow n INFEED and OUTFEED.	PR	19	Written in FDS
Other	Outfeed Screw ZH2201 not fully enclosed.	Potential for operator pinch points and trapped limbs if equipment is being inspected during operation. Potential for serious injury including loss of limbs.	1	S3	F3			1. Safe systems of w ork / Permit to w ork (RRF = 10) 2. Risk assessment / systems isolated prior to inspection /		F2		Provide adequate guarding around OUTFEED Screw ZH2201 to prevent operator or maintenance injury from rotating equipment.	SJ	20	Hopper to be mounted preventing injury.
Flow No / Less	Bridging in Storage Hopper ZB3001.	No flow of material into the KILN resulting in overheating and increased product temperatures w ithin the KILN. This can lead to minor internal damage on localised hot-spots. Potential for hotter material to exit the KILN above its auto ignition temperature (AIT) leading to a fire in the discharge PEN resulting in equipment damage. Potential for secondary fires due to poor housekeeping w hich may result in potential injury to operator.	1	S2	F3		1. TAH03/04 - High-High Temperature Trip (KILN Temperature) (RRF = 10) 2. TAH01 - High-High Temperature Trip (Product Discharge) (RRF = 0) 3. TAH02 - High-High Temperature Trip (Product Discharge	1. TT3101 High-Temperature Alarm (Gas to Oxidiser). (RRF = 10)		F0		Provide firefighting w ater spray to Discharge PEN.	CF	21	Fire suppression system designed and installed as requirement. Pens replaced w ith bagging frames.

Flow No / Less	Bridging in Storage Hopper ZB3001.	No flow of material into the KILN resulting in overheating and increased product temperatures w ithin the KILN. This can lead to minor internal damage on localised hot-spots. Potential for hotter material to exit the KILN above its auto ignition temperature (AIT) leading to a fire in the discharge PEN resulting in equipment damage. Potential for secondary fires due to poor housekeeping w hich may result in potential injury to operator.	1	S2	F3		1. TAH03/04 - High-High Temperature Trip (KILN Temperature) (RRF = 10) 2. TAH01 - High-High Temperature Trip (Product Discharge) (RRF = 0) 3. TAH02 - High-High Temperature Trip (Product Discharge	1. TT3101 High-Temperature Alarm (Gas to Oxidiser). (RRF = 10)		F0		Review additional temperature sensors as part of fire risk assessment.	CF	22	Not practical to install sensors as current controls are sufficient.		
Flow No / Less	LT3001 BPCS Failure Reading High.	No flow of material into the KILN resulting in overheating and increased product temperatures w ithin the KILN. This can lead to minor internal damage on localised hot-spots. Potential for hotter material to exit the KILN above its auto ignition temperature (AIT) leading to a fire in the discharge PEN resulting in equipment damage. Potential for secondary fires due to poor housekeeping w hich may result in potential injury to operator.	1	S2	F3		1. TAH03/04 - High-High Temperature Trip (KILN Temperature) (RRF = 10) 2. TAH01 - High-High Temperature Trip (Product Discharge) (RRF = 0) 3. TAH02 - High-High Temperature Trip (Product Discharge	1. TT3101 High-Temperature Alarm (Gas to Oxidiser). (RRF = 10)		F0		Provide mirror at the top of storage Hopper ZB3001 so that diver can see internal contents.	SJ	23	installed		
Flow No / Less	ZVV3001 fails closed due to mechanical or electrical failure.	1. No flow of material into the KILN resulting in overheating and increased product temperatures w ithin the KILN. This can lead to minor internal damage on localised hot-spots. Potential for hotter material to exit the KILN above its auto ignition temperature (AIT) leading to a fire in the discharge PEN resulting in equipment damage. Potential for secondary fires due to poor housekeeping w hich may result in potential injury to operator. 2. ZH3001/ZH3002 w ill continue to run w hich w ill block and jam resulting to mechanical damage to Screw Feeder. No Hazardous consequenses identified.	1	S2	F3		1. TAH03/04 - High-High Temperature Trip (KILN Temperature) (RRF = 10) 2. TAH01 - High-High Temperature Trip (Product Discharge) (RRF = 0) 3. TAH02 - High-High Temperature Trip (Product Discharge Chamber). (RRF = 0) 4. TT3101 Hight-High Temperature Trip (Gas to Oxidiser). (RRF =	1. TT3101 High-Temperature Alarm (Gas to Oxidiser). (RRF = 10)		F0		Activation of LS3001 on KILN should be configured to carry out a controlled shut-dow n.	PR	24	confirmed		
Flow No / Less	KILN ZD3101 stops rotating due to mechanical or electrical failure.	1. Loss of movement inside KILN resulting in a blockage in inlet w hich w ill back up into Screw Feeder ZH3101 and result in process delays. 2.Potential for the KILN to deform resulting in equipment damage. No hazardous consequense identified.					1. Battery back-up electrical supply for KLN rotation w ith indipendent drive.					Review emergency stop procedures to take into account the emergency drive and determine the E-Stop configuration scenarios for w hen the emrgency drive is required to be stopped or required to remain active.	PR	25	emergency drive disconnected		

Flow No / Less	ZVV3201 Not-Open due to operator error.	1. innability for material to be discahred from the KILN. The KILN will continue to fill, and material will eventually escape through the seals. Loss of primary containment of hot material ca. 700degC. Material is above AIT resulting in small localised fire. Operator exposure leading to burn injury.	1	S2	F4		1. ZVV3201 open limit switches will trip the KILN on valve not open. (RRF=10) 2. LSL01 - Level Switch will trip KILN on High-Level. (RRF = 0)	1. ZVV3201 open limit switches will alarm valve not open. (RRF = 10)	1. Occupancy assumed to be 10%. Operator would have to be adjecant to seal at the time of release. (RRF =10)	F1		Update P&ID to show LSL01 as LSH01.	MM	26	Completed.		
Start Up	Requirement to purge KILN and cnnecting piework/ductwork prior to start-up.	If the KILN is started up without an adequete purge sequence when the burner starts it could ignite flammable gasses inside the KILN resulting in internal detonation, any overpressure will escape through the seals. Loss of primary containment of hot gasses and/or small flash fire around the seals esulting in an injury if an operator is nearby.	1	S2	F4		1. Engineering controls BCU will prevent burner start-up without sufficient purge. (RRF = 100)	1. Guarding will be installed on the rollers adjecant to the seals to prevent access. (RRF = 10)	1. Occupancy assumed to be 10%. Operator would have to be adjecant to seal at the time of release. (RRF =10)	F0		Calculate the total volume of the KILN ZD3101 and associated pipework/ductwork and determine the running time of ZV3101 to achieve a minimum of 5 air changes.	MM	27	completed		
Start Up	Requirement to start screw feeders in correct order.											Ensure that start-up is configured such that cooling water circuit starts first followed by ZH3202, ZH3201, ZVV3202, ZD3101, ZH3101, ZVV3001, ZH3002 and ZH3001. This order should be reversed in shut-down.	PR	28	Written in FDS		
Emergency Shutdown	No hazardous causes identified.											Ensure that emergency shutdown of the KILN ZD3101 also shuts down INFEED and OUTFEED Screw Feeders.	PR	29	Completed		
Flow No / Less.	Cooling water Pump ZP3301 stops due to mechanical or electrical failure.	Static cooling water will be heated up va the product in the screw-Feeders which will boil. Overpressure and loss of containment of hot water glycol from a flange/joint or jacket rupture. Operator exposure leading to injury.	1	S1	F4		1. FS3301 - LL Low-Flow Trip will stop the KILN and ZH3201/ZH3202. (RRF = 10) 2. ZPRV3201/3202 - Thermal Relief Valves. (RRF =	1. FIT3301 - Low-Flow Alarm. (RRF =10) 2. System should be open to the Header Tank ZB3301 and any overpressure will be routed out		F0		Ensure that ZB3301 overflow and relief valve discharges ZPRV3201/3202 are routed to safe locations.	CF	30	Water system designed and installed as required.		
Flow No / Less	TT3203 control failure closes ZCV3201/3202/3203 manual valve closed due to operator error.	Loss of ability to apply cooling spray. On its own this scenario is not hazardous, however the product would exit ZH3202 at a higher temperature but not above AIT. Potential for operator exposure, burns/injury.	1	S1	F4				1. Occupancy assumed to be 10%. Operator would have to be inside the PEN at the time of release.	F3		Consider additional means of heat detection and alarm for hot material discharged into discharge PEN.	PR	31	fire detection system installed		
Temperature Low	Low ambient remperature.	Small bore Towns Water line to cooling screw sprays could freeze in periods of non-operation.										Consider insulation on Towns Water line to ZH3202.	MM	32	No lagging required.		
Emergency Shutdown	Requirement for shut-down/emergency shut-down.											Consider allowing the Glycol-Water system to continue running during shut-down/emergency shut-down.	PR	33	Apply for controlled shut-down, not on E-Stop scenario.		
Loss of Utilitiy - Inst Air	Loss of instrument air.	ZCV3201/3203/3203 have no designated air failure mode.										Update P&ID to show ZCV3201/3202/3203 as air-failed closed.	MM	34	Completed.		

Other	Outfeed Screw ZH3202 not fully enclosed.	Potential for operator pinch points and trapped limbs if equipment is being inspected during operation. Potential for serious injury.	1	S3	F4					F4		Provide adequate guarding around OUTFEED Screw ZH3202 to prevent operator or maintenance injury from rotating equipment.	SJ	35	No longer accessable
Flow No / Less	TIC112 malfunctions fully closing CV113.	1. Inability to remove excess heat from the dryer resulting in an internal fire and equipment damage. 2. Excess carryover of dust into Cyclone CY102 w hich w ill block leading to overpressure in the dryer and loss of primary containment of hot gasses by the seals, operator exposure w ould result in a serious injury.	1	S2	F4		1. TT2103 - High-High Temperature Trip (Gas Discharge) w ill close CV117 to stop heated air into the dryer ZD2101 (independent control system from initiating event.	1. TT2103 - High-Alarm (Gas Discharge). 2. TT2101 - High-Alarm (Product Discharge).	1. Occupancy assumed to be 10%. Operator w ould have to be adjecant to seal at the time of release.	F1		Review control system philosophy and how communications w ill w ork betw een individual control panels.	KD	36	master PLC now in place
Flow No / Less	PIC120 malfunctions stopping F801 dryer fan.	1. Inability to remove excess heat from the dryer resulting in an internal fire and equipment damage. 2. Excess carryover of dust into Cyclone CY102 w hich w ill block leading to overpressure in the dryer and loss of primary containment of hot gasses by the seals, operator exposure w ould result in a serious injury.	1	S2	F4		1. TT2103 - High-High Temperature Trip (Gas Discharge) w ill close CV117 to stop heated air into the dryer ZD2101 (independent control system from initiating event.	1. TT2103 - High-Alarm (Gas Discharge). 2. TT2101 - High-Alarm (Product Discharge). 3. PDSL119 Low differential pressure.	1. Occupancy assumed to be 10%. Operator w ould have to be adjecant to seal at the time of release.	F1		Provide PDSH on Cyclone CY102.	CF	37	PDSH added and confirmed by ERG.
Flow No / Less	Cyclone CY102 fully blocked.	Over-temperature and over-pressure in dryer leading to loss of containment of hot gasses leading to potential operator exposure and serious injury.	1	S2	F4		1. PIT122 w ill close CV117 to stop heated air to dryer.	1. TT2101 - High-Alarm (Product Discharge).	1. Occupancy assumed to be 10%. Operator w ould have to be adjecant to seal at	F1		1. Provide High-Level Sw itch on Cyclone CY102 to detec build-up of solids. 2. Close CV117 on High Pressure on PIC120.	CF	38	Both added and confirmed by ERG.
Flow No / Less	V001 inadvertantly closed due to operator error.	1. Inability to remove excess heat from the dryer resulting in an internal fire and equipment damage. 2. Excess carryover of dust into Cyclone CY102 w hich w ill block leading to overpressure in the dryer and loss of primary containment of hot gasses by the seals, operator exposure w ould result in a serious injury.	1	S2	F4		1. TT2103 - High-High Temperature Trip (Gas Discharge) w ill close CV117 to stop heated air into the dryer ZD2101 (independent control system from initiating event.	1. TT2103 - High-Alarm (Gas Discharge). 2. TT2101 - High-Alarm (Product Discharge). 3. PDSL119 Low differential pressure.	1. Occupancy assumed to be 10%. Operator w ould have to be adjecant to seal at the time of release.	F1		Lock or remove handle on V001 to ensure it cannot be moved after commissioning.	CF	39	Add to snagging list for final commissioning.
Flow No / Less	V002 inadvertantly closed due to operator error.	1. Inability to remove combustion gasses from the rotary KILN w hich w ill result in overpressure and loss of containment via the seals leading to operator exposure and serious injury. 2. Build-Up of flammable gasses inside the KILN combustion chamber w hich w ill ignite resulting in an internal explosion and blow out through the seals resulting in serious injury.	1	S2	F4		1.PT3102 - High-Pressure Trip w ill stop the KILN Burner-Package.	1. PT3102 - High-Pressure Alarm.	1. Occupancy assumed to be 10%. Operator w ould have to be adjecant to seal at the time of release.	F1		Lock or remove handle on V002 to ensure it cannot be moved after commissioning.	CF	40	Add to snagging list for final commissioning.

