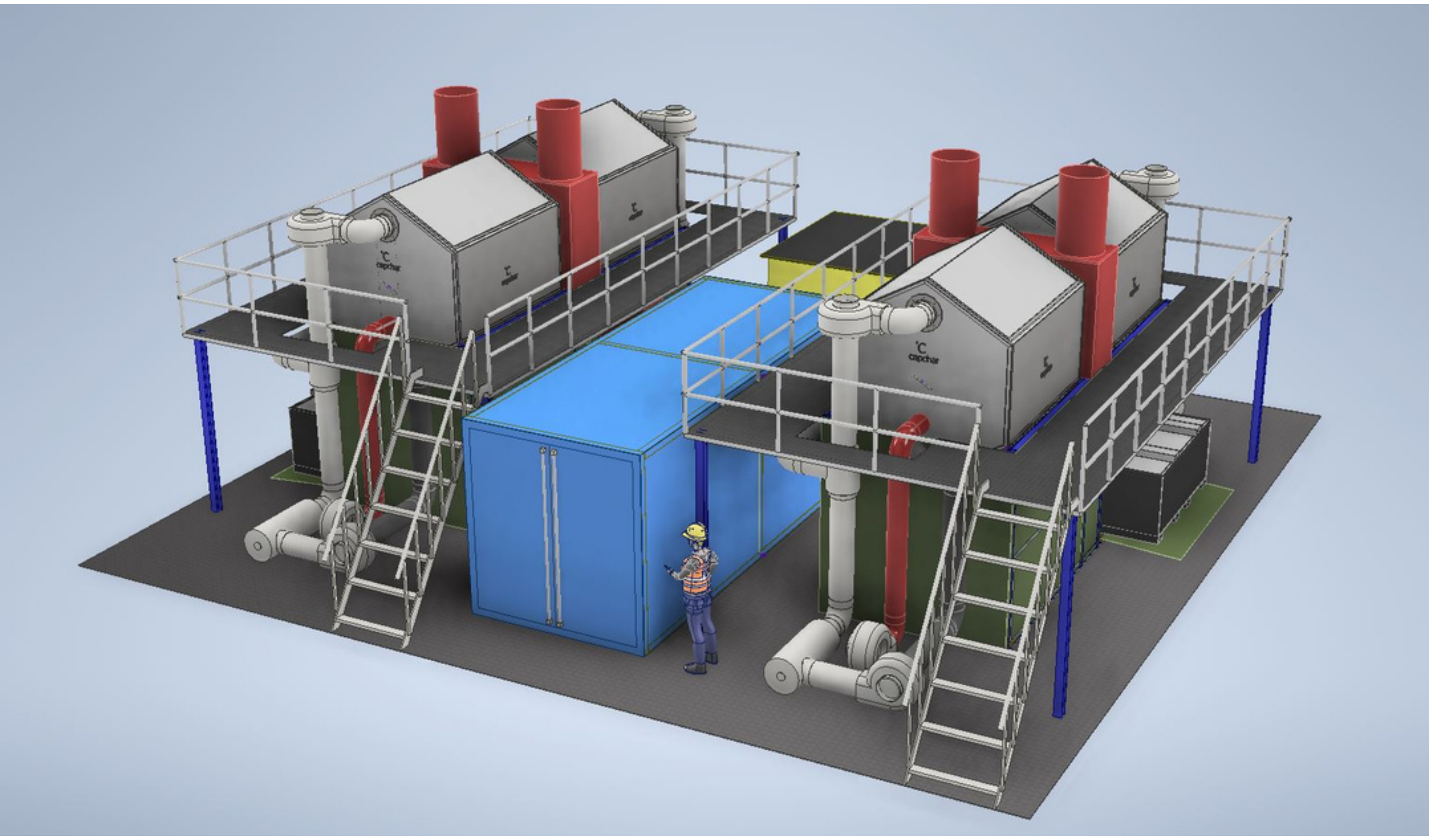
Greenhouse Gas Removal Programme: PHASE 1

Tender Reference Number: TRN 4696/11/2020



The CapChar Project Phase 1 Public Report

January 2022

Report prepared for BEIS by
CapChar Ltd
Biochar Project Services Ltd
UK Hardwoods Ltd

capchar

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1. Executive Summary

As part of the Business, Energy and Industrial Strategy department's effort to stimulate new Greenhouse Gas Removal (GGR) technology the CapChar project has developed a route to remove carbon dioxide using pyrolysis to create intractable carbon, biochar, from wet wood chip as a local, circular, decentralised GGR solution.

The technology to do this is innovative, cost effective and exploits this feedstock available throughout the UK in substantial quantities, but currently mostly goes to waste, decomposing to carbon dioxide and methane. The stepped approach to technology development will demonstrate the economics needed to make biochar commercially viable from 2025, with 100tCO_2e sequestered within a 1 year period and at a commercially viable cost during Phase 2. The approach will de-risk the scale-up strategy and pave the way to build a decentralised network of pyrolysis plants across the UK. This network has the potential to remove up to >350ktCO_2e per year or 7% of the UK Net Zero target for GGR by 2030 at <£200/t and potentially create up to 450 jobs across the UK.

Planning permission has been obtained, facilitating an early start in Phase 2 at its site in North Devon. The Project has stimulated considerable interest from universities, land/estate owners, farmers, developers, water companies and biochar enthusiasts with expressions of interest to deploy its technology at six additional sites. The Project is confident that at the end of Phase 2, it will be able to expand rapidly, without subsidy.

The carbon markets have also seen biochar offset purchases made by Microsoft, Shopify and Stripe, indicating that demand is growing and the need for a large-scale GGR solution in the UK is paramount. This "Made In the UK" solution, will generate local jobs in rural and urban areas driving local economies. Importantly this approach to GGR will be demonstrably secure using UK feedstocks. Assurance to customers will be provided through a transparent digital Chain of Custody. The proprietary technology has real export potential: cost effective, novel and straightforward to operate.

Biochar also provides a material with a range of benefits in agriculture, horticulture and forestry, through improved yields, better fertiliser utilisation, better soil health and more. Published work supports these claims. Beyond growing, biochar has potential in pollution control, land remediation and the construction industry. The surplus heat from the process will be used to dry incoming feedstock in a separate step; this will improve process efficiency and timing.

