DIRECT AIR CO2 CAPTURE & MINERALISATION

CAM202029

PHASE 1 FINAL REPORT (PUBLIC)

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DESCRIPTION OF THE DAC PROCESS.

Over the multi-billion-year life of our planet its temperature has remained fairly constant despite the sun growing significantly hotter. It has done this by removing most of the CO_2 that used to reside in the atmosphere. The dominant mechanism for this was the reaction of CO_2 with abundant Magnesium Silicate minerals produced by volcanic activity.

Cambridge Carbon Capture's Patented CO_2LOC technology greatly accelerates this natural process by first digesting these abundant Magnesium Silicate minerals. The CO_2LOC process has been developed to selectively capture CO_2, NO_x and SO_x from industrial emissions and converts them to commercially useful Magnesium Carbonate minerals. These gases exist in relatively high concentrations in the industrial emissions and this drives the reactions in the process. However, CO_2 in air is at a very low concentration and as a result the driving 'pressure' is low resulting in very slow reactions. In this project the CO_2LOC process has been adapted to capture CO_2 directly from air.

In the modified CO_2LOC process, a sustainable supply of magnesium hydroxide is produced by digesting Magnesium Silicate rocks or mine tailings with CCC's digestant. The Magnesium Silicate is first pulverised and blended with CCC's digestant and then reacted in a specially designed reactor. This produces Magnesium Hydroxide and Silica; the Magnesium Hydroxide is then used to capture and sequester CO_2 as Magnesium Carbonate.

SOURCE OF MATERIALS USED

The CO_2LOC process starts with abundant Magnesium Silicates, these materials are often what makes up mining tailings in many existing mineral/metal extraction operations so could be regarded as a waste stream. However, when at scale the process could inspire mining operations specifically aimed at the supply of Magnesium Silicates for the process. To this end, CCC are working with Metamorphic, a mining start-up in Norway with mineral rights for over a billion tonnes of serpentine minerals and are working with Camborne School of Mines to survey available resource across Europe and opportunities to add additional value through environmentally sustainable extraction of critical metals such as Nickel and Cobalt.

The digestion is not restricted to any one mineral. Talc has been chosen, but every Magnesium Silicate mineral studied so far has been digested by our process.

For the pilot the main feedstocks required for the process are ground soapstone or talc minerals, CCC's digestant, water and air. The silicate mineral (10 tonnes needed for the trials) and the CCC's digestant (11 tonnes needed for trials) will be sourced from European suppliers.

DISPOSAL OF WASTE

The philosophy behind the CO_2LOC process is that all the by-products of the process have value and are sold into existing or future markets generating revenues, the 50kt plant will therefore have no waste outputs. One of the purposes of the Pilot plant is to help develop local markets for the by-products by providing materials for trials with future customers for the by-products for the 50kt plant.

The CO_2 that is captured is locked away as Magnesium Carbonate and it is planned that this will be used as a construction material when at a commercial stage. CCC is working with Holcim, Saint Gobain, CRH and others to develop construction materials using our captured CO_2 and the plan with the pilot project is to provide the magnesium carbonate produced to these partners to enable them to develop and test materials. The Magnesium Carbonate produced is therefore removed from site free of charge by our construction materials development partners.

The pilot project will support the development of construction materials with partners so that, by the time the 50kt plant is being commissioned, there will be a local market demand for the magnesium carbonate produced, this market being of a sufficient size to take all the material produced at the site and at a gate price which helps support the venture as a going concern without the need for further UK Government support.

Another by-product will be the silica. At the pilot stage, the silica will also contain trace metals contained in the magnesium silicate feedstock and will be in a form which will depend greatly on the process conditions selected. It is the intention of the pilot project to explore the properties of the produced silica at differing process conditions and determine further process steps needed to extract the various metals contained within. These investigations will be carried out as part of the pilot trials. As there is currently not a customer for this by-product output from the pilot trials, this material will be collected and removed from site as a waste product. A budget will be allocated for this activity within the pilot project. However, the intention of the pilot trial is to establish a local market for the silica and metals produced. To this end, CCC have been working with an industrial expert in silicas and magnesium carbonates, and his contacts at PQ Corporation, (https://www.pqcorp.com/), to bring them in as partners in the pilot trial to explore properties achievable and develop markets for these materials and explore their use in existing target markets such as uses in high quality cement and a filler in tyres and other wear resistant rubber and plastic products. This will lead to the development of a market for the silica produced in time to offtake the silica produced by the 50kt Plant and generate further revenue for the plant.

1.2 ENERGY AND FUEL REQUIREMENTS

The pilot plant will use UK grid electricity for the heat and power needed for its operation as this is the most convenient option on the pilot site selected. The pilot has been designed to enable each of the 3 key reactions to be run independently to enable each to be optimised independently of each other. However, each part of the pilot is designed at the scale which would enable them to be linked to form an integrated process. The pilot therefore is designed to be flexible rather than efficient, and part of the integration exercise will be to look for areas where heat can be recovered and reused in the 50kt plant design.

A detailed TEA and LCA of the proposed 50kt Capture Plant was carried out as one of the key deliverables of this project. In this analysis the process was split into a number of stages and the energy and fuel requirements and subsequent CO_{2e} emissions have been calculated and presented in the following Table 1.

