BIOMASS TO BIOCHAR FOR FARM BIOECONOMY

Project Id: LLOC1010

FINAL REPORT

Authors: Bernard Carey[1] and Lisa Duncan

Date: 16th of January 2024

Website: www.biomasstobiochar.ie

[1] Email for correspondence: biomasstobiochar@gmail.com

Contents

1 Executive Summary

The EIP-funded Biomass to Biochar for Farm Bioeconomy (BBFB) project piloted the conversion of unutilised agricultural biomass, arising from management of pasture with rushes (*Juncus* spp.) and other unutilised biomass, into stable forms of recalcitrant biocarbon (i.e. biochar). When redeployed to the soil, biochar can confer multiple ecosystem benefits driving an innovative bioeconomy on and off the farm.

Once the BBFB project was established, landowners and contractors whom had previously expressed an interest in the provision of biomass material were contacted. Harvesting of biomass was carried out from February to October for rushes, June, July and Autumn for bracken, and September until March for hazel, depending on climatic conditions and habitat designation restrictions.

A prototype Mobile Pyrolysis Unit (MPU) was built to produce biochar on-site from baled rushes and other biomass. Prior to the commencing the fabrication of the MPU, the Operational Group developed an initial design philosophy and engineering strategy for a simplified and cost-effective biochar generation system which would incorporate a series of design constraints. A number of distinct engineering steps occurred in the fabrication and initial commissioning phase, and further adjustments were made to help resolve feedstock issues and to improve the functionality of the MPU, during the testing and re-engineering phase. Following design modifications to maximise the feed of rushes, the feed rate was still lower than the design requirements and there were problems with the MPU running continuously and efficiently. However, the MPU did run successfully when: the rush biomass fed continuously through the system without blockages; it was possible to control and sustain temperature in the pyrotube; and it could run in excess of 4 hours continuously. Under these conditions a high-quality consistent biochar was produced from rushes that was suitable for testing in a laboratory setting. This biochar was subsequently characterised using the *European Biochar Certificate Guidelines for a sustainable production of biochar*, and examined in various experimental projects.

A Life Cycle Assessment (LCA) was undertaken to consider the Global Warming Potential (GWP) of a series of Irish agricultural scenarios for managing unutilised rush biomass and for the production of biochar from rushes. Negative GHG balances calculated for the production and soil application of biochar, illustrate the beneficial GWP impact of harvesting and baling rush biomass, using this to produce biochar, and applying it to soil directly, or incorporating in slurry. GHG emissions that would have arisen from the decomposition of biomass were avoided and LCA results indicate the viability of carbon sequestration in rush biochar and the potential for long-term carbon storage through its incorporation in soil (e.g. remaining unmineralized in soil). These results show that the production of rush biochar from unutilised biomass presents readily available opportunities to remove CO_2 from the atmosphere as a Carbon Dioxide Removal (CDR) scheme. Pyrolysis technology and products such as rush biochar can be efficient at medium to small scale and so make it possible to have CDR schemes not only at local scale, but also as part of wider rural bio-economies.

Scenarios describing the application of non-amended and amended slurry (with 10% w/w rush biochar) to grassland soil were also developed in the LCA based on data from testing undertaken during this EIP project. These showed significant reductions in CH_4 emissions (42%) from treating slurry with rush biochar in slurry tanks, and a final lifecycle balance showing a significant reduction in GHG gases when rush biochar was added to slurry (i.e. 80%+) and then applied to land. LCA results for rush biochar, show it has excellent potential to reduce total gaseous losses arising from land application of dairy cattle slurry. Laboratory trials undertaken in the BBFB project also showed a statistical tendency towards the reduction of methane from ruminants when rush biochar was added to feed in a *n vitro* gas production system.

Ireland's national Climate Action Plan calls for reduction in emissions from the agricultural sector of between 22 and 30% by 2030. In 2050, the EU goal is for net-zero emissions. The EU Commission has recently published a proposal for a Carbon Certification scheme that sets out criteria for carbon removal activities including permanent carbon storage, carbon farming and carbon storage in long lasting products. Ireland also plans to develop a national Carbon Farming Framework that will set out key procedural and governance requirements, which will support future payments to farmers and landowners for carbon farming activities and/or ecosystem services. Therefore, the adoption of practices which reduce emissions within the agricultural sector and promote carbon farming is essential. Land application of biochar represents a valuable component of an integrated Carbon Farming Framework (through the sequestration of carbon, the reduction of GHG emissions, leading to further eco-system services benefits).

In line with EU and National policy, several project activities under this EIP were shown to be complementary with the protection of EU Natura sites and generated co-benefits for biodiversity with regard to species conservation and habitat protection. A portion of the rushes used to produce biochar in the MPU were from an EU Special Protection Area, where rushes are specifically managed to ensure the conservation of Hen Harrier. In addition, biochar was produced from cut hazel scrub in the Burren Beo project which involves the management of open habitat in a sensitive ecosystem to protect species rich grasslands. Further ecosystem benefits and protection of aquatic ecology can occur through the protection of water quality by the reduction of N leaching following the addition of biochar to soil and to slurry prior to spreading, and through the reduction of the use of chemical N fertilisers, which help meet the requirements of the Water Framework Directive.

Other opportunities for developing rush biochar products with long-lasting carbon storage that promote innovation and add value to the circular economy and rural bio-economies were investigated during this project. These included a study assessing the use of rush biochar as a supplementary cementitious material replacement in structural concrete, which concluded that further research should be undertaken given the rush biochar displayed the most promising results; and electrochemical testing on rush biochar, which concluded that this material presents strong potential for energy, supercapacitor application and also recommended further testing.

A key element of this EIP project was to use unutilised biomass streams to produce biochar, a renewable resource which does not have any implications or critical considerations for the displacement of food production. As part of this EIP project an on-line survey of farmers was undertaken to determine potentially available biomass sources from unwanted species typically found on Irish farms. Based on the results of this survey, it is apparent that rushes represent an untapped biomass resource that currently requires resources to control and are contributing to carbon emissions when left to rot. A key opportunity exists to use the availability and sustainability of this unutilised biomass to produce biochar which is perfectly suited for farm production as part of an innovative circular economy on the farm.

This EIP project has demonstrated practically how the production and use of biochar from existing unutilised biomass streams on farms has the potential to contribute to the objectives of EU, and national agricultural and climate action policies, while at the same time maintaining EU food security. This can be achieved through:

- carbon sequestration and more stable carbon storage arising from biochar production together with its storage in soil;
- opportunities to remove CO_2 from the atmosphere via Carbon Dioxide Removal (CDR);
- reducing total gaseous losses arising from land application of dairy cattle slurry;
- eco-system service benefits following its application to soil; and
- through the potential to counteract the GWP impacts from grazed lands and increase the sustainability of grassland management.

Further work is recommended to assess the production and use potential of biochar from unutilised biomass streams. This study also suggests that additional work in developing fixed-site pyrolosis units would lead to greater running efficiency and regional scale benefits. Work in such context should assess the scale of permanent carbon storage potential and CDR opportunities existing for biochar made from rushes and other unutilised agricultural biomass in Ireland and particularly, in the West of Ireland.

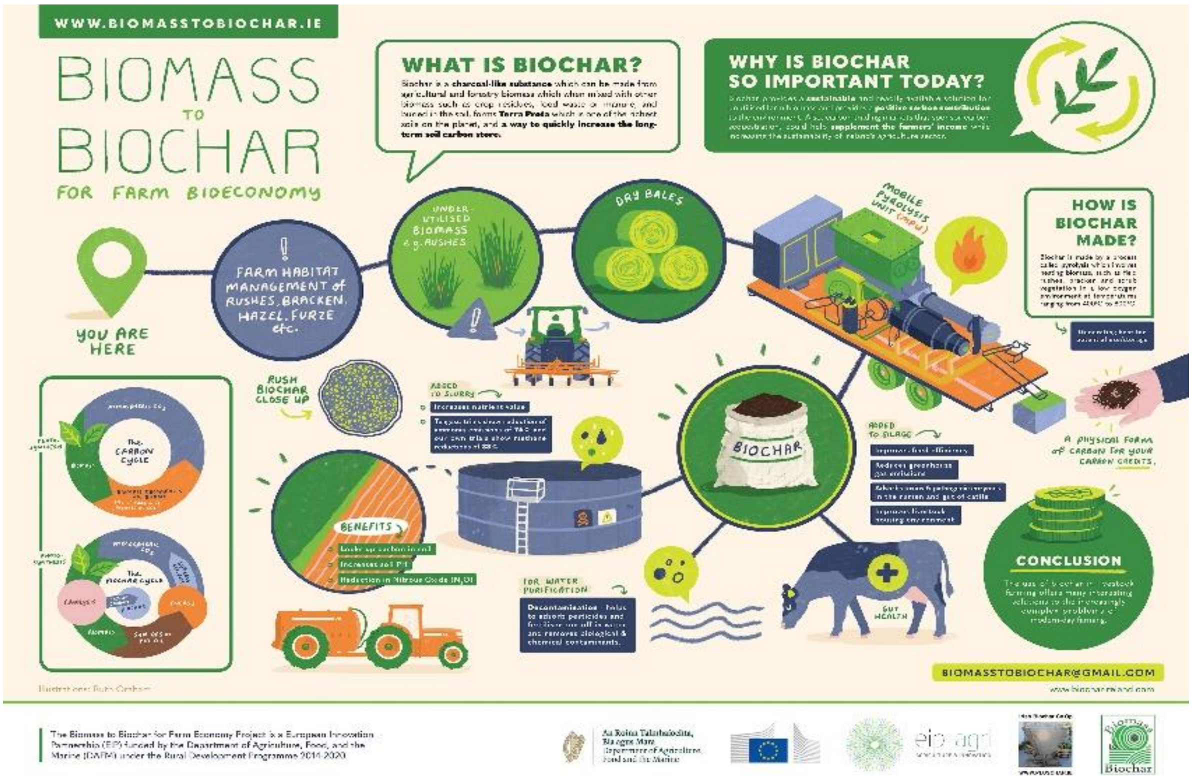


Figure 1.1: An infographic produced by the project for public dissemination use describes the production process, uses and benefits of biochar in an Irish farming context.

2 Background Context and Description of Project

The vision for the Biomass to Biochar for Farm Bioeconomy (BBFB) project was to model itself on the circular economy of heritage farming, where everything on the farm has a purpose, whether it is rushes and oat stalks for thatching roofs, the manure pile for the land, or coppicing for the wood stack. Working with the natural resources available and the sharing of the bigger farm machinery during the harvest, together with the tradition of *Meitheal*[2], lies at the heart of this project and how it all began.

The EIP-funded Biomass to Biochar for Farm Bioeconomy project ran from October 2018 until November 2023 in Mountshannon, Co. Clare, Ireland. Landowners here spend considerable time, effort and money to control rushes and other biomass, in order to comply with Department of Agriculture regulations to maintain their land in "good agricultural and environmental condition"[3] and to quality for eligibility under the Basic Payment Scheme[4]. Rushes can be controlled by weed-licking with glyphosate; sprayed with MCPA; cut for use as bedding, or left to decompose in fields and green waste burnt[5].

The project set out to provide a solution by piloting the conversion of unutilised agricultural biomass (particularly rushes), into stable forms of recalcitrant carbon (biochar) which would, when redeployed to the soil, present multiple ecosystem service benefits to soil and water systems, driving an innovative bio-economy on and off-farm.

This required the construction of a practical Mobile Pyrolysis Unit with a pyrolysis/gasification system capable of producing EBC certified biochar[6] which could demonstrate the on-farm conversion of biomass to biochar using unutilised agricultural biomass (rushes, gorse, bracken, hazel). It would also demonstrate at "grass-roots level" that a sustainable supply chain could be developed out of a renewable biological resource to potentially build a localised bio-economy. Ultimately the project aim was to present a methodology for Irish agriculture to develop a carbon-neutral approach to the management of undesirable biomass while at the same time increasing productivity and sustainability.

The project was able to gain valuable press coverage from the outset which assisted in forming collaborations with farmers, engineers, the commercial sector, non-governmental organisations and academic institutions to achieve shared learning, development and innovation.

---

2 Meitheal denotes the co-operative labour system in Ireland where groups of neighbours help each other in turn with farming work, such as harvesting crops.

3 DAFM. 2016. Explanatory Handbook for Cross compliance

4 DAFM. 2017. EU Basic Payment Scheme (BPS)/Greening Payment

5 As from March 2023, there is a ban of the burning of agricultural green waste. See: https://www.gov.ie/en/press-release/fa8a9-final-regulations-signed-on-burning-of-agricultural-green-waste/

6 The European Biochar Certificate (EBC) was developed by the Ithaka Institute https://ithaka-institut.org/

The emphasis was to investigate the potential use of biochar in terms of the Rural Development Programme (RDP) priorities, which for this project were:

- Improving water and farm runoff management, including fertilizer and pesticide management (4B).
- Reducing greenhouse gas and ammonia emissions from agriculture (5D)
- Carbon conservation and sequestration (5E)
- Forming a farmer's collaborative to achieve improved management of on-farm virgin waste biomass created as a by-product of good agricultural management activities such as rush control, hedge laying, gorse cutting etc.
- Shared innovation and best practice at the local, national and international level.
- Developing Farm Bioeconomy in Ireland.
- Producing a long-term carbon soil, soil amendment without the use of chemicals with improved soil structural, nutritional qualities and animal gut health.

> **"As a way of turning waste into a versatile and useful material, biochar seems a gift to the circular economy demanded for a sustainable world..."**
>
> MICHAEL VINEY, IRISH TIMES, JUNE 2022

3 Project Team

Bernard Carey	Project Leader
Lisa Duncan	Project Manager
Emer O Siochru	Chair of the Irish Biochar Co-Operative
Sean O' Grady	Design and manufacturing engineers *Premier Green Energy*
Dr. Brian Tobin	Expert advisor carbon sequestration, UCD
Dr. Michael Clancy	Life Cycle Analyser
Sion Brackenbury	Commons Vision UK advisor

4 Baseline data

Biochar is a charcoal-like product produced by heating biomass in low oxygen conditions to 400 ^{o}C +. At this temperature much of the volatile contents are removed leaving a stable, carbon-rich biochar with an open porous structure (see Image 4.1). Conversion of biomass to biochar through pyrolysis protects the majority of biomass carbon from microbial decomposition (Shrestha et al, 2023). According to Hammond et al. (2011) during the biochar manufacturing process, about 50 % of the original carbon in the biomass is retained in the final product, and the process also induces a reversal of the carbon cycle by removing organic compounds from the active C pool and converting them into refractory organic components (Das et al., 2014; Lee et al., 2010).

Biochar is not a fertilizer, but rather a nutrient carrier and a habitat for microorganisms (Schmidt, 2017). It has been used for millennia as a soil improver and is sometimes described as a battery, because to get the best results, it should be 'charged' or inoculated/activated with nutrients and microbes. Traditionally it was charged by being mixed with dung and kitchen waste. Today on farms the biggest potential for charging or co-composting [7] biochar is combining it with animal slurry.

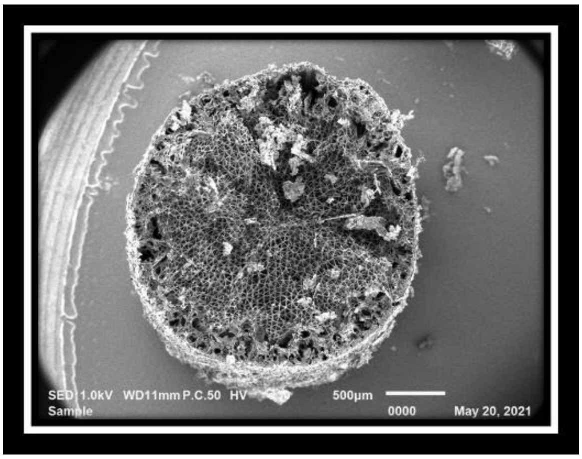


Image 4.1 Honeycomb type structure of Biochar making it a perfect habitat for nutrients and microbes

In recent years the strong interest in biochar has resulted in the development of industrialized units constructed across Europe and the world. This has increased the production and more widespread use of biochar and greatly improved the quality and consistency of the products.

There are many benefits from the application of biochar to land. A review by Shrestha et al. undertaken in 2023 on field-based studies undertaken over two decades focused on the effects of biochar application on GHG emissions, and the authors provide quantitative evidence of the reduction in GHG emissions that can be achieved through application of biochar to croplands (Shrestha et al., 2023).

[7] The term co-composted biochar (COMBI) refers to biochar which is mixed with compost feedstock (organic matter that is both rich in nutrients and labile organic carbon, such as sewage sludge, manure, and plant residues) before aerobic composting (Fischer and Glaser, 2012).

Biochar has also been proposed as an organic carbon (C) soil amendment for reducing leaching of soil compounds (Abdelrahman et al., 2018; O'Connor et al., 2018) and for improving soil quality (Crane-Droesch et al., 2013; Liu et al., 2013; Mehmood et al., 2017). Biochar has been found to reduce N leaching by 15 % due to adsorption of the ammonium ion predominantly by cation exchange (Ding et al., 2010). Borchard et al. (2019) also assessed interactions between biochar-induced effects on N_2O emissions and NO_3^- retention, and their results showed a significant reduction of overall N_2O emissions by 38% caused by biochar applications.

Hagemann et al. (2017) cite research suggesting that amending soil with biochar is a globally applicable approach to address climate change and soil degradation by carbon sequestration[8], reducing soil-borne GHG emissions and increasing soil nutrient retention. These authors outline how biochar has been shown to promote plant growth, especially when combined with nutrient-rich organic matter, e.g., co-composted biochar. Co-composting, which consists of mixing biochar with manure or other compost feedstock with high contents of both nutrients and labile organic carbon before starting an aerobic composting process, was shown to enhance the agronomic performance of biochar as a soil amendment (Kammann et al., 2015).

There are GWP (global warming potential) improvements and ecosystem benefits when biochar is applied to soil including: sequestration of carbon, the potential for Carbon Dioxide Removal, reduction of GHG emissions from soil; reduction of nitrate leaching and protection of water quality; nutrient retention and stimulation of soil fertility; and the use of biochar as a component of fertilisers to reduce the use of chemical N. Thus, land application of biochar represents a valuable component of Carbon Farming (through the sequestration of carbon and reducing the release of carbon from biogenic carbon pools which facilitates ecosystem benefits).

Further detailed information on the climate benefits and ecosystem services provided by biochar are presented in the LCA report which accompanies this report.

[8] Biochar added to soil by Amazonian peoples have been shown to remain in the soil over 1,000 years. These “Dark Earths” or *Tera preta* are known for their high fertility, high microbial activity and ability to store carbon in soils for long periods.

5 Key Performance Indicators

Several Key Performance Indicators (KPIs) were used to evaluate and assess the activities of this EIP project. These are listed in Table 5.1 and summaries of the work undertaken to deliver each KPI are given below.