2. The CapChar Project

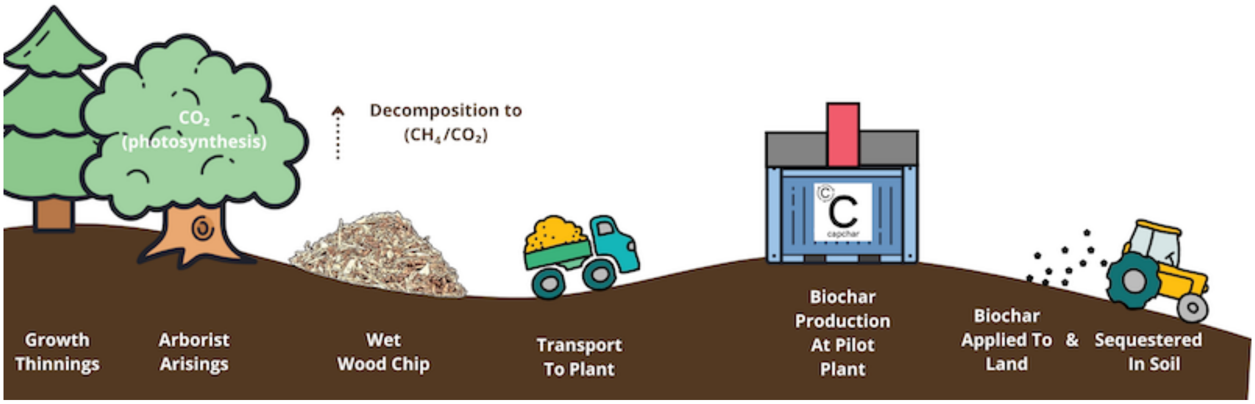
Phase 1 of this project has been funded from the Government's £1 billion Net Zero Innovation Portfolio, part of which looks to accelerate the commercialisation of low-carbon technologies and systems, through the Department for Business, Energy & Industrial Strategy's Direct Air Capture and Greenhouse Gas Removal Technologies competition. This competition provides funding for developing emerging technologies that enable the removal of greenhouse gases from the atmosphere in the UK. Led by CapChar Ltd, an exciting Net Zero start-up, alongside Consortium partners Biochar Project Services Ltd (BPS) and UK Hardwoods Ltd, The CapChar Project aims to demonstrate that wet wood chip can be converted into biochar (as a stable form of carbon) and sequestered in UK soils, cost effectively to provide immediate near permanent GGR. Today, the economics to scale biochar as a GGR solution in the UK are prohibitive, due to a lack of affordable technology solutions that provide a high enough biochar output. The CapChar Project aims to solve this challenge through innovation by initially building it's low CAPEX, modularised, proprietary Dryer/Kiln technology with a 1t/day biochar output (currently at TRL4) before moving to TRL6 through expansion to 2t/day.

The CapChar Project will be located alongside an existing saw mill in South Molton, North Devon to validate the solution in an operational setting and confirm the technical and environmental performance of the Dryer/Kiln technology at this output. A drying unit will be added to increase productivity and finally a second Dryer/Kiln unit plus a second drying unit will be added, doubling capacity to 2t/day. This will show how the modularised technology can readily scale to a 4t/day biochar output post Phase 2. Feedstock, Sequestration and Storage (Satellite site) partners will be engaged to provide feedstock, land application and storage to facilitate the process. The costs for removing carbon dioxide will be within the aims of the competition at less than £200/t CO_2e.

CapChar Ltd will provide its proprietary Carbon CapChar platform for use in the CapChar Project, which will take data from the process including: feedstock provenance, biochar production and sequestration/location data. This platform provides the data veracity, accountability and transparency needed to commercialise the process. Post Phase 2, this data will be converted into digital assets in the form of Carbon Removal Certificates. The new technology outlined in this plan has been reviewed and supported by an external consultant, Conversion and Resource

Evaluation Ltd[1], as has the business plan by Resilience Constellation Ltd[2] and the scale up plan by Cwm Harry Land Trust Ltd[3].

3. Description of the Science and Engineering



3.1 Feedstock

The process utilises wood chip both as a fuel to supply heat and as feedstock for conversion into biochar. Dry wood chip (15% moisture) will be supplied from the saw mill and will be used in a wood chip burner to supply heat. The feedstock for conversion will be wet wood chip (ca 50% moisture) and will be supplied by arborists. Research in Phase 1 showed that there should be enough feedstock from arborists and other woody feedstocks both for the local plant in North Devon (within ca 10 miles of the Pilot Plant) and across the UK for the planned 2030 roll out, which is predicted to demand 1.4Mt p.a.

3.2 Chemical and Physical Processes

Trees, hedges and plants convert CO_2 into complex carbon molecules through photosynthesis, becoming plant material. The conversion processes involved for converting wood chip into biochar are drying and pyrolysis. Wet wood chips contain up to 50% water, the bulk of it is driven off in the drying step before the process moves to the next stage, pyrolysis. The pyrolysis of wood chip at temperatures up to 480°C in the absence of oxygen creates biochar. Conducted carefully, half of the carbon is converted

[1] Conversion and Resource Evaluation Ltd - Link
[2] Resilience Constellation Ltd - Link
[3] Cwm Harry Land Trust Ltd - Link

to biochar with 75% or more of this carbon regarded as recalcitrant. The co-products of pyrolysis are a complex mixture of gases.

The pyrolysis process effectively breaks the carbon cycle, preventing CO_2 and CH_4 from being released as the wood decomposes or is burnt. This is Greenhouse Gas Removal. There is no 'moral hazard' for this project as tree residues that are usually discarded will be used - there is no deforestation.

The operation takes place in the Dryer/Kiln and occurs over five phases as illustrated in Figure 1 below:

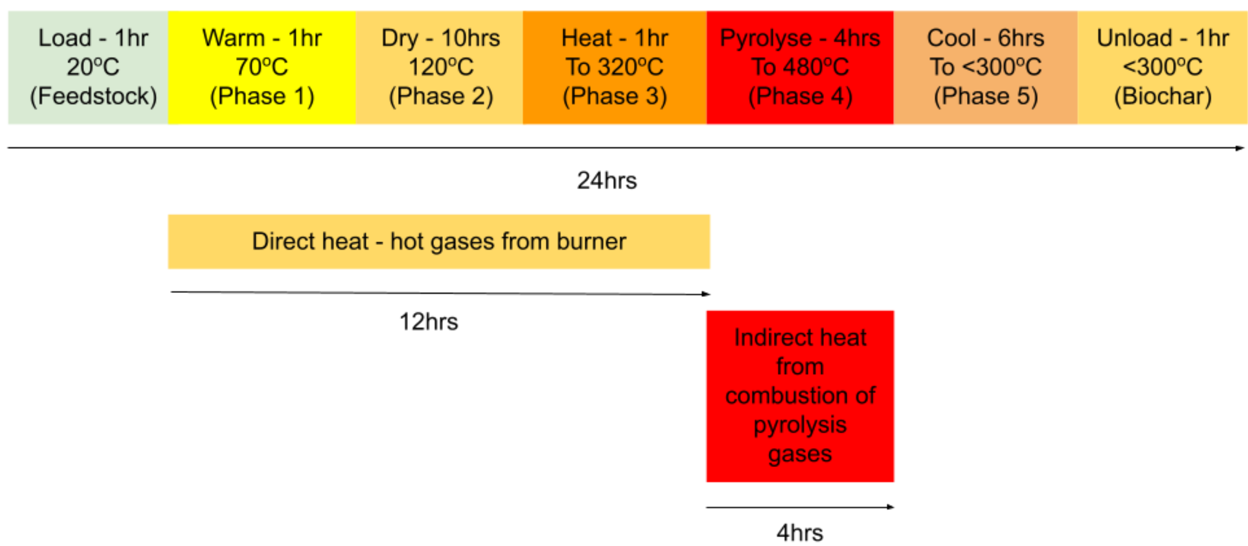


Figure 1 - Process steps to convert wet wood chip into biochar

The pyrolysis gases are combusted in the Dryer/Kiln and in the afterburner generating significant heat (>2MWh). The drying step ensures the pyrolysis gases have a low water concentration and are clean enough to be used for direct drying.

There are **no added materials** in the process other than the combustion gases from a wood chip burner which provides direct heating for the process.

The process will generate water vapour in the drying phase, 25% will be recovered as “knock-out” water. This will be used for biochar dampening and plant cleaning.

3.3 Energy and Fuel Requirements

The CapChar Project assumes the feedstock, wet wood chip, is collected within a 10 mile radius (market research supports) and biochar is used within a 20 mile radius of the plant using diesel-powered vehicles. Biochar will be incorporated into farmland using a number of agricultural application techniques typically using diesel-powered farm equipment. Electricity will power the trommel (sieving), forklift, plant (fans) and site. The Dryer/Kiln will be heated by a wood chip-fuelled burner. An LPG burner will ensure safe, clean combustion of all released gases. A wood chipper will be used infrequently.

Table 1 : Summary of Energy and Fuel Requirements per Tonne of Biochar			
Electricity*	**440kWh**	Diesel	**6l**
Wood Chip (15% moisture)**	**1100kg**	Petrol (wood chipper) LPG	**1.5l** **13kg**

Rounded figures. * covers demand for fans, trommel, elevator and ancillary plant and site operations.
** The energy content of 1100kg of wood is ca 4500kWh.

3.4 Environmental Impacts

As the project uses virgin woody materials both for fuel and conversion feedstock the fraction that gets combusted should be essentially the same material that is used in wood chip burners. The emissions of NOx, SOx, CO and VOC's from wood chip burners fall within the range of acceptable emissions. In the initial configuration these will be emitted to the atmosphere in later versions where the waste heat is used for drying; they may be partly scrubbed out by the wood chips. These emissions assumptions will be tested on the operating Dryer/Kiln unit during Phase 2.

A **Life Cycle Analysis** has been carried and, using the European Biochar Certificate (EBC)[4] approach, the following is determined:

The final CO_2e for every tonne of biochar produced using the EBC calculation is:

Recalcitrant Carbon 75% of biochar x Permanence 74%.
For each tonne of biochar CO_2e sequestration = 3.67 x 0.75 x 0.74 = 2.03t.

The final value is then corrected to account for the CO_2e produced during manufacture. In the case of the EBC, they exclude transport burdens to move biochar from the site of

[4] Summary Certification of the European Biochar Certificate (EBC) - Link

production and also exclude burdens for application to the land. If the electricity is "green" that is also discounted. For the CapChar Project the estimate for the CO_2e burden for feedstock transport is 6.6kg/t biochar. For transport, mixing and application the CO_2e burden is 35kg/t biochar, totalling to 41.6kg.

Table 2 : Final CO_2e for every Tonne of Biochar Produced
(3.67* x 0.74 x 0.75) - (0.0416) = **2.00t CO_2e**

*Molar weight ratio of Carbon Dioxide to Carbon is 44/12 = 3.67.
((CO_2 to C ratio) x (permanence over 100years) x (% carbon in the biochar produced)) - process emissions.[5]

EBC uses a "most conservative" 100 year permanence figure of 74% from a linear loss of 0.3%pa extrapolated. CapChar used 82% based on reported literature[6] in its initial proposal. More recently Joseph et al[7] reviewed residence time as discussed in several papers covering; 10 soil types, 6 tree species, 8 studies with 17 examples. All the biochar was from wood and was formed by pyrolysis at temperatures between 400-450°C, approximately the same as the project is planning to use, max 480°C. The average MRT for all 17 samples was **837 years**. The permanence figure for biochar is likely to be subject to continued academic work in coming years given the apparent differences between the EBC and current literature[4].

Cradle to Cradle Process Life Cycle Analysis - Notwithstanding the EBC approach the project has included a fuller range of environmental impacts from operating the plant to make biochar. These are summarised in Table 3 below:

Table 3 : Summary of CO_2 Emissions for one Tonne of Biochar		
Impact Categories	**Description**	**kg CO_2e/t biochar**
Transport & Handling	Chipping, transport, sieving handling & loading	20
Drying & Pyrolysis	Running equipment & site	88*
Dispatch & Application	Transport, Mixing, Tractor	35
	TOTAL	**143**

*Using renewable electricity (planned) reduces Drying and Pyrolysis step to 49 kg and overall 104 kg/t biochar
Wood chip fuel is taken as carbon neutral and not included.

[5] European Biochar Certificate (EBC) Summary - Link
[6] Ronsee et al - Link
[7] Joseph et al - Link

Construction, Operating and Decommissioning Life Cycle Analysis - The carbon dioxide burden embodied in constructing the site, manufacturing the plant (and decommissioning) and the ancillary equipment has been estimated, see Table 4 below:

Table 4 : Estimated Embodied CO_2e Burden for Site and Equipment		
Construction/ Manufacture	**Description**	**CO_2e burden kg/t of biochar**
*Site Construction	Concrete slab and buildings Based on est. mass of steel & concrete	36
# Dryer/Kiln unit Manufacture	Manufacturing Based on est. mass of steel & copper	17.4
*D/K Decommissioning	Recycling costs at project end Based on mass of steel recycled	5.25
§Ancillary Equipment	Trommel, forklift etc Based on mass of steel	0.7
	TOTAL	**59**

Depreciating over *20 years, # 5 years §10 years

These figures are based on a production rate of 250t pa i.e. the system in it's 1t/d configuration. At 2t/d or 500t pa the figures would be halved for the site construction, ancillary equipment and decommissioning, but remain the same for the manufacturing equipment; taking into account the second Dryer/Kiln unit system. This leads to a figure of 38kg/t biochar of embodied carbon. The embodied carbon is not normally included in sequestration accounting.