Process Step	Sub-step	Aspect of the Process	Process producing CO_2	CO_2 Source	CO_2 Produced (Kg CO_{2eq} / t CO_{2seq})	CO_2 Saved (Kg CO_{2eq} / t CO_{2seq})	Net CO_2 Emissions (Kg CO_{2eq} / t CO_{2seq})
Input Materials	Mineral extraction	Energy Input	Mining operations	Diesel		-	
	Mineral mine logistics	CO_2 from transport of tailings to dig plant	Transport	Diesel		-	
	Mineral Crushing	Energy Input	Crushing	Grid Electricity (Coal Fired PS)		-	
	Mineral Milling	Energy Input	Milling	Grid Electricity (Coal Fired PS)		-	
	Digestant Manufacture	Energy Input	Manufacturing process & delivery to site	CO_2 from chemical reaction		-	
Transport	Shipping of milled minerals to DAC site	CO_2 from transport of brucite to emitter	Shipping (1000 miles)	Diesel		-	
Digestion	Digestion Heat	Energy Input	Countering heat loss and reaction endotherm	Natural Gas		-	
	Digestion Process	CO_2 released from process	CO_2 from serpentine digestion to form $Mg(OH)_2$	Mineral /Digestant		-	
Solids Separation	Filtering of $Mg(OH)_2$	Energy Input	Pumping and mixing	Grid Electricity (Gas Fired PS)		-	
Air Capture	-	CO_2 Capture	Process		-		
Digestant Recovery	Digestant Recovered (80%)	Reagent Recycling	CO_2 reabsorbed by process				
	Heat input for digestion agent recovery process	Energy Input	CO_2 from heat needed to run evaporator	Heat recovered from digestion step			
Ultrafiltration	Silica extraction	Energy Input	Pumping	Grid Electricity (Gas Fired PS)		-	
Precious Metal Extraction	Electro-refining plant	Energy Input	PM extraction - Electrolysis	Grid Electricity (Gas Fired PS)		-	
CO_2 Sequestration	Mineralisation of CO_2	Energy Input	Electrical Power Input of Carbonator	Grid Electricity (Gas Fired PS)		-	
	Water recovery and mineral extraction	Energy Input	Electrical Power Input of slurry mixer and filter press	Grid Electricity (Gas Fired PS)		-	
Transport	$MgCO_3$ to construction materials customer	Energy Input	200 miles by rail	Diesel		-	
	Silica to customer	Energy Input	200 miles by rail	Diesel			
Fossil Fuel Used							**494.52**
Renewables Used							**181.14**

Table 1: Energy intensity and source breakdown

Table 1 lists the emissions produced by the process normalised to a tonne of captured CO_2. The conclusion is that for every tonne captured **495 KgCO_{2eq}** is released giving a NET benefit of **505 KgCO_{2eq}** for every tonne removed from the air.

This analysis was based on the use of electricity and heat generated from coal at the mine site and Natural Gas at the UK based plant. This represents the worst case. However, the mine we propose to use to supply magnesium silicate materials is being planned by Metamorphic Ltd in Norway. The mine site is located near a hydroelectric dam and, as the mine is yet to be developed, all plant and mine vehicles on the site are likely to be powered by renewable electricity from the dam. This would reduce the carbon intensity by 64 Kg CO_{2eq}. If the proposed DAC plant based on Merseyside is powered by the vast offshore wind farms nearby or by the onshore wind turbines at the Frodsham Wind Farm, adjacent to Protos, the proposed site of the 50kt DAC plant, this would reduce the emissions by a further 249 Kg CO_{2eq}. Both these options are reasonable and would probably be mandated for any new facility due to future net zero commitments. Therefore, if renewable energy sources are to be used, the carbon intensity of the DAC process would be **181 KgCO_{2e}** giving a NET benefit of **819 KgCO_{2e}** for every tonne of CO_2 removed from the air. Further CO_{2e} savings will be achieved through the substitution of carbon intensive alternatives by the by-products produced by the process. This could add a further **1,954kgCO_{2e}** saving, giving a Net CO_2 benefit of **2.773tCO_{2e}** per tonne of CO_2 captured from the air using CO2LOC technology.

1.3 ENVIRONMENTAL IMPACTS.

Other than the CO_2 benefits of the process described above in section 1.2, there are likely to be other environmental impacts from the by-products produced, other waste streams and site operations. The 50kt Plant will be governed by the same regulatory frameworks covering any new chemical processing plant in the UK and with the expertise and experience of Otto-Simon, CCC's engineering partners in this project, these considerations will be designed in from the start. However, the processes and chemistry used are benign and process water recycled, containing any potential contaminants from the process.

The proposed location of the plant is Protos (https://www.protos.co.uk/), this is located in a heavily industrialised region alongside Oil Refineries, waste to energy plant etc. and the site has already got permissions for a resource recovery park on their land under the Town and Country Planning Act 1990 – section 78.

OTHER CONTAMINENTS

The mineral feedstock contains trace amounts of various metals but the build-up of these metals in the recirculated/recovered water will not be an issue as, in the 50kt plant we will have a metal recovery step within the process so these metals would only be present below the limits that the metal recovery process can economically extract them. These remaining metal contaminants will end up in the magnesium carbonate mineral at the end of the process. As this material is to be used as a construction material, purity of the magnesium carbonate is not a big issue so there is likely to be a wide tolerance on acceptable contamination of the product. There may however be some issues around the possible leaching out of these materials and possible interactions with other construction materials in the built environment. One of the outputs of the collaboration with Holcim and other construction materials companies such as Forterra over the pilot project will be to explore the use of the magnesium carbonate produced and the assessment of the material properties tolerances necessary regarding compatibility issues and possible aging effects such as leaching of contaminants over time.

Mined products are never 100% pure and despite beneficiation at the mine site, clays and other alien non-toxic materials will enter the process. The process flow has the effect that any solid materials not taking part in the chemical process will filter through to the system and end up within the end magnesium carbonate product. As mentioned above, the construction sector is not concerned with high purity as the construction industry traditionally have a high tolerance for these materials.

NOISE

As the 50kt Plant will be drawing a huge volume of air through the system to capture the low concentration CO_2 there is a requirement to force this air through using fans. The fans used will be highly efficient and therefore low noise. However, these fans will produce some noise, and this will have an impact of the local communities and wildlife. Suitable guarding around the fans and the relatively slow air speed will prevent injury to birds. The proposed site for the plant is in a heavily industrialised area and away from any residential areas so noise will have a minimal impact to the local community.