Flow No / Less	V003 inadvertantly closed due to operator error.	See Entries 2 & 3.										Remove or lock-open V003.	CF	41	Add to snagging list for final commissioning.		
Flow No / Less	V004 inadvertantly closed due to operator error.	No heating leading to product quality issues. No hazardous consequenses identified.										Lock or remove handle on V004 to ensure it cannot be moved after commissioning.	CF	42	Add to snagging list for final commissioning.		
Flow More	PIC120 malfunctions running F801 dryer fan at 100%.	Fan running faster drawing more flow fom the oxidiser into the dryer and excess heat and carry over of dust into the cyclone CY102, increased dust level in CY102 resulting in No Flow (see Cyclone Entry above).										Provide means to empty Cyclone CY102 during operation (e.g. via rotary valve).	MM	43	Confirmed and actioned by ERG		
Flow Misdirected	Cyclone CY102 Discharge lack of air-lock on Cyclone base.	air ingress into the base of the cyclone and carry over of fines which may stick to fan blades leading to mechanical damage.										Consider provision of vibration monitoring of dryer fan F801	CF	44	PCM instrumentation in scope for installation. This has been supplied by ERG.		
Flow As Well As	Burner operational on dryer as well as heated air from thermal oxidiser.	ID Fan F401 will be overwhelmed resulting in an increased temperature and pressure inside dryer ZD201. Loss of hot gasses through the seals resulting in operator exposure and serious injury.	1	S2	F4					F4		PAHH120 - High-High Pressure Trip should shut-down dryer ZD2101 burner package.	CF	45	Confirmed and actioned by ERG		
Flow As Well As	Burner operational on dryer as well as heated air from thermal oxidiser.	ID Fan F401 will be overwhelmed resulting in an increased temperature and pressure inside dryer ZD201. Loss of hot gasses through the seals resulting in operator exposure and serious injury.	1	S2	F4					F4		Ensure that HMI is configured so that the operator can only run the dryer ZD2101 in burner mode or waste heat mode.	PR	46	confirmed		
Pressure More	MV303 closed.	2. Backflow of condensate to F401 resulting in equipment damage, which will overflow via TC118. Potential loss of containment of hot gasses from Thermal Oxidiser resulting in a fatality..	1	S4	F4					F4		Remove or lock open MV303.	CF	47	Add to snagging list for final commissioning.		
Pressure More	MV303 closed.	2. Backflow of condensate to F401 resulting in equipment damage, which will overflow via TC118. Potential loss of containment of hot gasses from Thermal Oxidiser resulting in a fatality..	1	S4	F4					F4		Ensure that orientation of ductwork containing TCV118 is directed upwards to safe location to prevent operator exposure.	CF	48	Confirmed and actioned by ERG		
Pressure More	Dust in Cyclone CY102	Potetnial for combustable dust which if ignited will result in a confined dust explosion inside Cyclone CY102. Potential for fataliy due to flying debris.	1	S4	F4					F4		1. Provide explosion panel on Cyclone CY102.	CF	49	Confirmed and actioned by ERG	F2	

Temperature Low	Low ambient temperatures (particularly during start-up).	Potential for condensation to occour in Cyclone CY102 and ductwork. Condensation mixed with fines could result in blockages in the Cyclone and ductowork, restricting flow (See No Flow for Hazardous consequences).										1. Provide adequate inspection points / rodding points on Cyclone CY102 and ductowk to reduce potential for blockages. Also provide Low-Point drains on an ductwork pockets.	CF	50	Confirmed and actioned by ERG		
Temperature High	Carry over of hot fines into cyclone.	internal fire within cyclone and/or dust collection bin. Operator exposure to fire leading to serious injury	1	S2	F4			1. Controlled procedures in place for emptying cyclone and collection bin		F3		provide temperature monitoring with high temperature alarms on both gas and solid discharge from cyclone CY102	CF	51	Confirmed gas temperature. Solid temperature considered engineering preferance and therefore excluded. Complete action to tolerable risk.		
Shutdown	Thermal oxidiser shut-down.											Ensure that CV119, TCV118 Fails-Open & CV117 Fails-Closed on Thermal Oxidiser Shut-Down.	CF	52	Consider options for fail-safe positions of valves. Valves are currently fail in position on loss of air and fail correctly on loss of 4-20mA. Spring safe actuators to be installed.		
Flow No / Less	QIT104 malfunctions, fully closing PCV119.	Incomplete combustion within the thermal oxidiser resulting in increased environmental emmisisions. Minor release wih offsite effects.	2	S1	F4					F4		Provide flow detection in additional combustion air line. .	CF	53	Confirmed and actioned by ERG		
Flow No / Less	QIT104 malfunctions, fully closing PCV119.	Incomplete combustion within the thermal oxidiser resulting in increased environmental emmisisions. Minor release wih offsite effects.	2	S1	F4					F4		Ensure PCV 119 is fitted with a minimum opening mechanical stop.	CF	54	confirmed		
Flow No / Less	Carry over of dust and tars from the KILN.	Overpressurisation of the KILN, resultantly force Syngas out of the drum seals. Syngas will auto ignite and cause flash fire leading to serious injury.	1	S1	F4		1. PT3101 - High-High Pressure Trip will stop the KILN. 2. PIC110 Increases the fan	1. PT3101 - High-High Pressure Alarm.	1. Occupancy assumed to be 10%. Operator would have to be adjecant to seal at	F1		Provide differential pressure indication across PIC110 & PT3101.	PR	55	DP added by ERG.		
Flow No / Less	Outlets of thermal oxidiser blocked	Loss of flow out of the thermal oxidiser resulting in an increased pressure and back-flow of Syngas through the additional combustion air-line. Syngas will auto ignite and cause flash fire leading to serious injury.	1	S1	F3					F3		Provide pressure indication for the combustion chamber on the thermal oxidiser on TO101.	CF	56	Confirmed and actioned by ERG		
Flow No / Less	Outlets of thermal oxidiser blocked	Loss of flow out of the thermal oxidiser resulting in an increased pressure and back-flow of Syngas through the additional combustion air-line. Syngas will auto ignite and cause flash fire leading to serious injury.	1	S1	F3					F3		Ensure that the additional combustion inlet is directed in a safe area away from walkways and personnel.	CF	57	confirmed in safe area		
Flow More	QIT104 malfunctions, fully opening PCV119.	Increased flow of additional combustion air into the thermal oxidiser, reducing the operational temperature of the ThermOX, which will increase the combustion air and natural gas supply to the burner to increase the temperature. In this scenario the ID Fan will increase speed and may be undersized which may result in increased pressure in the KILN. Overpressure of the KILN may result in loss of containment of Syngas from the drum seals. Syngas will auto ignite and cause flash fire leading to serious injury.	1	S1	F4		1. PT3101 - High-High Pressure Trip will stop the KILN.	1. PT3101 - High-High Pressure Alarm.	1. Occupancy assumed to be 10%. Operator would have to be adjecant to seal at the time of release.	F1		Review pipework design and valve arrangements of the additional combustion air and provide individual valves on each nozzle location if required.	CF	58	Confirmed and actioned by ERG		

Shutdown												Ensure that the ThermOX continues to operate w hen the KILN has been shut-dow n until the KILN reaches the minimum set-point temperature; then the ThermOX can be stopped.	PR	59	confirmed		
Flow No / Less	Blockage in outlet of thermal oxidiser TO101	Overpressure in ThermOX and increased back pressure in the KILN ZD3101 and loss of containment of hot gasses via the KILN seals, operator exposure leading to serious injury.	1	S2	F0			Plant preventative maintenance and plant cleaning.(RRF=10)		F0		Add a pressure transmitter / DP on the oxidiser outlet to indicate blockages.	CF	60.0	Confirmed and actioned by ERG for PT only, DP not required.		
Flow No / Less	TIC Reads Low w rongly closing TCV118	High temperature resulting in damage to F401 ID Fan or SK101 vent stack.	4	S2	F3					F3		Provide indipendent temperature reading on F401 fan discharge to momiter discharge temperatures and provide protection layer if the dryer is not running.	CF	61.0	installed		
Flow No / Less	MD301 Inadvertently closed due to operator error	Increased pressure in pipew ork / increased flow through CV117, w ould lead to overpressure / temperature in the dryer and or oxidiser. Loss of containment of hot gasses from KILN or dryer seals resulting in serious injury.	1	S2	F4				1. Occupancy assumed to be 10%. Operator w ould have to be adjecant to seal at the time of release. (RRF =10)	F3		Lock or remove handle to MD301 or add pressure transmitter / sw itch to line.	CF	62.0	Add to snagging list for final commissioning.		
Flow No / Less	V004 Inadvertently closed due to operator error	No flow of heated air to the dryer resulting in extended processing times. Heated air w ould be routed via the bypass CV113. As the dryer is cooling dow n CV113 w ill also close. No hazardous consequences identified.										Lock or remove handle to V004	CF	63.0	Add to snagging list for final commissioning.		
Flow More	ID Fan F401 runs to 100% due to mechanical, electrical or control (PIC110) failure.	Increased fan speed resulting in reduced KILN operating pressure resulting in air ingress and formation of a flammable atmosphere inside the KILN. Material and gasses w ill be above AIT. Ignition resulting in an internal fire and damage to the KILN and release of hot gasses through the seals.	1	S2	F4				1. Occupancy assumed to be 10%. Operator w ould have to be adjecant to seal at the time of release. (RRF =10)	F3		Provide Low-Low Pressure trip on PT3102	MM	64.0	PT3102 removed. Low pressure undertaken by PIC110.		
Equipment - Maintenance	Lack of fan maintenance.	Equipment damage to F401.					VA001 High-High vibration trip.	VA001 - High Vibration alarm.				Confirm w ith ERG that the fan F401 is being supplied w ith vibration monitoring as standard.	CF	65.0	Confirmed and actioned by ERG		
Loss of Utilitiy - Inst Air	Loss of instument air.	CV113 and CV117 both fail closed. Trapped 400degC gas betw een the valves could cool dow n and could potentially cause low pressure / vacuum and damage tof ductw ork.										CV113 to fail-open on loss of instument air.	CF	66.0	Fails open on loss of 4-20mA, fails in position on loss of air. New spring actuator to be fitted.		

HAZOP continued

External Fire	Electrical and or equipment fire.	Significant eqipment damage and production stops.	4	S3	F3					F3		Consider provission of fire-stop on electrical systems to prevent asset damage.	CF	1.0	Fire stop considered as part of fire risk assessment.		
External Fire	Fire in final product bag.	Localised fire in product bag which could spread to pallete and potential for burn injury.	1	S1	F3		1. Discharge cooling screws			F2		Develop procedure for safe storage of final product bags including seperation distances and requirement to local fire-fighting.	PR	2.0	TBC - Area needs to be determined and external storage to be reviewed in Fire Risk Assessment.		
Acute Exposure	Exposure to CO and CO2 due to loss of containment from gas seals.	Operator exposure leading to dizziness, sickness and short term nausea.	1	S1	F4		Building is open with air-flow and H-VAC. (RRF = 10)		Low occupancy area. (RRF=10)	F2		Consider providing operators with personal CO or O2 monitors.	PR	3.0	TBC		
Acute Exposure	Exposure to tar during cleanout of line from KILN to Oxidiser.	Operator exposure leading to dizziness, sickness and short term nausea.	1	S1	F4			Safe systems of work and permits to work. (RRF=10)		F3		Provide removable spool pieace to aid cleaning of tar from hot pipework from KILN to Oxidiser.	CF	4.0	Completed		
Acute Exposure	Exposure to ammonia from raw material.	Operator exposure leading to irritation and burn the skin, mouth, throat, lungs, and eyes	1	S1	F4					F4		Review ammonia concentration of raw material during commissioning and provide toxic gas monitoring if required.	PR	5.0	Only relavent when processing digestate		
Chronic Exposure	Unknown causes.	Unknown consequences with long term health effect										Confirm if there are any materials where exposure could lead to long term health effects and ensure all relavent mitigation and safeguards are applied in line with the long term hazards identified.	PR	6.0	Only relavent when processing digestate & dust risk		
Noise	Combustion air fans and vacuum pump.	Increased noise from new fans, potential for long term hearing damage.	1	S3	F3					F3		Conduct noise survey to ensure that fans and surrounding plant area is less than 85 dB at 1m. If assessment is not met, provide additional noise attenuation.	PR	7.0	No requirement for hearing protection as fans operate within safe audible limit. Conduct noise survey to ensure compliance.		
Natural Disaster	Lightning strike	Equipment damage and/or fire.	4	S3	F2					F2		Provide lightning protection for the new production building and vent stack.	PR	8.0	confirmed		
Operations	Increased vehicle movement in yard.	Potential for collision impact with plant or pedestrians, resulting in equipment damage or fatality.	1	S4	F3					F3		Review yard flow and unloading requirements due to increased vehicle movement, including any requirements for additional signage, barriers, banksman or other procedures.	PR	9.0	TBC		
Emergency Shutdown	Fire.	Plant shutdown requirements on confirmed fire not currently defined										Review shut-down requirements on detection of a fire.	PR	10.0	Review after fire risk assessment.		
Isolations	Uninhibited access to MCC room.	Potential for electricution and death.	1	S4	F3					F3		MCC room to be locked and restricted acess to authorised personnel only.	CF	11.0	confirmed		

Appendix 2 Output 4 Characterisation Methodologies

Proximate analysis

Proximate analysis was carried out by thermo-gravimetric analysis (TGA, Ta Instruments). About 30 mg of the biochar sample was weighed onto a platinum pan and heated to 110°C (10°C/min) under 100% N_2 (1 bar, 100 mL/min) and held for 30 minutes to determine moisture content. The temperature was then ramped to 900 °C (10°C/min, 1 bar, 100 mL/min, under 100% N_2) and held isothermally for 7 mins to determine the content of volatiles present. After that, the temperature was ramped to 815 °C (30°C/min, 1 bar, 100 mL/min, under 100% N_2), and the gas was switched to air (1 bar, 100 mL/min) and held isothermally for 30 mins to determine fixed carbon and ash contents. Samples were run in quintuplicate to obtain the average data, and the errors represent the dispersion of a dataset relative to its mean.