Secondary Environmental Benefits - Biochar can improve soils, through its liming effect, water retention, better use of fertilisers and benefits to the soil microflora and fauna which in turn can improve crop yields and enhance soil health.

Figure 2 - Plant roots growing through biochar particles and biochar aggregates. Credit Allan Samuel.

Removal of other Greenhouse Gases and better use of Soil Nutrients - Biochar also:

- Reduces the methane (would have been produced by decomposition of wood)
- Reduces nitrous oxide emissions from nitrogenous fertilisers[8] by 12-50%[9]

Much of the emission of nitrous oxide is attributed to soil-bacterial action on fertilisers and from manures and animal waste[10,11,]. Some work has already indicated that biochar in soil may afford better utilisation of the nitrogen as applied through fertilisers[3,5] and less run-off.

3.5 Monitoring, Reporting and Verification Methodology

- Key to GGR acceptance and validity is a clear and robust method to demonstrate the sequence of actions that support carbon dioxide equivalents have been removed from the atmosphere and sequestered
- The Carbon CapChar Platform will be used to support the monitoring, reporting and verification of the operation including:
    - Feedstock provenance
    - Data from batch processing steps & Quality Control (QC) data
    - Quantities and location of application (GPS) and sequestration verification
- Initial biochar samples will be analysed against EBC criteria to validate quality
- Periodic analyses will be subsequently carried out to ensure quality is being maintained
- Sequestration will be based on quantities applied and representative values for carbon content
- Permanence data will be taken from the literature until practical methods for monitoring in soil become available
- Emissions data will be measured using a Testo 350 flue gas analyser or equivalent to validate the performance of the system

[8] Wikipedia Nitrous Oxide - Link
[9] Schmidt, H.-P., Wilson, K. and Kammann, C. (2017) 'Using biochar in animal farming to recycle nutrients and reduce greenhouse gas emissions', Geophysical Research Abstracts, 19(2), pp. 2017– 5719
[10] Effects of biochar on soil available inorganic nitrogen: A review and meta-analysis TTN Nguyen, CY Xu, I Tahmasbian, R Che, Z Xu, February 2017 Geoderma 288 DOI: 10.1016/j.geoderma.2016.11.004
[11] Agyarko-Mintah, E. et al. (2017) 'Biochar increases nitrogen retention and lowers greenhouse gas emissions when added to composting poultry litter', Waste Management, 61, pp. 138–149. DOI: 10.1016/j.wasman.2016.11.027

4. Engineering Design

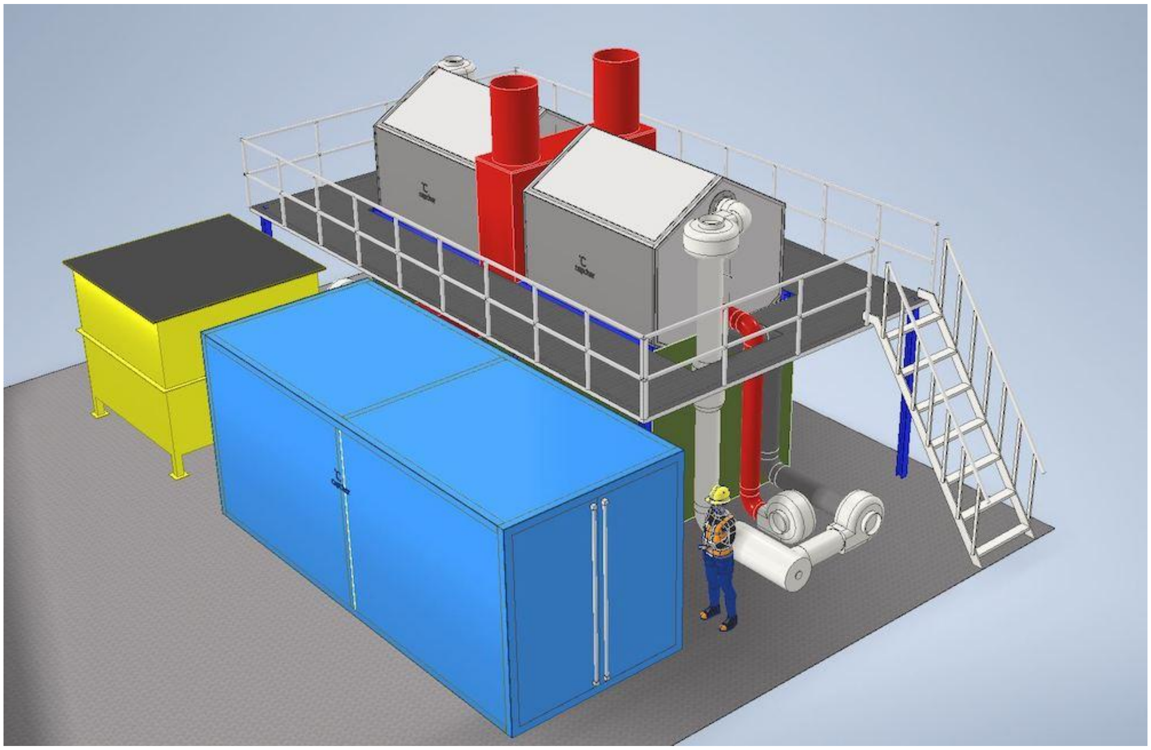


Figure 3 - Side view of a single Dryer/Kiln unit with services container and wood chip burner

The CapChar Project has developed a new approach to batch biochar production, combining the two separate stages of drying and pyrolysis in a single 10m^3 reactor. For smaller scales of biochar production, less than 5t/day, this has the potential to be more cost effective than continuous systems and more suitable for decentralised conversion of low grade biomass feedstocks. One reactor will produce 0.5t/day and two reactors are built into a single Dryer/Kiln unit, as shown in Figure 3. In Phase 2 the project will establish two Dryer/Kiln units with a Services Container as the standard module for producing biochar at 2t/day.