EMISSIONS

The only emissions from the site will be the processed air. As the air that passes through the system will pick up moisture from the scrubber, in certain weather conditions there is likely to be a plume of steam coming from the site. Again, this is an industrialised zone, and the region has many cooling stacks emitting steam including the cooling fans at the Ineos power plant in Runcorn and process steam from the Stanlow Oil Refinery, so this is unlikely to raise any concerns by the local community or adjacent industrial facilities.

TRANSPORTATION AND LOGISTICS

As the quantities of materials needed to feed the pilot are relatively small, materials will be palletised and brought onto site using available local delivery services.

For the 50kt plant, the magnesium silicate materials will be transported to site from Norway by ship. The site will have access to the canal berth on the Manchester Ship Canal, with some materials storage space nearby, so there will be a requirement for some material movement on site. The majority of transport from the quayside to the plant will be via conveyors. The plant will be producing 190kt of magnesium carbonate per annum which will need to be transferred to the construction material manufacturers facility. This equates to approx. 18 x 40 tonne tipper trucks movements per day, (assuming a 5-day week). As the region is well served by rail infrastructure with a number of rail heads available on the Stanlow oil refinery site and at the nearby CF Fertilisers plant, there is the opportunity for this material to be transported away from the site by rail or by barge using the Manchester Ship Canal.

Other materials outputs include silica and valuable non-ferrous metals. The metals are relatively small quantities and would result in a small number of road truck movements to metal smelting customers. The silica production however will be in significant quantities, circa 52kt per annum, approx. 5 truck movements per day off site and some internal materials transport within the plant.

The DAC plant will therefore result in the equivalent of 23 additional truck movements per day in the region. The Ince area is very well served by road and rail infrastructure with close proximity to both the M53 with links to the Port of Liverpool and North Wales and the M56 providing a link to Manchester industrial region and links to the M6 to serve both the North of England and beyond and the Midlands. The local roads were designed to service industrial plants already in the region and are underutilised at present as most bulk materials produced are transported by sea and rail. It is not expected that the additional road traffic caused by the DAC plant will have a detrimental impact on local traffic.

2 A DETAILED ENGINEERING DESIGN FOR A PILOT PROJECT

PILOT DESIGN SCOPE

The design of the pilot plant has been undertaken by Otto-Simon Ltd. Their study has shown a design that could be built with relatively standard items of equipment although it has also shown that optimising the design remains a key task for subsequent stages of work. This is particularly true of the energy balance for the pilot plant and the current scheme does not attempt energy integration as this would introduce a high level of risk to the design and operation of the plant. The pilot plant would be the mechanism for investigating and developing not only the core carbon dioxide capture technology but also the optimising of the whole process.

A programme of work has been developed for the next phases of design through to handover for pilot plant operations along with a proposed project structure that would become the basis for a detailed project execution plan. A capital cost estimate has also been prepared, with an assessment of an appropriate contingency level to apply.

The proposed site for the pilot plant has been reviewed and is seen to be a suitable choice.

The Pilot Plant will focus on demonstrating and proving the major key components and unit operations of the process consisting of the following:

- The Digester.
- The Direct Air Contactor/Stage 2 scrubber.

The Pilot Plant will be used to prove and optimise the ability to capture carbon dioxide from the air, conversion step to capture the CO_2 from air and Magnesium Hydroxide to use to sequester the CO_2 as Magnesium Carbonate for scale up to a larger scale plant. The pilot trials and supporting research would focus on the development of techniques for:

- The separation of the CCC’s digestant flux from silica.
- To produce a saleable silica product.
- The demonstration of the recycle of the CCC’s digestant within the Process.
- The recycle of water within the Process.

- The reuse of energy within the process, i.e. energy integration.

The by-products from the process will be used to develop and test markets for their use with commercial partners including PQ Corporation for the silica and Holcim for construction materials.

2.1 PILOT DESIGN.

Pilot Plant Flow Sheet was developed by Otto-Simon Ltd. From the Flow Sheet three items stand out as requiring particular attention during the design phases. Once the fundamental process duties were established, in conjunction with CCC and partners, OSL assessed these and discussed each with potential equipment suppliers to establish plausible solutions and in some cases alternatives.

Although much further work will be required in the future design stages the fundamental feasibility of these items for the duties defined by the Flow Sheet have been established. An early task for the detailed design phase in the Phase 2 project will be to re-visit these designs, taking into account any new information uncovered by any further chemical testing.

DIGESTER

The function of the digester is to create materials to be used in the CO_2 Capture Scrubber and there are various technologies available that could achieve this.

The following basic approaches have been identified:

- Digester
- Heated centreless screw
- Multi-hearth furnace
- Batch kiln (as typically used in the ceramics industry).

From these the current selection is for a Digester but a more comprehensive review of the options, once more information has been obtained from the supply chain, will be undertaken in the early stages of detailed design in Phase 2. Results from further material testing should also be brought to bear in this decision if and when it becomes available.

DIRECT AIR CONTACTOR

This scrubber unit is the heart of the carbon dioxide capture process. A specialist designer and supplier of such systems (Parson Ltd) is proposed.

The scrubber operates at ambient temperature which simplifies material selection and scrubber design. Polypropylene (PP) is the likely choice. Appendix A shows an air contactor unit similar to the one designed for the Phase 2 project.

This is a large unit due to the required high volumes of air that must pass through to allow for sufficient CO_2 capture (16,811 m^3/hr). A fan will deliver this air volume to the scrubber. The scrubber also has an internal heating coil to allow for additional heat injection to the chemical reaction should the trialling during the pilot plant trials show this to be required.

STAGE 2 MAGNESIUM OXIDE CONTACTOR

With the smaller flow rate this is a much smaller scrubber and would be constructed in PP.

ALL OTHER ITEMS

Otherwise, the equipment to be installed is of relatively standard design, pumps, tanks, conveyors, agitators, etc. and is readily available.