Table 5.1:Key Performance Indicators and targets for BBFB EIP Project

KPI 1: The development of a collaborative partnership between the Biochar Coop, farmers, engineers, non-governmental organisations and academic institutions in achieving shared learning, development and innovation.
Target 1: Formal establishment of the project's Operational Group, organisational structures in place and project up and running✓
Target 2: Formal establishment of farmer/landowner stakeholder network✓
KPI 2: The development of an innovative, mobile, farm-scale MPU and pyrolysis system designed and built in Ireland which is capable of being deployed within a range of agricultural and wildlife conservation situations.
Target 1: Design and fabrication of MPU underway with project team input to design prior to fabrication✓
Target 2: MPU constructed and commissioned✓
Target 3: MPU performance data (1) - Interim report post commissioning, setting out operation parameters for flue gases and temperature✓
Target 4: MPU performance data (2) - Report describing energy production capacity by feedstock type✓
KPI 3: The development of a valuable biomass stream from currently unutilised agricultural biomass by demonstrating effective cutting, collection and processing practices in a number of typical pilot areas.
Target 1: Biochar production from biomass on trial farm sites✓
Target 2: Characterisation of biomass feedstock and biochar product, assessed against quality criteria to ensure appropriate end use✓
Target 3: Assessment of the potential to produce biochar or torrefied products from other biomass streams such as forestry biomass, miscanthus, etc✓
KPI 4: Demonstrating that biochar utilisation can contribute to the sustainability of local bio-economies and help the agri-sector by reducing greenhouse gas emissions, improving land fertility and productivity, and protecting water quality.
Target 1: Establishment of biochar trial/use by producers within stakeholder network✓
Target 2: Support of scientific experimental set-up to test the field use and performance of biochar in applications such as soil fertility and structural improvement, augmentation of soil carbon sequestration, animal feeds, capture of waterborne pollutant or eutrophying agents✓
KPI 5: Dissemination of learning and promotion of the project at national and European levels.

Target 1: Launch of BBFB website, targeted contact with relevant interest groups and outreach programme✓
Target 2: Production of scientific reports and papers. Conference participation✓
Target 3: Cooperation with other areas within the EU with an interest in the management of on-farm biomass, the production of biochar and the sequestration of atmospheric carbon✓
KPI 7: Life Cycle Analysis to track the carbon cost and benefits through the complete lifecycle of the project from biomass harvesting operations to the deployment of the material to soil or as an additive to slurry tanks.
Target 1: Delivery of Life Cycle Analysis for project✓

5.1 KPI 1: The development of a collaborative partnership between the Biochar Coop, farmers, engineers, non-governmental organisations and academic institutions in achieving shared learning, development and innovation.

5.1.1 Target 1: Formal establishment of the project's Operational Group, organisational structures in place and project up and running

An operational group (see Figure 5.1) was established to incorporate motivated stakeholders with experience in the design and manufacture of pyrolysis units, the production of biochar from various biomass streams and in working with farmers on the ground to achieve improved farm management. The team provided on-the-ground project management and logistics support, in addition to a strong research background, an excellent working knowledge of the geographic area covered by the project and international communication exchange and technology transfer.

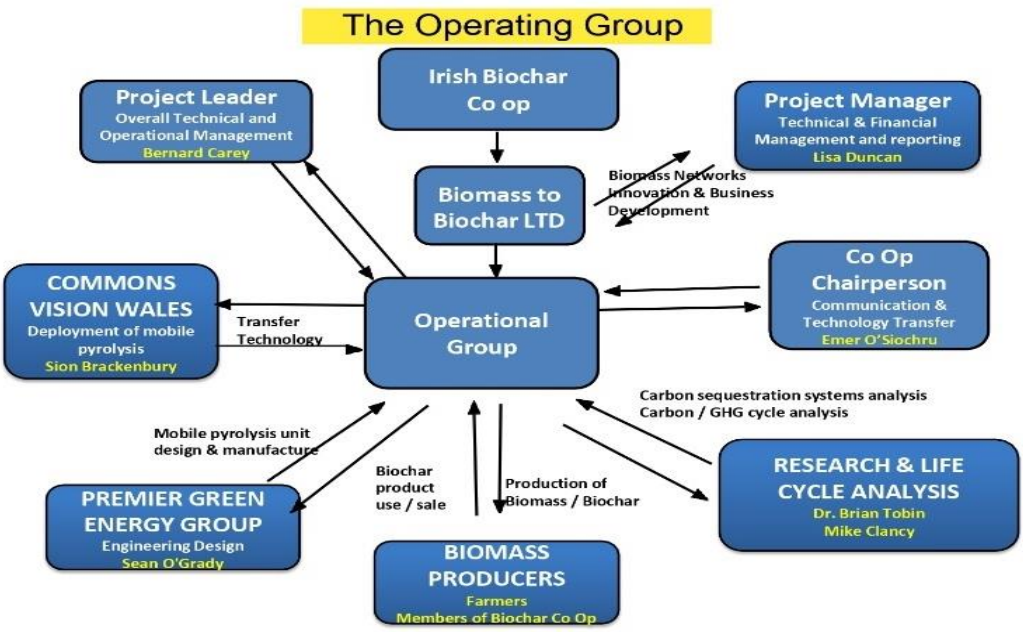


Figure 5.1: The operational structure of the BBFB project's operational group.

5.1.2 Target 2: Formal establishment of farmer/landowner/ stakeholder network

A formal farmer and landowner network was established via membership of the Biochar Cooperative[9] at the beginning of the project. During the project the team exhibited the MPU and made presentations at seminars and conferences both nationally and internationally, disseminating the knowledge and making contacts and continuously expanding the stakeholder network. Together with a number of tools including short films on YouTube, and media interviews such as 'Ear to the Ground', and info-graphic to simplify the concept, we were able to generate a network of stakeholders that were very important to the development of the remainder of the project in terms of field tests etc.

5.2 KPI 2: The development of an innovative, mobile, farm-scale MPU and pyrolysis system designed and built in Ireland which is capable of being deployed within a range of agricultural and wildlife conservation situations.

5.2.1 Target 1: Design and fabrication of MPU underway with project team input to design prior to fabrication

In November 2018, work commenced on the design phase of the proposal to build, pilot and test a Mobile Pyrolysis Unit (MPU), suited to Irish climate and agricultural conditions, and to produce biochar on-site from unutilised biomass, effectively bringing the factory to the farm-yard. Prior to the commencing the fabrication of the MPU, the Operational Group developed and agreed an initial design philosophy and engineering strategy for a simplified and cost-effective biochar generation system which would incorporate a series of important design constraints.

These required the MPU:

- be light weight and have a compact design which was necessary for comparative ease of transportation;
- have a flexible operation (allowing adaptation to changes in feed material and potential for harvesting of derived energy);
- be cost effective with an efficient design;
- operate an energy efficient conversion process;
- be efficient and safe for maintenance and operation; and
- have a safe operation system easily visible for demonstration purposes.

The MPU prototype design went through a series of stages and modifications before the final arrangement illustrated in Figure 5.2 was agreed. The design consisted of three systems that included the "infeed hopper", the "combustion unit" and the "pyrolysis tube". These systems combined to allow

9 Biochar Cooperative: https://www.biomasstobiochar.ie/biochar-coop.html

for the input of feedstock material and the pyrolysis of the feedstock, along with the combustion of syngas within the combustor.

The design was developed in this format to comply with the constraints of a mobile unit including accommodating the desirable throughput and a compact scale, adhering to budgetary requirements and ensuring the mobility of the system, given the preferred feedstock types intended for processing.

The project system requirement for mobility was fulfilled by being mounted on an agriculture trailer and towed by a tractor.

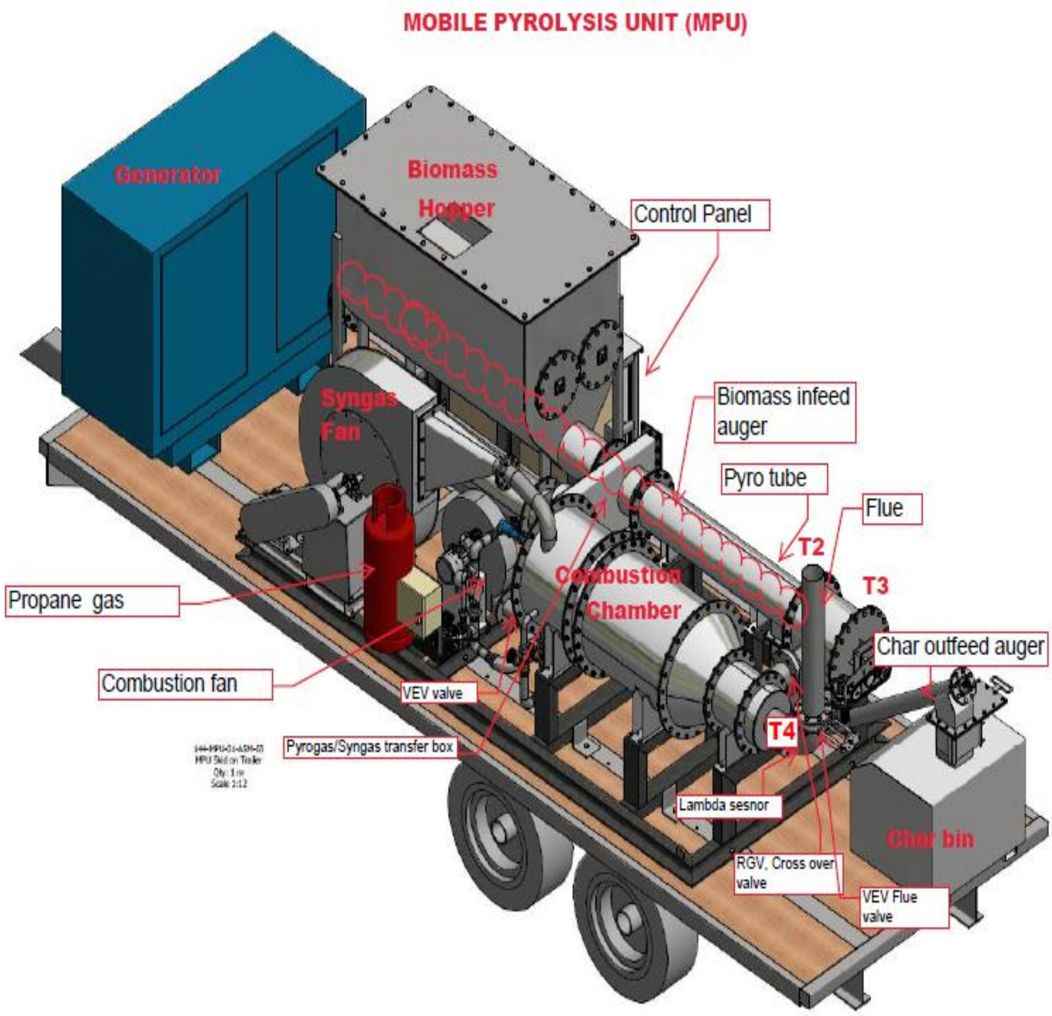


Figure 5.2: The prototype design for the Mobile Pyrolysis Unit (MPU).

5.2.2 Target 2: MPU constructed and commissioned

The construction and initial commissioning of the MPU began in October 2019 and was completed in Spring 2021. This phase of the project is discussed below under General System Fabrication.

Once this phase ended, re-engineering and design improvements were undertaken throughout the remaining project period following the transportation of the MPU to Mountshannon. This phase of the project is discussed below under Testing and Re-Engineering.

5.2.2.1 General System Fabrication

The following distinct steps occurred in the fabrication and initial commissioning phase (Images 5.1 to 5.4 illustrate this phase of the project):

- Fabrication commenced with the manufacture of a skid which acted as a framework on which to install the three systems of the MPU including the “infeed hopper”, the “combustion unit” and the “pyrolysis tube”. These were later mounted onto a trailer for transportation.
- The electrical system was designed to control and regulate the pyrolysis system, from the feed intake and combustion path, to the circulation of gases and energy, and the output of the char. Monitoring and data recording was also achieved through the electrical loom capacity. The electrical design, installation and programming of the MPU were undertaken with a “cold” test to see if all the motors and valves were functioning properly. Running the hot trials, while successful in producing syngas and successful in being self-sufficient for heat energy generation, were not successful initially in producing biochar of a consistent quality.
- Installation of a data logger in the control panel was undertaken to record operational parameters such as pyro tube temperature and pressure.
- Bins were fabricated for storage of biochar as it exited the MPU discharge tube, to allow it to cool safely. Weather proofing of the control cabinet, motors, hopper lid, flue gas exhaust, gas valves and burning shield was also undertaken.
- Initial trial runs using woodchip proved successful in maintaining MPU operation on syngas for short periods of time while maintaining reliable temperatures and generating sufficient exothermic heat to maintain operation. However, the feed auger clogged up on numerous occasions with uncharred large wood chip fractions and charred rushes, resulting in the pyrolysis system having to be shut down.

Therefore, a body of work was undertaken to specifically address feedstock issues as outlined below.

Image 5.1

Image 5.2

Image 5.3

Image 5.4

5.2.2.2 Resolving Feedstock Issues

The following engineering adjustments were made to help resolve feedstock issues:

- Modifications were made to the auger to allow more even heat treatment of the feedstock material. Observations showed that the woodchip was only partially charred. It wasn't anticipated that this would present any significant difficulties and it was anticipated that the auger modification and dialling in the MPU controls to slow down the movement of material, while extracting additional syngas would result in successful charring of the woodchip.
- However, further work was also needed to devise a successful method to feed rushes, a comparatively light and less substantial material, which was inclined to clump and block the auger system. Hot running with chopped rushes was attempted on a number of occasions and proved to be one of the most difficult challenges in operating the MPU. Various system refits and modifications were attempted, including modifications of the feed auger, modification of the feed hopper, upgrading of the auger motor and gearbox to increase torque, variation in feed rates, and manual feeding of auger to prevent clogging. An add-on system where rushes were fed via belt into the hopper was developed off-site and a successful mock-up was constructed to tease out bulked rushes into a continuous stream.
- Char being produced at this stage was inconsistent in quality, with many size fractions unevenly or incompletely pyrolysed. The main auger was removed and small agitation paddles were added to the flights at the point where material would be in the hot zone. The flights were to allow for stirring of material for better heat transfer and more complete pyrolysation. It was decided to consider using a conveyor belt system to evenly feed chopped rushes into the feed hopper, and from there they could be processed slowly into the auger and into the pyro tube. As the feed of rushes by the augers was problematic, a larger motor (4 kW) with greater reduction gearbox was also installed to give greater pushing power to the system.
- Bales of rushes were sent for hammer milling to see if this process could aid with moving the rushes through the auger. A trial with a pellet mill was also carried out. A conveyor belt was initially hired to ascertain if it was a viable option to fill the hopper, and once established as successful, a used conveyor was purchased and fitted. A bench-scale hopper and auger were also fabricated to resolve the ongoing rush feed issue.

Following these design modifications to maximise the feed of woodchip, the feed rate was still lower than the design requirements; however, this was deemed acceptable for progressing the project given the demonstration/proof-of-concept nature of the project.

Biochar from rushes was not successfully produced at this stage of the project. The production of rush biochar was a focus point of the testing and re-engineering phase of the project as outlined below.

5.2.2.3 Testing and Re-Engineering

The construction phase and initial commissioning phase ended in Spring 2021 and the MPU components were mounted on the trailer and transported to Mountshannon for further testing, re-engineering and on-site production of rush biochar and biochar from other biomass (see Images 5.5 and 5.6).

The following testing and engineering adjustments occurred in this phase to improve the functionality of the MPU to produce biochar:

- Testing of the MPU began and the biochar outfeed auger was changed due to ongoing issues with blockages. The material handling improved slightly over a series of adjustments. The factory-produced biochar outfeed auger was upgraded to a larger-diameter auger.
- Initial tests with the new auger were mostly positive. It appeared to be able to handle more variable woodchip size and during the course of a short trial it was able to transfer uncharred chopped rushes without difficulty.
- An inspection glass was installed on the syngas transfer box inspection plate which allowed for real-time observation of causes of spikes in temperature. Modifications were made to decrease the amount of oxygen and charred biomass going from the auger into the syngas transfer box - due to the data obtained from the newly-installed data logger. This data logger proved to be invaluable in characterising the operating period, albeit not in real time. During operation, manual data sensors provided reference throughout live runs. Data logger recordings showed temperature peaks and indicated combustion of syngas during circulation as illustrated in Figure 5.3. Once adjustments were made the temperature levels were more stable as illustrated in Figure 5.4. Post operation the manual data records were cross referenced with graphed plots to better diagnose any issues.
- Reprogramming of the control panel was also carried out to facilitate manual control via the visual display unit of the feed auger. This allowed for manual intervention when pyrolysis was proceeding. This also led to advantages from a safety point of view, as it meant the new biochar outfeed auger could quickly evacuate the feed hopper should the need arise.
- The initial modifications of the flight pitch for the new feed auger weren't completely successful, and it was returned to the manufacturer for further modifications to increase the agitation of material whilst in the pyro tube. All modifications made to the auger were due to lessons learned using the bench-scale hopper and auger which was also run by a hydraulic motor.
- Pressure sensor malfunctions were investigated, and adjustments made to improve temperature build-up and physical improvements to reduce carbon build-up. These issues appeared to stem from failures of the sensors or inadequacies in the control panel software, indicating that the sensors and valves were not communicating effectively, preventing the MPU control panel from modulating these operational parameters, as per the original design. Where more than one variable changed (such as ambient or internal temperature, flow of combustion gas or oxygen content) the pyrolysis process became unstable and manual corrective actions were necessary to maintain any level of feedstock conversion to biochar. In short, the system monitoring devices were not adequately communicating during operation, resulting in a system that was not always self-sustaining with syngas and which could result in uneven charring of the biomass.
- A further modification was made by bypassing the syngas box with additional pipework to allow for blockages. This resolved most blockage issues, allowing longer uninterrupted pyrogas flow and the MPU produced more consistent temperatures for separate runs using woodchip.
- Bales of rushes were examined to determine the correct feed system. Samples were collected to examine moisture content, particle length and size. Various screen sizes in bale chopping systems were tested to determine the most suitable for feedstock processing.
- After experimenting with the Teagle Bale Chopper to find the optimal size screen for chopping dried rushes ready for processing into char, a small 12-15 mm diameter screen was selected as this was the most successful.