4.1 The Dryer/Kiln Technology

The design is based on a previously successful design (TRL4) using an established approach to construction and operation. This methodology has proven successful in developing batch kiln products where the required design dataset has been incomplete and the non-steady state conditions that can apply in batch vapour drying and hot gas pyrolysis have to be accomodated:

2010 - vertical 1.5m3 with internal gasifier heat supply and natural draft heat circulation for wet logs
2012 - vertical 1.5m3 with internal combustor for wet wood chips
2014 - vertical 2 x 6m3 with external combustor for drying and pyrolysing

The method allows for rapid convergence on practical solutions for the difficult challenges of heat transfer, heat distribution and pyrolysis outcomes. It has proven to be efficient in terms of both time and resource consumption compared to more conventional technology development methodologies.

The design is based on managing the heat flow and temperature profiles in the reactor over the drying and pyrolysis cycles by controlling the gas phase conditions. Two of these reactors are mounted, back to back, at the top of a 20' ISO Container frame with the necessary fans and valves located at each of the ends and connected to a separate, Central Services unit. Overhead feedstock loading is combined with biochar delivery to the base of the enclosed frame.
The engineering carried out in the Phase 1 design study included deliverables:

• Process flow diagram
• Heat and mass balance
• P&ID
• PLC design
• Operating philosophy
• HAZID
• Safety plan
• Site plan

These deliverables set out a base design with a number of specific innovations to manage gas and heat flow, enhance safety and environmental performance. The services are housed in a single unit to supply multiple Dryer/Kiln units. Further scaling of reactor size is possible without significant site or layout changes.

The Services unit will provide:

Heat - to drive the warming, drying and heating processes at startup, supplied by a fuel chip burner where afterburner heat is not available to the heating manifold
Electricity and **Control/PLC** - to drive the fans and operate the valves
LPG - for pilot burner support
Nitrogen - for inerting

The Services unit also provides a central point for developing the recovery of surplus heat via the hot manifold; this will be as exhaust gases and will be used to separately dry a fraction of the incoming feedstock for sale to the energy and dry chip markets.

4.2 Innovation

The engineering is innovative and relatively straightforward:

- Single vessel for simplicity and efficiency
- Enables wet feedstock to be converted economically and safely into biochar
- Relatively low energy inputs and waste heat recovery

This enables the utilisation of feedstocks from many sources, to be converted to biochar with consistent properties, and to be economically viable as a soil amendment. In this Project the opportunity is to progress from TRL4 to TRL6 and:

- Shorten the cycle time (<1 day/cycle)
- Scale the reactor to higher capacities (1t/cycle)
- Reduce attendance levels (<1 manday/t)
- Minimise external energy input
- Path to reduce capital cost of Dryer/Kiln technology
- Deliver low feedstock conversion costs

4.3 Process Control and Automation

An important part of Phase 2 will be the automation of the process sequence. The warming and drying phases of the process cycle, which run overnight, will be operated under Proportional Integral Derivative (PID) Control under Programmable Logic Controller (PLC) supervision. The initial set points will be entered manually and subsequently re-set automatically as the phases progress.

Operating the Dryer/Kiln through the full cycle requires 24 system elements to be controlled during normal working procedures. There can be operational hazards running hot equipment with a combination of solid and gaseous fuels and the design approach has been to minimise and manage these. The aim of design is to deny an unplanned ignition/combustion opportunity to the feedstock. In this situation an alarm would be triggered and, unless cancelled, a ‘fail safe’ shutdown would be initiated.

4.4 Modelling

To obtain a better understanding of kiln performance a predictive model has been developed through Choate Technology Services Ltd[12]. The constitutive parts of the model have all been written, coded, run and tested. The maths has been developed from original work by the Di Blasi[13] and the Sandia group[14]. It has proved possible to obtain coupled solutions for pressure, temperature (thermal convection) and gas saturation based on the current moisture retention model. Further work continues to implement gas mixture boundary conditions and interphase heat transfer. Work in Phase 2 will continue to develop the model to enhance the performance of the Dryer/Kiln and inform future designs.

4.5 The Pilot Plant

The pilot plant will provide all the necessary facilities and equipment to run a biochar production operation. The site will house a large 36 x 12m building that will be used to provide a drop off area for feedstock deliveries, store wood chip feedstock and fuel, house a trommel for grading incoming feedstock and removing wood dust, provide a storage area for equipment and a location for incoming electricity. The project will proceed in three steps:

- Construction, commissioning and testing of the Dryer/Kiln unit with associated Services Container: with an output of 1t biochar/day
- Addition of a wood chip drying unit to recover/utilise the waste heat
- Expansion of the project to include a similar second Dryer/Kiln unit plus 2nd wood chip dryer, of 2t biochar/day

An office housed in a container will be stacked on top of a workshop/laboratory container. The plant will also have four char storage containers stacked 2x2, this will hold the 10t maximum site biochar inventory.

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[12] Choate Technology Services Ltd - Link

[13] C. Di Blasi and C Branca, Fuel 104 (2013) 847-860: “Modeling a stratified downdraft wood gasifier with primary and secondary air entry”

[14] Sandia National Laboratories report: SAND94-0379 By M.J. Martinez, June 1995: "Formulation And Numerical Analysis Of Nonisothermal Multiphase Flow In Porous Media"

4.6 Safety

A HAZID review has been carried out by Haztech Consultants Ltd[15]. The resulting actions have all been addressed and unresolved actions are embedded into the Phase 2 plan. The most serious finding concerned the management of explosion risk within the Dryer/Kiln. A HAZOP, SIL assessment, Human Error Assessment and Safety Critical Task Analysis will be carried out in Phase 2.