Ultimate analysis

Ultimate analysis was carried out by elemental analysis (EA) with a CHN analyser (Leco Instruments). Calibration was carried out using BBOT ((2, 5-Bis (5-ter-butyl-benzoxazol-2-yl) thiophene). Approximately 60 mg of sample was used to determine the contents of Carbon (C), Hydrogen (H), and Nitrogen (N) under combustion at 950°C in 100% O_2. Samples were run in quintuplicate to obtain the average data, and the errors represent the dispersion of a dataset relative to its mean. H/C Ratio in the tables was calculated on an atomic basis from ultimate analysis results. The H/C Ratio for the wet basis (as received) samples contains the H from water. Carbon yield was calculated based on the carbon content of produced biochar and its feedstock from the ultimate analysis.

Heavy metals and PAH measurement

The concentrations of heavy metals such as As, Pb, Cd, Cu, Ni, Zn, and Cr were measured using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) as per the DIN EN ISO 17294-2 (E29): 2017-01 standard method. Mercury (Hg) concentrations were determined using Cold Vapor Atomic Absorption Spectroscopy (CV-AAS) following DIN 22022-4: 2001-02. PAH concentrations were analyzed through Gas Chromatography-Mass Spectrometry (GC-MS) in accordance with DIN EN 17503, Verfahren 10.2.3: 2022-08.

Appendix 2.1 Eurofins EBC results-Kiln screening AD biochar 650 °C

	N. O	Parameter Name	Result	Uncertainty	Unit	Reference Substance	Method	Standard
Biochar properties	1	Bulk density < 3 mm	391		kg/m³	dry basis	Gravimetry	based on VDLUFA-Methode A 13.2.1
	2	Bulk density	411		kg/m³	as received	Gravimetry	DIN EN ISO 17828: 2016-05
	3	water holding capacity (WHC) < 2 mm	66.0		%	dry basis	Gravimetry	DIN EN ISO 14238, A: 2014-03
	4	Moisture	9.2	0.28	% (w/w)	as received	Gravimetry	DIN 51718: 2002-06
	5	Ash content (550°C)	40.1		% (w/w)	as received	Calculation	DIN 51719: 1997-07
	6	Ash content (550°C)	44.1		% (w/w)	dry basis	Calculation	DIN 51719: 1997-07
	7	Total carbon	46.0		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	8	Total carbon	50.7		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	9	carbon (organic)	44.2		% (w/w)	as received	Calculation	Calculation
	10	carbon (organic)	48.7		% (w/w)	dry basis	Calculation	Calculation
	11	Hydrogen	1.2		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	12	Hydrogen	1.3		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	13	Total nitrogen	1.63		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	14	Total nitrogen	1.80		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	15	Sulphur (S), total	0.47		% (w/w)	as received	Calculation	DIN 51724-3: 2012-07
	16	Sulphur (S), total	0.51		% (w/w)	dry basis	Calculation	DIN 51724-3: 2012-07
	17	Oxygen	7.5		% (w/w)	as received	Calculation	DIN 51733: 2016-04
	18	Oxygen	8.3		% (w/w)	dry basis	Calculation	DIN 51733: 2016-04
	19	Total inorganic carbon (TIC)	2.0		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06

	20	Total inorganic carbon (TIC)	1.8		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	21	carbonate-CO2	6.7		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	22	carbonate-CO2	7.4		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06
	23	H/C ratio (molar)	0.30			as received	Calculation	Calculation
	24	H/C ratio (molar)	0.30			dry basis	Calculation	Calculation
	25	H/Corg ratio (molar)	0.32			as received	Calculation	Calculation
	26	H/Corg ratio (molar)	0.31			dry basis	Calculation	Calculation
	27	O/C ratio (molar)	0.122			as received	Calculation	Calculation
	28	O/C ratio (molar)	0.123			dry basis	Calculation	Calculation
	29	pH in CaCl2	8.4			as received	Conductometry	DIN ISO 10390: 2005-12
	30	salt content	23.7		g/kg	as received	Calculation	BGK III. C2: 2006-09
	31	salt content	9.26		g/l	as received	Calculation	BGK III. C2: 2006-09
	32	Conductivity at 1,2 t pressure	4.8		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	33	Conductivity at 2 t pressure	6.3		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	34	Conductivity at 3 t pressure	8.8		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	35	Conductivity at 4 t pressure	9.1		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	36	Conductivity at 5 t pressure	11		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
Elements from the micro wave pressure digestion acc. to DIN 22022-1: 2014-07	37	Arsenic (As)	1.2		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	38	Lead (Pb)	14		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	39	Cadmium (Cd)	< 0.2		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01

	40	Copper (Cu)	95	15	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	41	Nickel (Ni)	64	9.9	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	42	Mercury (Hg)	< 0.07		mg/kg	dry basis	CV-AAS	DIN 22022-4: 2001-02
	43	Zinc (Zn)	703	190	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	44	Chromium (Cr)	85		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	45	Boron (B)	29		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	46	Manganese (Mn)	447		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	47	Silver (Ag)	< 5		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
Elements fr. the borate digestion of ash 550 °C acc. to DIN 51729-11:1998-11(AR)	48	Calcium as CaO	31.4		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	49	Iron as Fe2O3	10.7		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	50	Potassium as K2O	3.0		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	51	Magnesium as MgO	2.6		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	52	Sodium as Na2O	3.0		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	53	Phosphorus as P2O5	9.1		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	54	sulphur as SO3	2.2		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	55	Silicon as SiO2	10.0		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
Macronutrients	56	Total nitrogen	16.3		g/kg	as received	Calculation	DIN 51732: 2014-07
	57	Total nitrogen	18.0		g/kg	dry basis	Calculation	DIN 51732: 2014-07
Macronutrients-LiBO2/Li2B4O7/LiBr-	58	Phosphorus as P2O5	40.0		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09

melt of ash 550°C [DIN 51729-11:1998-11] (OS)	59	Potassium as K2O	13.1		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	60	Calcium as CaO	139		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	61	Magnesium as MgO	11.6		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	62	Sodium as Na2O	13.3		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	63	sulphur as SO3	9.7		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
Elements fr. the borate digestion of ash 550°C acc. to DIN 51729-11:1998-11(OS)	64	Iron (Fe)	33.2		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	65	Silicon (Si)	20.6		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
Organic contaminants from toluene extraction acc. to EN 17503	66	Naphthalene	24		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	67	Acenaphthylene	4.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	68	Acenaphthene	1.2		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	69	Fluorene	6.8		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	70	Phenanthrene	15		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	71	Anthracene	3.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	72	Fluoranthene	3.3		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	73	Pyrene	4.3		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	74	Benz(a)anthracene	1.8		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	75	Chrysene	2.3		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	76	Benzo(b)fluoranthene	1.0		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

	77	Benzo(k)fluoranthene	0.3		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	78	Benzo(a)pyrene	1.0		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	79	Indeno(1,2,3-cd)pyrene	0.3		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	80	Dibenz(a,h)anthracene	0.2		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	81	Benzo(g,h,i)perylene	0.4		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	82	Total 8 EFSA-PAH excl. LOQ	7.3		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	83	Total 16 EPA-PAH excl. LOQ	69.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	84	Benzo(e)pyrene	1.0		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	85	Benzo-(j)-fluoranthene	n.b.		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

Appendix 2.2 Eurofins EBC results-Pilot bagasse biochar 650 °C

	N.O.	Parameter Name	Result	Uncertainty	Unit	Reference Substance	Method	Standard
Biochar properties	1	Bulk density < 3 mm	455		kg/m³	dry basis	Gravimetry	based on VDLUFA-Methode A 13.2.1
	2	Bulk density	562		kg/m³	as received	Gravimetry	DIN EN ISO 17828: 2016-05
	3	water holding capacity (WHC) < 2 mm	89.1		%	dry basis	Gravimetry	DIN EN ISO 14238, A: 2014-03
	4	Moisture	25.6	0.77	% (w/w)	as received	Gravimetry	DIN 51718: 2002-06
	5	Ash content (550°C)	14.3		% (w/w)	as received	Calculation	DIN 51719: 1997-07
	6	Ash content (550°C)	19.2		% (w/w)	dry basis	Calculation	DIN 51719: 1997-07
	7	Total carbon	56.0		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	8	Total carbon	75.3		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	9	carbon (organic)	55.9		% (w/w)	as received	Calculation	Calculation
	10	carbon (organic)	75.1		% (w/w)	dry basis	Calculation	Calculation
	11	Hydrogen	0.9		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	12	Hydrogen	1.3		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	13	Total nitrogen	0.42		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	14	Total nitrogen	0.57		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	15	Sulphur (S), total	0.08		% (w/w)	as received	Calculation	DIN 51724-3: 2012-07

	16	Sulphur (S), total	0.10		% (w/w)	dry basis	Calculation	DIN 51724-3: 2012-07
	17	Oxygen	3.6		% (w/w)	as received	Calculation	DIN 51733: 2016-04
	18	Oxygen	4.8		% (w/w)	dry basis	Calculation	DIN 51733: 2016-04
	19	Total inorganic carbon (TIC)	0.2		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06
	20	Total inorganic carbon (TIC)	0.1		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	21	carbonate-CO2	0.5		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	22	carbonate-CO2	0.6		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06
	23	H/C ratio (molar)	0.20			as received	Calculation	Calculation
	24	H/C ratio (molar)	0.20			dry basis	Calculation	Calculation
	25	H/Corg ratio (molar)	0.20			as received	Calculation	Calculation
	26	H/Corg ratio (molar)	0.20			dry basis	Calculation	Calculation
	27	O/C ratio (molar)	0.048			as received	Calculation	Calculation
	28	O/C ratio (molar)	0.048			dry basis	Calculation	Calculation
	29	pH in CaCl2	9.1			as received	Conductometry	DIN ISO 10390: 2005-12
	30	salt content	1.96		g/kg	as received	Calculation	BGK III. C2: 2006-09
	31	salt content	0.893		g/l	as received	Calculation	BGK III. C2: 2006-09
	32	Conductivity at 1,2 t pressure	2.2		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	33	Conductivity at 2 t pressure	2.9		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040

	34	Conductivity at 3 t pressure	3.5		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	35	Conductivity at 4 t pressure	4.3		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	36	Conductivity at 5 t pressure	5.2		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
Elements from the micro wave pressure digestion acc. to DIN 22022-1: 2014-07	37	Arsenic (As)	< 0.8		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	38	Lead (Pb)	< 2		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	39	Cadmium (Cd)	< 0.2		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	40	Copper (Cu)	8	1.3	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	41	Nickel (Ni)	2	0.31	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	42	Mercury (Hg)	< 0.07		mg/kg	dry basis	CV-AAS	DIN 22022-4: 2001-02
	43	Zinc (Zn)	50	14	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	44	Chromium (Cr)	8		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	45	Boron (B)	4		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	46	Manganese (Mn)	70		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	47	Silver (Ag)	< 5		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
Elements fr. the borate digestion of ash 550 °C acc. to DIN 51729-11:1998-11(AR)	48	Calcium as CaO	17.6		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	49	Iron as Fe2O3	4.6		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	50	Potassium as K2O	4.6		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09

	51	Magnesium as MgO	2.9		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	52	Sodium as Na2O	0.5		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	53	Phosphorus as P2O5	1.5		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	54	sulphur as SO3	1.1		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	55	Silicon as SiO2	56.6		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
Macronutrients	56	Total nitrogen	4.2		g/kg	as received	Calculation	DIN 51732: 2014-07
	57	Total nitrogen	5.7		g/kg	dry basis	Calculation	DIN 51732: 2014-07
Macronutrients-LiBO2/Li2B4O7/LiBr-melt of ash 550°C [DIN 51729-11:1998-11] (OS)	58	Phosphorus as P2O5	2.9		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	59	Potassium as K2O	8.9		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	60	Calcium as CaO	33.9		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	61	Magnesium as MgO	5.5		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	62	Sodium as Na2O	0.9		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	63	sulphur as SO3	2.1		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
Elements fr. the borate digestion of ash 550°C acc. to DIN 51729-11:1998-11(OS)	64	Iron (Fe)	6.2		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	65	Silicon (Si)	50.9		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
Organic contaminants from toluene extraction acc. to EN 17503	66	Naphthalene	8.6		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	67	Acenaphthylene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