2.2 OSL DRAWINGS AND DOCUMENTS

A full suite of drawings has been produced; these include:

- Process Flow Diagram
- P&IDs
    - Materials Feed
    - Digester
    - Solids Separation
    - Direct Air Contactor
    - Stage 2 Scrubber
- Programme
- Cost estimate

2.3 MASS BALANCE.

The key model to inform the pilot design is the mass and energy balances. This tracks the flow of materials through the process and the energy either released or consumed at each process step. This defines the size of each component within the pilot and subsequently the energy requirement and cost.

2.4 COST SAVINGS COMPARED WITH EXCLUSIVE DEVELOPMENT CONTRACTS.

Cambridge Carbon Capture Ltd.’s main goal in this project is to explore the possible commercial application of CO_2LOC technology to Direct Air Capture and accelerate development of their core technology. As such, all funds due to CCC over this project will be 100% focused on these goals and are therefore in direct alignment with the scope of this competition. CCC will be making no profits from this project.

Project partners/sub-contracts to this project include University of Chester, providing the pilot site and access to research facilities, Otto-Simon Ltd, providing engineering design and pilot construction and commissioning and Parsons, providing bespoke scrubber systems. These suppliers have been selected for this project as CCC have established relationships with these organisations and mutual interest in exploration of new opportunities in the developing carbon capture market. As such these suppliers already have a good knowledge of CO_2LOC technology and are motivated to deliver a successful project rather than viewing this as a profit-making project. Cost estimates are therefore competitive and have been prepared on standard commercial terms in line with industrial best practices and represent good value.

3 PROJECT PLAN

3.1 THE SELECTED PILOT SITE.

The selected site for the pilot is University of Chester's Thornton Science Park campus at Pool Lane, Ince. Chester CH2 4NU. The site used to be the Shell Fuel Development facility and much of the infrastructure and permissions at the site are still in place making it the ideal location for a pilot of a new chemical process. (See Appendix B)

The selected site is adjacent to Chester University facilities giving access to labs, expertise and scientific analytical equipment needed to assess the performance of the pilot. The plan is to have the University of Chester as a sub-contract to the project to give us access to their facilities and expertise. This will enable students to access the technology and could support research projects looking at various aspects of the technology to further develop the technology.

The site is also adjacent to Protos, the proposed site for the 50kt plant and the HyNET project, (see Appendix B). Proximity to the proposed deployment site and industrial partners such as Peel Environmental Ltd (owners of the Protos site) would help develop the commercial relationships and confidence in the technology needed to successfully develop the subsequent plans for the 50kt DAC facility.

The risk in using this site is that there is currently a change of management company managing the site. This is making it difficult to establish a firm price for the hosting of the pilot plant as this situation may lead to delays in securing leases for the site. However, the University of Chester is very supportive of this project and new innovative technologies, especially in technologies addressing the climate emergency. This support is echoed by the new site management company who will be keen to exploit the publicity and kudos that this project will generate for the site.

3.2 INTERACTION WITH CURRENT OR PROPOSED USE OF THE SITE OR ACTIVITIES UNDERTAKEN AT IT.

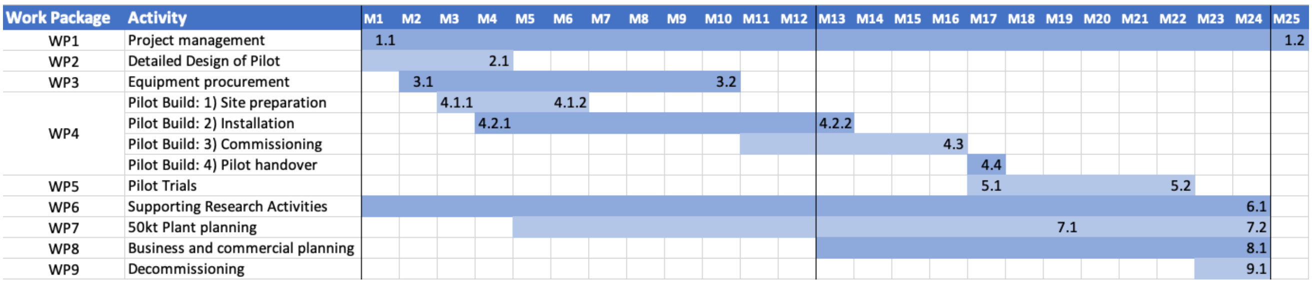
The proposed site is currently owned by the University of Chester and aligns very well with their research interests. The specific area where the pilot will be located at the site has been selected as it is a good distance from the buildings housing labs and offices so any fan noise and/or steam emissions generated by the facility will not impact the working environment of other users of the site. The site is located in the now disused area of the site surrounded by disused industrial facilities, storage tanks and open fields and has its own road access, so would not have any interactions with current or future users of the site or impact any surrounding commercial activities.

3.3 PILOT PROJECT GANTT CHART.

The pilot project is split into the following Work Packages:

- WP1: Project Management
- WP2: Detailed Design of Pilot
- WP3: Equipment Procurement
- WP4: Pilot Build
    - Site preparation
    - Installation
    - Commissioning
    - Pilot Handover
- WP5: Pilot Trials
- WP6: Supporting research activities
- WP7: 50kt Plant design and planning
- WP8: Business and commercial planning
- WP9: Decommissioning

The project Gantt Chart is presented in below.



The project will run over 2 years and 1 month (25 months) from the start of the project.

The following is a table of key milestones.