Image 5.5 MPU crossing the River Shannon at Killaloe Bridge Co. Clare

Image 5.6 MPU on location in Mountshannon Co. Clare

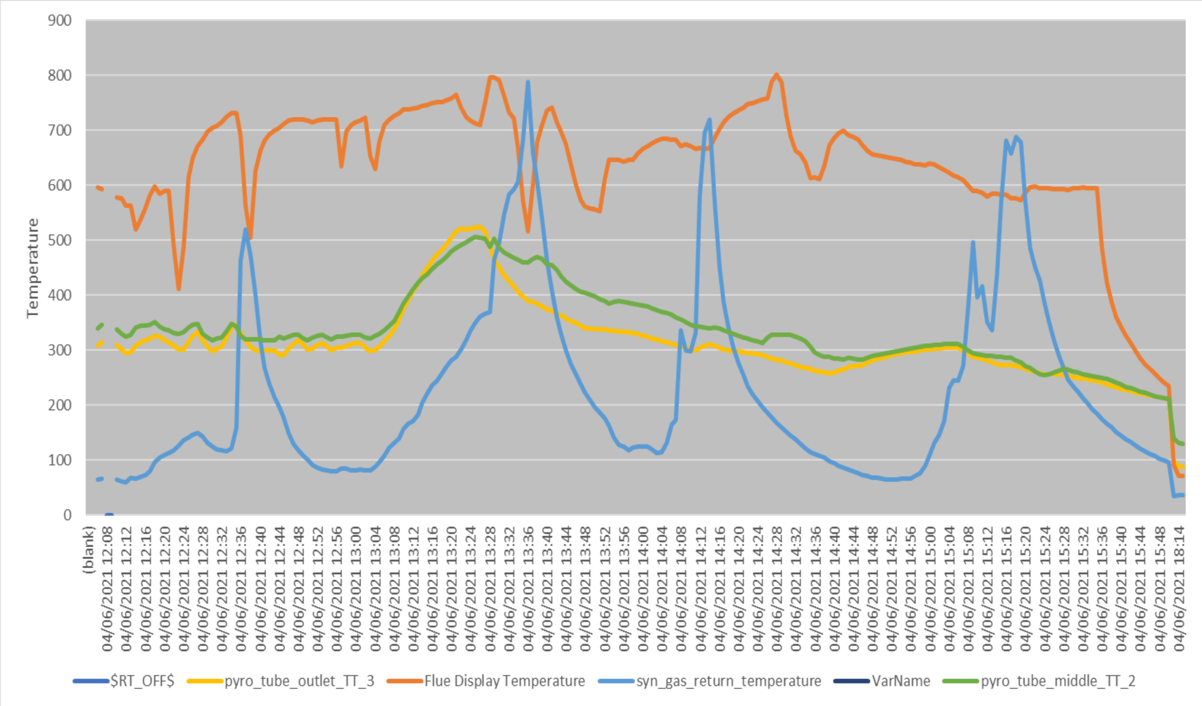


Figure 5.3: MPU operational chamber temperature profiles, as recorded by the controller's data logger, were used as a diagnostic tool to streamline feed intake, residence time and to trouble-shoot system failures.

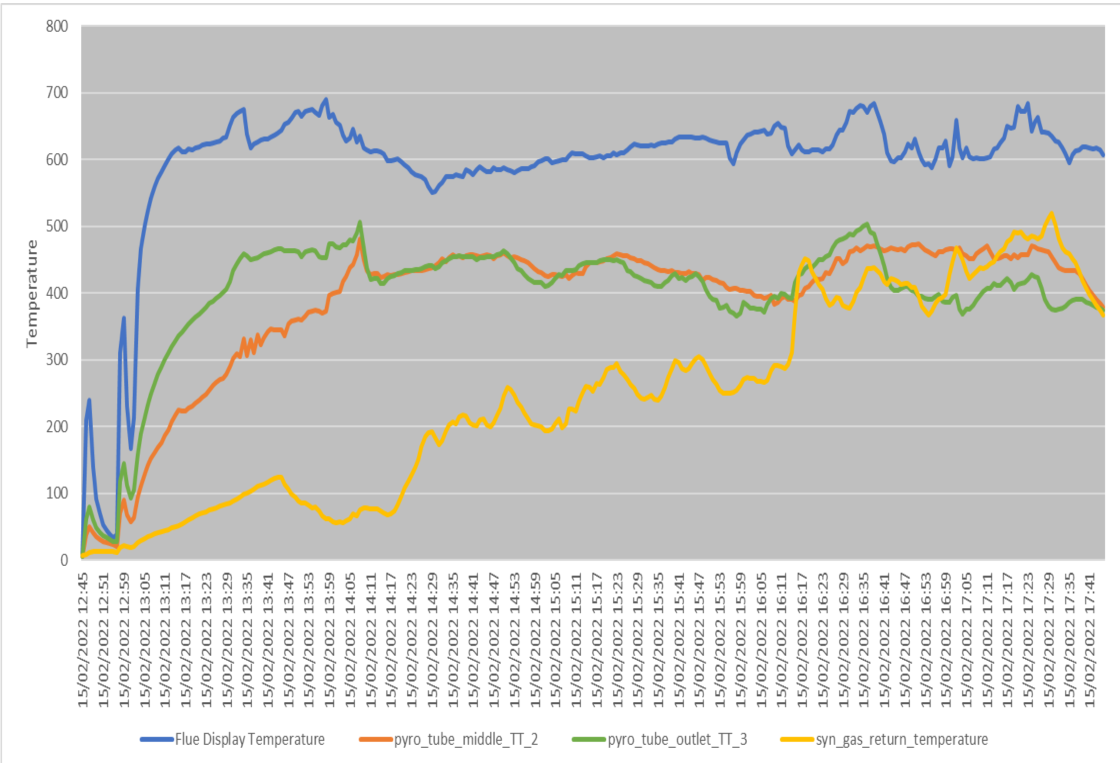


Figure 5.4: The linear nature of the chart temperature traces (from various points along the pyrolysis pathway) indicated a consistent char was being produced.

Explanation of terms in Figures 5.3 and 5.4

- Flue Display Temperature was the temperature measured at the base of the flue which exits the combustion chamber; a range of between 600 – 700 ^{o}C was typical at this point in the system.
- Pyro tube middle was the temperature measured near the char exit point, during system operation this was often utilised as a target temperature.
- Pyro tube outlet was measured between the biochar outfeed auger and the combustion chamber.
- Syn gas return temperature was the temperature measured in the syngas transfer box and was a lower temperature than the above three measurement points.

5.2.2.4 Findings

Ultimately, findings in relation to feed material handling were that a uniform particle size was necessary to achieve a steady feed rate into the pyrotube. In addition, a low moisture content was essential as biomass needs to be below 20% moisture content (MC) to achieve pyrolysis in the MPU. MCs between 10% and 15% were used (achievable outdoors for biomass samples during dry summer periods). Fine particles do not work as they fill up the spaces between the larger chips, and gases and moisture cannot move through pyrotube. Pellets do not work as they absorb the moisture from the steam created and degrade, causing blockages in the pryrotube.

Following all of the design modifications to maximise the feed of rushes, the feed rate was still lower than the design requirements and there were problems with the MPU running continuously and efficiently. It was not possible to run the MPU pyrolysis unit in a completely self-sustaining manner for long periods of time. A key element to improving the process lies with the control system and finding an algorithm that has sufficient range and stability to cope with changes in the feed and ambient conditions.

However, the MPU did run successfully when:

- it did not cut out;
- the rush biomass fed continuously through the system without blockages;
- it was possible to control and sustain temperature in the pyrotube (within the range of 350 – 460 degrees centigrade); and
- it could run in excess of 4 hours continuously.

Under these conditions a high-quality consistent biochar was produced from rushes that was suitable for testing in a laboratory setting. This biochar was subsequently characterised and examined in various experimental projects as discussed later in this document and in the Life Cycle Assessment Study Report for this EIP.

Overall, this project was designed as a proof of concept for a system of biochar production and use in Irish agriculture. The mobile aspect of the pyrolysis system unit served the demonstration and interactive nature of the EIP project concept. However, consideration of all of the learnings in the design, fabrication, testing and commissioning phases of this project suggests that further work in developing fixed-site pyrolosis units would lead to greater running efficiency and regional scale benefits. Future systems developed as fixed-location installations will be able to generate greater efficiency in production (to run for extended periods directly on syngas) as well as much higher energy recycling and recovery (e.g. for immediate energy/power generation or for harnessing in feedstock drying treatment etc.). Co-location at sites already running anaerobic digesters or at processing mills would create further efficiencies.

5.2.3 Target 3: MPU performance data (1) - Interim report post commissioning, setting out operation parameters for flue gases and temperature.

An emission test was due to be carried out at the end of the project to test for the following emissions: oxygen, carbon dioxide, carbon monoxide, oxides of nitrogen, sulphur dioxide, and total organic carbon. In addition to these, a particulate and flow rate test was also due to be carried out. *It should be noted that when the MPU was running successfully, there was no visible smoke during operation.*

After consultation with an emissions technician, the operational group were advised that due to the size of the flue, the particulate and flow rate test would not be possible. Additionally, in order to effectively undertake the emissions testing, the MPU would need to run at a steady state for a period of time which was difficult to achieve at that particular time. As a result of this, it was not possible to undertake this testing.

5.2.4 Target 4: MPU performance data (2) - Report describing energy production capacity by feedstock type.

An assessment was undertaken to examine the fuel qualities of biochar produced by the EIP project and the results are presented in the report: *Biomass 2 Biochar – Evaluation of biochar for solid fuel use*[10]. The evaluation was not to advocate for biochar to be used as a solid fuel, but rather as an indication of use other than the already known benefits (e.g. soil conditioner, reduction of emissions when added to slurry etc.). If domestic heat were the sole exploitation of the biomass used, then it would be far simpler to densify and burn in pellet or briquette form.

Analytical elemental analysis data for *Juncus Effusus* (rush) biomass, and for biochar made from Bracken, *Ulex, Corylus* and *Juncus Effusus* was examined. Each of the biochar types vary significantly in their composition, this is related to 1) biomass feedstock type and the elemental analysis (lignocellulosic, protein and inorganic/ ash content), 2) physical characteristics (bulk density, particle size, moisture content) and 3) processing conditions (pyrolysis temperature, reaction time, heat transfer etc.).

---

[10] https://www.biomasstobiochar.ie/scientific-studies/evaluation-of-biochar-for-solid-fuel-use

Biochar produced from the pyrolysis process forms a stable product, resistant to further degradation. For solid fuel use, all the biochar produced would be suitable for domestic combustion purposes, such as open fire or in a stove, provided some form of densification process were employed. This would include methods such as briquetting, agglomeration, or pelletization. Binders may be required, depending on the densification method used. The fuel ranking for the chars based on composition would be *Ulex* > *Corylus* > Bracken > *Juncus Effusus*. The difference between Bracken and *Corylus* is small due to their similar composition. As a domestic fuel, the user experience would vary depending on the appliance in which it was used, giving a similar performance to fossil coals.

5.3 KPI 3: The development of a valuable biomass stream from currently unutilised agricultural biomass by demonstrating effective cutting, collection and processing practices in a number of typical pilot areas.

5.3.1 Target 1: Biochar production from biomass on trial farm sites

Once the BBFB project was established, landowners and contractors whom had previously expressed an interest in the provision of biomass material were contacted. Dissemination and word-of-mouth generated more interest. An incentive for those farmers/landowners participating in the BBFB project was that rushes were purchased at €11 per bale to account for the additional cost of operating on difficult sites and to encourage the cutting and saving of their rushes rather than spraying them with herbicides.

Harvesting of biomass was carried out from February to October for rushes, June/July and autumn for bracken and September until March for hazel depending on climatic conditions and habitat designation restrictions. Existing farm machinery was used for harvesting biomass such as mowers and round balers which are ubiquitous in rural Ireland and bales were transported to a dry standing area for storage, with a minimum gap of 20 cm left between each bale to allow air circulation. Storage in traditional hay sheds was found to be the most desirable storage method.

All biomass was harvested as dry as possible, with an ideal moisture content range of 16 – 20 % as moisture content above 20% results in degradation and mould growth. Biomass harvesting was achieved using the following guidelines:

- Bracken: After cutting, the biomass was dried for 1-2 days and turned, depending on the weather; then baled in the afternoon after rowing up in the morning to allow for more drying.
- Hazel and furze: After cutting and placing in heaps, drying took place over at least six months. Chipping took place in dry weather followed by further drying where possible in an open shed, turning at least once.
- Rushes: Using conventional mowing machinery , a hay turner for turning and rowing, and a standard round baler for baling. It was important to have the bales well packed and then stored in sheds preferably with pallets under the bales and with gaps between to allow for further drying.

Images 5.7, 5.8 and 5.9 illustrate the harvesting of biomass, the production of bales and the transportation of bales for pyrolysis for this EIP project.

Image 5.7: Harvesting rushes for the BBFB EIP project in County Clare.

Image 5.8: Baled rushes gathered from participating farmers by the BBFB EIP project for pyrolysis.

Image 5.9: Harvested rush bales being transported by trailer for pyrolysis during BBFB EIP project.

When transporting the MPU to farms, the unit was towed behind the tractor, with two follow-up trips to bring the bale chopper (via tractor) and the conveyor belt (by trailer), along with ancillaries such as barrels and lids to collect the biochar and propane gas to start the MPU. The positioning of the conveyor belt was done using the front loader of the tractor and it was possible one person to set up and run the whole unit.

A 3-phase generator mounted on the trailer was the only source of electricity as most farms have do not have 3-phase electricity. The heat for the start-up was generated using propane gas and reaching the required temperature took approximately 60 – 90 minutes depending on outside temperatures. After the initial test runs, two 4 kW heat pads were attached to the pryro tubes in order to obtain a more consistent temperature, taking electricity from the generator.

The bale chopper was driven by 115 hp tractor with screens to get a fine chop in order to prevent tangling in the auger. It took approximately 10 - 15 minutes to chop a bale, considering the small screen size and depending on how well packed the bale was. It was found that chopping the biomass resulted in a temperature rise of 30 ^{o}C.

Initially, time was spent trying to convey pre-chopped material consistently onto the auger inside the hopper. Ultimately a better result came from directly chopping the rushes onto the conveyor belt which fed the hopper. This avoided issues with the increase of moisture content if pre chopped and stored and also utilised the heat that was generated by the chopping process. The MPU hopper has an agitator to help prevent bridging of the material above the auger and to insure a consistent flow of material. As the MPU hopper emptied, the chopper would begin again, to half fill the MPU hopper. Bridging of material was an ongoing issue and feeding the pyrotube feed auger required on-going observation using a camera installed inside the hopper for continuous checking during operation from the control panel VDU.

Images 5.10, 5.11 and 5.12 illustrate the MPU ready for transport to farm sites, the MPU on site at a farm in County Clare where baled rushes were available for the production of biochar, and rush biomass in comparison to biochar produced from rushes.

Using steel barrels with lids to store the biochar was found to be the most convenient method as the barrels are relatively simple to obtain, easy to handle manually and the lids seal well in order to prevent air ingress (see Images 5.13, 5.14 and 5.15 below).

Image 5.10: The Mobile Pyrolysis Unit ready for transport.

Image 5.11: MPU at a farm site where baled rushes were available.

Image 5.12: Rush biomass and the resulting rush biochar produced by the MPU.

Images 5.13, 5.14 and 5.15 Collection of Rush biochar

5.3.2 Target 2: Characterisation of biomass feedstock and biochar product, assessed against quality criteria to ensure appropriate end use.

5.3.2.1 Biochar Characterisation and Laboratory Analysis

The purpose of laboratory testing within the BBFB project was to establish firstly, that biochars produced from different feedstocks did not contain bio-accumulated contaminants, secondly that the biochar's produced were fit for deployment to soil and finally to understand the physical and chemical characteristics of the biochar produced (surface area, exchangeable nutrients etc.) which would influence its likely future use. Samples of four biochar's produced from four different feedstock, namely gorse (*Ulex),* hazel (*Corylus*), bracken (*Pteridium*) and rushes (*Juncus effsus*) were tested by Eurofins, an accredited test laboratory, in Germany in 2022. All four of these biochar's were produced using the Mobile Pyrolysis Unit.

These biochars were analysed according to the ***European Biochar Certificate Guidelines for a sustainable production of biochar***, version 10.1 from 10/1/2022 [11]. The aim of the European Biochar Certificate (EBC) is to guarantee compliance with all environmentally relevant limit values and to declare those biochar properties which are relevant for the respective application class. It does not seek to analyze, regulate and guarantee all possible parameters, but rather those that are necessary to ensure safety and sustainability.

The analysis carried out by Eurofins on the four biochars from this EIP project were undertaken according to the EBC Basic Analysis Package covering different certification classes (including EBC-Feed, EBC-Agro, EBC-AgroOrganic, ECB-Urban, ECB-Consumer Materials and ECB-Basic Materials) and additional analysis covering the EBC-Feed package.

Table 5.2 presents an overview of the most important analytical parameters, limit values and declaration requirements for EBC biochar (EBC, 2022).

Each biochar (gorse (*Ulex),* hazel (*Corylus*), bracken (*Pteridium*) and rushes (*Juncus effusus*)) were analysed for a series of characteristics including elemental analysis, potential toxic elements, organic pollutants (PAHs) and heavy metals. The Eurofins test results for *Juncus effusus* are outlined in Tables 5.3a, b, c and d. These results for show it is compliant with ECB limit values. The value for "Total 16 EPA-PAH" is slightly elevated at 8.3 mg/kg. However, the EBC biochar limits for this parameter are $4\underline{+}2$ gt^{-1} DM for EBC-Agro Organic and $6.0\ \underline{+}2.2\ gt^{-1}$ DM for EBC-Agro, and the very low PAH limit values only allow Eurofins an analytical accuracy of 50% and 40% respectively for these limit values which implies an accuracy of 4±2 mg/kg db and 6±2.4 mg/kg db respectively. Therefore, the value for this parameter for *Juncus effusus* biochar is within range for EBC-Agro.

---

[11] https://www.biomasstobiochar.ie/scientific-studies/european-biochar-certificate-guidelines

The Eurofins laboratory results for gorse, hazel and bracken are outlined under the lab-results section of the BBFB webpage[12]. All of these results show these biochars are compliant with ECB limit values.