	68	Acenaphthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	69	Fluorene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	70	Phenanthrene	1.0		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	71	Anthracene	0.4		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	72	Fluoranthene	0.4		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	73	Pyrene	0.4		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	74	Benz(a)anthracene	0.2		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	75	Chrysene	0.2		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	76	Benzo(b)fluoranthene	0.2		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	77	Benzo(k)fluoranthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	78	Benzo(a)pyrene	0.2		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	79	Indeno(1,2,3-cd)pyrene	0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	80	Dibenz(a,h)anthracene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	81	Benzo(g,h,i)perylene	0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	82	Total 8 EFSA-PAH excl. LOQ	1.0		mg/kg	dry basis	Calculation	calculated
	83	Total 16 EPA-PAH excl. LOQ	11.8		mg/kg	dry basis	Calculation	calculated
	84	Benzo(e)pyrene	0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

	85	Benzo-(j)-fluoranthen	n.b.		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

Appendix 2.3 Eurofins EBC results-Pilot waste wood[a] biochar 650 °C

	N.O.	Parameter Name	Result	Uncertainty	Unit	Reference Substance	Method	Standard
Biochar properties	1	Bulk density < 3 mm	160		kg/m³	dry basis	Gravimetry	based on VDLUFA-Methode A 13.2.1
	2	Bulk density	377		kg/m³	as received	Gravimetry	DIN EN ISO 17828: 2016-05
	3	water holding capacity (WHC) < 2 mm	283.7		%	dry basis	Gravimetry	DIN EN ISO 14238, A: 2014-03
	4	Moisture	56.8	1.7	% (w/w)	as received	Gravimetry	DIN 51718: 2002-06
	5	Ash content (550°C)	4.9		% (w/w)	as received	Calculation	DIN 51719: 1997-07
	6	Ash content (550°C)	11.4		% (w/w)	dry basis	Calculation	DIN 51719: 1997-07
	7	Total carbon	35.4		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	8	Total carbon	82.1		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	9	carbon (organic)	35.2		% (w/w)	as received	Calculation	Calculation
	10	carbon (organic)	81.6		% (w/w)	dry basis	Calculation	Calculation
	11	Hydrogen	0.8		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	12	Hydrogen	1.8		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	13	Total nitrogen	0.57		% (w/w)	as received	Calculation	DIN 51732: 2014-07

	14	Total nitrogen	1.32		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	15	Sulphur (S), total	0.10		% (w/w)	as received	Calculation	DIN 51724-3: 2012-07
	16	Sulphur (S), total	0.23		% (w/w)	dry basis	Calculation	DIN 51724-3: 2012-07
	17	Oxygen	1.8		% (w/w)	as received	Calculation	DIN 51733: 2016-04
	18	Oxygen	4.2		% (w/w)	dry basis	Calculation	DIN 51733: 2016-04
	19	Total inorganic carbon (TIC)	0.5		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06
	20	Total inorganic carbon (TIC)	0.2		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	21	carbonate-CO2	0.8		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	22	carbonate-CO2	1.9		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06
	23	H/C ratio (molar)	0.26			as received	Calculation	Calculation
	24	H/C ratio (molar)	0.26			dry basis	Calculation	Calculation
	25	H/Corg ratio (molar)	0.26			as received	Calculation	Calculation
	26	H/Corg ratio (molar)	0.26			dry basis	Calculation	Calculation
	27	O/C ratio (molar)	0.038			as received	Calculation	Calculation
	28	O/C ratio (molar)	0.038			dry basis	Calculation	Calculation
	29	pH in CaCl2	8.7			as received	Conductometry	DIN ISO 10390: 2005-12
	30	salt content	1.97		g/kg	as received	Calculation	BGK III. C2: 2006-09
	31	salt content	0.316		g/l	as received	Calculation	BGK III. C2: 2006-09
	32	Conductivity at 1,2 t pressure	1.1		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	33	Conductivity at 2 t pressure	1.5		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	34	Conductivity at 3 t pressure	2.2		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040

	35	Conductivity at 4 t pressure	2.3		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	36	Conductivity at 5 t pressure	2.8		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
Elements from the micro wave pressure digestion acc. to DIN 22022-1: 2014-07	37	Arsenic (As)	9.7		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	38	Lead (Pb)	38		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	39	Cadmium (Cd)	< 0.2		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	40	Copper (Cu)	184	30	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	41	Nickel (Ni)	22	3.4	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	42	Mercury (Hg)	< 0.07		mg/kg	dry basis	CV-AAS	DIN 22022-4: 2001-02
	43	Zinc (Zn)	316	87	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	44	Chromium (Cr)	66		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	45	Boron (B)	22		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	46	Manganese (Mn)	419		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	47	Silver (Ag)	< 5		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
Elements fr. the borate digestion of ash 550 °C acc. to DIN 51729-11:1998-11(AR)	48	Calcium as CaO	22.4		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	49	Iron as Fe2O3	8.4		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	50	Potassium as K2O	4.5		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	51	Magnesium as MgO	3.7		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	52	Sodium as Na2O	2.7		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	53	Phosphorus as P2O5	2.9		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09

	54	sulphur as SO3	5.7		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	55	Silicon as SiO2	36.3		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
Macronutrients	56	Total nitrogen	5.7		g/kg	as received	Calculation	DIN 51732: 2014-07
	57	Total nitrogen	13.2		g/kg	dry basis	Calculation	DIN 51732: 2014-07
Macronutrients-LiBO2/Li2B4O7/LiBr-melt of ash 550°C [DIN 51729-11:1998-11] (OS)	58	Phosphorus as P2O5	3.3		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	59	Potassium as K2O	5.1		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	60	Calcium as CaO	25.4		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	61	Magnesium as MgO	4.2		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	62	Sodium as Na2O	3.1		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	63	sulphur as SO3	6.5		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
Elements fr. the borate digestion of ash 550°C acc. to DIN 51729-11:1998-11(OS)	64	Iron (Fe)	6.7		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	65	Silicon (Si)	19.3		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
Organic contaminants from toluene extraction acc. to EN 17503	66	Naphthalene	31		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	67	Acenaphthylene	1.2		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	68	Acenaphthene	0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	69	Fluorene	0.2		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	70	Phenanthrene	8.6		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	71	Anthracene	1.8		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	72	Fluoranthene	2.9		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

	73	Pyrene	2.0		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	74	Benz(a)anthracene	0.9		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	75	Chrysene	1.3		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	76	Benzo(b)fluoranthene	1.0		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	77	Benzo(k)fluoranthene	0.5		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	78	Benzo(a)pyrene	0.6		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	79	Indeno(1,2,3-cd)pyrene	0.2		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	80	Dibenz(a,h)anthracene	0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	81	Benzo(g,h,i)perylene	0.2		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	82	Total 8 EFSA-PAH excl. LOQ	4.8		mg/kg	dry basis	Calculation	calculated
	83	Total 16 EPA-PAH excl. LOQ	52.6		mg/kg	dry basis	Calculation	calculated
	84	Benzo(e)pyrene	0.7		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	85	Benzo-(j)-fluoranthen	n.b.		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

Appendix 2.4 Eurofins EBC results-Hazel nutshell biochar 650 °C

	N.O.	Parameter Name	Result	Uncertainty 6	Unit	Reference Substance	Method	Standard
Biochar properties	1	Moisture	47.5	1.4	% (w/w)	as received	Gravimetry	DIN 51718: 2002-06
	2	Ash content (550°C)	8.8		% (w/w)	as received	Calculation	DIN 51719: 1997-07
	3	Ash content (550°C)	16.8		% (w/w)	dry basis	Calculation	DIN 51719: 1997-07
	4	Total carbon	40.7		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	5	Total carbon	77.5		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	6	carbon (organic)	40.1		% (w/w)	as received	Calculation	Calculation
	7	carbon (organic)	76.4		% (w/w)	dry basis	Calculation	Calculation
	8	Hydrogen	1.1		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	9	Hydrogen	2.1		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	10	Total nitrogen	0.51		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	11	Total nitrogen	0.97		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	12	Sulphur (S), total	0.09		% (w/w)	as received	Calculation	DIN 51724-3: 2012-07
	13	Sulphur (S), total	0.17		% (w/w)	dry basis	Calculation	DIN 51724-3: 2012-07
	14	Oxygen	2.8		% (w/w)	as received	Calculation	DIN 51733: 2016-04
	15	Oxygen	5.2		% (w/w)	dry basis	Calculation	DIN 51733: 2016-04
	16	Total inorganic carbon (TIC)	1.1		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06

	17	Total inorganic carbon (TIC)	0.6		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	18	carbonate-CO2	2.2		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	19	carbonate-CO2	4.1		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06
	20	H/C ratio (molar)	0.33			as received	Calculation	Calculation
	21	H/C ratio (molar)	0.33			dry basis	Calculation	Calculation
	22	H/Corg ratio (molar)	0.33			as received	Calculation	Calculation
	23	H/Corg ratio (molar)	0.33			dry basis	Calculation	Calculation
	24	O/C ratio (molar)	0.052			as received	Calculation	Calculation
	25	O/C ratio (molar)	0.050			dry basis	Calculation	Calculation
	26	pH in CaCl2	8.8			as received	Conductometry	DIN ISO 10390: 2005-12
	27	salt content	1.73		g/kg	as received	Calculation	BGK III. C2: 2006-09
	28	Conductivity at 1,2 t pressure	0.05		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	29	Conductivity at 2 t pressure	0.06		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	30	Conductivity at 3 t pressure	0.09		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	31	Conductivity at 4 t pressure	0.10		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	32	Conductivity at 5 t pressure	0.11		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
Elements from the micro wave pressure digestion acc. to DIN 22022-1: 2014-07	33	Arsenic (As)	< 0.8		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	34	Lead (Pb)	5		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	35	Cadmium (Cd)	< 0.2		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	36	Copper (Cu)	47	7.6	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	37	Nickel (Ni)	10	1.6	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	38	Mercury (Hg)	< 0.07		mg/kg	dry basis	CV-AAS	DIN 22022-4: 2001-02

	39	Zinc (Zn)	91	25	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	40	Chromium (Cr)	24		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	41	Boron (B)	37		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	42	Manganese (Mn)	297		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	43	Silver (Ag)	< 5		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
Elements fr. the borate digestion of ash 550 °C acc. to DIN 51729-11:1998-11(AR)	44	Calcium as CaO	36.2		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	45	Iron as Fe2O3	3.7		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	46	Potassium as K2O	3.0		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	47	Magnesium as MgO	2.9		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	48	Sodium as Na2O	0.9		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	49	Phosphorus as P2O5	10.8		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	50	sulphur as SO3	2.3		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	51	Silicon as SiO2	10.6		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
Macronutrients	52	Total nitrogen	5.1		g/kg	as received	Calculation	DIN 51732: 2014-07
	53	Total nitrogen	9.7		g/kg	dry basis	Calculation	DIN 51732: 2014-07
Macronutrients-LiBO2/Li2B4O7/LiBr-melt of ash 550°C [DIN 51729-11:1998-11] (OS)	54	Phosphorus as P2O5	18.2		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	55	Potassium as K2O	5.1		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	56	Calcium as CaO	60.8		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	57	Magnesium as MgO	4.9		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	58	Sodium as Na2O	1.6		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	59	sulphur as SO3	3.9		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
Elements fr. the borate digestion of ash 550°C acc. to	60	Iron (Fe)	4.4		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	61	Silicon (Si)	8.4		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09

DIN 51729-11:1998-11(OS)								
Organic contaminants from toluene extraction acc. to EN 17503	62	Naphthalene	16		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	63	Acenaphthylene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	64	Acenaphthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	65	Fluorene	0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	66	Phenanthrene	1.0		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	67	Anthracene	0.4		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	68	Fluoranthene	0.4		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	69	Pyrene	0.4		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	70	Benz(a)anthracene	0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	71	Chrysene	0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	72	Benzo(b)fluoranthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	73	Benzo(k)fluoranthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	74	Benzo(a)pyrene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	75	Indeno(1,2,3-cd)pyrene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	76	Dibenz(a,h)anthracene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	77	Benzo(g,h,i)perylene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	78	Total 8 EFSA-PAH excl. LOQ	0.2		mg/kg	dry basis	Calculation	calculated
	79	Total 16 EPA-PAH excl. LOQ	18.5		mg/kg	dry basis	Calculation	calculated

	80	Benzo(e)pyrene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	81	Benzo-(j)-fluoranthen	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

Appendix 2.5. Eurofins EBC results-Olive stone biochar 650 °C

	N.O	Parameter Description	Result	Uncertainty	Unit	Reference Substance	Method	Standard
Biochar properties	1	Moisture	6.4	0.19	% (w/w)	as received	Gravimetry	DIN 51718: 2002-06
	2	Ash content (550°C)	4.9		% (w/w)	as received	Calculation	DIN 51719: 1997-07
	3	Ash content (550°C)	5.3		% (w/w)	dry basis	Calculation	DIN 51719: 1997-07
	4	Total carbon	83.8		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	5	Total carbon	89.5		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	6	carbon (organic)	83.1		% (w/w)	as received	Calculation	Calculation
	7	carbon (organic)	88.8		% (w/w)	dry basis	Calculation	Calculation
	8	Hydrogen	1.9		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	9	Hydrogen	2.0		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	10	Total nitrogen	0.46		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	11	Total nitrogen	0.49		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	12	Sulphur (S), total	0.04		% (w/w)	as received	Calculation	DIN 51724-3: 2012-07