WP.MS	Milestone	Deliverable	Date
1.1	Project Start	Kick-off meeting report	M1
1.2	Project Completed	Close Out meeting report	M25
2.1	Pilot design completed	Full design documentation available	M4
3.1	Long lead-time equipment procured	Delivery schedule, purchase orders	M2
3.2	Equipment delivered to site	Equipment delivered to site	M10
4.1.1	Site work started	Work schedule available	M3
4.1.2	Site ready for pilot build	Site ready for pilot build	M6

4.2.1	Plant installation started	Work schedule available	M4
4.2.2	Plant Installed on site	Pilot plant on site	M13
4.3	Pilot commissioned	Operational pilot plant	M16
4.4	Pilot handed over to demo team	Demo team on site	M17
5.1	Pilot trials begin	Trial plan available	M17
5.2	Pilot trial completed	Pilot performance report	M22
6.1	Research summary reports available	Research summary report	M22
7.1	Outline FEED study for a 50kt plant	Design Report/FEED	M19
7.2	Costing and construction plan for 50kt plant	Costing and construction plan	M25
8.1	Business plan for 50kt plant completed	Business Plan	M25
9.1	Decommissioning	Pilot site cleared	M24

BUDGET

The total budget is £2,999,876.00. This budget is split across 9 Work Packages as described below:

Work Package	Activity	Budgets Estimate
WP1	Project management	£275,465
WP2	Detailed Design of Pilot	£125,000
WP3	Equipment procurement	£925,000
WP4	Pilot Build: Site preparation	£780,000
	Pilot Build: Installation	
	Pilot Build: Commissioning	
	Pilot Build: Pilot handover	
WP5	Pilot Trials	£254,604
WP6	Supporting Research Activities	£473,810
WP7	50kt Plant planning	£77,331
WP8	Business and commercial planning	£38,666
WP9	Decommissioning	£50,000
TOTAL		**£2,999,876**

A more detailed breakdown of project cost and milestones can be found in Appendix C: The Project Delivery Plan.

4 PROGRAMME AND BUSINESS PLAN

Unlike many other DAC concepts, CO_2LOC technology offers the opportunity to make revenues from various by-products. This creates opportunities for multiple businesses to work together for mutual benefit. It also produces a complex web of businesses with varying demand profiles and cost bases. Early discussions were complicated by decisions on who gets the benefit of the carbon credit. In some suggested business models SizewellC would provide heat and off-peak electricity for free and take the carbon credit to offset carbon intensity of the nuclear power it produces. Other models, the credits are claimed by the construction materials manufacturers and commercial rates are charged by SizewellC for the heat and power. One further model is being explored, whereby the plant is owned by investors, heat and power purchased from SizewellC and the carbon credits sold to Stripe, Microsoft and others as a means of offsetting their hard to abate emissions.

Over the course of the Phase 1 project, it became apparent that the concept developed did not benefit from the available waste heat at SizewellC and being located near a nuclear power station created a great deal of complexity to any future project and nuclear power stations. Also, nuclear power stations are generally located away from areas of high population and other industries so therefore markets for by-products produced. This added further cost and increased the carbon intensity of the concept. As a result, the project team found an alternative location at the Protos site and SizewellC will no longer be part of the consortium going forward. Local supply chain partners have been located on or near the Protos site to support the business opportunity presented by the 50kt plant at that location. Partners identified include:

- Site - Peel Group
- Carbon credits – Goldman Sachs, Stripe and Microsoft as customers and Blockchain and Climate Initiative carbon trading platform partners
- Serpentine Supply - Metamorphic Ltd (Norway)
- Metals – Critical Minerals Association
- Silica – PQ Corporation
- Magnesium Carbonate – Aggregate Industries (Holcim)

See figure 1 below.

Figure 1: Potential future consortium members located on or near the proposed Protos site

4.1 CAMBRIDGE CARBON CAPTURE'S DAC BUSINESS MODEL

Cambridge Carbon Capture Ltd's business model to exploit the DAC opportunity is to generate revenues from the sale of Silica, Metals, Magnesium Hydroxides and Magnesium Carbonates into local markets and sell carbon credits to Stripe, Microsoft and Goldman Sachs.

The healthy revenues would attract the investment needed to support the CAPEX for the project offering commercially viable Internal Rate of Returns (IRR).

As part of this project deliverables, CCC have carried out a Techno-Economic and Life Cycle Analysis for a 50kt facility located at the Protos site.

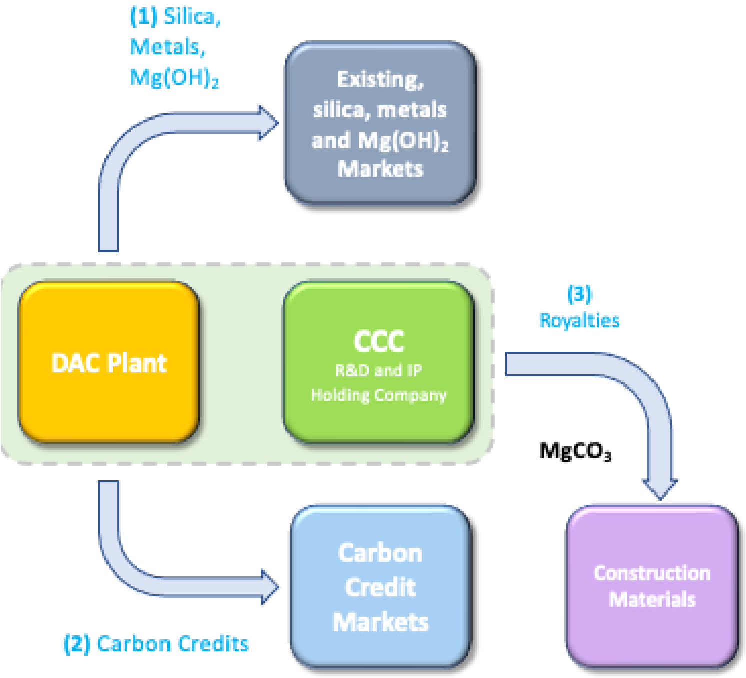


Figure 2: Schematic of CCC's business model

The table below is a summary of the TEA outputs taken from that report.

CAPEX	£138,924,702	
OPEX	£21,974,365	
Total Annual Materials Cost	£19,566,455	
Total Revenue	£55,843,020	
COST TO CAPTURE 1 TONNE CO2	**£286**	profit
Not amortorised		

This TEA suggests that NET revenues from capturing a tonne of CO_2 from the air using CO2LOC technology is £286/tCO_{2eq}. The Life-Cycle Analysis LCA is presented in section 1.2 of this report.

