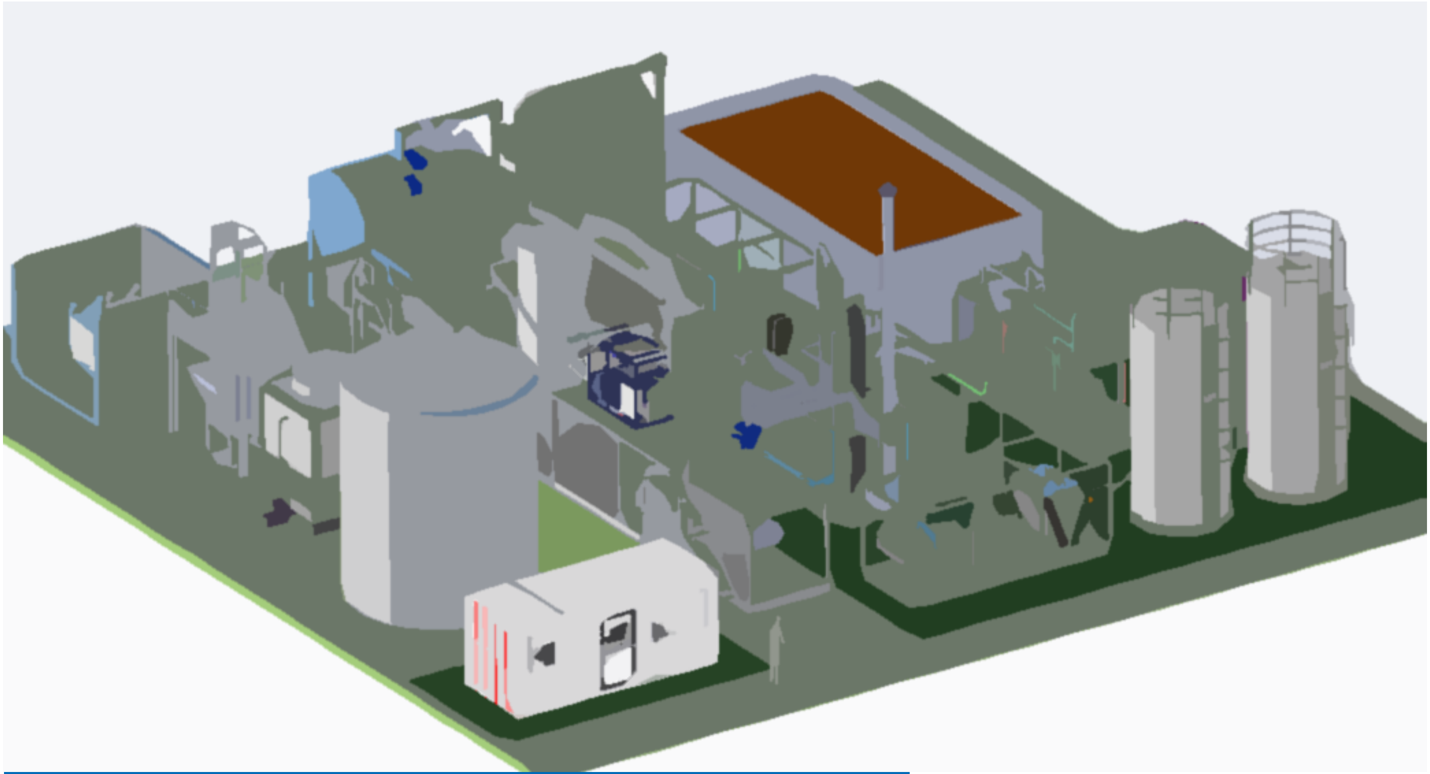

D1.3 Design Study - Publishable

RD21-68701-1

ED14737/R023171 | Issue number 1 | 14 January 2022

Customer:

Department for Business, Energy and Industrial Strategy

Customer reference:

4696/11/2020 – BIOCCUS

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Ref: ED14737/R023171

Ricardo is certified to ISO9001, ISO14001, ISO27001 and ISO45001

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1 Introduction

Following the Paris Agreement in 2015 and the publication of the Fifth Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC), Negative Emission Technologies (NETs), also known as Greenhouse Gas Removal (GGR) and Carbon Dioxide Removal (CDR) technologies, have become essential to meeting 2050 CO_2 emission reduction targets. Such technologies are thought to be necessary as they will help address residual emissions from hard-to-decarbonise sectors such as aviation and construction. Biomass-based technologies (combustion, gasification, pyrolysis) combined with carbon capture and storage (BECCS) are key GGR technologies as highlighted by the Royal Society and Royal Academy of Engineering (RAEng)[1]. Modelling shows that around 50Mt CO_2/year in 2050 might be required from BECCS in order to achieve net zero in the UK. However, BECCS is a pre-commercial technology. The UK is fortunate in being well-placed in bioenergy development as well as having suitable CO_2 storage capacity. This means that there is currently an opportunity for the UK to become a global technology leader for carbon capture, utilisation and storage (CCUS) and to work with industry and internationally to drive down deployment costs[2].