	13	Sulphur (S), total	0.04		% (w/w)	dry basis	Calculation	DIN 51724-3: 2012-07
	14	Oxygen	3.0		% (w/w)	as received	Calculation	DIN 51733: 2016-04
	15	Oxygen	3.2		% (w/w)	dry basis	Calculation	DIN 51733: 2016-04
	16	Total inorganic carbon (TIC)	0.7		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06
	17	Total inorganic carbon (TIC)	0.7		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	18	carbonate-CO2	2.4		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	19	carbonate-CO2	2.6		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06
	20	H/C ratio (molar)	0.27			as received	Calculation	Calculation
	21	H/C ratio (molar)	0.26			dry basis	Calculation	Calculation
	22	H/Corg ratio (molar)	0.27			as received	Calculation	Calculation
	23	H/Corg ratio (molar)	0.27			dry basis	Calculation	Calculation
	24	O/C ratio (molar)	0.027			as received	Calculation	Calculation
	25	O/C ratio (molar)	0.027			dry basis	Calculation	Calculation
	26	pH in CaCl2	8.5			as received	Conductometry	DIN ISO 10390: 2005-12
	27	salt content	2.12		g/kg	as received	Calculation	BGK III. C2: 2006-09
	28	Conductivity at 1,2 t pressure	3.9		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	29	Conductivity at 2 t pressure	5.2		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	30	Conductivity at 3 t pressure	6.2		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	31	Conductivity at 4 t pressure	7.9		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	32	Conductivity at 5 t pressure	9.6		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040

Elements from the micro wave pressure digestion acc. to DIN 22022-1: 2014-07	33	Arsenic (As)	< 0.8		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	34	Lead (Pb)	< 2		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	35	Cadmium (Cd)	< 0.2		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	36	Copper (Cu)	22	3.6	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	37	Nickel (Ni)	5	0.78	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	38	Mercury (Hg)	< 0.07		mg/kg	dry basis	CV-AAS	DIN 22022-4: 2001-02
	39	Zinc (Zn)	31	8.6	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	40	Chromium (Cr)	36		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	41	Boron (B)	20		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	42	Manganese (Mn)	75		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	43	Silver (Ag)	< 5		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
Elements fr. the borate digestion of ash 550 °C acc. to DIN 51729-11:1998-11(AR)	44	Calcium as CaO	14.9		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	45	Iron as Fe2O3	4.5		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	46	Potassium as K2O	14.6		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	47	Magnesium as MgO	5.1		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	48	Sodium as Na2O	2.7		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	49	Phosphorus as P2O5	2.5		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	50	sulphur as SO3	1.8		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	51	Silicon as SiO2	36.4		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09

Macronutrients	52	Total nitrogen	4.6		g/kg	as received	Calculation	DIN 51732: 2014-07
	53	Total nitrogen	4.9		g/kg	dry basis	Calculation	DIN 51732: 2014-07
Macronutrients-LiBO2/Li2B4O7/LiBr-melt of ash 550°C [DIN 51729-11:1998-11] (OS)	54	Phosphorus as P2O5	1.3		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	55	Potassium as K2O	7.7		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	56	Calcium as CaO	7.9		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	57	Magnesium as MgO	2.7		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	58	Sodium as Na2O	1.4		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	59	sulphur as SO3	1.0		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
Elements fr. the borate digestion of ash 550°C acc. to DIN 51729-11:1998-11(OS)	60	Iron (Fe)	1.7		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	61	Silicon (Si)	9.0		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
Organic contaminants from toluene extraction acc. to EN 17503	62	Naphthalene	6.3		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	63	Acenaphthylene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	64	Acenaphthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	65	Fluorene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	66	Phenanthrene	0.3		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	67	Anthracene	0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	68	Fluoranthene	0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	69	Pyrene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	70	Benz(a)anthracene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	71	Chrysene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	72	Benzo(b)fluoranthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

	73	Benzo(k)fluoranthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	74	Benzo(a)pyrene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	75	Indeno(1,2,3-cd)pyrene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	76	Dibenz(a,h)anthracene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	77	Benzo(g,h,i)perylene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	78	Total 8 EFSA-PAH excl. LOQ	<0.8		mg/kg	dry basis	Calculation	calculated
	79	Total 16 EPA-PAH excl. LOQ	6.8		mg/kg	dry basis	Calculation	calculated
	80	Benzo(e)pyrene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	81	Benzo-(j)-fluoranthen	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

Appendix 2.6 Eurofins EBC results-Waste wood[b] biochar 650 °C

	N.O.	Parameter Description	Result	Uncertainty	Unit	Reference Substance	Method	Standard
Biochar properties	1	Moisture	60.0	1.8	% (w/w)	as received	Gravimetry	DIN 51718: 2002-06
	2	Ash content (550°C)	3.8		% (w/w)	as received	Calculation	DIN 51719: 1997-07
	3	Ash content (550°C)	9.6		% (w/w)	dry basis	Calculation	DIN 51719: 1997-07
	4	Total carbon	33.3		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	5	Total carbon	83.2		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	6	carbon (organic)	33.0		% (w/w)	as received	Calculation	Calculation

	7	carbon (organic)	82.4		% (w/w)	dry basis	Calculation	Calculation
	8	Hydrogen	0.8		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	9	Hydrogen	2.0		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	10	Total nitrogen	0.55		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	11	Total nitrogen	1.37		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	12	Sulphur (S), total	0.05		% (w/w)	as received	Calculation	DIN 51724-3: 2012-07
	13	Sulphur (S), total	0.12		% (w/w)	dry basis	Calculation	DIN 51724-3: 2012-07
	14	Oxygen	1.9		% (w/w)	as received	Calculation	DIN 51733: 2016-04
	15	Oxygen	4.8		% (w/w)	dry basis	Calculation	DIN 51733: 2016-04
	16	Total inorganic carbon (TIC)	0.8		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06
	17	Total inorganic carbon (TIC)	0.3		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	18	carbonate-CO2	1.2		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	19	carbonate-CO2	3.0		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06
	20	H/C ratio (molar)	0.28			as received	Calculation	Calculation
	21	H/C ratio (molar)	0.28			dry basis	Calculation	Calculation
	22	H/Corg ratio (molar)	0.29			as received	Calculation	Calculation
	23	H/Corg ratio (molar)	0.28			dry basis	Calculation	Calculation
	24	O/C ratio (molar)	0.043			as received	Calculation	Calculation
	25	O/C ratio (molar)	0.043			dry basis	Calculation	Calculation
	26	pH in CaCl2	9.2			as received	Conductometry	DIN ISO 10390: 2005-12

	27	salt content	6.25		g/kg	as received	Calculation	BGK III. C2: 2006-09
	28	Conductivity at 1,2 t pressure	0.38		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	29	Conductivity at 2 t pressure	0.48		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	30	Conductivity at 3 t pressure	0.68		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	31	Conductivity at 4 t pressure	0.71		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	32	Conductivity at 5 t pressure	0.86		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
Elements from the micro wave pressure digestion acc. to DIN 22022-1: 2014-07	33	Arsenic (As)	8.7		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	34	Lead (Pb)	29		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	35	Cadmium (Cd)	< 0.2		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	36	Copper (Cu)	251	41	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	37	Nickel (Ni)	13	2	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	38	Mercury (Hg)	< 0.07		mg/kg	dry basis	CV-AAS	DIN 22022-4: 2001-02
	39	Zinc (Zn)	196	54	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	40	Chromium (Cr)	74		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	41	Boron (B)	26		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	42	Manganese (Mn)	339		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	43	Silver (Ag)	< 5		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
Elements fr. the borate digestion of ash 550 °C acc. to DIN 51729-11:1998-11(AR)	44	Calcium as CaO	18.1		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	45	Iron as Fe2O3	4.6		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	46	Potassium as K2O	7.3		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	47	Magnesium as MgO	3.3		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	48	Sodium as Na2O	4.9		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09

	49	Phosphorus as P2O5	1.6		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	50	sulphur as SO3	3.3		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	51	Silicon as SiO2	31.3		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
Macronutrients	52	Total nitrogen	5.5		g/kg	as received	Calculation	DIN 51732: 2014-07
	53	Total nitrogen	13.7		g/kg	dry basis	Calculation	DIN 51732: 2014-07
Macronutrients-LiBO2/Li2B4O7/LiBr-melt of ash 550°C [DIN 51729-11:1998-11] (OS)	54	Phosphorus as P2O5	1.5		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	55	Potassium as K2O	6.9		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	56	Calcium as CaO	17.3		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	57	Magnesium as MgO	3.2		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	58	Sodium as Na2O	4.7		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	59	sulphur as SO3	3.1		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
Elements fr. the borate digestion of ash 550°C acc. to DIN 51729-11:1998-11(OS)	60	Iron (Fe)	3.1		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	61	Silicon (Si)	14.0		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
Organic contaminants from toluene extraction acc. to EN 17503	62	Naphthalene	29		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	63	Acenaphthylene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	64	Acenaphthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	65	Fluorene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	66	Phenanthrene	0.9		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	67	Anthracene	0.4		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	68	Fluoranthene	0.4		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	69	Pyrene	0.4		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

	70	Benz(a)anthracene	0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	71	Chrysene	0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	72	Benzo(b)fluoranthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	73	Benzo(k)fluoranthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	74	Benzo(a)pyrene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	75	Indeno(1,2,3-cd)pyrene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	76	Dibenz(a,h)anthracene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	77	Benzo(g,h,i)perylene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	78	Total 8 EFSA-PAH excl. LOQ	0.2		mg/kg	dry basis	Calculation	calculated
	79	Total 16 EPA-PAH excl. LOQ	31.3		mg/kg	dry basis	Calculation	calculated
	80	Benzo(e)pyrene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	81	Benzo-(j)-fluoranthen	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

Appendix 2.7 Eurofins EBC results-PKS biochar 650 °C

	N.O.	Parameter Description	Result	Uncertainty	Unit	Reference Substance	Method	Standard
Biochar properties	1	Moisture	22.7	0.68	% (w/w)	as received	Gravimetry	DIN 51718: 2002-06
	2	Ash content (550°C)	13.3		% (w/w)	as received	Calculation	DIN 51719: 1997-07
	3	Ash content (550°C)	17.2		% (w/w)	dry basis	Calculation	DIN 51719: 1997-07
	4	Total carbon	60.5		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	5	Total carbon	78.3		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	6	carbon (organic)	60.2		% (w/w)	as received	Calculation	Calculation
	7	carbon (organic)	77.9		% (w/w)	dry basis	Calculation	Calculation
	8	Hydrogen	1.6		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	9	Hydrogen	2.1		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	10	Total nitrogen	0.82		% (w/w)	as received	Calculation	DIN 51732: 2014-07
	11	Total nitrogen	1.06		% (w/w)	dry basis	Calculation	DIN 51732: 2014-07
	12	Sulphur (S), total	0.09		% (w/w)	as received	Calculation	DIN 51724-3: 2012-07
	13	Sulphur (S), total	0.12		% (w/w)	dry basis	Calculation	DIN 51724-3: 2012-07
	14	Oxygen	1.1		% (w/w)	as received	Calculation	DIN 51733: 2016-04
	15	Oxygen	1.5		% (w/w)	dry basis	Calculation	DIN 51733: 2016-04
	16	Total inorganic carbon (TIC)	0.4		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06

	17	Total inorganic carbon (TIC)	0.3		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	18	carbonate-CO2	1.2		% (w/w)	as received	Calculation	DIN 51726: 2004-06
	19	carbonate-CO2	1.6		% (w/w)	dry basis	Calculation	DIN 51726: 2004-06
	20	H/C ratio (molar)	0.32			as received	Calculation	Calculation
	21	H/C ratio (molar)	0.32			dry basis	Calculation	Calculation
	22	H/Corg ratio (molar)	0.32			as received	Calculation	Calculation
	23	H/Corg ratio (molar)	0.32			dry basis	Calculation	Calculation
	24	O/C ratio (molar)	0.014			as received	Calculation	Calculation
	25	O/C ratio (molar)	0.014			dry basis	Calculation	Calculation
	26	pH in CaCl2	8.5			as received	Conductometry	DIN ISO 10390: 2005-12
	27	salt content	1.02		g/kg	as received	Calculation	BGK III. C2: 2006-09
	28	Conductivity at 1,2 t pressure	0.06		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	29	Conductivity at 2 t pressure	0.10		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	30	Conductivity at 3 t pressure	0.12		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	31	Conductivity at 4 t pressure	0.15		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
	32	Conductivity at 5 t pressure	0.15		mS/cm	dry basis	Conductometry	Internal Method SAA-H-Lf-Pflanzenkohle.040
Elements from the micro wave pressure digestion acc. to DIN 22022-1: 2014-07	33	Arsenic (As)	1.0		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	34	Lead (Pb)	4		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	35	Cadmium (Cd)	< 0.2		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	36	Copper (Cu)	81	13	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01