Table 5.2 Overview of the most important analytical parameters for EBC biochar

EBC -Certification Class		EBC-Feed	EBC-AgroOrganic	EBC-Agro	EBC-Urban	EBC-ConsumerMaterials	EBC-BasicMaterials
Elemental analysis	Declaration of Ctot, Corg, H, N, O, S, ash						
	H/Corg	< 0.7					
Physical parameters	Water content, dry matter (@ < 3mm particle size), bulk density (TS), WHC, pH, salt content, electrical conductivity of the solid biochar						
TGA	Needs to be presented for the first production batch of a pyroylsis unit						
Nutrients	Declaration of N, P, K, Mg, Ca, Fe						
Heavy metals	Pb	10 $g\ t^{-1}$ (88%DM)	45 $g\ t^{-1}$ DM	120 $g\ t^{-1}$ DM	120 $g\ t^{-1}$ DM	120 $g\ t^{-1}$ DM	declaration, no limit values for certification
	Cd	0.8 $g\ t^{-1}$ (88% DM)	0.7 $g\ t^{-1}$ DM	1,5 $g\ t^{-1}$ DM	1,5 $g\ t^{-1}$ DM	1,5 $g\ t^{-1}$ DM	
	Cu	70 $g\ t^{-1}$DM	70 $g\ t^{-1}$DM	100 $g\ t^{-1}$ DM	100 $g\ t^{-1}$ DM	100 $g\ t^{-1}$ DM	
	Ni	25 $g\ t^{-1}$ DM	25 $g\ t^{-1}$ DM	50 $g\ t^{-1}$ DM	50 $g\ t^{-1}$ DM	50 $g\ t^{-1}$ DM	
	Hg	0.1 $g\ t^{-1}$ (88% DM)	0.4 $g\ t^{-1}$ DM	1 $g\ t^{-1}$ DM	1 $g\ t^{-1}$ DM	1 $g\ t^{-1}$ DM	
	Zn	200 $g\ t^{-1}$ DM	200 $g\ t^{-1}$ DM	400 $g\ t^{-1}$ DM	400 $g\ t^{-1}$ DM	400 $g\ t^{-1}$ DM	
	Cr	70 $g\ t^{-1}$ DM	70 $g\ t^{-1}$ DM	90 $g\ t^{-1}$ DM	90 $g\ t^{-1}$ DM	90 $g\ t^{-1}$ DM	
	As	2 $g\ t^{-1}$ (88% DM)	13 $g\ t^{-1}$ DM	13 $g\ t^{-1}$ DM	13 $g\ t^{-1}$ DM	13 $g\ t^{-1}$ DM	
Organic contaminents	16 EPA PAH	declaration	4±2 $g\ t^{-1}$ DM	6.0+2.2 $g\ t^{-1}$ DM	declaration	declaration	not required
	8 EFSA PAH	1.0 $g\ t^{-1}$ DM					4 $g\ t^{-1}$ DM
	benzo[e]pyrene benzo[j]fluoran-thene	< 1.0 $g\ t^{-1}$ DM for each of both substances					
	PCB, PCDD/F	See chapter 10	Once per pyrolysis unit for the first production batch. For PCB: 0.2 $mg\ kg^{-1}$ DM, for PCDD/F: 20 $ng\ kg^{-1}$ (I-TEQ OMS), respectively				

Tables 5.3a, b, c and d outline laboratory test results for Eurofins testing of biochar made from **Juncus Effusus** (rush). Analysis was performed by Eurofins according to guidelines for the sustainable production of biochar - EBC, Version 10.1E - of 10/01/2022.

[12] https://www.biomasstobiochar.ie/lab-results

										Description		Biochar	
				Limit values						Sample number		122042756	
Parameter	**Lab**	**Accr.**	**Method**	EBC-Feed	EBC-Agro Organic	EBC-Agro	EBC-Urban	EBC-Con-sumer Materials	EBC-Basic Materials	**LOQ**	**Unit**	**ar**	**db**
Biochar properties													
Bulk density < 3 mm	FR		in Anlehnung an VDLUFA-Methode A 13.2.1								kg/m³	-	44
specific surface (BET)	SND2/o		DIN ISO 9277: 2014								m²/g	-	92.58
water holding capacity (WHC) < 2 mm	FR		DIN EN ISO 14238, A: 2014-03								%	-	570.5
Moisture	FR	RE000FY	DIN 51718: 2002-06							0.1	% (w/w)	8.9	-
Ash content (550°C)	FR	RE000FY	DIN 51719: 1997-07							0.1	% (w/w)	20.4	22.4
Total carbon	FR	RE000FY	DIN 51732: 2014-07							0.2	% (w/w)	60.2	66.1
carbon (organic)	FR	RE000FY	berechnet								% (w/w)	59.7	65.6
Hydrogen	FR	RE000FY	DIN 51732: 2014-07							0.1	% (w/w)	1.6	1.7
Total nitrogen	FR	RE000FY	DIN 51732: 2014-07							0.05	% (w/w)	1.62	1.78
Sulphur (S), total	FR	RE000FY	DIN 51724-3: 2012-07							0.03	% (w/w)	0.29	0.32
Oxygen	FR	RE000FY	DIN 51733: 2016-04								% (w/w)	9.2	10.1
Total inorganic carbon (TIC)	FR	RE000FY	DIN 51726: 2004-06							0.1	% (w/w)	0.5	0.5
carbonate-CO2	FR	RE000FY	DIN 51726: 2004-06							0.4	% (w/w)	1.8	2.0
H/C ratio (molar)	FR	RE000FY	berechnet									0.31	0.31
H/Corg ratio (molar)	FR	RE000FY	berechnet	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7			0.32	0.31
O/C ratio (molar)	FR	RE000FY	berechnet									0.115	0.115
pH in CaCl2	FR		DIN ISO 10390: 2005-12									9.8	-
salt content	FR		BGK III. C2: 2006-09							0.005	g/kg	80.8	-
salt content	FR		BGK III. C2: 2006-09							0.005	g/l	3.56	-
Conductivity at 1,2 t pressure	FR		Inhouse Method							0.01	mS/cm	-	< 0.01

Table 5.3a Eurofins EBC test results for Juncus Effusus Biochar Page 1

										Description		Biochar	
				Limit values						Sample number		122042756	
Parameter	Lab	Accr.	Method	EBC-Feed	EBC-Agro Organic	EBC-Agro	EBC-Urban	EBC-Con-sumer Materials	EBC-Basic Materials	LOQ	Unit	ar	db
Conductivity at 2 t pressure	FR		Inhouse Method							0.01	mS/cm	-	< 0.01
Conductivity at 3 t pressure	FR		Inhouse Method							0.01	mS/cm	-	< 0.01
Conductivity at 4 t pressure	FR		Inhouse Method							0.01	mS/cm	-	< 0.01
Conductivity at 5 t pressure	FR		Inhouse Method							0.01	mS/cm	-	< 0.01
Elements from the micro wave pressure digestion acc. to DIN 22022-1: 2014-07													
Arsenic (As)	FR	RE000 FY	DIN EN ISO 17294-2 (E29): 2017-01		13	13	13	13		0.8	mg/kg	-	< 0.8
Lead (Pb)	FR	RE000 FY	DIN EN ISO 17294-2 (E29): 2017-01		45	120	120	120		2	mg/kg	-	3
Cadmium (Cd)	FR	RE000 FY	DIN EN ISO 17294-2 (E29): 2017-01		0.7	1.5	1.5	1.5		0.2	mg/kg	-	0.4
Copper (Cu)	FR	RE000 FY	DIN EN ISO 17294-2 (E29): 2017-01	70	70	100	100	100		1	mg/kg	-	37
Nickel (Ni)	FR	RE000 FY	DIN EN ISO 17294-2 (E29): 2017-01	25	25	50	50	50		1	mg/kg	-	16
Mercury (Hg)	FR	RE000 FY	DIN 22022-4: 2001-02		0.4	1	1	1		0.07	mg/kg	-	< 0.07
Zinc (Zn)	FR	RE000 FY	DIN EN ISO 17294-2 (E29): 2017-01	200	200	400	400	400		1	mg/kg	-	229
Chromium (Cr)	FR	RE000 FY	DIN EN ISO 17294-2 (E29): 2017-01	70	70	90	90	90		1	mg/kg	-	25
Boron (B)	FR	RE000 FY	DIN EN ISO 17294-2 (E29): 2017-01							1	mg/kg	-	27
Manganese (Mn)	FR	RE000 FY	DIN EN ISO 17294-2 (E29): 2017-01							1	mg/kg	-	7800
Silver (Ag)	FR	RE000 FY	DIN EN ISO 17294-2 (E29): 2017-01							5	mg/kg	-	< 5

Table 5.3b Eurofins EBC test results for Juncus Effusus Biochar Page 2

										Description		Biochar	
				Limit values						Sample number		122042756	
Parameter	Lab	Accr.	Method	EBC-Feed	EBC-Agro Organic	EBC-Agro	EBC-Urban	EBC-Con-sumer Materials	EBC-Basic Materials	LOQ	Unit	ar	db
Elements fr. the borate digestion of ash 550 °C acc. to DIN 51729-11:1998-11(AR)													
Calcium as CaO	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	% (w/w)	-	7.1
Iron as Fe2O3	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	% (w/w)	-	1.8
Potassium as K2O	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	% (w/w)	-	24.4
Magnesium as MgO	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	% (w/w)	-	5.2
Sodium as Na2O	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	% (w/w)	-	6.6
Phosphorus as P2O5	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	% (w/w)	-	7.4
sulphur as SO3	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	% (w/w)	-	3.4
Silicon as SiO2	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	% (w/w)	-	20.6
Macronutrients													
Total nitrogen	FR	RE000 FY	DIN 51732: 2014-07							0.5	g/kg	16.2	17.8
Macronutrients-LiBO2/Li2B4O7/LiBr-melt of ash 550°C [DIN 51729-11:1998-11] (OS)													
Phosphorus as P2O5	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	g/kg	-	16.5
Potassium as K2O	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	g/kg	-	54.7
Calcium as CaO	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	g/kg	-	16.0
Magnesium as MgO	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	g/kg	-	11.7
Sodium as Na2O	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	g/kg	-	14.7
sulphur as SO3	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	g/kg	-	7.7
Elements fr. the borate digestion of ash 550°C acc. to DIN 51729-11:1998-11(OS)													
Iron (Fe)	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	g/kg	-	2.8
Silicon (Si)	FR	RE000 FY	DIN EN ISO 11885 (E22): 2009-09							0.1	g/kg	-	21.6
Organic contaminents from toluene extraction acc. to EN 16181:2019-08 (method 2)													

Table 5.3c Eurofins EBC test results for Juncus Effusus Biochar Page 3

										Description		Biochar	
				Limit values						Sample number		122042756	
Parameter	**Lab**	**Accr.**	**Method**	EBC-Feed	EBC-Agro Organic	EBC-Agro	EBC-Urban	EBC-Consumer Materials	EBC-Basic Materials	**LOQ**	**Unit**	**ar**	**db**
Naphthalene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	5.1
Acenaphthylene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	0.4
Acenaphthene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	0.4
Fluorene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	0.3
Phenanthrene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	1.1
Anthracene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	0.1
Fluoranthene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	0.4
Pyrene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	0.4
Benz(a)anthracene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	< 0.1
Chrysene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	0.1
Benzo(b)fluoranthene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	< 0.1
Benzo(k)fluoranthene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	< 0.1
Benzo(a)pyrene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	< 0.1
Indeno(1,2,3-cd)pyrene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	< 0.1
Dibenz(a,h)anthracene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	< 0.1
Benzo(g,h,i)perylene	FR	RE000FY	DIN EN 16181:2019-08							0.1	mg/kg	-	< 0.1
Total 8 EFSA-EPA excl. LOQ	FR	RE000FY	DIN EN 16181:2019-08	1	1	1	1	1	4		mg/kg	-	0.1
Total 16 EPA-PAH excl. LOQ	FR	RE000FY	DIN EN 16181:2019-08		4[1)]	6[1)]					mg/kg	-	8.3
Benzo(e)pyrene	FR	RE000FY	DIN EN 16181:2019-08	< 1	< 1	< 1	< 1	< 1	< 1	0.1	mg/kg	-	< 0.1
Benzo-(j)-fluoranthen	FR	RE000FY	DIN EN 16181:2019-08	< 1	< 1	< 1	< 1	< 1	< 1	0.1	mg/kg	-	< 0.1

Table 5.3d Eurofins EBC test results for Juncus Effusus Biochar Page 4

[1)] The very low PAH limit values only allow an analytical accuracy of 50% for the limit value: "sum 16 EPA-PAH" of 4 mg/kg and of 40% for the limit value of 6 mg/kg which implies an accuracy of ± 2 mg/kg db and ± 2.4 mg/kg db, respectively.

Also, EBC biochar limits for Total 16 EPA-PAH are 4±2 gt^{-1} DM for EBC-Agro Organic and 6.0 ±2.2 gt^{-1} DM for EBC-Agro.

5.3.3 Target 3: Assessment of the potential to produce biochar or torrefied products from other biomass streams such as forestry biomass, miscanthus, etc.

A key element of this EIP project was to use unutilised biomass streams to produce biochar, a renewable resource which does not have any implications or critical considerations for the displacement of food production. As part of this EIP project an evaluation was undertaken of potentially available biomass sources from unwanted species typically found on Irish farms. This evaluation was based on information from specific project undertakings, feedback from farmers and conversations during networking opportunities at conferences and events, and a focused online survey of farmers and landowners.

Various communications media including emails, Twitter (now called X), Facebook and Done Deal were used to disseminate this on-line survey and 114 responses from 21 counties were received when the survey closed in May 2022. Farmers were asked a number of questions regarding available biomass on their farms and how this is currently managed/used and is available on the BBFB website.[13] Table 5.4 outlines these survey questions.

Table 5.4 Questions for Farmers/Landowners in 2022 Farmers Survey on Biomass

What county are you farming in?
Does your farm contain rushes and if so, approximately how many hectares?
Do you: spray your rushes/ top your rushes/ mulch your rushes/ harvest your rushes/Other
If you harvest your rushes, how many bales would you make in a typical year?
If you don't harvest, please state why, e.g., wet/inaccessible/conservation reasons
How do you usually store your bales? In field/ In yard/ In shed/ Other
What do you use the rushes bales for? Bedding/ Fodder/ Other
Do you have any bracken (fern) and if so, what's the approximate area covered by bracken in hectares?
Do you have any furze (gorse) and if so, what is the approximate area covered by furze in hectares?
Do you have any hazel and if so, what is the approximate area covered by hazel in hectares?
To harvest rushes and keep in dry storage, how much would you expect to get paid per bale?

[13] https://www.biomasstobiochar.ie/blog/according-to-our-survey-of-irish-farms-across-21-counties

The following outlines the results of the evaluation of valuable biomass streams from currently unutilised agricultural biomass:

5.3.3.1 Rushes (Juncus spp.)

Rushes grow in abundance in several farms located within the West of Ireland and on other farms throughout Ireland which have areas of wet and gley soils. Of all biomass streams considered rushes are by far, the easiest to access. The 2022 Farmers Survey indicated that of the 114 farmers surveyed 84% top their rushes, 33% spray, and 24% harvest and produce bales (using them generally for bedding). Given farmers manage rushes by topping indicates they are using farm machinery, and the ground is traversable and suggests a higher percentage of rushes could be harvested while accounting for the usual restrictions of weather. Rushes must be dried in same way as hay to be processed into biochar.

Of the 35 that answered that they harvested their rushes, the numbers of bales harvested ranged from less than 10% harvesting up to 10 bales per year, to 3.5% harvesting more than 50 bales per year. In addition, 50% of these respondents store their bales in a shed and a further 33% store in their yard, indicating that 83% of the respondents were already using their rushes for bedding or fodder rather than allowing them to rot in the field.

Table 5.5 below shows what percentage of landowners had land with rushes in each hectare range. Using a conservative yield of 7 bales per ha/year the median bales yield was determined. Based on the Teagasc information note on straw use, a heating oil equivalent of 393L/ ton of dry hay was used to calculate the potential heating oil yield. The biochar yield was based on a 20% conversion factor.

Based on this survey, rushes represent an untapped biomass resource that currently requires resources (money, machinery, fuel) to control and are contributing to carbon emissions when left to rot. The spraying of rushes could be converted into harvesting, thus reducing herbicide use. A key opportunity exists to use the availability and sustainability of this unutilised biomass to produce biochar which is perfectly suited for farm production as part of an innovative circular economy on the farm.

Table 5.5 Percentage of landowners with rushes in each hectare range, and potential bale and biochar yield

Range	**Respondents**	**Median**	**Heating oil equivalent**	**Biochar yield**
Ha	**%**	**Bale yield**	**Litres**	**Tons**
1- 5 ha	49.6	35	3,439	1.75
6-10 ha	21.5	57	5,600	2.85
11-15ha	10.7	91	8,941	4.55
16-20ha	7.4	126	12,380	6.3
21-25 ha	3.3	161	15,818	8.05
26-30 ha	3.3	210	20,633	10.5
31-35 ha	1.7	231	22,696	11.55
35 ha+	2.5	231	22,696	11.55

5.3.3.2 Hazel (Corylus)

Hazel is problematic in that the scrub spreads onto previously worked agriculture land, as can be seen in the Burren, and can impact on protected habitats and species rich grasslands. Accessibility is a particular problem for machinery; for example within Karst landscapes. Generally, hazel must be hand cut with a chainsaw and extracted to an area suitable for processing.

During this EIP project, hazel was collected from the Burren after it had been cut and left uncovered to dry for a year. Chipping took place during a very dry spell to ensure that was no surface moisture.

Hazel biochar would be perfectly suited for farm production as a part of farm bioeconomy.

5.3.3.3 Furze (Ulex spp.)

Furze was found to be similar to hazel apart from the fact that it is more readily available and therefore perfectly suited for farm production into biochar as part of a farm bioeconomy.

5.3.3.4 Bracken (Pteridium)

There were limited amounts of bracken (*Pterdium*) found on farms, which is not always easy to access. Bracken is often controlled with Asulam, leaving a negative impact on the environment. Harvesting requires good access which is quite often a challenge.

During this EIP project bracken was harvested then dried and chopped with a bale chopper, before being processed into biochar.

5.3.3.5 Forestry Biomass

Forestry biomass (brash) can often be contaminated with soil and stones and would not be suitable for biochar commercially. It would however be suitable for farm production /own use.

5.3.3.6 Rhododendron (Rhododendron ponticum)

Generally, rhododendron is difficult to access and harvest and so in this case, would not really be suitable for harvesting as biomass to biochar using the MPU. However, in certain circumstances where access allows, it could be considered. Other low-tech alternatives would be more appropriate.

In summary, further exploration of the production and use of biochar from unutilised biomass, and how this can be scaled up and fine-tuned to regional contexts over the longer-term, deserves attention. This includes the opportunity for driving an innovative bioeconomy on and off the farm.

5.4 KPI 4: Demonstrating that biochar utilisation can contribute to the sustainability of local bio-economies and help the agri-sector by reducing greenhouse gas emissions, improving land fertility and productivity, and protecting water quality.

5.4.1 Target 1: Establishment of biochar trial/use by producers within stakeholder network

A number of studies were undertaken during the course of this EIP project to assess how biochar produced from unutilised biomass can contribute to the sustainability of local bio-economies and assist the agricultural sector by reducing GHGs, improving soil condition and protecting water quality. These studies are listed below with summaries of their results. More detailed reports are available on the Scientific-Studies page of the BBFB website.

Also, the LCA undertaken for this EIP has shown how the production and use of biochar from existing unutilised biomass streams on farms has the potential to contribute to the objectives of EU and national agricultural and climate action policies, while at the same time maintaining EU food security. This can be achieved through: carbon sequestration and stable carbon storage arising from biochar production together with its storage in soil; opportunities to remove CO_2 from the atmosphere via CDR; reducing total gaseous losses arising from land application of dairy cattle slurry; eco-system service benefits following its application to soil; and, through the potential to counteract the GWP impacts from grazed lands and increase the sustainable management of grasslands. This is discussed further under KPI 7 in this report and in detail in the final Life Cycle Assessment Study Report for the project.

<table>
<tr><th>Project Collaboration</th><th>Study</th><th>Supplied</th></tr>
<tr><td>Bernard Carey, Biomass to Biochar</td><td>Biochar added to Slurry using different biomass sources</td><td>Juncus biochar, Ulex biochar, Corylus biochar</td></tr>
<tr><td colspan="3">Two initial on-site field studies were carried out by the BBFB project team to examine the reduction in GHG emissions following the addition of 10 % biochar w/w to slurry. The first field study was set up using 4 x 700 L tanks filled with slurry including: a control, and addition of 10 % w/w of Juncus, Ulex, and Corylus biochars. This was followed by a second repeat field study.