4.7 Expansion to 2t/day

In Year 3 a further Kiln/Dryer pair will be added, taking advantage of the modular approach. Beyond Phase 2, two further Dryer/Kiln units are planned raising production to 4t/day. The sequence is illustrated in Figure 4 below:

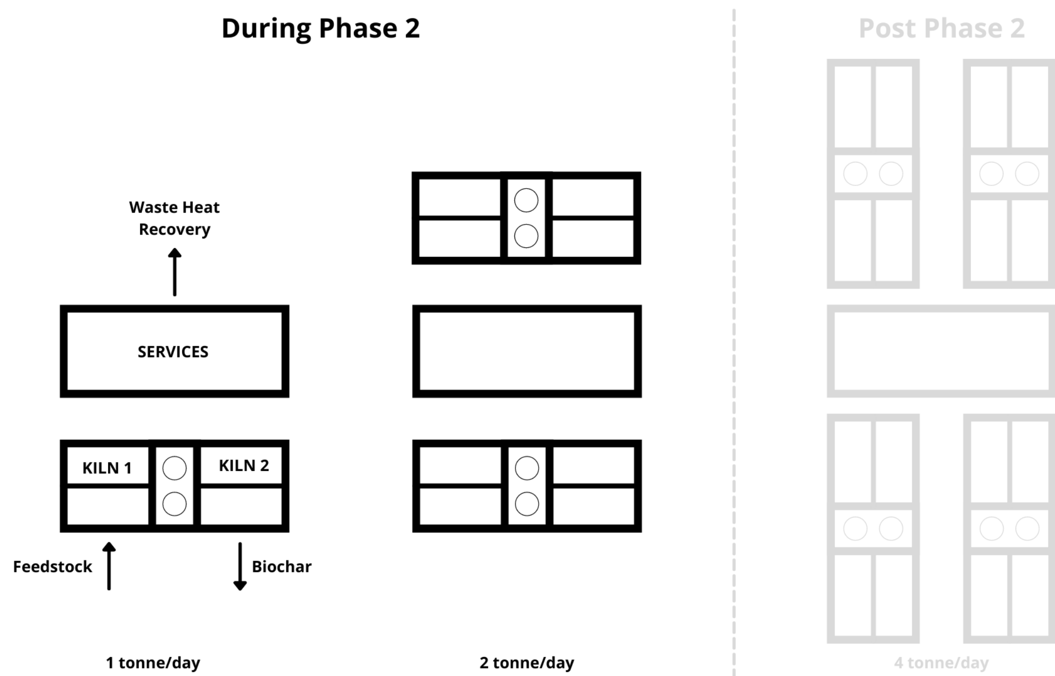

Figure 4 - Modular Dryer/Kiln concept from 1 to 2 tonnes in Phase 2 and 4 tonne configuration post Phase 2

4.8 Cost Savings

The CapChar Project describes an innovative system that is much cheaper than current commercial systems for continuous pyrolysis with a configuration and operating strategy that allows biochar to be produced within the target cost. The project believes this will

[15] Haztech Consultants Ltd - Link

offer a cost effective and value for money approach for Greenhouse Gas removal meeting the Government's targets.

5. Detailed and Costed Development Plan - Phase 2

The overall objectives for Phase 2 are to achieve a commercially attractive conversion cost, successfully sequester 100tCO_2e within a 1 year period and show how the scale-up strategy (decentralised network of plants) can be de-risked through development of a risk assessment framework and field trials work. To achieve biochar production cost decreases - CAPEX, OPEX and labour costs will be reduced through operational efficiency and increased throughput, by increasing Dryer/Kiln capacity from 1 to 2t/day and use of heat recovery for drying wet wood chips. Table 6 shows the corresponding estimated production of biochar and CO_2e sequestered during the project timeline at a 1:2 ratio shown in Table 2.

Table 6 : Estimated Production of Biochar and CO_2e Sequestered

	22/23	23/24	24/25
Approx Biochar production (t)	15	60	175
Approx CO_2e sequestered (t)	30	120	350

5.1 The Site

The site will be a new development on land owned by Consortium partner, UK Hardwoods Ltd. The site is adjacent to a saw mill and wood yard, surrounded by woodland. It's address is Folly Ln, South Molton, EX36 3EE. The site benefits the project by offering a supply of dry wood chip fuel (250-400t/y), biomass by-product from existing activities, and a supply of wet wood biomass from the felling of on-site mature biomass (100t) in Year 1. Initial sequestration can be enabled locally, as adjacent farmland is owned by the Consortium partner. In addition the site has access to its own substation and solar farm (privately owned but connected to the grid), mobile mast (4G connection) within 100m of the site, on-site well (fire fighting water) and a reed-bed water treatment system.

The rural location reduces impact on others and is visually obscured by surrounding woodland. Large vehicles currently transport logs to the saw mill and dispatch finished flooring, so the site has the appropriate entrance and size to accommodate. At scale, the new pilot plant expects some feedstock to arrive by articulated lorries, which will pass through the saw mill yard. The frequency will be limited, perhaps one per day once the plant is fully operational in 2024/25. The owner and Consortium member, will provide managerial support to the Pilot plant.

5.2 The Approach

Planning Permission - Has been granted for the Building, Yard and access road via Permitted Development. The project is ready to start. Planning permission will be sought for expansion to accommodate the double Dryer/Kiln pair.
Environmental Permit - As the pilot plant will have its own source of feedstock this will not fall under waste and will allow the pilot plant to operate freely in Year 1 and part of Year 2. Research shows that the project will be excluded from the Waste Incineration Directive (WID) and the Industrial Emissions Directive (IED) Chapter 4. However the team is seeking further clarification from North Devon Council in regards to whether the pilot plant will need an environmental permit to operate in early 2023.
Site Expansion Planning - If the new road access is not permitted all the vehicle traffic would need to pass through the saw mill yard, which in Year 3 could be an inconvenience to both operations, but can be suitably managed.
Feedstock Waste Wood - Once initial feedstock has been exhausted, feedstock partners will be created to deliver their arborists' arisings. These currently fall under the ‘waste wood’ category. The pilot plant will need to adhere to the Low Waste Risk Positions (LWRP) 60 and 61 for biochar. These include only storing 30 tonnes of waste wood and 10 tonnes of biochar at the pilot plant at any one time, spreading rates of only 1 tonne per hectare every 12 months and a maximum throughput of 50kg/h. The throughput is a risk as this would only allow for 1.2 tonnes of feedstock per day. A derogation will be sought from the Environment Agency to allow the pilot plant to operate for the Phase 2 timeline.
Satellite Site - Will need to apply to the Environment Agency for an S2 exemption to store up to 100 tonnes of wood chip on behalf of the pilot plant.

5.3 Phase 2 Plan

Technology - To progress the Dryer/Kiln technology from TRL4 to TRL6, and also improve scale economies, requires an evolution in the technology design. In Phase 1 a specific design has been identified, but it is not expected that this will necessarily provide the final design answer, further design changes and improvements may be introduced through an Engineering Implementation Strategy.

Resource Allocation - Significant resources are needed to supplement the current consortium team. Recruitment of 4 staff, 6 specialist subcontractors for Dryer/Kiln and 10 subcontractors to support the plan.

Work Packages - The project plan consists of five work packages over the three year timeline.