	37	Nickel (Ni)	8	1.2	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	38	Mercury (Hg)	< 0.07		mg/kg	dry basis	CV-AAS	DIN 22022-4: 2001-02
	39	Zinc (Zn)	41	11	mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	40	Chromium (Cr)	98		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	41	Boron (B)	18		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	42	Manganese (Mn)	140		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
	43	Silver (Ag)	< 5		mg/kg	dry basis	ICP-MS	DIN EN ISO 17294-2 (E29): 2017-01
Elements fr. the borate digestion of ash 550 °C acc. to DIN 51729-11:1998-11(AR)	44	Calcium as CaO	2.4		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	45	Iron as Fe2O3	7.9		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	46	Potassium as K2O	3.0		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	47	Magnesium as MgO	1.7		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	48	Sodium as Na2O	0.2		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	49	Phosphorus as P2O5	2.3		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	50	sulphur as SO3	1.2		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
	51	Silicon as SiO2	62.1		% (w/w)	dry basis	ICP-OES	DIN EN ISO 11885 (E22): 2009-09
Macronutrients	52	Total nitrogen	8.2		g/kg	as received	Calculation	DIN 51732: 2014-07
	53	Total nitrogen	10.6		g/kg	dry basis	Calculation	DIN 51732: 2014-07
Macronutrients-LiBO2/Li2B4O7/LiBr-melt of ash 550°C [DIN 51729-11:1998-11] (OS)	54	Phosphorus as P2O5	3.9		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	55	Potassium as K2O	5.1		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	56	Calcium as CaO	4.1		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	57	Magnesium as MgO	3.0		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09

	58	Sodium as Na2O	0.3		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	59	sulphur as SO3	2.0		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
Elements fr. the borate digestion of ash 550°C acc. to DIN 51729-11:1998-11(OS)	60	Iron (Fe)	9.5		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
	61	Silicon (Si)	49.9		g/kg	dry basis	Calculation	DIN EN ISO 11885 (E22): 2009-09
Organic contaminants from toluene extraction acc. to EN 17503	62	Naphthalene	8.8		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	63	Acenaphthylene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	64	Acenaphthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	65	Fluorene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	66	Phenanthrene	0.6		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	67	Anthracene	0.2		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	68	Fluoranthene	0.2		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	69	Pyrene	0.2		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	70	Benz(a)anthracene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	71	Chrysene	0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	72	Benzo(b)fluoranthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	73	Benzo(k)fluoranthene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	74	Benzo(a)pyrene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	75	Indeno(1,2,3-cd)pyrene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

	76	Dibenz(a,h)anthracene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	77	Benzo(g,h,i)perylene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	78	Total 8 EFSA-PAH excl. LOQ	0.1		mg/kg	dry basis	Calculation	calculated
	79	Total 16 EPA-PAH excl. LOQ	10.1		mg/kg	dry basis	Calculation	calculated
	80	Benzo(e)pyrene	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08
	81	Benzo-(j)-fluoranthen	< 0.1		mg/kg	dry basis	GC-MS	DIN EN 17503, Verfahren 10.2.3: 2022-08

Appendix 3 Output 6 Mesocosm experiments
1. Crop yields

Across both sites, crops harvested to date include winter wheat, spring barley and oats. Harvesting was carried out using a small combine harvester which removed grain from a 2 m strip along the 12 m length of each plot.

Oat yield at Sutton Bonington (sandy loam soil), 2022 The trials at Sutton Bonington and Clifton began with application of two different wood-based biochars. The first harvest occurred in the late summer after deployment the previous autumn. No effect of treatment on either the yield (Figure A3.1) or the 1000-grain weight was observed; the latter ranged from 34.03 g for the control to 33.86 g for the Wood A biochar and 33.48 g for the oats grown with the Wood B1 biochar (LSD = 1.33). The neutral effects of the biochars indicated no immediate negative effects of adding biochar to the soil so further treatments were subsequently deployed. This result was pleasing because 'raw' biochar was utilised here as it is simpler to apply than pre-charged biochar. The aim was to simulate the most likely commercial and cost-effective scenario. Following this harvest, biochars were subsequently further deployed, including a compost amendment (at 30 t ha^{-1}) both with and without Wood B biochar. The crop at the Clifton site was fodder maize and samples were not taken.

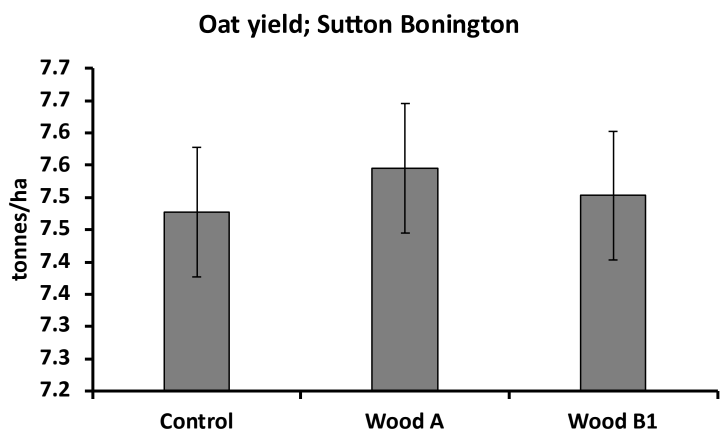


Figure A3.1 Oat yield at the Sutton Bonington site. Wood A and Wood B1 biochars were deployed in 2021 prior to seed sowing. Harvest was in summer 2022.

Winter wheat yield at Sutton Bonington (sandy loam soil, 2023). Grain yields for plots treated with two different wood-based biochars (Wood A and Wood B) prior to sowing are shown in Figure A3.2. Wood A was deployed once in 2021, whilst Wood B biochar was applied either once (Wood B2 in 2022) or twice (Wood B1 [2021] & B2 [2022]). The data shown are designated 'all data' and 'adjusted for lodging'. Adverse weather conditions prior to harvest resulted in some lodging (which occurs when stems are bent to ground level, usually because of heavy rain). The 'all data' yields represent the data obtained across all plots irrespective of lodging and thus represent the absolute yield. However, in order to determine biochar treatment effects, lodging was accounted for in further statistical analysis and these data are shown as 'adjusted for lodging'. The 'all data' yields were significantly lower in the Compost+Wood B2 plots relative to all other treatments (p=0.006, LSD 1.44). This is not surprising because lodging was most severe in these plots; the reason for that is unknown and it may simply be chance. A key cause of lodging is a high soil nitrogen concentration, but in this case, there were no significant differences in either total nitrogen or water-extractable nitrogen in these plots. It is possible that any additional N released by the compost may have been rapidly sequestered by the soil microorganisms, but this needs further examination. However, when lodging was corrected for, no significant treatment effect was observed. The difference between the actual yield ('all data') and the 'lodging adjusted yield' equates to 1.2 tonnes per hectare for the Compost+Wood B2 plots and 0.4 tonnes per hectare for the Compost only plots. Therefore, at the rates applied, the wood-based biochars did not affect crop yield in the sandy-loam soil at the Sutton Bonington site, irrespective of year of application or concentration.

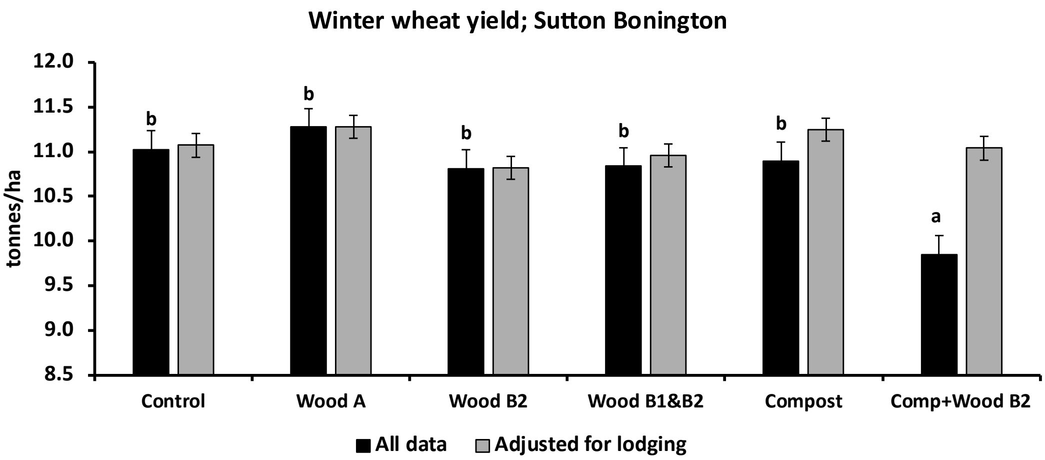


Figure A3.2 Winter wheat yield at the Sutton Bonington site. Harvest was in 2023 and included more treatments than the previous year. Columns similarly superscripted are not significantly different.

A further measurement, the 1000-grain weight may be used as an indicator of stress, but no differences across treatments were observed with weights ranging from 39.73 – 42.13 g (LSD = 2.5). The higher weights were from the biochar-treated plots (single applications), but the differences were not significant (Figure A3.3).

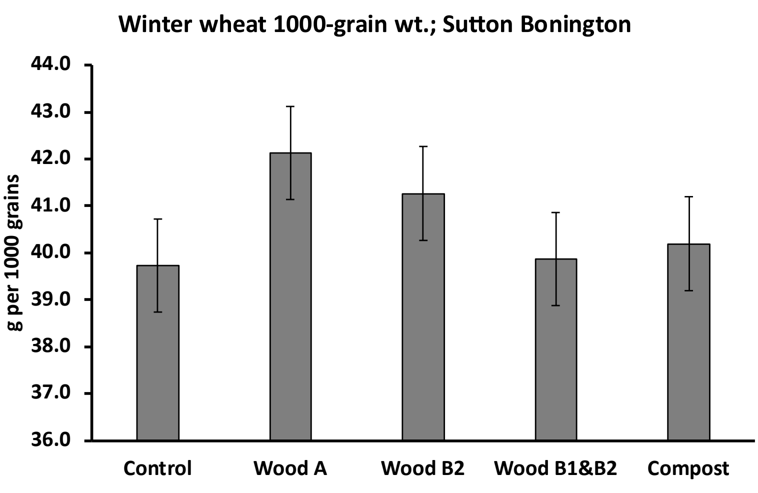


Figure A3.3 The 1000-grain weights of winter wheat grown at the Sutton Bonington site. Harvest was in 2023.

<ins>Winter wheat yield at Clifton (clay soil, 2023)</ins> The crop growing on the heavy clay soil at the Clifton site was badly affected by lodging irrespective of treatment. This is reflected in the lower 1000-grain weights (26.74 – 28.30 g per 1000 grains) and

yields (overall average of 6.76 tonnes ha^{-1} across all plots) compared to the same crop at the Sutton Bonington site. The crop was harvested, but no lodging adjustments were made because of the 'blanket effect' across the field (Figure A3.4). No significant treatment differences were observed.

Figure A3.4 Severe lodging of the winter wheat crop because of heavy rain at the Clifton site.

Spring barley yield at Clifton (clay soil, 2024) Following the 2024 harvest, an additional biochar made from cocoa husk was deployed at 10 t ha^{-1} at both sites, either as a single treatment or with a previously deployed wood biochar. No significant yield differences were observed (LSD = 1.55). Neither the timing of the biochar applications nor the concentration applied affected the yield Figure A3.5). Simultaneous application of compost did not enhance any effects of the biochar. This may be because the field is commercially farmed, and sufficient nutrients had been applied for optimum barley growth making others effectively redundant.

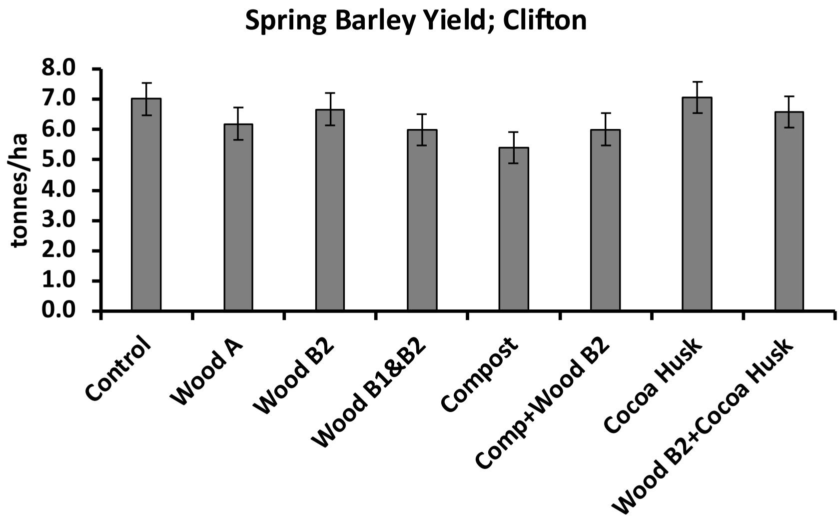


Figure A3.5 Spring barley yield at the Clifton site. Harvest was in summer 2024.