Carbon capture, utilisation and storage (CCUS) refers to a chain of technologies which aim to keep carbon dioxide, produced from industrial sites and power plants, from entering the atmosphere and contributing to the greenhouse gas effect. It is an essential element in the fight against climate change. According to the International Energy Agency (IEA), CCUS has the potential to reduce CO_2 emissions by almost 20% and can reduce the cost of tackling climate change by 70%[3] in the next three decades.

It is now a well-established fact that the UK's target of 'net-zero' is not possible without the implementation of CCUS. At present, there are about 20 carbon capture projects worldwide operating commercially, with the USA, Canada, Norway, and China being the market leaders. The most advanced CCUS project in the UK is the Drax BECCS project.

Ricardo and Bluebox Energy have developed an attractive solution that delivers valuable products as well as heat and electricity (BIOCCUS) and does so whilst being net carbon negative. This objective of this study was to explore the BIOCCUS concept in more detail, to evaluate its commercial viability and to produce the engineering designs of the system.

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[1] The Royal Society and the Royal Academy of Engineering (2018) Greenhouse gas removal www.royalsociety.org/greenhouse-gas-removal and www.raeng.org.uk/greenhousegasremoval, 2018.

[2] Ricardo Energy & Environment, Analysing the potential of bioenergy with carbon capture in the UK to 2050 (publishing.service.gov.uk), 2020.

[3] J. Ambrose, What is carbon capture, usage and storage – and can it trap emissions?, The Guardian (2020) Available at: https://www.theguardian.com/environment/2020/sep/24/what-is-carbon-capture-usage-and-storage-and-can-it-trap-emissions

2 Scientific basis of the concept

Ricardo and Bluebox Energy received funding from the UK Government under the Direct Air Capture & Other Greenhouse Gas Removal (GGR) Technologies competition to design an innovative GGR technology (BIOCCUS).

The BIOCCUS concept is designed with the aim of maximising negative emission potential, combining two established GGR concepts, namely biochar and BECCS. BIOCCUS is a biomass pyrolysis-based cogeneration system with biochar production and CO_2 capture, utilisation and permanent storage. The technology uses undried and un-processed waste wood (i.e., not pelleted) from sustainably-sourced domestic timber to produce electricity and heat in addition to biochar and commercial grade carbon dioxide.

The chemical process is currently in the process of being patented and so cannot be described in detail in this report.

Over the past two decades, many project demonstrations of post-combustion CO_2 capture from flue gas in the power sector (e.g. Boundary Dam project in Canada, Petra Nova in Texas) have been conducted with the aim to improve efficiency and reduce energy requirements associated with the CO_2 capture process. These demonstrations are, however, very large in scale. BIOCCUS offers the opportunity to demonstrate CO_2 capture from flue gas at a small scale, allowing its deployment in communities where there is demand for heat and electricity.

The key benefit of the system is that it will provide value from all four outputs, giving a low cost for carbon dioxide sequestration. Due to its modular nature, it can be easily and quickly deployed within the community, at farms or near greenhouses addressing the need for decentralised heat and electricity requirements. Community scale CCUS systems allow the development of the CO_2 capture and utilisation supply chain in industry without having to wait for the development of the important but complex and expensive CO_2 transport and storage infrastructure. A modular approach, with numerous smaller BECCS deployments rather than a few large ones, commonly involves smaller unit costs, quicker build schedules, and less risk to investors.

The BIOCCUS system is also well integrated so that it maximises heat recovery to improve energy performance and overall efficiency. The purpose of designing and building a BIOCCUS prototype and demonstrating its performance is to reduce the associated costs and ensure feasibility of the approach.

3 Phase 2 project plan

The following section describes the plan for the Phase 2 demonstration project, including a description of the chosen site.