The results of the field studies were that Rush biochar reduced GHG emissions by 60% more than the control. Furze biochar increased GHG emissions 25% more than the control, making it suitable for biogas production scenario. See Image 5.16 and Figures 5.5 and 5.6.

These were followed by a laboratory study undertaken by Celignis Laboratories in Limerick[14].</td></tr>
</table>

[14] https://www.biomasstobiochar.ie/lab-results/biochar-added-to-slurry-reduces-methane-ammonia.

The laboratory study showed a 42% decrease of methane production after 10% Juncus biochar was added to the cattle slurry samples. See Figure 5.7.

One of the main findings of this work was that different biochars had different effects on methane production. Biochar made from *Juncus* had a significant negative effect on methane production, whereas *Ulex* biochar increased the production of methane indicating interesting possibilities for anaerobic digestion technology. [15]

Image 5.16 On-site field studies carried out by the BBFB project team to examine the reduction in GHG emissions following the addition of 10 % biochar w/w to slurry.

[15] Additionally, the incorporation of small quantities of biochar (e.g. 1% on a dry matter basis) in batch biodigesters have been shown to increase gas production by >30% after 30 days of continuous fermentation (Inthapanya et al., 2012). Such recycling of a biomass feed source to produce biochar and biogas, and additionally treating solid organic waste sludge in an anaerobic digester (reducing its CO_2 emission by up to 86%) and producing a high-grade bio-CH4 for direct use e.g. upload to the natural gas supply grid (Shen et al., 2015), is a prime example of how the bio-economy can increase long-term sustainability and help the economy move away from fossil-based dependence.

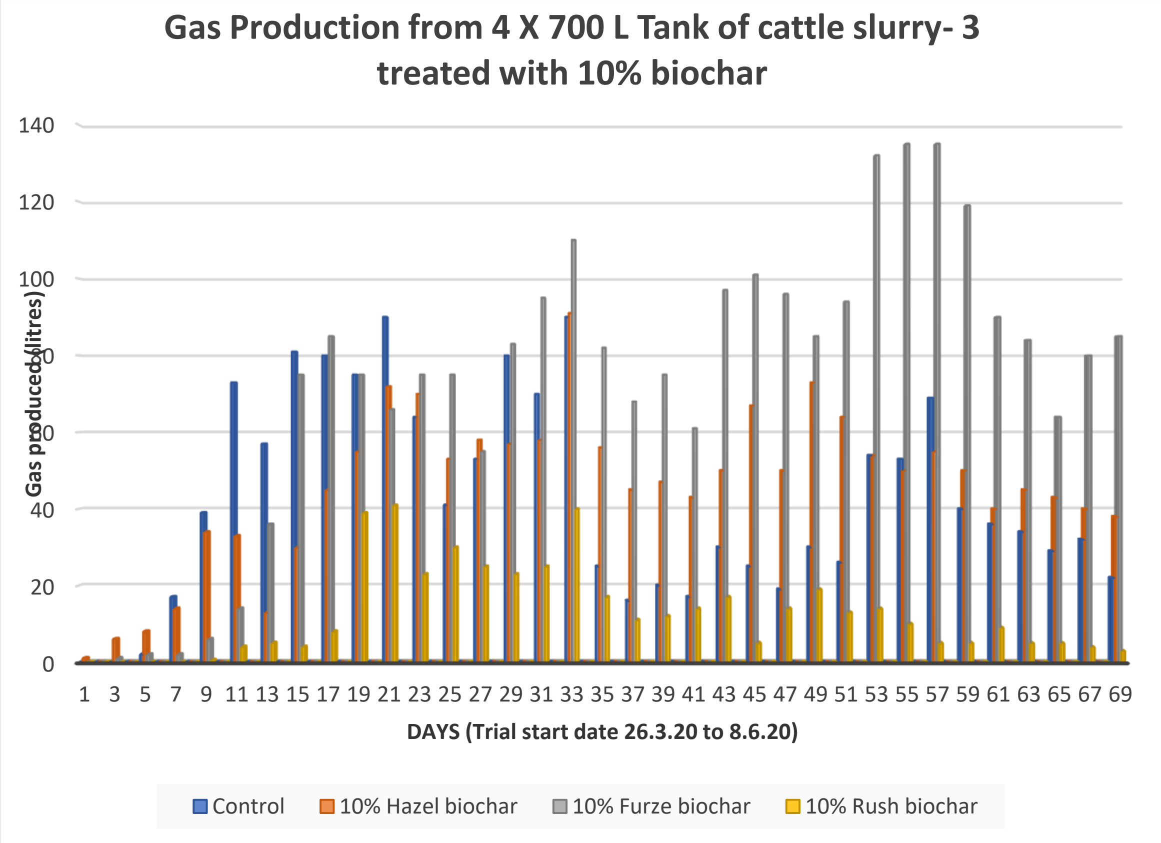


Figure 5.5 Graph of gas production from tanks of cattle slurry treated with 10 % biochar.

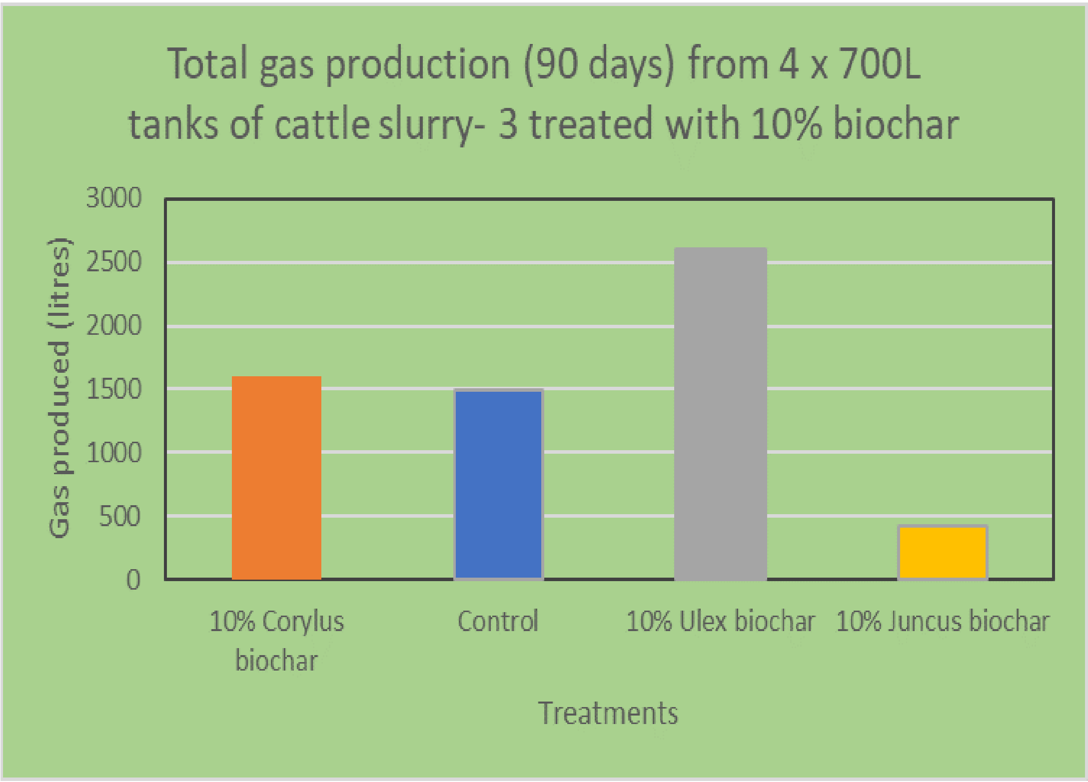


Figure 5.6 Total gas production from slurry tanks treated with 10 % biochar and control

Biogas and Biomethane Potential (BMP) - Volatile Solids Basis (Litres per kg VS)												
Sample Name	Days Digested	BMP at Day	Biogas Production					Biomethane Potential (BMP)				
			Average	Rep #1	Rep #2	Rep #3	Std. Dev	Average	Rep #1	Rep #2	Rep #3	Std. Dev
BIOMASS TO BIOCHAR CATTLE SLURRY	28	28	**211.7**	189.3	188.7	257.1	39.3	**176.4**	158.3	157.6	213.3	31.9
BIOMASS TO BIOCHAR CATTLE SLURRY WITH 10% CHAR	28	28	**148.2**	176.7	150.0	118.0	29.4	**102.9**	122.1	104.2	82.5	19.8

Figure 5.7 Laboratory study of methane emissions from slurry treated with biochar and control (Ceilignis, 2022)

Project Collaboration	**Study**	**Supplied**
Feidhlim Harty FH Wetland Systems	Field Study Using Rush biochar as filter medium for water protection	Rush biochar Woodchip biochar

This field study looking at the benefits of using biochar made from rushes for treating pond water.

The microbiological analysis for Total coliforms and E. coli both showed improvements based on filtration compared with the controls. This suggests that biochar may be used as a filter medium within agricultural catchments to reduce the overall contamination of coliform bacteria and potentially other microbial pathogens for the general improvement in water quality health throughout our farmland catchments.

Although the results of this pilot work were inconclusive, it served to better identify practical constraints for a future controlled study to quantify the uses of biochar for protecting aquatic environments and water bodies from pollutant ingress.

Project Collaboration	Study	Supplied
Bernard Carey, Biomass to Bio-char	Urea coated with Rush biochar to reduce ammonia	Rush char

A short experiment was undertaken by the BBFB team to examine the potential for biochar to reduce ammonia emissions from urea. Using Gastec ammonia detector tubes in two sealed containers one with urea (control) and other treatment (urea and biochar). Ammonia emissions were noted after 4 days, 6 days and 15 days. This simple experiment indicated that with the addition of biochar ammonia emissions (indicated by yellow in the Gastec tubes in Image 5.17) were reduced compared to the control.

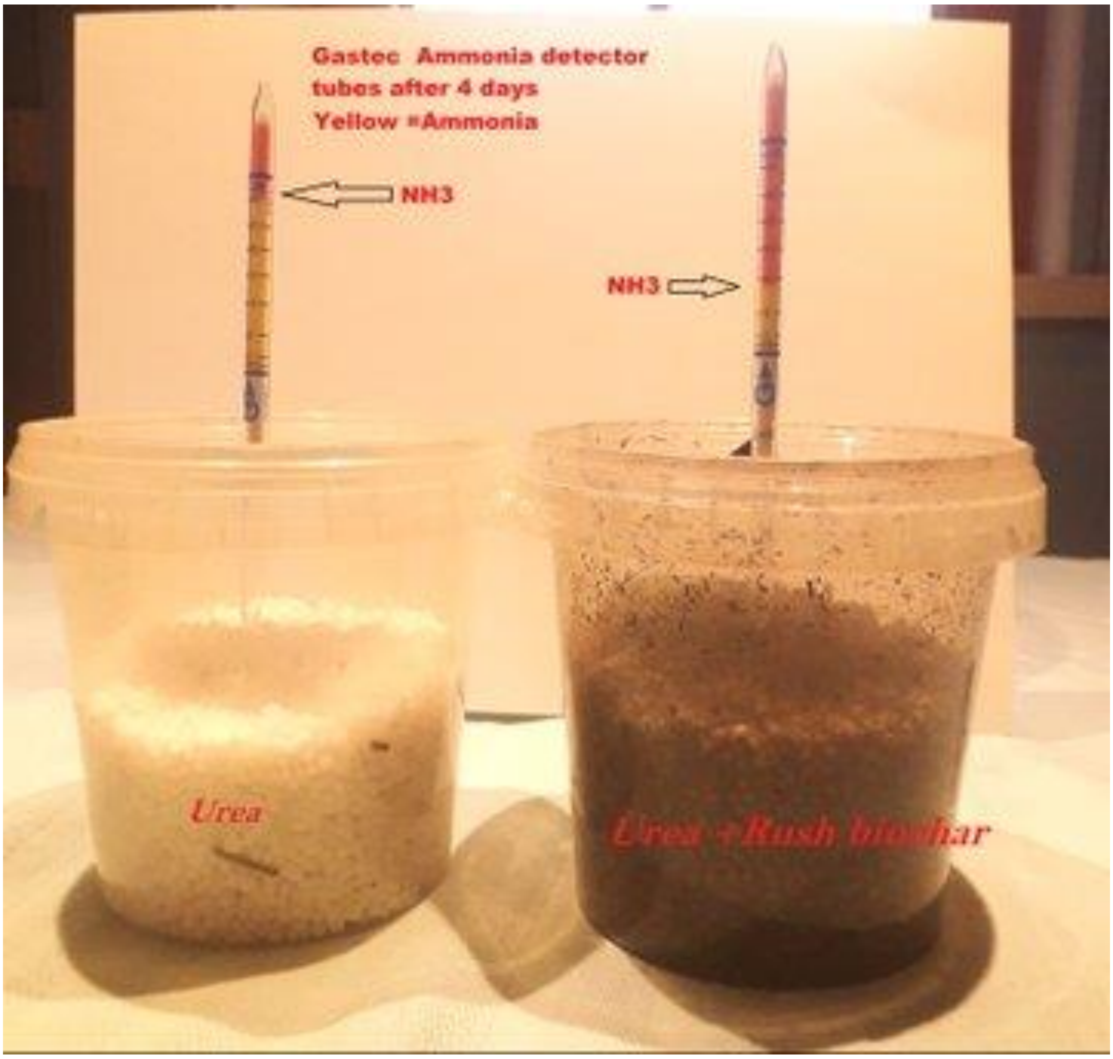


Image 5.17 Gastec ammonia detector tubes in two sealed containers one with urea (control) and other treatment (urea and biochar).

Stakeholder Name	Study	Supplied
Maurice Deasy, Co Tipperary (Farmer)	Coating cereal seed mix of bio-char and seaweed[16]	Rush Char (plus olive stone bio-char supplied by Arigna)
This study was caried out to demonstrate the positive effect of inoculating seeds with biologicals including biochar as a home for microbiology. Results/ Observations The seed treatment which included biochar did not have an inhibitory effect. Visual assessment would show it appeared to have a positive effect on the root development. The main benefit of biochar would be to extend the useful lifetime of the seed dressing on the seed, therefore testing after different times of storage would be useful to evaluate the level of biology surviving over time.		

Stakeholder Name	Study	Supplied
Michael Gaffney, Teagasc	Testing rush biochar in potting media	Rush Char
'Beyond Peat' Project was to replace peat in horticultural medium. Sample of biochar sent to Teagasc for potting media trials to replace peat Samples were analysis and were found to be high in phosphorus and potassium. Pot trials on straw-berries were carried out but as of writing there were no confirmed results.		

[16] https://www.biomasstobiochar.ie/scientific-studies/trial-coating-cereal-with-biochar

5.4.2 Target 2: Support of scientific experimental set-up to test the field use and performance of biochar in applications such as soil fertility and structural improvement, augmentation of soil carbon sequestration, animal feeds, capture of waterborne pollutant or eutrophying agents.

The final phase was the supply of biochar for scientific trials within the stakeholder network to test the field use and performance of biochar for reducing GHG emissions, soil fertility and structural improvement, augmentation of soil carbon sequestration, animal feeds, capture of waterborne pollutant or eutrophying agents.

<table>
<tr><th>Project Collaboration</th><th>Study</th><th>Supplied</th></tr>
<tr><td>BBFB and Dr Stafford Vigors, University College Dublin</td><td>Rush Biochar added to 24 Artificial Rumens</td><td>Rush char</td></tr>
<tr><td colspan="3">As part of this EIP project an experiment was undertaken with University College Dublin to test the impact of using biochar as a feed additive for ruminant animal diet inclusion. The use of biochar as a feed additive has been suggested as a potential method for reducing methane emissions from ruminant livestock. This study aimed to evaluate the effects of different inclusion rates of biochar on ruminal fermentation characteristics, dry matter digestibility, and gas production in a batch culture system using rumen fluid collected from dairy cows.

The results showed that the inclusion of biochar significantly affected dry matter digestibility and gas production, with an overall increase in dry matter digestibility and decrease in gas production as the inclusion rate increased. However, there was no significant effect on pH. The data also showed no clear trend for the protozoa variable.

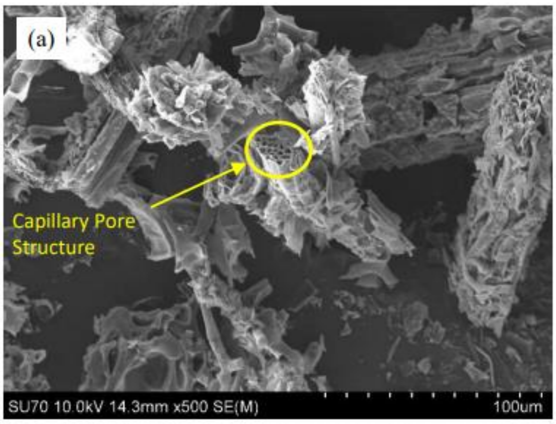
The inclusion of a rush-based biochar had no significant effect on the measured experimental parameters however there was a statistical tendency (P = 0.07) towards a reduction of both the proportion of methane and the concentration of methane (mmol/day) produced. This will be further assessed in ongoing work. Initial indications are that rush biochar could potentially reduce methane production by up to 17% whereas other biochar made from spruce and Bracken had negligible impact on methane reduction.

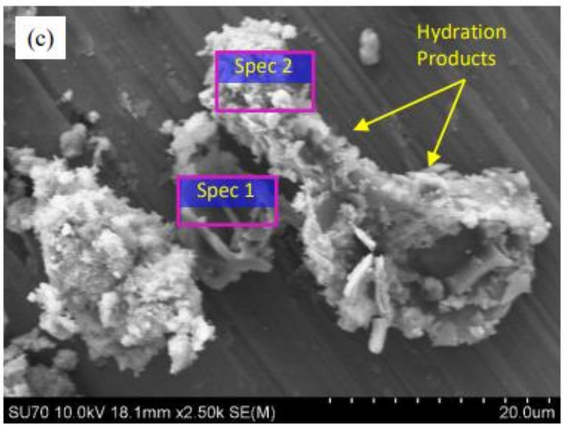
These findings suggest that the inclusion of biochar in ruminant feed may have potential for reducing methane emissions.</td></tr>
</table>

Project Collaboration	Study	Supplied
BTB and University of Limerick Masters Thesis: Cunningham and Keane, 2023[17]	Testing Biochar in Building Blocks 80% Rush Biochar 20% cement	Rush char

Researchers at University of Limerick recently undertook a study assessing the use of biochar as a cementitious replacement in structural concrete (Cunningham and Keane, 2023). Cement production accounts for between 4% - 8% of total global anthropogenic CO_2 emissions (Amran et al. 2021). The use of supplementary cementitious materials (SCM) is seen as a way to reduce the environmental burdens of cement production (Cunningham and Keane, 2023). The (Irish Government's 2023 Climate Action Plan mandates the use of low-carbon cement on all public body construction projects as well as supporting the research and development of novel binders and fillers in low-carbon cement (Cunningham and Keane, 2023).