The 1000-grain weight was not significantly affected by treatment, biochar concentration, or application date. The weights range from 42.81 - 46.84 g (LSD = 5.41). There appears to be a trend towards a slightly higher grain weight following application of Wood B biochar, but since this is not statistically significant, it should be discounted (Figure A3.6).

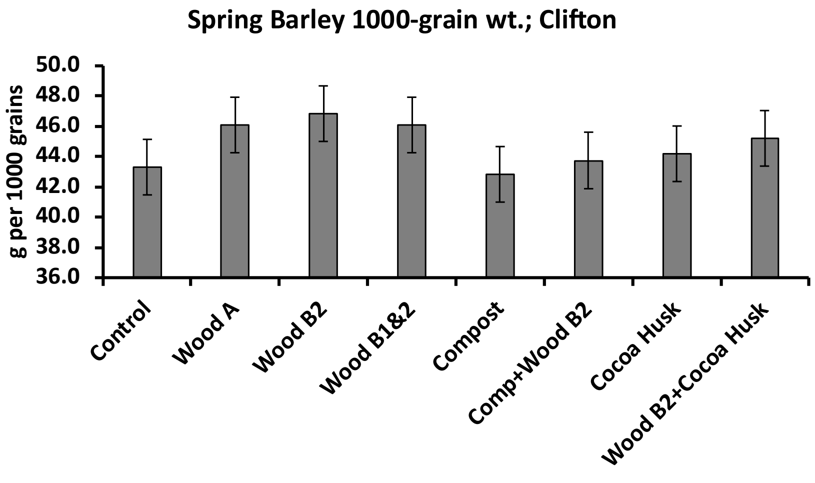


Figure A3.6 The 1000-grain weight of spring barley harvested in 2024. The crop was grown at the Clifton site.

2. Soil nutrient status

Soil samples were, and are, taken at intervals from each plot every year from initial set-up. A complete suite of analyses has been, and is being, undertaken. For simplicity, data for key macro- and micro-nutrients sampled in February 2023 are shown below because this sampling point followed harvest of wheat from both sites the previous Autumn, therefore any differences are unlikely to be crop-induced. The data shown are for water-extractable nutrients because these are plant-available and arguably more meaningful than total nutrient content.

Treatments at the Sutton Bonington site did not significantly affect the available elemental concentrations or the pH of the sandy loam soil. The one exception was water-exchangeable carbon concentrations which were higher in the plots amended with compost (alone) than in the control (21.05 mg kg^{-1} versus 17.99 mg kg^{-1} respectively; $p=0.047$, LSD = 1.84).

In contrast, treatment effects were observed in the Clifton (clay) soil for most of the elements analysed. The separation across samples is illustrated by the Discriminant Analysis plot (Figure A3.7), which shows clear separation of both compost treatments (single and with biochar) along the y-axis, whilst the two Wood B treatments (B1 & B2 and B2 alone) were separated from the Wood A and Control soils along the x-axis.

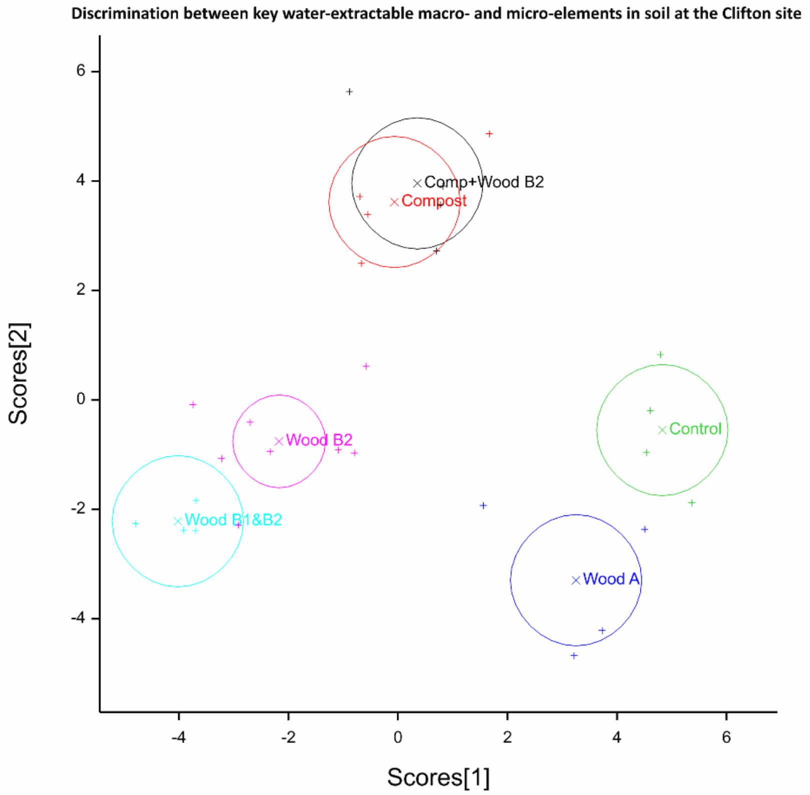


Figure A3.7 Discriminant analysis of key macro- and micro-nutrients showing separation of the treatment groups.

A key driver of the separation of the two compost treatments was the broadly higher concentrations of a range of extractable nutrients in plots amended with those two treatments. This is exemplified here with data relating to pH and available potassium concentrations (Figure A3.8 a & b). Generally, the Control and Wood A amended soils had lower extractable elemental concentrations than plots where Wood B biochars had been deployed. Doubling the Wood B biochar concentration over a year to 20 t ha^{-1} made little difference. The data so far suggests that both sandy loam and clay soils can be amended with 20 t ha^{-1} of wood-based biochar without any adverse effects on cereal crop yield or on soil nutrients, including nitrogen.

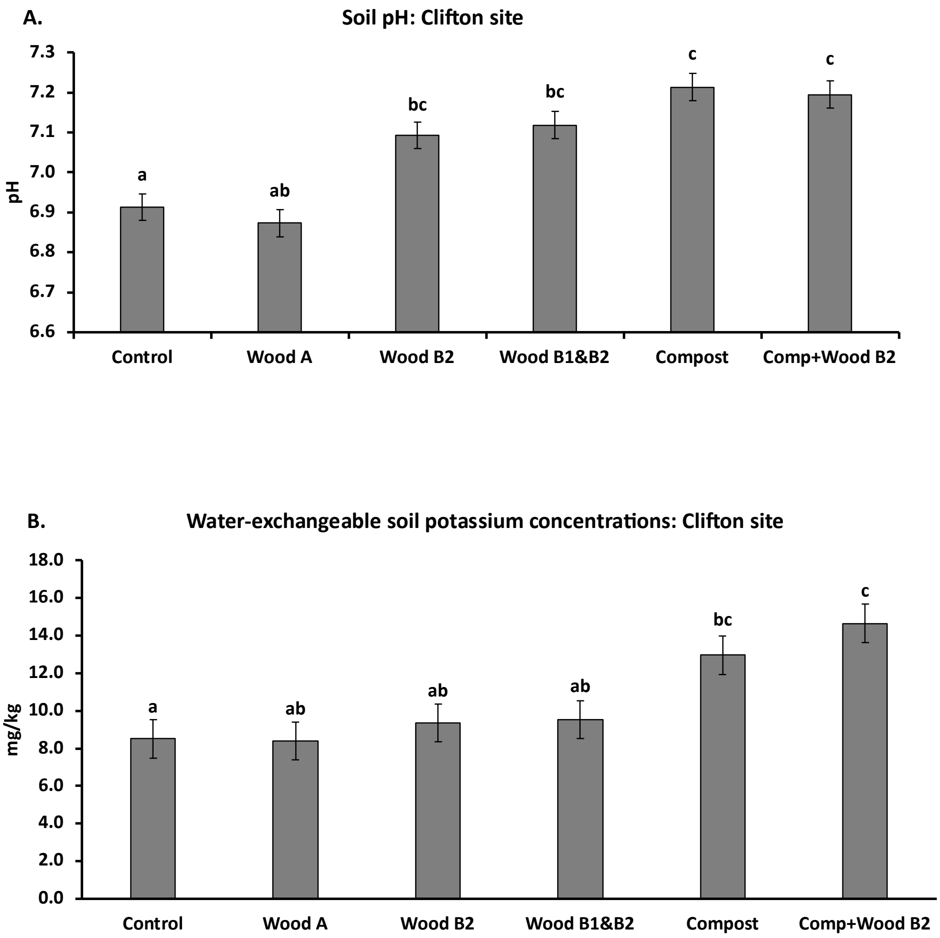


Figure A3.8 A: pH of soil amended with a ranged of biochar/compost treatments. Significant differences were observed ($p<0.001$; LSD = 0.14). B: Potassium concentrations illustrating the effects of the two compost treatments ($p<0.001$; LSD = 3.0).

Appendix 4 Invica Industires Commercial Plan

1. Introduction

Brief overview of the Invica Industries Invica Industries are amongst the largest producers of smokeless solid fuels in Europe for domestic heating. Invica have a solid fuel production capacity of 400,000 tonnes annually across the United Kingdom (UK) and Ireland and were established over 40 years ago.

For majority of the last 40 years, Invica sold only coal-based products, including regular house coal and coal-based smokeless solid fuel (low smoke producing coals) suitable for use in smoke-controlled areas. Following the ban of house coal in 2021 (DEFRA, 2021), Invica now exclusively sell smokeless fuel or ‘ready to burn’ certified fuel (biomass products). Invica Industries are now embarking on a journey to produce biochar from inhouse technology. Invica Industries are open to be a technology provider, biochar producer and also, a biochar off taker.

Mission statement Invica Industries our mission is to harness the potential of waste materials to produce high-quality biochar, contributing to carbon sequestration, decarbonisation, and a sustainable future. We are committed to transforming organic waste into valuable resources, reducing greenhouse gas emissions, and promoting environmental stewardship. Through innovative technologies and sustainable practices, we aim to create a positive impact on the planet while providing versatile solutions for agriculture, industry, and beyond.

Key Company Objectives Our key objectives in this project revolve around producing biochar that serves multiple purposes, including carbon sequestration and decarbonisation within the steel industry. By utilising a variety of waste materials, we aim to create biochar that not only enhances soil health but also stores carbon, thereby reducing greenhouse gas emissions. This functionality positions our biochar as a valuable resource for agricultural, industrial, and other environmental applications such as a low-level activated carbon for flue gas treatment (FGT). Our commitment to sustainability and innovation drives us to continuously improve our processes and expand the potential uses of biochar, contributing to a greener and more sustainable future. Producing biochar is a strong commercial vehicle for Invica Industries. If Biochar production is proven to be commercially viable it will create a new division within the group and create many new jobs moving forward.

2. Market Analysis

<u>Industry overview</u>

PESTEL	Weaknesses and Threats	Strengths and Opportunities
Political	• Carbon credit system replaced • Reduced investment and Government support into carbon sequestration technologies	• Net Zero targets • Climate change • Carbon credits • Carbon tax • R&D incentives Immediate carbon removal capability, not dependent on CO2 sequestration. • Potential direct Government support for biochar
Environmental	• Biochar sequestration shows potential issues when buried in certain environments when the biochar does not meet certain standards, for examples, agriculture use, where leaching could then occur.	• Biochar production locks carbon in the ground preventing CO_2 emissions • Soil remediation – soil carbon improvement droughts, surface water run off, nutrient retention, potentially increased crop growth. • Less coal used in FGT products • Diverting waste destined for landfill and incineration

		• Removal of microplastics from AD digestate
Social	• Plant location could raise public opposition.	• Potential to use any excess heat for local area • Collection and disposal of food waste • Jobs
Technological	• Other alternatives to carbon sequestration in development	• Use of biochar in other sectors before sequestration – water, flue gas. • Energy recovery system used in other sectors
Economic	• Gate fee reduction • Land spreading cost • Inflation - Capital cost increase • Carbon credit decrease • Biochar price for combustion decrease	• Carbon credit increase • Biochar price for combustion increase • Renewable energy generation • Biochar potentially competitive against other technologies in terms of £tCO_2/e
Legal	• Biochar standard legislation change	• Regulations on recycling food waste and other materials, such as oversized compost that carry waste codes preventing their current use for biochar production. • Biochar standard regulation change

The PESTEL analysis offers insight into external influences that can impact the commercial viability of biochar production technology from food AD screenings. The analysis has been divided into two sections to highlight the strengths and opportunities, as well as the weaknesses and threats. Overall, there are many positives to be taken from the PESTEL analysis.

The concern over climate change is well-documented, and targets are in place to achieve net zero. Without technologies such as carbon sequestration, these targets will be difficult to meet and curb net anthropogenic CO_2 emissions. However, with the cost-of-living crisis, it is possible that renewable targets will be pushed back on the priority list.

Environmentally, this project can have many positive impacts, including the reduction of atmospheric CO_2, replacing coal in FGT, and improving soil quality. Socially, a process like this will create management-level and operator jobs in local communities. Technological advancements in the project can also be implemented in other sectors, such as producing non-wood BBQ fuels, helping to decarbonise industries that use fossil solid fuels, or biochar for activated carbon production.