Being in Lot 1, the Phase 2 project needs only to demonstrate part of the carbon capture process. CO_2 capture system costs for a full-size (four module) plant have been verified through supplier discussions to be consistent with the commercial calculations performed in Phase 1. However, for the single-module Phase 2 demonstrator plant, the costs of the CO_2 capture system are not able to be fully contained within the maximum budget for Phase 2 projects. Therefore, the Phase 2 project will demonstrate the biochar production part of the BIOCCUS system and will include a partial demonstration of the CO_2 separation using a CO_2 capture system that operates on a percentage of the exhaust stream and can be accommodated within the budget.

Following discussions with interested parties during Phase 1, Icknield Farm (marked in Figure 1) has been selected for the Phase 2 demonstration site. Located in Oxfordshire, approximately 10 miles northwest of Reading, Icknield Farm is a 700ha, integrated farm enterprise with experience in investing in green technology.

Figure 1 - Location of Icknield Farm

Since 2014, Icknield Farm has been operating a biogas plant as an integral part of the farm operations (IEA Bioenergy Task 37, 2018). The annual biomethane output is sufficient to supply 4,000 homes along the Thames Valley. The farm represents an ideal end-user for the BIOCCUS demonstrator as it already operates a gas-fired CHP system to generate on-site heat and export electricity to the grid (as well as biomethane). In addition, the use of biochar in the anaerobic digestors has recently been implemented with the benefit of increased stability of methane production. Hence the biochar produced by the BIOCCUS system has an immediate use on-site, minimising the carbon footprint from its delivery elsewhere.

The outputs from the pilot plant will be used in the following ways:

- Biochar: The produced biochar will replace the biochar already used in the anaerobic digestors, providing an operational cost saving. The pilot plant will produce more biochar than the digestors currently consume, so the remaining biochar will be used as a soil improver on the farmland, it will be sufficient to dose ~10-15% of the farmland at 1 tonne per hectare per year.
- CO_2: The CO_2 produced by the system will be vented to atmosphere for the duration of the Phase 2 project. Discussions with suppliers during Phase 1 have confirmed the willingness to provide a liquefaction plant and enter a commercial contract for its collection, but this can only be pursued once the BEIS contract is terminated. The biogas site already operates a CO_2 separation system, which also currently vents to atmosphere. Beyond the end of Phase 2, it should be possible to combine these output streams and enter a contract for its collection. If such an agreement is reached, the likely end-use will be the food and drink sector, however the project partners will continue discussions and potentially perform lab trials with a concrete manufacturer during Phase 2 to aim to create an end-user for the CO_2 that results in longer-term greenhouse gas removal (in addition to that from the biochar).
- Electricity: Despite the on-site CHP system, the biogas plant is currently a net importer of electricity from the grid due to the requirements of the existing CO_2 separation system. The electricity produced by the pilot plant will be used by the biogas plant, reducing the operational energy costs.
- Heat: Under typical conditions, the biogas site does not require additional heat. However, there may be requirements at certain times of year, particularly during winter if the weather conditions lead to a reduction in the digestor operating temperatures. Other potential uses of the heat will be discussed with the biogas operator and landowner.

Figure 2 - Biogas plant on Icknield Farm, available land shown in red, BIOCCUS pilot shown in green

The specific location for the plant is shown in the red rectangle in Figure 2. It is currently leased to another business, however this will expire in the coming months and the land will become vacant. The site is very well sized for the BIOCCUS demonstrator and the existing access road and brownfield nature should enable a smooth planning permission process.

4 Programme and business plan

The proposed pilot phase will result in a TRL 6 demonstration, defined in the competition guidance as Prototype System Verified, as it will have been tested in a relevant environment. The production system will feature four modules of the pilot system, the final design of which will be generated as part of the Phase 2 exploitation activities. The test data generated within Phase 2 will provide the information required to perform any re-design to the system prior to its first full-scale deployment and will likely be done either in the final activities within Phase 2, or as the initial part of the first customer contract. Hence, a successful demonstration of the pilot in Phase 2 will enable the consortium to offer full-size systems to the market from early 2024.

The ideal customers are those that require heat and power on-site, as well as one or both of biochar and CO_2. This means the primary list of customers are:

- Concrete manufacturers – CO_2 can be used in the curing process, biochar in construction products (in the future)
- Commercial greenhouses – CO_2 can be used to aid growth, biochar can be mixed with compost
- Biomethane-to-grid sites (anaerobic digestors) – biochar can be used to improve yield / stability. CO_2 separation and collection may already be implemented from the biomethane plant
- Wastewater treatment sites – similar uses to anaerobic digestors

Secondary customers who may be interested in exporting CO_2 and/or biochar are:

- Timber / furniture production facilities
- District heating schemes
- Urban industrial facilities (e.g. leisure centres)

In the case of commercial greenhouses, biomethane-to-grid sites and wastewater treatment sites, the GGR performance of the system may rely solely on the biochar production. The greenhouses will use the CO_2 directly for yield boosting and the biomethane-to-grid and wastewater treatment sites will export the CO_2, where at present the likely use would be in the food and drinks industry.