- **Work Package 1** : Includes planning application, site construction, equipment delivery, Dryer/Kiln commissioning and recruitment of three new team members.
- **Work Package 2** : Includes the engineering implementation strategy to build, trial, refine and test the technology driving efficiency, developing initial feedstock and sequestration partnerships, producing biochar against production milestones and producing technology reports.
- **Work Package 3** : Includes setting targets for modelling, automation and carbon balances driving productivity, deploying a waste heat recovery operation for greater energy efficiency, migrating from manual to more automated data collection to the Carbon CapChar Platform including stakeholder training and developing further feedstock and sequestration partnerships.
- **Work Package 4** : Includes commissioning a second Dryer/Kiln unit and drying container providing a path to scale, conducting ten field trials, building a risk assessment framework for future plant locations including five case studies, developing a satellite storage partner and recruiting a field trials manager.
- **Work Package 5** : Includes project management and reporting by the core project team, marketing and dissemination of information, sales market testing, stakeholder engagement, demo days/site visits and dialogue with regulators.

6. Programme and Business Plan

The project team has a vision to be able to reach >350ktCO_2e sequestered in the year 2030. To achieve this ambitious goal it will be important to scale up production quickly and inline provide the demand via a robust direct sales channel. CapChar Ltd intends to trade the carbon assets/removal certificates through the CapChar brand.

Resilience Constellation Ltd provided a report on the carbon markets and whether the proposed business model of selling carbon certificates was viable. The outcome was positive, but as the market is nascent, it needs to be followed closely.

6.1 Next Stage of Development Post Phase 2

Pilot Plant - Move towards commercialisation by starting full operation and potentially increasing capacity to 3-4t output per day.
Modularisation Development - The next technology goal is to achieve a 4t biochar production output operation. This will allow for further economic efficiencies and provide volume options to production partners.
Production Partner Programme - A turnkey solution will be developed to provide finance, training, maintenance and support to onboard new production partners. The network will provide producers access to carbon markets and biochar opportunities.
Instant Location Scale - By the end of Phase 2, it is expected that at least five locations will be ready to join the production partner programme straight away. It is expected that a second location in Devon will be one of the five new locations as many relationships will have been consolidated over the three year period. The project has already had expressions of interest from six individuals/businesses in Kent, London, Essex, Devon and Somerset, with two more (Midlands, N Wales) pending.
Employment and Development - It is expected beyond Phase 2 that every new plant will create two jobs per site, assuming 4t/day operations, directly and approximately 0.5 jobs indirectly. So at the indicated scale, 180 sites, 450 new jobs could be created.
Path to ca 360kt CO_2e - A key target post Phase 2 is to reach 50kt CO_2e per year by 2030, it is expected that this would be achieved in late 2026. By 2030 the goal is to reach >350kt CO_2e per year. This is an ambitious expansion plan that requires capital investment and funding for a sales team to provide the production partner programme. Table 7 below shows the predicted path with an improving efficiency ratio of feedstock to biochar.

Table 7 : Path to Sequestering ca 360kt CO_2e per year

	2025	2026	2027	2028	2029	2030
Total plants in operation	6	26	60	100	140	180
Total feedstock input (kt/y)	48	208	480	800	1120	1440
Total char output (kt/y)	6	26	60	100	140	180
CO_2 sequestered (kt/y)	**12**	**52**	**120**	**200**	**280**	**360**

The plan assumes an improvement in efficiency as surplus heat is used to dry feedstock. The feedstock is a natural material with properties that will vary from batch to batch, the figures above are a guide only. The above also assumes the plants are producing biochar at 4t/d for 250 days or 1kt pa. There is scope for significantly improving throughput via 24/7 operation.

There is a strong interest in the technology; the project is currently receiving several requests for information per week at the time of writing. Given this situation and in conjunction with the IBCM tool being developed many additional sites should be achievable.
Carbon Removal Certificate Sales - Complete the commercialisation of all sequestered biochar from Phase 2 with approval from BEIS. Launch sales of carbon removal certificates to UK organisations.
Capital Raising and Finance Partners - Capital raising will provide the finance necessary to scale the team and provide a 'turnkey' solution to production partners.
Regulation - Continued work on any regulatory hurdles affecting scale up.

6.2 How Work in Phase 2 will Inform Future Development

Phase 2 success will provide the opportunity to test and evaluate elements of the scale up strategy. This will derisk the underlying business model and provide a route for carbon investment funds to invest in the scale-up phase.

Technology - The technology will be progressed from TRL4 to TRL6 during Phase 2 and a clear pathway to commercialisation in TRL9 will be established. The opportunities for price reduction in volume manufacture and the opportunities for optimisation of Dryer/Kiln performance through model simulations will be fully explored.
Integrated Biomass Carbon Management (IBCM) Plan - Creating a decentralised network of production partners presents the challenges of variability from feedstock, equipment, on site services and multiple local stakeholders. In identifying these challenges and providing a risk assessment tool, a scale up strategy can be developed to determine the best opportunities for growth across the UK.
Fields Trials - Biochar use in agriculture and biochar production from low grade biomass are both new. Methodologies and processes do not yet exist, so the need to understand, collect data, develop and trial these is important. This work will help provide data that can be added to the IBCM framework for assessment and show how processes will work in practice.
Planning - Understanding the planning process and how these pyrolysis plants will be viewed by local authorities will help inform the best strategies for helping production partners in future approaches.
Regulation - Working closely with the Environment Agency (EA) may lead to a change in the position of wood waste.
Safety - Operational experience will result in health and safety procedures and a safe operating manual, which can be used at new plants.

Marketing - Engaging with stakeholders and the general public will inform how to create the right message at both a local and national level.
Sales and Pricing - Demand and price for carbon removal certificates, dry wood chips/logs and biochar for other applications will be tested, so a commercialisation and scale strategy can be finalised.
Carbon Market - Following the carbon market during the three years will help inform the commercialisation strategy.