Cunningham and Keane (2023) investigated the use of locally produced rush biochar from the MPU in this EIP project and from Sitka Spruce pellets harvested in Co. Roscommon. The physical and chemical properties of both biochar's were characterised using elemental analysis, scanning electron microscopy, and thermogravimetric analysis before being added to the concrete at varying cement replacement levels from 0–6% (see Figures 5.18 (a) and 5.18 (b)). The effects of its introduction on the mechanical properties and durability of concrete were investigated through experimental analysis. Biochar was found to reduce the workability of concrete significantly. Both sources of biochar caused reductions in compressive strength when compared to the control, however, the addition of 4% rush biochar led to an increase in flexural and split tensile strength. It was also found that both the timber and rush biochar increased the permeability of the concrete by 45% and 20% respectively. A "cradle to gate" life cycle assessment undertaken found that a carbon-neutral cement can be achieved with 20% by weight biochar addition.





[17] https://www.biomasstobiochar.ie/scientific-studies/assessing-the-use-of-biochar-as-a-cementitious-replacement-in-structural-concrete

Image 5.18 (a): Scanning Electron Microscopy image of Juncus biochar produced in BBFB EIP project.

Image 5.18 (b): Biochar concrete composites with Juncus, the hydration products in the biochar pores and EDX spectrums taken can be seen. Source: Cunningham and Keane, 2023.

In their conclusions, the authors recommend that as the rush biochar displayed the most promising results, further research on the effect of varying the conditions of pyrolysis and cement replacement level from 0–6% should be undertaken to optimise its performance as an SCM. The analysis revealed that the rush biochar was not fully pyrolyzed; therefore, increasing the pyrolysis temperature would increase the carbon content and modify the internal pore structure (Cunningham and Keane, 2023). Assessing the effects of dry curing was also recommended as there is strong evidence in the literature of improved performance of biochar-added concrete vs a control when it is dry cured (Sirico et al. 2021) and determining the long-term performance of biochar concrete composites was also recommended (Cunningham and Keane, 2023).

Image 5.19 Carbon block produced using 80 % rush biochar and 20 % cement.

Project Collaboration	**Study**	**Supplied**
University of Limerick Dr Anne Beaucamp Mc Loughlin Professor Maurice Collins	Electrochemistry testing on biochar from *Juncus* rushes 2023[18]	Rush char

As part of the BBFB EIP project, University of Limerick undertook electrochemistry testing on rush biochar produced by the MPU (UL, 2023). The analysis revealed the biochar presented a honeycombed structure with no capacitance properties, and the carbonisation allows for retention of the structure and capacitance effect with a Cp close to 10 F/g. Thus, it was concluded that this material presents strong potential for energy, supercapacitor application and further testing was recommended after activation of the biochar to open mesopores and micropores to increase Cp (UL, 2023).

Stakeholder Name	**Study**	**Supplied**
Eric Hynes, University College Cork	Masters Thesis: Biochar as a Plant Growth Substrate Amendment[19]	Oak biochar Rush Biochar

This study evaluated the effects of 2 biochars (BC) and peat-free (PF) compost treatments on the plant growth of perennial ryegrass (PRG) (*Lolium perenne*) and oilseed rape (OSR) (*Brassica napus*).

Overall, the addition of an oak and rush biochar to a peat-free compost as separate growth media treatments had mostly neutral to negative effects on plant-growth promotion. However, the positive effect of rush biochar on perennial ryegrass in treatment 2 using peat free compost and rush biochar, and treatment 4 which consisted of peat free compost and rush biochar incubated for 6 months, would suggest that perennial ryegrass may be an ideal target plant for rush biochar or as part of a biochar and peated/peat free compost treatment.

---

18 https://www.biomasstobiochar.ie/scientific-studies/electrochemistry-testing-on-biochar-from-juncus-rushesabeaucampul

19 https://www.biomasstobiochar.ie/scientific-studies/biochar-as-a-plant-growth-substrate-amendment-ucce-hynes

While this study indicated that adding biochar to mature compost yielded neutral to negative results in plant growth, this highlights the value of the COMBI* method of adding biochar at the beginning of the composting process which has shown many benefits to crop production and soil health amelioration. This highlights the synergy that occurs between biochar and composting and the need for biochar to be primed. *The term co-composted biochar (COMBI) refers to biochar which is mixed with compost feedstock (organic matter that is both rich in nutrients and labile organic carbon, such as sewage sludge, manure, and plant residues) before aerobic composting (Fischer and Glaser, 2012).

Stakeholder Name	**Study**	**Supplied**
Dr Simon Hodge, UCD	The Effects of Insect Frass Fertilizer and Biochar on the Shoot Growth of Chicory and Plantain [20]	Hardwood & Olive Stones Biochar produced by Arigna & supplied by the Project
The aims of this study were to use glasshouse trials to: (1) examine the survival and growth of plantain and chicory seedlings after the application of insect frass fertilizer at different rates; (2) investigate the effect of frass fertilizer on seedling growth when applied to growing media with different basal nutrient levels; (3) compare the plant growth obtained with frass fertilizer to that obtained using a standard organic fertilizer; (4) examine the effect of frass fertilizer on the regrowth of chicory and plantain after harvest; and (5) investigate the combined effects of frass fertilizer and biochar on plant growth[21] There were indications to suggest that, when biochar was added to growing media that also contained 4 g HF (close to the optimal HF application rate identified in the dose–response trials), it resulted in an increase in the shoot growth in addition to that caused by the HF alone. The results suggest that farmers aiming to increase the carbon content of their soils by applying biochar and, thus, reduce their farms' overall carbon footprints, could do so without negatively impacting the growth of these forage species.		

[20] https://www.biomasstobiochar.ie/scientific-studies/the-effects-of-two-organic-soil-amendments-biochar-and-insect-frass-fertilizer-on-shoot-growth-of-cereal-seedlingsshodgeucd

[21] Hodge, S.; Conway, J. The Effects of Insect Frass Fertilizer and Biochar on the Shoot Growth of Chicory and Plantain, Two Forage Herbs Commonly Used in Multispecies Swards. Agronomy 2022, 12, 2459. https://doi.org/10.3390/agronomy12102459.

This study also shows neutral results when biochar is added to mature compost as opposed to being co-composted which has a 'priming' effect on the biochar.

Stakeholder Name	Study	Supplied
Dr Simon Hodge, UCD	The Effects of Two Organic Soil Amendments, Biochar and Insect Frass Fertilizer, on Shoot Growth of Cereal Seedlings	*Ulex* and *Juncus* supplied by the project and processed by Arigna
The application of finely ground or crushed biochar (*non-primed)*) produced from four different feedstocks (*Ulex*, *Juncus*, woodchip, olive stone) had no consistent positive or negative effects on cereal shoot growth. Overall, our results indicate that insect frass-based fertilizers have good potential in low-input, organic, or regenerative cereal production systems. Based on our results, biochar appears to have less potential as a plant growth promoting product, but could be used as a tool for lowering whole-farm carbon budgets by providing a simplistic means of storing carbon in farm soils[22].		

Stakeholder Name	Study	Supplied
Dr. David O'Connell, Trinity College Dublin	Research on the sorptive capacity of biochar for water	Rush char
The research group assessed the nutrient and heavy metal sorption capacity of pristine and bespoke modified biochar for potential applications to produce drinking water, treat runoff water and wastewater. This work is part of the NuReCycle Project at TCD (4 PhD students) which is funded through the Kinsella Foundation. At time of writing this project in on going.		

[22] Carroll, A.; Fitzpatrick, M.; Hodge, S. The Effects of Two Organic Soil Amendments, Biochar and Insect Frass Fertilizer, on Shoot Growth of Cereal Seedlings. Plants 2023, 12, 1071. https://doi.org/10.3390/ plants12051071.

Stakeholder Name	Study	Supplied
John Sims, Mary Immaculate School Lisdoonvarna, BT Young Scientist	Rush Biochar coated Urea[23]	Woodchip biochar

BT Young Scientist & Technology Project was to combat the rapid rise of greenhouse gas emissions by promoting a greener and safer way to fertilise soil with inclusion of a biochar coating which will create a carbon sink, therefore reducing CO2 emissions.

To see if coating urea with different amounts of biochar would reduce the release of ammonia by the urea.

To see if different types of biochar would give different results.

To compare our emissions with those of the urea and protected urea.

Results

Biochar coated urea released less ammonia gas at the start of the trials compared to the regular urea, but by the end they caught up with each other.

After running many different trials with different ratios of biochar, it was concluded that the type of biochar had little effect on the outcome overall.

The trials carried out on protected urea had released little to no gas by day four, and when coated with biochar, this release was slowed even further.

[23] https://www.biomasstobiochar.ie/scientific-studies/rush-biochar-coated-ureayoung-scientist

5.5 KPI 5: Dissemination of learning and promotion of the project at national and European levels.

The BBFB strategy for dissemination is represented in the Figure 5.8 below. Although the project was specific to Ireland and the Irish climate, it is interesting that followers on social media came from all over the world and particularly from developing nations. It is hoped that this project can continue to be disseminated to the wider agricultural sector within Ireland to bring about a sharing of knowledge on a larger scale. During the project, the BBFB project team came into contact with individuals, SME's and large enterprises from both Ireland and Europe.

Figure 5.8 BBFB EIP Project Strategy for dissemination

Regular dissemination was made through the BBFB website and social media, specifically twitter. However, we have reached some farmers through Done Deal, which is where we put out a call for bales of rushes and this has been a useful source for direct advertising to farmers.

The website for the project is a central point for storing our information, our progress, photographs, graphs, studies and updates. It has been regularly updated and has seen a steady flow of visitors. Twitter & Facebook is where updates on the project are shared and Twitter is where anything which improves knowledge and learning in the field of biochar has been shared, including the production of biochar and how to make biochar; specific to the microcosm of Ireland.

The most positive way of dissemination occurred through networking and forming personal relationships; gaining contacts for help required for this project and explaining the benefits of biochar to farmers in person. The learning from this was that the feedback was far more positive than had been presumed. A reluctance to change had been expected; however, the feedback from all of the interaction with farmers was enthusiastic, with genuine interest and an openness to the potential for biochar to create a farm bioeconomy.

Image 5.20 BBFB EIP project set up at conferences.

Image 5.21 Attending EU CAP seminar in Porto, Portugal December 2022

The most practical tool for dissemination was the BBFB EIP Infographic Poster (See Fig 1.1& Image 5.21). This was a game changer when talking to people, as they were able to quickly visualise the concept, the outcome and the benefits. A number of these posters were sent to Agricultural Colleges for display.

The ability to speak at a conference was an extremely effective way of sparking interest and caused an increase in farmers, companies and teaching facilities reaching out to us. The age demographic was very wide.

5.5.1 Target 1: Launch of BBFB website, targeted contact with relevant interest groups and outreach programme

This EIP project has spent considerable efforts disseminating the findings and promoting the project at national and European levels. The following tables outline BBFB activity on various social media platforms, specific interviews and articles on TV, radio and newsprint, and interaction with relevant interest groups.

Dissemination of Learning	Link	Followers @31/03/2023
Website	www.biomasstobiochar@gmail.com	1194
Flyer	https://www.biomasstobiochar.ie/media/project-leaflet	4,500 distributed
Facebook	https://www.facebook.com/Biomasstobiochar/	361
Twitter	https://twitter.com/bbiochar	798
YouTube Channel	https://www.youtube.com/chan-nel/UC9z8HMN7BIlYE77XLOelC-Q	10 videos
Infographic	https://www.biomasstobiochar.ie/blog/infographic	
Video Explainer	https://www.youtube.com/watch?v=u_b_g7JJ274	
Short Film about the Project	https://www.youtube.com/watch?v=vLqqDD47vws	

Available on Project Website:

Media Dissemination	Date	Medium
Mairead Lavery, Newstalk	2019	Radio
Clare Champion	Jan 2019	Newspaper
Farmers Journal	Jan 2019	Newspaper
'Ear to the Ground'	Feb 2020	Television
'Ear to the Ground'	Jun 2020	Television
Clare Champion	Apr 2022	Newspaper
Agriland	Nov 2023	Online
Agri insider	Nov 2023	Podcast

Relevant Interest Groups		
Irish Bioenergy Association (IrBEA)	Member	Collaboration Call for Expert Evidence 2023 as part of Ireland's Climate Action Plan 2023 Discussions an alternative proposal to the regulations for the burning of agricultural green waste
Ireland's Climate Action Plan 2023	Call for Expert Evidence 2023	
The Irish Biochar Co-operative Society	Member	Membership platform for farmers etc. to be able to produce and certify biochar-based products
114 farmers as part of survey over 24 counties		Outreach programme interacting with farmers as part of survey
Agricultural Colleges / schools		Dissemination of Infographic Posters distributed

5.5.2 Target 2: Production of scientific reports and papers.[24] Conference participation.

This EIP project has spent considerable efforts disseminating the findings and promoting the project at national and European levels conferences and farming events. The following tables outline BBFB presentations and exhibitions at these events.

Dissemination/ Conference Participation	***Year***	***Presentation***	***Exhibition***
Conference 'Biochar and Activated Carbon' Western Development Commission, Mayo	2018	✓	
EIP-AGRI National Conference, Teagasc, Oakpark	2019	✓	
EIP-AGRI Workshop, Vilnius, Lithuania	2019	✓	
Re-Direct Biochar Conference, Baden BADEN, Germany	2019		
Biochar Workshop, Portlaoise	2019	✓	
3-day International Biochar Initiative study tour in Tampere, Finland	2019		
Wales	2019		
National Ploughing Championship Carlow	2019		✓
The Woodland League, Agroforestry - biochar presentation	2021	✓	
EIP event Burren Winterage, Kinvara	2021		
Nordic Webinar: Biochar Workshop Series, Helsingborg	2021		
IrBEA Bioenergy Conference, Kilkenny	2022		✓
Scariff Agricultural Show	2022		✓
Bioeconomy Summit, Tullamore	2022		✓

[24] See KPI no.4 for scientific reports and papers

Dissemination/ Conference Participation	*Year*	*Presentation*	*Exhibition*
EIP presentation, Backweston, Kildare	2022		✓
Burren Winterage with MPU	2022		✓
Athlone EIP-AGRI National Conference	2022	✓	✓
EU CAP seminar, Porto, Portugal	2022	✓	✓
EIP Advisory Committee meeting, Kildare	2022		✓
Munster Technology University – Circular Bioeconomy Research	2022	✓	
Carrick on Shannon National Biochar & Carbon Products Conference	2023	✓	✓
Presentation for The National Economic and Social Council	2023	✓	
Online presentation- Informbio Project webinar	2023	✓	

5.5.3 Target 3: Cooperation with other areas within the EU with an interest in the management of on-farm biomass, the production of biochar and the sequestration of atmospheric carbon.

The following table outlines BBFB co-operation with various international entities with interests in biochar and sequestration of atmospheric carbon.

Project/ Company Name EU	Stakeholder Name	Details
www.terraffix.co.uk	Sion Brackenbury	Pyrolysis project in Wales
IKKA, Finland, California	ilkka@carboculture.com	Batch, pelletising system. Looking into alternative biomass
ATB, Germany	Thomas Heinrich theinrich@atb-potsdam.de	looking at turning poor quality grasses into biochar
Foodlabs, Germany	anastasssiarowe anastassia@foodlabs.de	interested of widespread abatement technology and the challenges it faces and main barriers preventing large-scale and cost-effective production of biochar
Kingspan, Ireland	Hannagh Roughneed R&D Engineer Hammer milled rushes	Investigation on the potential of rushes as a pontential bio-based fibre
Promeco, Wood Fibercompany, EU	Veronica Caspani	Juncus processing mixed with wood

5.6 KPI 7: Life Cycle Analysis to track the carbon cost and benefits through the complete lifecycle of the project from biomass harvesting operations to the deployment of the material to soil or as an additive to slurry tanks.

5.6.1 Target 1: Delivery of Life Cycle Analysis for project.

A Life Cycle Assessment (LCA) was undertaken for this EIP project to consider the Global Warming Potential (GWP) of a series of Irish agricultural scenarios for managing unutilised rush biomass and for the production of biochar from rushes. LCA models were developed for nine different scenarios covering a) existing agricultural practices resulting in the production of unutilised biomass, b) the farm operations involved in producing rush biomass as a pyrolysis feedstock, c) the operations specifically related to the farmyard production of biochar using the MPU, and d) the end-use of the biochar as a soil amendment, or as a slurry amendment applied to the soil.

Negative GHG balances calculated for the production and soil application of biochar, illustrate the beneficial GWP impact of harvesting and baling rush biomass, using this to produce biochar and applying it to soil directly or incorporating in slurry. GHG emissions that would have arisen from the decomposition of biomass were avoided and LCA results indicate the viability of carbon sequestration in rush biochar and the potential for long-term carbon storage through its incorporation in soil (e.g. remaining unmineralized in soil). These results show that the production of rush biochar from unutilized biomass presents readily available opportunities to remove CO_2 from the atmosphere as a Carbon Dioxide Removal (CDR) scheme. Pyrolysis technology and products such as rush biochar can be efficient at medium to small scale and so make it possible to have CDR schemes not only at local scale, but also as part of wider rural bio-economies.

Scenarios describing the application of non-amended and amended slurry (with 10% w/w rush biochar) to grassland soil were developed based on data from tests undertaken during this EIP project. These showed significant reductions in CH_4 emissions (42%) from treating slurry with rush biochar in slurry tanks, and a final lifecycle balance showing a significant reduction in GHG gases when rush biochar was added to slurry (i.e. 80%+) and then applied to land. LCA results for rush biochar, show it has excellent potential to reduce total gaseous losses arising from land application of dairy cattle slurry. Laboratory trials undertaken in the BBFB project also showed a statistical tendency towards the reduction of methane from ruminants when rush biochar was added to feed.

In addition, published research indicates that improved pasture and rangeland practices that promote land-based carbon sequestration have the potential to contribute to climate change mitigation by reducing net GHG emissions from beef-production systems. These improved land management strategies could be further assisted through the use of biochar for direct carbon sequestration and as a soil amendment.

The LCA has demonstrated practically how the production and use of biochar from existing unutilised biomass streams on farms has the potential to contribute to the objectives of EU, and national agricultural and climate action policies, while at the same time maintaining EU food security. This can be achieved through:

- carbon sequestration and more stable carbon storage arising from biochar production together with its storage in soil;
- opportunities to remove CO_2 from the atmosphere via CDR;
- reducing total gaseous losses arising from land application of dairy cattle slurry;
- eco-system service benefits following its application to soil; and

  through the potential to counteract the GWP impacts from grazed lands and increase the sustainability of grassland management.

The final report for the LCA entitled "Life cycle assessment (LCA) study of the production and use of biochar from unutilised agricultural biomass in Ireland" should be read in conjunction with this report. It outlines the LCA in detail and the conclusions and recommendations arising from this study.