The reasons for selecting food-grade CO_2 as a requirement for the system was to ensure there was an immediate market need for the technology. As CCUS deployment grows worldwide, applications for carbon dioxide utilisation will also grow. Some, mostly direct, CO_2 applications are existing well-established applications (e.g. greenhouses, slaughterhouses, fire extinguishers, enhanced oil and gas recovery, etc.) although clearly some of these uses have negative environmental impacts. Others uses for CO_2 are in emerging markets aimed at ensuring permanent storage (e.g. green cement, concrete curing, aggregates, etc.). These are shown below in Figure 3.

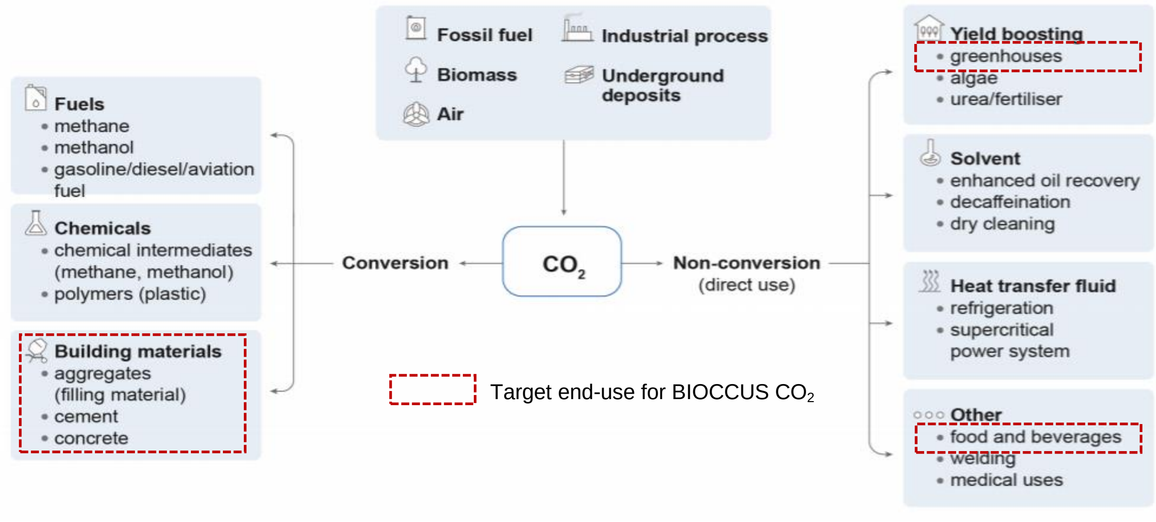

Figure 3 Existing and emerging carbon dioxide uses

By ensuring that the system is designed for direct CO_2 usage, the technology will be able to be rolled out rapidly, as it will not be reliant on the CO_2 market developing for use in building materials. As the building material CO_2 market increases, the system can easily be modified to produce CO_2 at the required (lower) purity, which will likely bring a further cost saving.

Finally, it should be noted that even in the scenarios where the CO_2 is used directly, there remains a net benefit in terms of greenhouse gas emissions. At present, the largest source of food-grade CO_2 is from ammonia production for fertiliser use. 45% of the UK's CO_2 is produced in this manner, and it is the sole source for Air Liquide products who have a 40% UK market share[4]. Ammonia production relies on natural gas. Due to inefficiencies and the associated N_2O and CH_4 emissions, the net impact of the production process is ~1.41 kg CO_2 released to the atmosphere, per kilogram of CO_2 used (Hoxha & Christensen, 2018), ignoring any emissions associated to its transport. On the same basis, use of CO_2 generated from a BIOCCUS system is effectively net zero due to its use of sustainably sourced biomass. Therefore, even though the greenhouse gas *removal* performance of the system is reduced if the CO_2 is used in these direct applications, there is still a strong contribution towards net-zero by reducing the generation of these emissions.

A mapping exercise has been performed to identify, within the target customer groups, the precise location of the customers and their proximity to the existing UK biomass supply chain (including proximity to sawmills as potential providers of unprocessed waste product).