6.3 Dependencies and Assumptions

The growth and feasibility of a decentralised network of up to 180 pyrolysis plants across the UK is dependent on the following factors:
Technology - The 2t Dryer/Kiln setup with drying units can be doubled again to 4t and associated drying units to allow for a 2 man operation.
Efficiency - In a 4t output operation the waste heat can be moved around in such a way that very little fuel is needed. In effect acting as a continuous batch process.
Carbon Price - The price continues to climb and becomes competitive to biochar products based in Europe and globally.
Carbon Purchasers - Demand for ‘transparent’ carbon offset products is high.
Planning - Local planning rules recognise pyrolysis as a new and needed technology and grant permissions quickly.
Regulation - Updating of policy to increase all position statements on biochar, change the status of wood chip to non waste wood or creation of a new Quality Protocol for end of waste status.
Feedstock Availability - Based on research conducted during Phase 1, there is enough feedstock from a range of opportunities to achieve the 360ktCO_2e target, but this assumes it is easily available and will not be used for other purposes.
Partnership Uptake - There are enough businesses/partners in the UK, who would be interested in ‘buying’ into this model to become part of the network and that they have the right site locations and assets to keep outlay costs to a minimum.
Energy Markets - If energy markets promote the use of wood chip as a ‘renewable’ fuel this could continue to push the price higher. However the model does counterbalance this argument with its ability to dry wood chip as part of the process.
Carbon Tariff - Depending on the methodology and process the current carbon tariff is somewhere between 2-3tCO_2e for every 1t of biochar produced (2t/t biochar for the EBC).
Investors/Financing - The business model has been derisked enough to make it attractive for investment and debt financing.
Plant Cost - Reduce the plant cost down by 30%.

Carbon Tax - The model is not reliant on a carbon tax or subsidies but any opportunities to provide subsidies for farmers to purchase the biochar for land remediation through a scheme like ELMS would make the economics more attractive.

7. Conclusion

The CapChar Project has set out a Phase 2 plan to demonstrate a Greenhouse Gas Removal end-to-end solution that can achieve the competition objectives to sequester 100tCO_2e within a year timeframe and increase the Technology Readiness Level from TRL4 to TRL6.

The Project offers:

- An effective equipment design - the Dryer/Kiln - that should lead to better energy utilisation and more controlled and safer operation under process control and automation. It draws on prototype designs, developed over a decade.
- A low CAPEX technology that offers a cost effective alternative to continuous systems on the market.
- A practical route to sequester atmospheric carbon dioxide cost effectively, turning wet wood chip into biochar and sequestering it in local soils.
- Utilisation of existing low value arborist arisings in the volumes necessary for Phase 2 and scaling up.
- The path to a decentralised network of pyrolysis plants that can manage smaller volumes (30t) of ‘waste’ material inline with current regulation, which can provide true circular value, engage the local community as part of efforts towards Net Zero, drive local economies, and provide jobs in both rural and urban areas.
- Production of a value added material that can improve soils for enhanced plant growth, nutrient recycling and reduced run-off, as well as applications to decarbonise other industries.
- Export potential to other areas of the world that need cost effective solutions.
- A business model does not rely on any government subsidies to be economically viable and utilises an existing financial instrument with growing demand.
- The potential to reach 50kt pa CO_2e by 2026.
- The ambitious scale-up plan could see this technology reach >350kt pa CO_2e by 2030 contributing to the Government's goal of achieving removals in the Mt pa CO_2e scale.

8. List of Acronyms

Acronym	Full Name
ATEX	European Directives for controlling Explosive Atmospheres
BBM	Baseline Biochar Metrics
BECCS	Bio-Energy Carbon Capture and Storage
BEIS	Department for Business, Energy & Industrial Strategy
BEIS/MO	BEIS Monitoring Officer
BoD	Basis of Design
BPS	Biochar Project Services Ltd
BW	Biochar Works Limited
CAG	CCS Advisory Group
CAPEX	Capital Expenditure
CC	CapChar Limited
CCC	Committee on Climate Change
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Utilisation and Storage
CDM	Construction (Design Management) Regulations 2007
CFD	Computerised Fluid Dynamics
CO	Carbon Monoxide
CoC	Chain of Custody
COD	Chemical Oxygen Demand
CORC	CO2 Removal Certificate (CORC)
COSHH	Control of Substances Hazardous to Health
CWM	CWM Harry Land Trust Limited
DAC	Direct Air Capture
DEFRA	Department of Environment, Farming and Rural Affairs
DEP	Design, Engineering and Procurement
D/K	Dryer Kiln
DOI	Digital Object Identifier
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations
EA	Environment Agency
EBC	European Biochar Certificate
ELMS	Environmental Land Management Schemes
ENVID	Environmental hazard Identification
EPC	Engineering, Procurement and Construction
EU	European Union
FAO	Food and Agriculture Organisation of the UN
FEED	Front End Engineering Design
FID	Final Investment Decision

FLOX	A combustion process developed by WS Wärmeprozesstechnik GmbH.
IBC	Intermediate Bulk Container
IBCM	Integrated Biochar Carbon Management
IBI	International Biochar Initiative
IED	Industrial Emissions Directive
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
GDP	Gross Domestic Product
GDPR	General Data Protection Regulations
GGR	Greenhouse Gas Removal
GHG	Greenhouse Gas
GPS	Global Positioning System
GS(M)R	Gas Safety (Management) Regulations 1996
GVA	Gross Value Add
HAZID	Hazard Identification
HAZOP	Hazard & Operability study
HGV	Heavy Goods Vehicle
HHV	Higher Heating Value
HMG	Her Majesty's Government
HMI	Human Machine Interface
HSE	Health & Safety Executive or Health, Safety and Environment
ID	Induced Draft
LCA	Lifetime Cycle Analysis
LPG	Liquified Petroleum Gas
LRWP	Low Risk Waste Position
MHSWR	Management of Health and Safety at Work Regulations 1999
MRT	Mean Residence Time
MWth	Megawatts Thermal
MWe	Megawatts Electrical
NC	Normally Closed
NDC	North Devon Council
NFU	National Farmers Union
OPEX	Operational Expenditure
P&ID	Piping and Instrumentation Drawing
PID	Proportional integral derivative controller
PLC	Programmable Logic Controller
PPE	Personal Protective Equipment
PUWER	Provision and Use of Work Equipment Regulations 1998
QC	Quality Control
QP	Quality Protocol
RAM	Reliability, Availability & Maintainability study

RAU	Royal Agricultural University
REAL	Research Energy Assurance Ltd (Assoc of Compost Manufacturers)
REACH	UK Registration, Evaluation, Authorisation & restriction of Chemicals
REL	Recommended Exposure Limit
SOM	Soil Organic Matter
SPV	Special Purpose Vehicle company
SWP	Safe working procedures
T&S	Transport & Storage
TDS	Total Dissolved Solids
TIC	Total Installed Cost
TRL	Technology Readiness Level
UKH	U.K. Hardwoods Limited
UKRI	UK Research and Innovation
VOC	Volatile Organic Carbon
VPN	Virtual Private Network
VSD	Variable Speed Drive
WID	Waste Incineration Directive