6 Closing Evaluation

The EIP-funded Biomass to Biochar for Farm Bioeconomy (BBFB) project piloted the conversion of unutilised agricultural biomass, arising from management of pasture with rushes (*Juncus* spp.) and other unutilised biomass, into stable forms of recalcitrant biocarbon (i.e. biochar). When redeployed to the soil, biochar can confer multiple ecosystem benefits driving an innovative bioeconomy on and off the farm.

6.1 Unutilised Biomass – A Valuable Resource for the Rural Circular Bioeconomy

Once the BBFB project was set-up and running, public meetings were held to bring farmers, landowners and contractors together who expressed an interest in the provision of biomass material. Harvesting of biomass was carried out from February to October for rushes, June/July and autumn for bracken, and September until March for hazel, depending on climatic conditions and habitat designation restrictions. All biomass was harvested as dry as possible, with an ideal moisture content range of 16 – 20 % as moisture content above 20% results in degradation and mould growth. A key element of this EIP project was to use unutilised biomass streams to produce biochar, a renewable resource which does not have any implications or critical considerations for the displacement of food production. As part of this EIP project an on-line survey of farmers was undertaken to determine potentially available biomass sources from unwanted species typically found on Irish farms. Based on the results of this survey, it is apparent that rushes represent an untapped biomass resource that currently requires resources to control and are contributing to carbon emissions when left to rot. A key opportunity exists to use the availability and sustainability of this unutilised biomass to produce biochar which is perfectly suited for farm production as part of an innovative circular economy on the farm.

6.2 Mobile Pyrolysis Unit – Design Considerations

A prototype Mobile Pyrolysis Unit (MPU) was built and produced biochar on-site from baled rushes and other biomass. Prior to the commencing the fabrication of the MPU, the Operational Group developed and agreed an initial design philosophy and engineering strategy for a simplified and cost-effective biochar generation system which would incorporate a series of important design constraints. A number of distinct engineering steps occurred in the fabrication and initial commissioning phase and further adjustments were made to help resolve feedstock issues and to improve the functionality of the MPU to produce biochar during the testing and re-engineering phase. Ultimately, findings in relation to feed material handling were that a uniform particle size was necessary to achieve a steady feed rate into the MPU and, a low moisture content was essential as biomass needs to be below 20% moisture content to achieve pyrolysis in the MPU. Following all of the design modifications to maximise the feed of rushes, the feed rate was still lower than the design requirements and there were problems with the MPU running continuously and efficiently. However, the MPU did run successfully when: it did not cut out; the rush biomass fed continuously through the system without blockages; it was possible to control and sustain temperature in the pyrotube; and it could run in excess of 4 hours continuously. Under these conditions a high-quality consistent biochar was produced from rushes that was suitable for testing in a laboratory setting. This biochar was subsequently characterised using the *European Biochar Certificate Guidelines for a sustainable production of biochar*, and examined in various experimental projects.

Overall, this project was designed as a proof of concept for a system of biochar production and use in Irish agriculture. The mobile aspect of the pyrolysis system unit served the demonstration and interactive nature of the EIP project concept. However, consideration of all of the learnings in the design, fabrication, testing and commissioning phases of this project suggests that further work in developing fixed-site pyrolysis units would lead to greater running efficiency and regional scale benefits. Future systems developed as fixed-location installations will be able to generate greater efficiency in production (to run for extended periods directly on syngas) as well as much higher energy recycling and recovery (e.g. for immediate energy/power generation or for harnessing in feedstock drying treatment etc.). Co-location at sites already running anaerobic digesters or at processing mills would create further efficiencies.

6.3 Life Cycle Assessment Results – Beneficial Climate Action Potential

A Life Cycle Assessment (LCA) was undertaken to consider the Global Warming Potential (GWP) of a series of Irish agricultural scenarios for managing unutilised rush biomass and for the production of biochar from rushes. Negative GHG balances calculated for the production and soil application of biochar, illustrate the beneficial GWP impact of harvesting and baling rush biomass, using this to produce biochar and applying it to soil directly or incorporating in slurry. GHG emissions that would have arisen from the decomposition of biomass were avoided and LCA results indicate the viability of carbon sequestration in rush biochar and the potential for long-term carbon storage through its incorporation in soil (e.g. remaining unmineralized in soil). These results show that the production of rush biochar from unutilised biomass presents readily available opportunities to remove CO_2 from the atmosphere as a Carbon Dioxide Removal (CDR) scheme. Pyrolysis technology and products such as rush biochar can be efficient at medium to small scale and so make it possible to have CDR schemes not only at local scale, but also as part of wider rural bioeconomies.

Scenarios describing the application of non-amended and amended slurry (with 10% w/w rush biochar) to grassland soil were also developed in the LCA based on data from testing undertaken during this EIP project. These showed significant reductions in CH_4 emissions (42%) from treating slurry with rush biochar in slurry tanks, and a final lifecycle balance showing a significant reduction in GHG gases when rush biochar was added to slurry (i.e. 80%+) and then applied to land. LCA results for rush biochar, show it has excellent potential to reduce total gaseous losses arising from land application of dairy cattle slurry. Laboratory trials undertaken in the BBFB project also showed a statistical tendency towards the reduction of methane from ruminants when rush biochar was added to feed.

6.4 EU/National Policy on Climate Action, Carbon Farming and Protection of Biodiversity

This EIP has contributed specifically to the aims of the Rural Development Programme (RDP) by contributing specifically to RDP Priority 5 which focuses on *'Promoting resource efficiency and supporting the shift towards a low carbon and climate resilient economy in agriculture, food and forestry sectors'.* Focus Area 5C was the primary objective of this project and involves *'Facilitating the supply and use of renewable sources of energy, of by-products, wastes and residues and of other non-food raw materials for the purposes of the bio-economy'*. Focus Areas 5D and 5E are also relevant to this EIP project as they include *'Reducing greenhouse gas and ammonia emissions from agriculture'.*

Ireland's national Climate Action Plan calls for reduction in emissions from the agricultural sector of between 22 and 30% by 2030. In 2050, the EU goal is for net-zero emissions. The EU Commission has recently published a proposal for a Carbon Certification scheme that sets out criteria for carbon removal activities including permanent carbon storage, carbon farming and carbon storage in long lasting products. Ireland also plans to develop a national Carbon Farming Framework that will set out key procedural and governance requirements, which will support future payments to farmers and landowners for carbon farming activities and/or ecosystem services. Therefore, the adoption of practices which reduce emissions within the agricultural sector and promote carbon farming is essential. Land application of biochar represents a valuable component of an integrated Carbon Farming Framework (through the sequestration of carbon, the reduction of GHG emissions, leading to further eco-system services benefits).

In line with EU and National policy, several project activities under this EIP were shown to be complementary with the protection of EU Natura sites and generated co-benefits for biodiversity with regard to species conservation and habitat protection. A portion of the rushes used to produce biochar in the MPU were from an EU Special Protection Area, where rushes are specifically managed to ensure the conservation of Hen Harrier. In addition, biochar was produced from cut hazel scrub in the Burren Beo project which involves the management of open habitat in a sensitive ecosystem to protect species rich grasslands. Further ecosystem benefits and protection of aquatic ecology can occur through the protection of water quality by the reduction of N leaching following the addition of biochar to soil and to slurry prior to spreading, and through the reduction of the use of chemical N fertilisers, which help meet the requirements of the Water Framework Directive.

Other opportunities for developing rush biochar products with long-lasting carbon storage that promote innovation and add value to the circular economy and rural bio-economies were investigated during this project. These included a study assessing the use of rush biochar as a supplementary cementitious material replacement in structural concrete, which concluded that further research should be undertaken given the rush biochar displayed the most promising results; and electrochemical testing on rush biochar, which concluded that this material presents strong potential for energy, supercapacitor application and also recommended further testing.

6.5 Final Overview

This EIP project has demonstrated practically how the production and use of biochar from existing unutilised biomass streams on farms has the potential to contribute to the objectives of EU, and national agricultural and climate action policies, while at the same time maintaining EU food security. This can be achieved through:

- carbon sequestration and more stable carbon storage arising from biochar production together with its storage in soil;
- opportunities to remove CO_2 from the atmosphere via CDR;
- reducing total gaseous losses arising from land application of dairy cattle slurry;
- eco-system service benefits following its application to soil; and
- through the potential to counteract the GWP impacts from grazed lands and increase the sustainability of grassland management.

Further work is recommended to assess the production and use potential of biochar from unutilised biomass streams. This study also suggests that additional work in developing fixed-site pyrolysis units would lead to greater running efficiency and regional scale benefits. Work in such context should assess the scale of permanent carbon storage potential and CDR opportunities existing for biochar made from rushes and other unutilised agricultural biomass in Ireland and particularly, in the West of Ireland.

7 Value for Money

Biomass to Biochar for Farm Bioeconomy has consistently provided value for money in terms of having clear goals that have been fulfilled with the development of an innovative prototype farm-scale mobile pyrolysis machine designed and built in Ireland. It has developed a valuable biomass stream from currently unutilised agricultural biomass by demonstrating effective cutting, collection and processing practices in a number of typical pilot areas; demonstrating that biochar utilisation can contribute to the sustainability of local bio-economies and help the agri-sector by reducing greenhouse gas emissions, improving land fertility and productivity, and protecting water quality.

The project has disseminated the learnings and promoted the project at national and European levels and produced a Life Cycle Analysis to track the carbon cost and benefits through the complete lifecycle of the project from biomass harvesting operations to the deployment of the biochar.

Some of the research will continue beyond the project, adding further to its value.

The total cost of the project came below budget and opportunities stemming from this project show obvious potential. The need for this project has come at an extremely important time for Irish Agriculture and Ireland's Climate Action Plan, and the project's contribution to Call for Expert Evidence as part of the Climate Action Plan.

The cost efficiency of a pyrolysis plant producing biochar can be significantly extended through co-location with another unit to:

- take advantage of the extensive heat energy produced (e.g. by a grain drying facility or for direct use in reducing the moisture content of the biomass feedstock entering the pyrolysis plant;
- capitalise on the pyrolysis gas produced from the biomass by further refining in an anaerobic digester to produce higher quality biogas (e.g. pipeline-quality biomethane) (Li et al., 2017).

The number of studies that came about as a result of the project was extensive. The results show good potential and studies in biochar should continue as a priority in Ireland.

Throughout the project, by attending events, displaying the MPU and explaining this project, the project has witnessed a more positive response than was expected, particularly within the farming community, who were quick to see opportunities for a circular economy, not unlike the circular economy which existed in traditional farming.

We believe that the impact of this project will continue to offer value for money and information for future studies.

The economic generation opportunities through the supply chain from the producer to the end user can be broken down as follows:

Producer (Local farmers)	Best farming practice generates waste biomass from activities such as rush topping, hedgerow and gorse cutting and bracken control at a direct economic cost to the farmer. Conventionally these materials are either burnt or left to decompose releasing, combustion products, carbon dioxide and methane back to the atmosphere, resulting in an environmental cost. This waste biomass, when repurposed, can achieve an economic value by conversion to biochar. As a point of reference, a ton of biochar can between €300 and €2000 depending on the quality.
Contractor (Farmer/contractors)	As part of this programme of work, the BBFB project confirmed the economic value of this unutilised agricultural biomass within our supply chain. The intention is for the farmers to realise an income from the material generated to incentivise harvesting of the biomass rather than disposal by burning or decomposition. Within our supply chain we were able to highlight potential benefits to local contractors in harvesting the unwanted biomass for biochar production. As this biomass is generally collected outside of the harvesting period it widens opportunities for the use of mowing, cutting, silage cutting and baling equipment that may otherwise be standing idle. By having a use for the biomass , there is a value placed on it and in turn a reason to harvest it. Thus it is financial viable to harvesting it and in the case of this project €11 per bale was paid to the farmer to cover costs.
Processor (Biochar cooperative)	The protype MPU has shown the potential to utilise the spare thermal energy (heat) for on-farm drying applications. The energy generated from the pyrolysis plant could also be used to pre-dry the feedstocks, reduce the moisture content of fresh biomass, thereby improving the efficacy of the pyrolysis plant.Our EIP provides an agri solution for the conversion of biomass into biochar. The pyrolysis/gasification unit will reduce the total volume of the biochar during the pyrolysis at a ratio of approximately 5:1 with an estimated yield of c. 22% by weight.

8 Financial Report

Project Costs	Budget	Spend
Project leader – B. Carey	€234,240.00	€260,965.72
Project managemt NG/LD	€116,480.00	€129,639.99
E. O'Siochru	€4,250.00	€1,750.00
B. Tobin	€8,000.00	€7,000.00
S. O'Grady	€9,500.00	€2,000.00
S. Brackenbury	€8,000.00	€2,750.00
M. Clancy	€40,000.00	€40,000.00
Annual Accounts	€8,000.00	€12,041.58
TOTAL ADMINISTRATION	**€428,470.00**	**€456,147.29**
Design & fabricate MPU	€326,940.00	€326,940.49
Maintenance & re-engineering	€54,000.00	€23,349.67
Moisture meter	€1,157.00	€416.97
Tractor Loader attachments	€900.00	€1,932.00
Bale chopper	€10,560.00	€10,762.50
IR temperature meter	€500.00	€542.77
Loadcells/field pallet balance	€700.00	€389.00
Project IT	€1,250.00	€4,892.94
	€0.00	€0.00
Biomass Lab analysis	€24,000.00	€16,151.54
TOTAL MANAGEMENT	**€420,007.00**	**€385,377.88**
Health and Safety Statement	€4,000.00	€677.12
Public liability insurance	€7,200.00	€9,585.89
Purchase of baled feedstock	€27,000.00	€6,079.00
Biochar manufacture consmb.	€12,500.00	€6,725.93
Woody biomass chipping	€10,000.00	€150.00
Field maintenance & upkeep	€8,500.00	€2,975.50
Office consumables	€6,000.00	€4,637.57
		€0.00
Mileage	€12,500.00	€9,389.91
Conference	€3,000.00	€33.70
Tractor diesel	€9,500.00	€4,542.85
Project dissemination	€13,200.00	€17,213.53
Tractor lease	€24,320.00	€27,176.86
Flue-gas analyser rental	€4,600.00	€0.00
TOTAL OVERHEADS	€142,320.00	€89,187.86
TOTAL	€990,797.00	€930,713.03

9 Lessons learned

The following is a summary of lessons learned during this EIP project:

Biomass Moisture Content

- The moisture level of biomass was one of the most critical factors of the projects' success. Biomass needs to have no more than between 12-18 % moisture content for the MPU to be able to process into biochar in a consistent manner. Each biomass type presented different issues with regard to moisture and the machine reacted differently when processing biomass with different moisture content and in varying weather conditions. At times, bales of rushes were stored inadequately and this affected moisture content which prevented the MPU from working correctly. Whilst logistically bringing the machine from farm to farm wasn't particularly problematic, having the MPU in a semi-permanent location with a pre drying facility would eliminate some of the issues of running biomass with various moisture contents. A semi-permanent location could also have the ability to capture heat for future possibilities of rural heating schemes.

Mobile Pyrolysis Unit

- The engineering and fabrication phases of the project proved to be critical for understanding both the capabilities and the limitations of the MPU. Engineering knowledge for this kind of machine is limited both within Ireland and worldwide to a small number of experts. It is only in recent years that that interest in Pyrolysis has gained momentum. A prototype project would benefit from being based within an engineering hub that has the space for the project to carry out its full activities, including the testing of each biomass. Any actions carried forward would require that there is both a lead engineer familiar with gasification or pyrolysis plus additional engineering/mechanical/electrical support which is employed by the project throughout, enabling meaningful and progressive work. An engineering plan is required with a full-time engineer on site to work through each engineering challenge, with access to a control panel installation engineer to make adjustments in terms of fan, temperature requirements etc., so that pyrolysis can be achieved on an automated basis. Additionally, some form of external communication package is necessary to allow an offsite qualified person to re-programme the control panel if necessary.

The following design elements aided the functionality of the MPU:

- A larger diameter char discharge auger was installed than originally designed. This was a positive change as the small diameter of the original factory version clogged easily. It also allowed for ease of emptying the hopper at the end of a run.
- A dual gas regulator was fitted to allow for two gas cylinders to be used at the same time as there was a large draw on gas, resulting in the single cylinder freezing up, thus causing issues with getting the combustion chamber back up to the operational temperature.
- Installation of a stove glass to act as viewing port gave a better understanding of what was happening inside the pyro tube as it was running.

- Ports were installed on site to remove tar as there were none present in the factory build. This helped with preventing tar build-up which caused running issues and potential fire risks.
- An agitator was fitted inside the hopper to reduce the amount of biomass bridging.
- A camera was installed in the hopper, so internal conditions could be viewed continuously and bridging, or any other issue with the biomass, could be corrected immediately.
- Multiple modifications were made with the feed auger which eventually enabled the smooth movement of rushes through the pyro tube.
- A roof was installed over the combustion chamber as there was no built-in protection for electronics, sensors and insulation from the weather.
- An external heat panel was installed on the pyro tube to help with pyrolysis, as the generator had excess capacity and this required very little additional energy to run and added considerably to the consistency of runs.

Activating Biochar Prior to Use

- The BBFB project supplied biochar for a number of scientific studies. Some of these were found to be inconclusive. However, when examined more closely, there appeared to be inconsistencies in activating biochar prior to use in these studies. The nature of biochar and its ability to adsorb nutrients has been shown to be beneficial when activated/primed prior to being added to soil. The activation/priming of biochar prior to use is necessary to achieve optimal results.

Life Cycle Assessment

- The LCA results show that harvesting and baling unutilised rush biomass and using it to produce biochar, rather than allowing it to decompose, creates a negative Green House Gas (GHG) balance of -404 kg CO_2eq, which illustrates the beneficial GWP impact of producing this biochar. This figure is conservative in that it does not account for emissions reductions attributable to the use of syngas to run the MPU and will improve when the effects of running on syngas are fully integrated.
- The use of the MPU in this project resulted in a yield of 20% biochar from the rushes harvested from a hectare, with a carbon content of 66.11%. This equates to approximately 27% of the original C in the rush biomass being retained in the final biochar. This yield should improve with improvements in machine design and technology to ensure organic compounds are fully combusted. Overall, the negative GHG balance calculated for the production of biochar in this LCA, and the carbon content of the biochar indicates the viability of carbon sequestration in biochar made from rushes and the potential for more stable carbon storage.
- Significant reductions in CH_4 emissions (42%) resulted from treating slurry with rush biochar in slurry tanks. The final life cycle GHG balance shows a significant reduction (i.e., 80%+) in GHG gases when rush biochar is added to slurry and then land applied. Overall, LCA results for rush biochar, which complement those from Brennan et al. (2015), show that biochar has excellent potential to reduce total gaseous losses arising from land application of dairy cattle slurry.

More Opportunities for Dissemination

- The BBFB project spent substantial time ensuring it had a social media presence. Nonetheless it was challenging competing with the noise on social media to gain attention. The project found it difficult sometimes to understand why one post was successful, and another one less so; despite spending time understanding the medium. However, ultimately the BBFB team learnt that consistency is necessary and the project followers grew, particularly on Twitter.