Economic situations can have a positive or negative impact on the commercial viability of the project. Carbon credits are unstable, and whilst gate fees are on the rise, there is always the potential for alternative technology to emerge, making it viable to dispose of waste for free. Inflation has also caused the plant CAPEX to increase, potentially leading to longer payback periods.

External legal influences include regulations relating to biochar standards for sequestration and the push to increase food recycling across the UK. Both can aid the project's commercial success; however, if not implemented, they could flood the market with low-quality, unstable biochar and reduce the food waste volumes available for AD. However, more unstable biochar would reduce payments from carbon trading platforms. Specifications for given uses now exist and could be adopted by the UK.

Target market and market needs

The current market needs for biochar are primarily driven by its applications in agriculture, aggregates, environmental management, and industrial uses. Although still early stages Invica believe biochar has potential use in agriculture with biochar’s ability to enhance soil fertility, improve water and nutrient retention, and increase crop yields. Research suggests that farmers are increasingly adopting biochar as a sustainable alternative to chemical fertilisers or to try and minimise fertiliser use giving carbon savings. Additionally, biochar's role in carbon sequestration makes it an attractive option for reducing greenhouse gas emissions and promoting environmental sustainability. It is unclear at this time how the commercials would work with the farmers who would need to see some clear benefit before taking the biochar for free.

In the industrial sector, biochar is used as a low-value activated carbon for filtration and purification processes. Its ability to remove contaminants from water and air makes it a valuable resource for industries seeking to improve their environmental footprint. Furthermore, biochar is being explored for its potential in various applications, such as a fabric additive in the textile industry, a raw material in building materials, and a shield against electromagnetic radiation in electronics.

Additionally, Invica are seeking biochar to blend with activated carbon for filtration and purification processes. For example, flue gas treatment in waste to energy sites. By maximising the value of biochar through these applications before it is sequestered, we can tap into diverse markets and contribute to sustainable practices and carbon sequestration efforts. Invica Industries can also use biochar in their ecoke product to help decarbonise the steel industry.

Looking ahead, the future market needs for biochar are expected to expand as technological advancements and environmental awareness continue to drive demand. The biochar market is projected to grow significantly, with increasing applications in agriculture, carbon capture, and industrial uses. The construction industry is also recognising biochar's potential and are starting to incorporate it into building materials to enhance insulation properties and reduce the carbon footprint of structures. Additionally, the growing interest in carbon credit markets is expected to bolster the biochar industry, as companies and governments seek innovative ways to offset their carbon emissions.

2. Financial Plan

The three options considered are:

1. AD Digestate Screenings at Immingham or Severn Trent Green Power site (delivery will still be required)
2. Cleaned and sized oversized compost
3. Blend of AD screenings and oversized compost

The second and third options with oversized compost are included to demonstrate cases where there the quantities of AD digestate screenings are below the required amount of 10,000 tonnes p.a. (dry basis) to operate a plant without any other feedstocks. The cost of transport of feedstock is included in the analysis, but not biochar since it will be deployed close to the point of production, and it has a considerably higher bulk density than the feedstocks considered here. A feedstock transportation distance of 10 miles is considered in every case, with a cost per mile of £0.36 for each tonne.

AD Digestate Screenings To recap, the project has shown the HTC followed by Pyrolysis (Route 1) can be ruled out with the added CAPEX removing any energy benefit of going through HTC rather than using waste heat to dry the feedstock. The comparison in Figure 6.1 (Output 6) indicates Route 1 is now even less attractive due to the increasing capital costs for HTC and Route 2 is profitable solely on the gate fee received (Table A4.1), without considering the income from carbon trading and commercial applications of the biochar. This has arisen through the reduced capital costs operating at a scale of 10kt/y dry feedstock, using the maximum size of kiln available. Further, the net CO_2 equivalent sequestered is greater for route 2 (Figure 6.2), at 1.83 tonnes per tonne of biochar.

Table A4.1 Costs for processing AD screenings with the only income is from the gate fee

Pyrolysis		
Gate fee	-£483.33	£/t-biochar
Digestate transportation	£40.00	£/t-biochar
Fixed OPEX	£180.82	£/t-biochar
Variable OPEX	£45.80	£/t-biochar
Annualised CAPEX (20 years)	£101.85	£/t-biochar
Total	**-£114.86**	£/t-biochar

AD screenings can produce biochar at low cost, making it an attractive option. However, this cost-effectiveness comes with a trade-off: the resulting biochar often contains higher levels of ash. This increased ash content can limit the biochar's application potential, as it may not meet the quality standards required for certain commercial uses for example in ecoke, filtration or may contain too many metals for soil enhancement. This can be negated by co-feeding the AD screenings with another feedstock, as demonstrated here with oversized compost. Additionally, feeding AD screenings into the plant on its own can present challenges due to low density causing issues with feeding screws.

Despite these challenges, the economic benefits of using AD screenings for biochar production make it a viable option (Table1). The process is cost-negative due to a an estimated gate fee of £58 per wet tonne of digestate. However, gate fees aren't always stable and this needs to be taken into consideration. Income from carbon trading has not been considered which would make the process more profitable. Trials are currently underway to densify the AD screening further to reduce moisture content, which could enhance the efficiency and quality of the resulting biochar. With around 12,000 wet tonnes of AD screenings available from Severn Trent Green Power now, and this amount set to double by 2030, the potential for biochar production from AD screenings is significant.

Oversized Compost **I**nvica Industries is exploring the use of oversized compost as an alternative feedstock for biochar production. This approach leverages the availability of oversized compost, which can be delivered to Invica at a low cost. The estimated production cost for biochar using oversized compost is just over £500 including the purchase price and transportation (Table A4.2 and Output 6, Figure 6.3), making it a possibility solution for sustainable biochar production. This is because the ash in oversized biochar is much lower and can be used for higher value applications such as in ecoke. The oversized feedstock once shredded can be fed into the plant relatively easily. The level of carbon sequestration achieved for the oversized compost is higher than for the digestate (2.25 tonnes CO_2 equiv. (Output 6, Figure 6.4) due to its higher carbon content.

Table A4.2 Costs for processing oversized compost

Pyrolysis		
Oversized fee	£40.00	£/t-biochar
Oversized transportation	£32.01	£/t-biochar

Fixed OPEX	£241.09	£/t-biochar
Variable OPEX	£61.07	£/t-biochar
Annualised CAPEX	£135.80	£/t-biochar
Total	**£509.97**	£/t-biochar

Digestate Screenings: Oversized Compost (70:30) Blending AD screenings and oversized compost in a 70:30 ratio could be an ideal solution for biochar production. This combination leverages the strengths of both materials, with AD screenings providing a cost-effective feedstock and oversized compost contributing to lower ash content. By mixing these materials, the resulting biochar can achieve a balance of quality and cost-efficiency. The blend can be fed into the waste heat dryer and then into the rotary kiln, optimising the production process. The production cost of biochar can be brought down to £30 per tonne (Table A4.3 and Output 6, Figure 6.5), excluding potential income from flue gas treatment and carbon credits. While ash content will still need to be considered, for certain applications, a higher ash content is acceptable in others such as flue gas treatment. As expected, the level of carbon sequestration is close to 2 tonnes CO_2 equivalent per tonne of biochar (Output 6, Figure 6.6).

Table A4.3 Costs for processing digestate screenings: oversized compost (70:30)

Pyrolysis		
Gate fee	-£365.77	£/t-biochar
Oversized compost fee	£9.73	£/t-biochar
Digestate/ Oversized transportation	£30.27	£/t-biochar
Fixed OPEX	£195.48	£/t-biochar
Variable OPEX	£49.51	£/t-biochar
Annualised CAPEX	£110.11	£/t-biochar
Total	**£29.34**	£/t-biochar

3. Biochar value

Invica Industries is exploring the use of digestate biochar combined with oversized compost as an activated carbon filler for flue gas treatment. This pathway represents the highest value for Invica, aside from using the biochar in ecoke. However, in ecoke applications, the biochar is combusted, whereas in flue gas treatment, the biochar is eventually sequestered, providing a more sustainable solution and can gain further income through access to carbon credits.

Table A4.4 Financial Analysis

AD Screenings 70%, Oversized Compost 30%	10,000 (tonnes pa,db)
Biochar plant CAPEX + 20% contingency	£4,000,000
Biochar production net cost/t	-£59.71
Biochar Production tonnes	3700
Total cost	-£220,927
Carbon content of biochar wt%	56.65%
Carbon credits £100/t CO2eq	£207.72
Revenue Carbon Credit potential	£768,551.67

4. Plant operations cost example:

The below costings are based on OPEX of a plant based at Immingham UK for 10,000 tonnes (db) feedstock input per year.

Staff	**Amount**		**Annual Cost**
OP estimated (5 shifts)	5	£30,000.00	£150,000.00
FLT estimated (5 shifts)	5	£27,500.00	£137,500.00
supervisor	1	£32,000.00	£32,000.00
Manager	1	£38,000.00	£38,000.00
Plant Equipment Rental			
FLT	52	£130.00	£6,760.00
Telehandler	52	£300.00	£15,600.00
Cooler	52	£56.00	£2,912.00

Utilities (see usage tab)			
Gas Est - Kwh	880000	£0.05	£44,000.00
Ele Est - Kwh	532000	£0.22	£117,040.00
Land Rent			
Acre	1	£30,000.00	£30,000.00
Training			
Staff	12	£1,000.00	£12,000.00
H+S			
equipment	1	£5,000.00	£5,000.00
Workwear			
Staff	12	£350.00	£4,200.00
Consumables			
Bags	2700	£5.00	£13,500.00
Pallets	2700	£10.00	£27,000.00
bag labels	2700	£0.50	£1,350.00
stationary			
R&M			
routine maintenance	1	£50,000.00	£50,000.00
		Total	**£686,862**

4. Implementation Plan

2026/2027: Commercial Design

- **Q1 2026**: Begin designing the commercial biochar production plant, incorporating insights from R&D.
- **Q2 2026**: Develop detailed engineering plans and specifications for the commercial plant.
- **Q3:Q4 2027**: Secure necessary permits and approvals for plant construction.
- **Q1 2027**: Finalize commercial plant design and prepare for construction phase.
- **Q2 2027**: Order equipment and materials required for plant construction.
- **Q3+Q4 2027**: Begin initial site preparations and groundwork for the commercial plant.

2028: Commercial Plant Build

- **Q1 2028**: Commence full-scale construction of the commercial biochar production plant.
- **Q2 2028**: Continue construction, focusing on key infrastructure and installation of major equipment.
- **Q3 2028**: Complete construction and begin commissioning and testing of the commercial plant.
- **Q4 2028**: Finalize commissioning, conduct trial runs, and prepare for full-scale commercial production.

5. Funding for commercialisation

To achieve commercial-scale biochar production, Invica Industries will require significant investment. This can be sourced internally or through external investors, or via a joint venture with other companies such as STGP. Internal funding would allow Invica to maintain full control over the project, while external investors could provide the necessary capital infusion to expedite the process. A joint venture with STGP or other organisations such as water companies and councils could leverage shared resources, expertise, and infrastructure, reducing the financial burden on Invica and fostering collaborative innovation. Regardless of the funding source, the investment will be crucial for scaling up production and ensuring the commercial viability of biochar.

6. Risk Analysis for Commercialising a Biochar Production Facility

<u>1. Financial Risks</u>

- **Risk:** High initial capital investment and potential cost overruns during construction and commissioning.
- **Mitigation:** Invica will aim to secure diverse funding sources, including internal funds, external investors, and joint ventures. Establish a detailed budget and contingency fund to cover unexpected expenses.

<u>2. Technical Risks</u>

- **Risk:** Technical challenges in scaling up production processes from demonstrator to commercial scale.
- **Mitigation:** Conduct thorough R&D and pilot testing to refine processes and selection of feedstocks to design the plant around.

<u>3. Supply Chain Risks</u>

- **Risk:** Inconsistent supply of feedstock materials, such as AD screenings and oversized compost.

- **Mitigation:** Establish long-term contracts with reliable suppliers. Diversify feedstock sources to reduce dependency on a single supplier.

4. Regulatory Risks

- **Risk:** Changes in environmental regulations and compliance requirements.
- **Mitigation:** Invica will stay informed about regulatory changes and engage with regulatory bodies. Implement best practices for environmental compliance and obtain necessary permits and certifications.

5. Market Risks

- **Risk:** Fluctuations in market demand and biochar prices and available applications.
- **Mitigation:** Conduct market research to understand demand trends. Explore other value-added applications, such as flue gas treatment and carbon credits, to enhance revenue streams.

6. Operational Risks

- **Risk:** Equipment failure and operational downtime.
- **Mitigation:** Implement a preventive maintenance program and invest in high-quality equipment. Train staff on proper operation and maintenance procedures. Establish contingency plans for equipment replacement and repair.

7. Environmental Risks

- **Risk:** Potential environmental impact of biochar production, such as emissions and waste management. PFAS contamination is also a key area to focus on during production.
- **Mitigation:** Implement sustainable production practices and invest in emission control technologies.

8. Strategic Risks

- **Risk:** Competition from other biochar producers and alternative technologies.
- **Mitigation:** Invica will continue with innovation and R&D. Develop strategic partnerships and collaborations to enhance market position.