Following a successful Phase 2 pilot demonstration, the first orders are anticipated in 2024. To emphasise the strength of the business case, low and high forecasts are shown in Figure 4. The environmental impact has been calculated for both forecasts, considering both the greenhouse gas removal (long-term storage) impact as well as

[4] https://www.ft.com/content/c35e1504-1910-4c20-851f-070fbbd282ef

the CO_2 reduction from the technology roll-out considering its displacement of heat, electricity and CO_2 generated from non-renewable sources. The sites and their uses of CO_2 are assumed to be the same as those identified from the market analysis, hence only a proportion of the future sales consider the separated CO_2 to be permanently stored (those located at concrete facilities).

Using the high and low forecasts, the GGR potential for the technology is estimated to be 310kt – 820kt CO_2/annum by 2030. The reduction in CO_2 emissions is estimated to be 340kt – 900kt CO_2/annum. Therefore, the total contribution of the technology towards net-zero is estimated to be 650kt – 1720kt CO_2/annum.

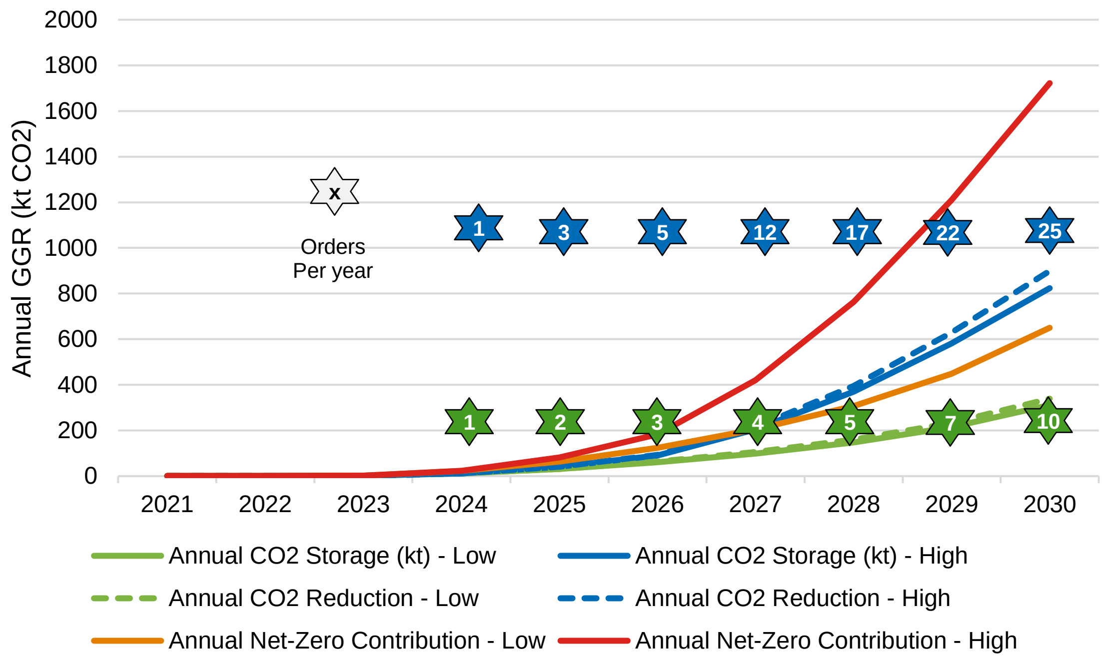

Figure 4 - Sales Forecast & GGR Impact

5 Conclusions

This Phase 1 design study has defined a novel concept for a GGR technology incorporating a pyrolysis-based biomass CHP system with a closely integrated CO_2 separation system. The BIOCCUS system produces four valuable outputs from its input feedstock; biochar, CO_2, heat and power.

The analysis performed on the system has verified its viability and has led to the identification of the ideal configuration to maximise the usage of the available heat and minimise parasitic loads. Detailed CAD models of the whole system have been generated, suppliers are engaged and some have already provided quotes for Phase 2. The overall control architecture and strategies for each of the sub-systems have been defined and the controller hardware selected.

A demonstration site for Phase 2 has been selected and the project plan is mature. Two additional partners have been identified to be added to the consortium for Phase 2.

The business model and target customers have been further defined through additional research during Phase 1. There is a strong business case for future deployment and a wide set of customers for whom the BIOCCUS system should be compelling, based on conservative estimates for the values of the outputs.

The successful delivery of this Phase 1 design study has enabled the consortium to develop the technical details and commercial plans for the technology, providing a solid foundation for a Phase 2 application. The partners are incredibly positive towards the outputs of Phase 1 and the opportunity to pursue the technology further in Phase 2, which perfectly fits our technical and business strategies, has excellent and lasting environmental benefits and is commercially strong.

A1 References

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