10 Actions to carry forward

The following recommendations, and actions to carry forward, arise from the activities undertaken during this EIP and from the LCA of the production and use of biochar from unutilised agricultural biomass in Ireland:

- A key element of this EIP project was to use unutilised biomass streams, specifically rushes, to produce biochar, a renewable resource which does not have any implications or critical considerations for the displacement of food production. Rushes grow in abundance in several farms located within the West of Ireland and on other farms throughout Ireland which have areas of wet and gleyed soils. The survey of western farmers undertaken during this EIP has shown that these farmers manage rushes by topping or mulching indicating they are using farm machinery and the ground is traversable, which suggests a higher percentage of rushes could be harvested while accounting for the usual restrictions of weather. Rushes represent an untapped biomass resource that currently requires costly resources to control, and which contribute to carbon emissions when left to decompose. A key opportunity exists to use the availability and sustainability of this unutilised biomass to produce biochar as part of an innovative circular economy on the farm. ***Further exploration of the production and use of biochar from unutilised biomass, and how this can be scaled up and fine-tuned to regional contexts over the longer-term, deserves attention. This includes the opportunity for driving an innovative bioeconomy on and off the farm.***
- According to Pathak et al. (2022), the United Nations Intergovernmental Panel on Climate Change stated in its April 2022 report on mitigating climate change that CDR is "…an essential
- element of scenarios that limit warming to 1.5 °C or below 2 °C by 2100, regardless of whether global emissions reach near zero, net zero or net negative levels" (Pathak et al. 2022). Woolfe et al. (2021) have noted that given the rising urgency of finding ways to remove excess CO_2 from the atmosphere, there is a clear need for GHG accounting protocols that quantify the mitigation impact of CDR practices, such as biochar, that have the potential to be deployed at scale. Biochar can also increase net primary productivity (Crane-Droesch et al., 2021; Jeffery et al., 2021), thereby increasing net removal rates of atmospheric CO_2, particularly if the increased biomass is itself utilized for carbon sequestration or bioenergy (Woolfe et al., 2010). Lefebvre et al. (2023) recommend that further research is urgently needed at the scale of individual countries to obtain reliable data for biomass residue generation rates etc. to facilitate rapid expansion of the biochar industry to a scale needed to counteract continuously rising atmospheric CO_2 levels. ***Therefore, further work is recommended to assess the scale of permanent carbon storage potential and CDR opportunities that exist for biochar made from rushes and other unutilised agricultural biomass in Ireland and particularly, in the West of Ireland.***
- This fits in with the EU Commission's recently published proposal for a Carbon Certification scheme that sets out criteria for carbon removal activities including permanent carbon storage, carbon farming and carbon storage in long lasting products. The EU AGRI Committee has also proposed amendments to this scheme that recognises the significant potential of biochar carbon removal as a permanent CDR option and recognise 'biochar as a soil additive' as a pivotal component of a diverse range of carbon farming activities. Carbon farming represents great potential in contributing to and reaching EU climate objectives. Through carbon farming actions, farmers should be able to bring added value and combined effects not only to the environment, but also to ecosystem services and biodiversity while at the same time maintaining EU food security. ***Further work is recommended to assess the scale of stable carbon storage potential that exists for biochar made from rushes and other unutilised***

agricultural biomass to meet future EU Carbon Certification requirements and the proposed national Carbon Farming Framework which in future will support payments to farmers for carbon farming activities.

- Overall, the LCA results for rush biochar which complement those from Brennan et al. (2015) show that biochar has excellent potential to reduce total gaseous losses arising from land application of dairy cattle slurry. ***Further work is recommended to drive on the development of this use of biochar given the level of CH_4 and N_2O emissions from agricultural slurries and the quantity of animal manures produced annually in Ireland.***
- Land application of biochar represents a valuable component of Carbon Farming through the sequestration of carbon and the reduction of GHG emissions with further eco-system services benefits. These ecosystem services are extremely important in terms of value for the bioeconomy and ***further LCA modelling is recommended to fully integrate these benefits into overall LCA accounting.***
- The LCA reported a number of ways that the production of biochar from unutilised biomass can reduce GHG emissions from agricultural practices and these can be used to counteract the GWP impacts from grazed lands and increase the sustainable management of grasslands. LCA is an opportunity to manage environmental impacts (e.g. some operations seen as carbon sinks such as carbon sequestration strategies on grazed land). ***Further exploration of the use of management strategies in the dairy and beef sectors using biochar deserves attention.***
- This EIP project was designed as a proof of concept for a system of biochar production and use in Irish agriculture. The mobile aspect of the pyrolysis system unit served the demonstration and interactive nature of the EIP project concept. Future systems developed as fixed-location installations will be able to generate greater efficiency in production (to run for extended periods directly on syngas) as well as much higher energy recycling and recovery (e.g. for immediate energy/power generation or for harnessing in feedstock drying treatment etc.). Co-location at sites already running anaerobic digesters or at processing mills would create further efficiencies.

Future MPU prototypes need to be built in line with all the lessons learnt from the first prototype with a lead engineer on board and should consider the following:

- Investigate the possibility of redirecting the combustion gases around the pyrotube in a sealed enclosure as opposed to passing them internally through the pyrotube, adding moisture to the incoming biomass and thus hampering attempts at converting pelletised biomass into biochar
- MPU control panel needs to have a programmed algorithm with input data from Lamda sensor, temperature thermocouples and pressure sensors which would control the flue and cross over valves in addition to the syngas fan speed flow, as per the original design.
- The pyro tube needs to be enlarged to obtain a significant material throughput. L/D ratio should be 10 -12.
- More temperature thermocouple measurements added on combustion chamber and on the pyrolysis kiln.
- Install Nitrogen purging from feed-end to prevent air ingress, stop internal combustion and ensure pyrolysis and not Gasification.
- Problems of moisture affecting motors and electronics needs to be addressed.

- ➢ Propane gas pipes need to be made with a larger diameter to prevent problems with gas burner malfunctioning.
- ➢ A more efficient operation of the MPU would be to install in a semi-permanent position in order to utilise the heat generated to ensure that the biomass is adequately dried and for the machine to be in a position to harvest the heat for rural heating schemes.

- There is a clear need to train farmers in the production of biochar from available on-farm biomass as **an alternative to the burning of agricultural green waste, banned as from November 2023**. *The alternatives involve both non-fire (composting, mulching, chipping etc) and managed fire approaches (wood-fuel, biochar production, off-site energy recovery). The unique opportunity, value and environmental co-benefits of biochar production on Irish farms, which uses managed fire approaches, using specific technology and techniques should not be mistaken or confused with the open pile-burning the subject of the waste management legislation ban. It is important to recognise that biochar production is a thermal conversion process rather than a combustion (A feasibility study to explore sustainable management of agricultural green waste in Ireland Prepared by the Irish Bioenergy Association (IrBEA)* for the Department of Agriculture, Food and the Marine November 2022).* Actions to carry forward for the project would be to set up a training programme trial involving low tech managed fire approaches (biomass to biochar) which could then be rolled out on a national level.
- The heat generated during the operation of the MPU is somewhere between 400-800 degrees centigrade, which clearly has future potential for rural community heating. However, for the purpose of this project, actions to carry forward would be to use the heat to combat the Irish damp problem of drying biomass and establish a drying method as part of the biochar system.
- There are other opportunities for developing rush biochar products with long-lasting carbon storage that promote innovation and add value to the circular economy and rural bio-economies which were investigated during the course of this EIP. Researchers in University of Limerick (Keane and Cunningham, 2023) undertook a study assessing the use of biochar as a supplementary cementitious material (SCM) replacement in structural concrete which is seen as a way to reduce the environmental burdens of cement production. These researchers investigated the rush biochar produced by the MPU and while it was found to reduce compressive strength compared to the control, it also led to an increase in flexural and split tensile strength. A "cradle to gate" LCA found that a carbon-neutral cement can be achieved with 20% by weight biochar addition. ***In their conclusions, the authors recommend that as the rush biochar displayed the most promising results, further research on the effect of varying the conditions of pyrolysis and cement replacement level should be undertaken to optimise its performance as an SCM.*** Also, as part of this EIP project, University of Limerick undertook electrochemistry testing on rush biochar and concluded that this material presents strong potential for energy, supercapacitor application and ***further testing was recommended after activation of the biochar to open mesopores and micropores to increase Cp*** (UL, 2023).
- **A test of biochar as a feedstock for industrial energy production** should be carried out in collaboration with a commercial company (at the time of the writing of this report, Agrina Fuels have shown a considered interest). The use of pyrolyzed material as a fuel will increase the potential end-uses of the biochar products increasing the adaptability of the system to meet a variety of market needs.

11 References

Abdelrahman, H., Hofmann, D., Meyer, N., Bol, R., Borchard, N., 2018. Historical charcoal additions alter particulate organic matter fractions and affect soil C composition and stabilization. J. Plant Nutr. Soil Sci. (2011), 1–9 https://doi.org/10.1002/ jpln.201800261. As cited in Borchard et al., 2019.

Borchard, N., Schirrmann, M. Cayuela, M.L., Kammann, C., Wrage-Mönnig, N., Estavillo, J. M., Fuertes-Mendizábal, T., Sigua, G., Spokas, K., Ippolito, J.A., Novak, J., 2019. Biochar, soil and land-use interactions that reduce nitrate leaching and N2O emissions: A meta-analysis. Science of the Total Environment 651 (2019) 2354–2364

Brennan, R.B., Healy, M.G., Fenton, O., Lanigan, G.J., 2015. The Effect of Chemical Amendments Used for Phosphorus Abatement on Greenhouse Gas and Ammonia Emissions from Dairy Cattle Slurry: Synergies and Pollution Swapping. PLOS ONE 10, e0111965. https://doi.org/10.1371/journal.pone.0111965

Celignis, A., 2022. Biochar Analysis, Production and Evaluation - Celignis Biomass Analysis Laboratory. Biochar Services at Celignis Biomass Lab. URL https://www.celignis.com/biochar.php (accessed 4.21.22).

Crane-Droesch, A.; Abiven, S.; Jeffery, S.; Torn, M. S. Heterogeneous global crop yield response to biochar: a meta-regression analysis. Environ. Res. Lett. 2013, 8, 044049. As cited in Woolfe et al., 2021, and in Borchard et al., 2019.

Cunningham, C. M and Keane, S. P., 2023. Assessing the use of Biochar as a Cementitious Replacement in Structural Concrete. Dissertation submitted to the Faculty of Science and Engineering University of Limerick, Limerick, Ireland.

Das, S. K., Avasthe, R. K., Singh, R., & Babu, S., 2014. Biochar as carbon negative in carbon credit under changing climate. Current Science, 107(7), 1090–1091. https://web.p.ebscohost.com/ehost/pdfviewer/pdfviewer?vid=5&sid=95deb17c-d726-4b36-832a78da35c9677e%40redis. As cited in Shrestha et al. 2023.

Dept. of Agriculture, Food and the Marine (DAFM), 2023. Guidance to inform Consultation on the development of a Carbon Farming Framework for Ireland. https://www.gov.ie/en/org

Department of the Environment, Climate and Communications. (2023) Climate Action Plan 2023, Government of Ireland. As cited in Cunningham and Keane, 2023.

Ding, Y., Liu, Y.-X., Wu, W.-X., Shi, D.-Z., Yang, M., Zhong, Z.-K., 2010. Evaluation of biochar effects on nitrogen retention and leaching in multi-layered soil columns. Water Air Soil Pollut. 213, 47–55. As cited in Borchard et al., 2019 and Brennan et al., 2015.

Hammond, J., Shackley, S., Sohi, S., & Brownsort, P., 2011. Prospective life cycle carbon abatement for pyrolysis biochar systems in the UK. Energy Policy, 39(5), 2646–2655. https://doi.org/10.1016/j.enpol.2011.02.033 As cited in Shrestha et al. 2023.

Hagemann, N., Joseph, S., Schmidt, H.P., Kammann, C., L., Harter, J., Borch, T., Young, R., B., Varga, K., Taherymoosavi, S., Elliott, K. W., McKenna, A., Albu, M., Mayrhofer, C., Obst, M., Conte, P., Dieguez-Alonso, A., Orsetti, S., Subdiaga, E., Behrens, S., and Andreas Kappler, 2017. Organic coating on biochar explains its nutrient retention and stimulation of soil fertility. *Nature Communications* volume 8, Article number: 1089 (2017)

Ithaka Institute. (n.d.). Retrieved from https://www.european-biochar.org/.

Jeffery, S.; Abalos, D.; Spokas, K. A.; Verheijen, F. G. Biochar effects on crop yield. Biochar for Environmental Management: Science, Technology and Implementation; Routledge, 2015; p 2. As cited in Woolfe et al., 2021.

Kammann C. I. et al. 2015. Plant growth improvement mediated by nitrate capture in co-composted biochar. *Sci. Rep*. **5**, 11080. As cited in Hagemann et al., 2017.

Lee, J. W., Hawkins, B., Day, D. M., & Reicosky, D. C., 2010. Sustainability: The capacity of smokeless biomass pyrolysis for energy production, global carbon capture and sequestration. Energy & Environmental Science, 3(11), 1695–1705. https://doi.org/10.1039/ C004561F. As cited in Shrestha et al. 2023.

Lefebvre, D., Fawzy, S., Aquije C. A., Osman, A. L., Draper, K. T. and Trabold, T.A. 2023. Biomass residue to carbon dioxide removal: quantifying the global impact of biochar. Biochar (2023) 5:65 https://doi.org/10.1007/s42773-023-00258-2

Liu, X., Zhang, A., Ji, C., Joseph, S., Bian, R., Li, L., Pan, G., Paz-Ferreiro, J., 2013. Biochar's effect on crop productivity and the dependence on experimental conditions-a meta-analysis of literature data. Plant Soil 373, 583–594. As cited in Borchard et al., 2019.

Mehmood, K., Garcia, E.C., Schirrmann, M., Ladd, B., Kammann, C., Wrage-Mönnig, N., Siebe, C., Estavillo, J.M., Fuertes-Mendizabal, T., Cayuela, M., Sigua, G., Spokas, K., Cowie, A.L., Novak, J., Ippolito, J.A., Borchard, N., 2017. Biochar research activities and their relation to development and environmental quality. A meta-analysis. Agron. Sustain. Dev. 37. As cited in Borchard et al., 2019.

O'Connor, D., Peng, T., Li, G., Wang, S., Duan, L., Mulder, J., Cornelissen, G., Cheng, Z., Yang, S., Hou, D., 2018. Sulfur-modified rice husk biochar: A green method for the remediation of mercury contaminated soil. Sci. Total Environ. 621, 819–826. As cited in Borchard et al., 2019.

Pathak M, Slade R, Shukla PR, Skea J, Pichs-Madruga R, Ürge-Vorsatz D. 2022. Technical Summary. In: P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. Diemen van, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.). Climate Change: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge New York. As cited in Lefebvre et al., 2023.

Schmidt. (2017). *Biochar Activation.* Retrieved from http://www.ithaka-journal.net/wege-zu-terra-preta-aktivierung-von-biokohle?lang=en

Shrestha, R. K., Jacinthe, P.A., Lal, R., Lorenz, K., Singh, M. P., Demyan, S. M., Ren, W., and Lindsey, L.E., 2023. Biochar as a negative emission technology: A synthesis of field research on greenhouse gas emissions. J. Environ. Qual. 2023;52:769–798. https://doi.org/10.1016/j-enpol.2011.02.033

University of Limerick. 2023. Electrochemistry test results on rush biochar produced by Mobile Pyrolysis Unit undertaken for this EIP.

Woolf, D., Lehmann, J., Ogle, S., Kishimoto-Mo, A.W., McConkey, B., Baldock, J., 2021. Greenhouse Gas Inventory Model for Biochar Additions to Soil. Environ. Sci. Technol. 55, 14795–14805. https://doi.org/10.1021/acs.est.1c02425

Woolf, D.; Amonette, J. E.; Street-Perrott, F. A.; Lehmann, J.; Joseph, S. 2010. Sustainable biochar to mitigate global climate change. Nat. Commun. 2010, 1, 56. As cited in Woolfe et al., 2021.

Appendix

Operational Group Members

Roles and Project Responsibilities of OG members	
Bernard Carey	This key position was to bring insight into the needs and issues facing landowners. As Project Leader and project concept initiator, Bernard Carey provided the technical link between all members of the project team whilst liaising with all members of the Operational Group and the broader Partnership. As Project Leader he steered all fieldwork to be undertaken in the project and played a pivotal role in assessing and monitoring the project • Development of MPU design • Schedule for cutting and baling biomass within selected geographical area • Development of MPU transportation logistics • Production of biochar from biomass using MPU on site • QA and QC of biochar • Exploration of on-farm end-users and off-farm end-users • Research agencies and demonstration/research trials • Re-engineering the MPU • Analysis and report writing • Dissemination
Lisa Duncan	The role of Project Manager (PM) for this project was to assist Project Leader to steer the project and ensure all elements of the proposal were carried out in an efficient manner and within budget, whilst ensuring the timely delivery of milestones and deliverables. The PM's role involved day-to-day project management, financial management, logistics, administration and support. PM assisted in the compilation of EIP technical and financial reports using data from multiple sources. • Organising, coordinating and taking minutes of 6-monthly Operational Group meetings • Cash flow and budget control, sign-off on checks • Organising invoiced payments of project staff • Management of milestones/delivery timing, risk management • Setting up and maintaining website • Record keeping for dissemination activities, project purchasing, expenditure • Preparing material for all reports to DAFM.

Roles and Project Responsibilities of OG members	
Emer O'Siochru	Chair of the Irish Biochar Co-Operative. The Biochar Co-Op business model is based on distribution and mostly independent production of biochar by Producer Members for a guaranteed Biochar Co-Op price.
Brian Tobin	Expert advice throughout the project on carbon sequestration in soils and advice on aspects pertaining to assessment of environmental impacts, GHG emissions from product trials and in interrogating sources of external research funding for scientific investigation of biochar product uses. He was involved in on-going analysis and reporting of project outputs and for reviewing technical project reports.
Sean O'Grady and Premier Green Energy	Design and manufacturing engineers for the project. Their role was the design, fabrication and commissioning of the Mobile Pyrolysis Unit. They implemented a design philosophy and engineering strategy for a simplified and cost-effective biochar generation system, based upon pyrolysis technology, which incorporated a multiplicity of design constraints. Their role was to produce an innovative, mobile, farm-scale pyrolysis system designed and built in Ireland which was capable of being deployed within a range of agricultural and wildlife conservation situations.
Sion Brackenbury and *Commons Vision*	Provided detailed technical and practical know-how from their ongoing experience in using pyrolysis systems to produce biochar in agricultural areas with high conservation value.
Mike Clancy	Responsible for undertaking a cradle-to-grave Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) of biochar production from previously unutilised farm biomass in this project. This formed a critical aspect of the project's analysis and demonstrated the environmental impact and the financial viability of the biochar production cycle. This analysis calculates the economic and lifecycle (carbon cost) of harvesting virgin waste biomass from farms and make recommendations about the most cost-effective steps in the process. The LCA appraisal is undertaken from the biomass harvest to its deployment back to soil as biochar.