As the CAPEX for the plant will be a total of £139m this gives a healthy Internal Rate of Return (IRR) for the project. Table 2 shows the result of IRR analysis of the project at various future carbon prices and amortisation periods, a discount rate of 10% was assumed.

	CAPEX	Annual Revenue
Revenue, Carbon price @ £30	(£139,000,000)	£14,300,000.00
IRR (10 years)	1%	
Revenue, Carbon price @ £30	(£139,000,000)	£14,300,000.00
IRR (20 years)	8%	
Revenue, Carbon price @ £40	(£139,000,000)	£14,800,000.00
IRR (20 years)	9%	
Revenue, Carbon price @ £50	(£139,000,000)	£15,300,000.00
IRR (20 years)	9%	
Revenue, Carbon price @ £60	(£139,000,000)	£15,800,000.00
IRR (20 years)	10%	
Revenue, Carbon price @ £100	(£139,000,000)	£17,800,000.00
IRR (20 years)	11%	

Table 2: IRR Analysis

For a plant of this size, a 20-year investment window would be considered reasonable and carbon prices are likely to track up past £50 per tonne. This suggests an IRR of 9% which compares favourably with expected IRRs of below 4% on a typical offshore wind project. (Grant Thornton - https://www.grantthornton.co.uk/insights/valuing-renewable-energy-assets-does-capm-work/)

4.2 NEXT STAGE IN THE DEVELOPMENT.

The pilot project will enable CCC and Otto-Simon determine key process reaction speeds and dynamics and better understand the opportunities for system integration and areas where heat can be recovered and reused within the process. This will inform the more detailed design of the 50kt Plant and be used to refine the process modelling to optimise the design. This data driven model will provide a more accurate picture of CAPEX and OPEX of the 50kt plant and this will be used to prepare a detailed project plan to develop and operate the 50kt plant.

In parallel, the pilot project will enable CCC and potential customers for the by-products to assess the quality and properties of the by-products of the process and develop plans and commercial relationships to exploit the outputs of the 50kt plant. This will lead to the development of a business plan to support the securing of the £140m needed to build the 50kt plant from a combination of investors, partner companies, grants and loans/bonds.

The CCC team are also entering the X-Prize Carbon Removal Prize. The results of this Phase 1 project being used to support the application in the first round. Success in the first round will result in $1m USD investment in CCC which will be used to enhance R&D activities which in turn will benefit the Phase 2 project. Success of the Phase 2 project will then put CCC in the running for the subsequent $50m USD prize which, if won, will be used to part fund the planned 50kt DAC Plant.

CCC are also exploring the potential of advance sales of future carbon credits to Microsoft, Goldman Sachs and Stripe and the use these to secure funding. CCC are fellows of the Blockchain and Climate Initiative (https://blockchainclimate.org/) and are exploring the concept of tokenising the captured CO_2 from the future plant

The pilot plant is planned to be located at Thornton Science Park which is in close proximity to the Protos site, owned by The Peel Group. The Peel Group are keen to follow the progress of the Pilot with the possibility of their future involvement and the siting of the 50kt DAC Plant on the Protos site. The Peel Group own a significant proportion of the land on which the HyNET project will be based and are a key contributor to that project. Through our relationship with Peel Group CCC hope to be integrated into the HyNET project as our technology nears commercialisation.

4.3 HOW THIS DEVELOPMENT WOULD BE INFORMED BY INFORMATION GAINED DURING PILOT PHASE.

The chemical processes involved in direct air capture using CO2LOC have been demonstrated in the laboratory and have been shown to be very effective at a small scale. However, many issues still need to be addressed before the technology can be scaled to a full-scale plant. The pilot will allow CCC and partners to explore these issues and settle on a design for a full-scale plant. The key unknowns the team will be exploring with the pilot are:

- Scalability of the capture of CO_2 from air using CO2LOC technology.
- Scalability of the production of Magnesium Hydroxide from Magnesium Silicate minerals.
- Re-generation of CCC's digestant at scale.

Secondary research questions addressed by research activities running in parallel with the pilot operations will include:

- Recovery of heat and water.
- Separation of silica from CCC's digestant.
- Improvements in the recovery of CCC's digestant.
- Post processing of the produced silica to add value.
- Recovery and upgrading of trace metals.

Materials produced by the pilot will also enable CCC to work with partners in the construction sector to develop and test construction materials to create a market for the materials produced by a future 50kt plant. Similarly, with the silica and metals market to maximise revenues from both the silica and metals produced.

Results from this work will enable the detailed design of the 50kt Plant and validate the economics of the process. It will also help develop the commercial relationships necessary to enable a 50kt Plant project to be developed and provide the evidence needed to support efforts to raise funding required to deliver the project.

4.4 DEPENDENCIES.

The plan for the Pilot Plant is to address all the major technical knowledge gaps and demonstrate the technology to TRL 6. The technology is currently at TRL 4 so assumptions have been made as to how of the process will scale to a commercially relevant size based on known analogous large scale industrial processes.

The commercial viability of the technology at a 50kt scale is highly dependent on the future prices of silica, metals and magnesium carbonate and the local market demand for these materials. In our analysis in this Phase 1 project, 5-year average prices have been used for the various by-products and recent average UK energy prices assumed. However, there has been an upward trend in commodity prices and as our by-products will be effectively NET Zero emissions, a premium may well be possible offering higher revenues than anticipated in our financial model.

To a lesser extent the business model supporting the 50kt Plant is also dependent on the prevailing carbon price. This is also likely to increase in price over the coming years as more companies are starting to engage with the carbon market, generating more demand and greater liquidity in the market.

5 APPENDIX A

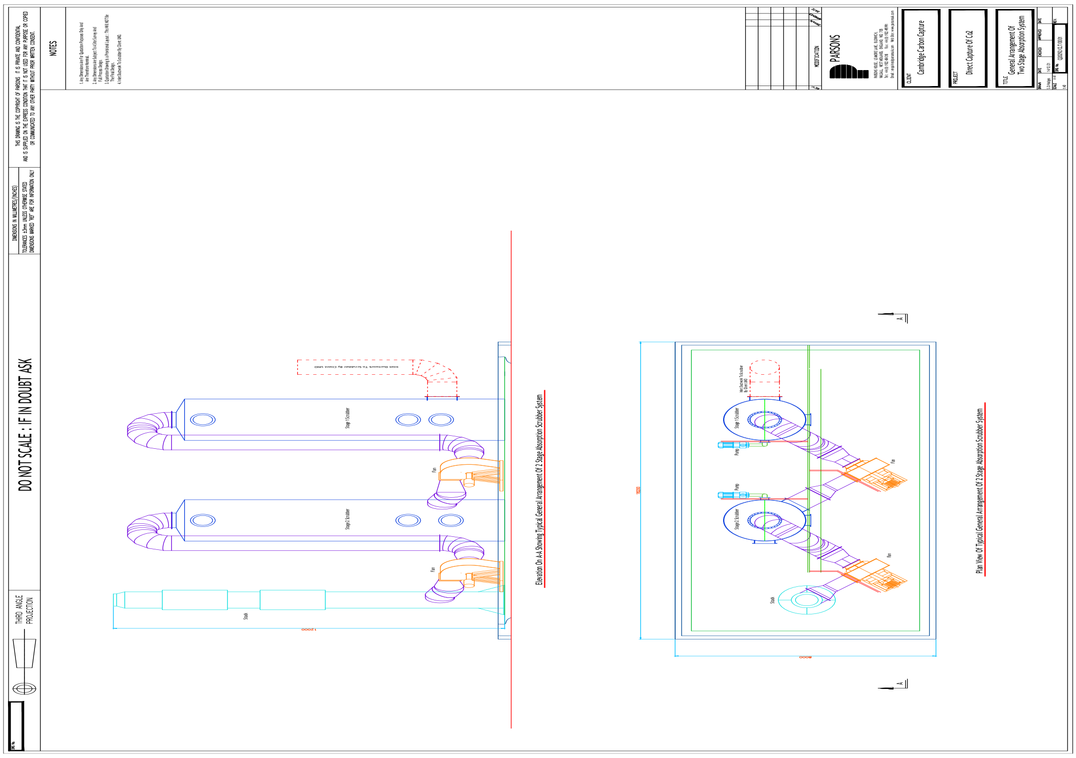


Figure 3: Scrubber GA

Figure 4: Air contactor supplied by Parsons UK

6 APPENDIX B: PILOT SITE SELECTION

Figure 5: Selected site for the pilot at Chester University's Thornton Science Park Campus

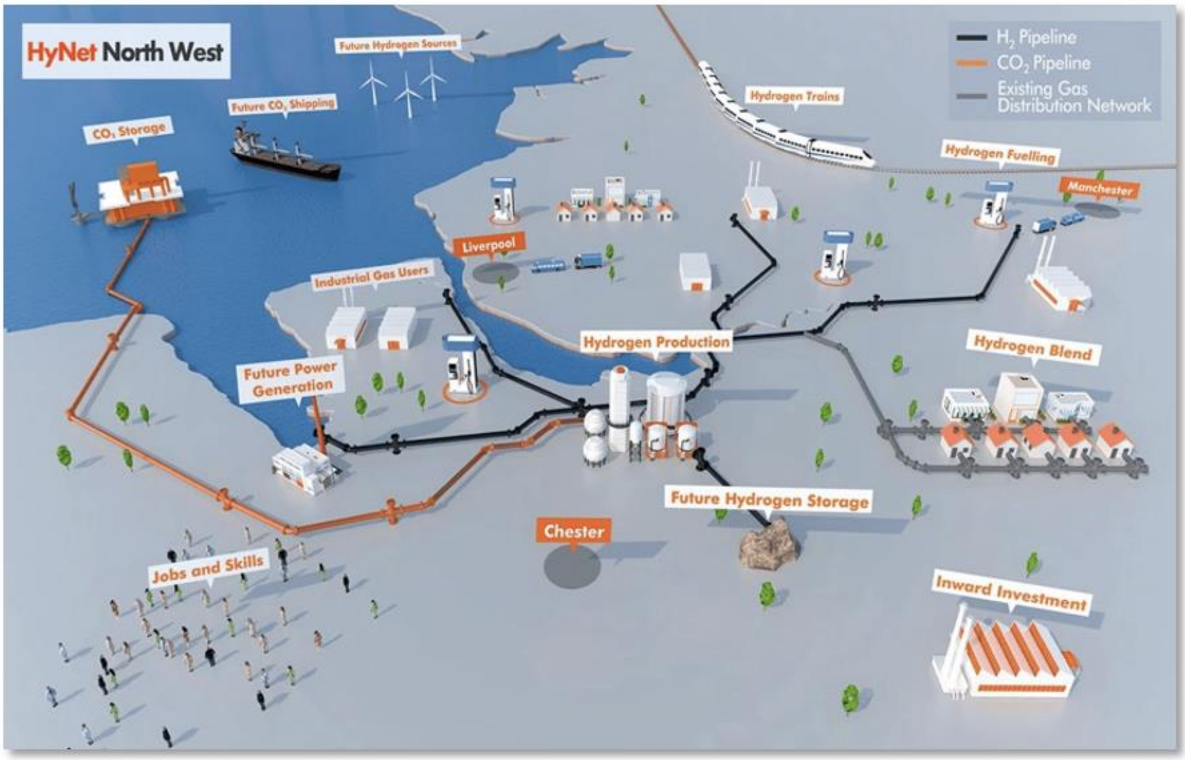


Figure 6: Pilot site is in the centre of the HyNET project

7 APPENDIX C: PROJECT PLAN & MILESTONE REGISTER

PROJECT TITLE: CO_2LOC DAC Phase 2

PROJECT ID: CAM 202029

Date: 24th December 2021 Vs: V1.0

Phase 2 Project Plan

The project has been split into 9 discreet work packages:

1. Project management
2. Detailed design of the pilot
3. Equipment procurement
4. Pilot build
    4.1. Site preparation
    4.2. Installation
    4.3. Commissioning
    4.4. Pilot handover
5. Pilot Trials
6. Supporting research activities
7. 50kt Plant planning
8. Business and commercial planning
9. Decommissioning

Work Package Description and Milestone Plan

Work Package 1: Project Management
Start date : M1 End date : M25 Work Package Leader: Cambridge Carbon Capture Ltd (CCC) Contributing Partners: Otto-Simon Ltd (OSL)
Work Package Objectives: • To ensure the smooth running of the project, manage time against project plans ensuring timely delivery of milestones and planned deliverables.
Description of work • Project management, chairing of project review meetings and quarterly meetings with assigned monitoring officer. • Maintenance of risk register and coordinator of risk mitigation strategy planning and execution.

Milestones:

MS1.1: Project Started
MS1.2: Project completed

Equipment and Facilities

- N/A

Summary of Deliverables : Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External / Internal (E/I)	Responsibility	Due Date	Comments / Notes
D1.1	Project start-up meeting presentation	E	CCC	M1	
D1.2	Project summary report	E	CCC	M25	

Dependencies

Items which must be available for this Work Package	Responsibility
Signed contract with BEIS	CCC
Work Packages dependent on this Work Package	**Responsibility**
All WPs	CCC

Work Package 2: Detailed Design of Pilot

Start date : M1
End date : M10
Work Package Leader: OSL
Contributing Partners: CCC

Work Package Objectives:

- Detailed design and construction planning of the pilot based on detailed site information and available budgets

Description of work

Detailed design of the plant and review of construction planning. Negotiation of contracts with key delivery partner, service providers and subcontractors.

Milestones:

MS2.1 – Detailed design completed.

Equipment and Facilities • N/A					
Summary of Deliverables: Detail the planned external (E) and internal (I) deliverables					
Del. Ref	Title	External /Internal (E/I)	Responsibility	Due Date	Comments / Notes
D2.1	Detailed design specification and installation plan available	I	OSL	M4	
Dependencies					

Items which must be available for this Work Package	Responsibility
MS1.1	CCC
Work Packages dependent on this Work Package	Responsibility
WP3-5	OSL

Work Package 3: Equipment procurement
Start date : M2 End date : M10 Work Package Leader: CCC Contributing Partners: OSL
Work Package Objectives: • Purchase of third party manufactured equipment • Delivery of equipment to site
Description of work **Task 1:** Negotiation of price of equipment with OEMs **Task 2:** Place purchase orders **Task 3:** Coordination of deliveries to site **Milestones:** **MS3.1** – Purchase orders placed for long lead-time equipment **MS3.2** – All equipment delivered to site
Equipment and Facilities • N/A
Summary of Deliverables: Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External /Internal (E/I)	Responsibility	Due Date	Comments / Notes
D3.1	Purchase Orders available	I	CCC	M2	

Dependencies	
Items which must be available for this Work Package	Responsibility
MS1.1	CCC
Work Packages dependent on this Work Package	Responsibility
WP4-5	CCC

Work Package 4: Pilot Build
Start date : M3 End date : M17 Work Package Leader: OSL Contributing Partners: CCC
Work Package Objectives: • Build, test & commission the pilot plant
Description of work **Task 1:** Site preparation **Task 2:** Installation of equipment **Task 3:** Commissioning of the pilot **Task 4:** Pilot handover to the trials team **Milestones:** **MS4.1.1** – Site preparation work started **MS4.1.2** – Site ready for pilot install **MS4.2.1** – Installation started **MS4.2.2** – Plant installed **MS4.3** – Plant commissioned **MS4.4** – Pilot handed over to pilot trials team
Equipment and Facilities • Demonstration unit, CCC lab facilities and scientific services.
Summary of Deliverables: Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External /Internal (E/I)	Responsibility	Due Date	Comments / Notes
D4.1.1	Site cleared	I	OSL	M3	
D4.1.2	Site ready for equipment installation	I	OSL	M6	
D4.2.1	Installation of equipment started	I	OSL	M4	
D4.2.2	All equipment installed	I	OSL	M13	

Dependencies	
Items which must be available for this Work Package	Responsibility
WP2&3	CCC & OSL
Work Packages dependent on this Work Package	Responsibility
WP5	CCC

Work Package 5: Pilot Trials

Start date : M17 End date : M22 Work Package Leader: CCC Contributing Partners: OSL
Work Package Objectives: • Analysis of pilot outputs to test for purity and possible toxicity • Determine the effectiveness of CO2 removal from air • Optimisation of process parameters • Carry out a full mass balance on the pilot inputs and outputs
Description of work **Task 1:** Conduct initial trial runs **Task 2:** Optimise process conditions to maximize efficiency **Task 3:** Analysis of by-products **Task 4:** Carry out full mass balance **Task 5:** Produce a report **Milestones:** **MS5.1** – Beginning of trials **MS5.1** – Pilot trials end
Equipment and Facilities • Pilot Plant, CCC/University of Chester lab facilities and scientific services.
Summary of Deliverables : Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External /Internal (E/I)	Responsibility	Due Date	Comments / Notes
D5.1	Trial experimental plan	I	CCC	M17	
D5.2	Report on results of mass balance an trial data	I	CCC	M22	

Dependencies

Items which must be available for this Work Package	Responsibility
WP2-4	CCC
Work Packages dependent on this Work Package	Responsibility
WP7-9	CCC

Work Package 6: Support Research Activities
Start date : M1 End date : M22 Work Package Leader: CCC Contributing Partners: UoC/OSL
Work Package Objectives: • Confirmation of key reaction rates and temperatures in support of detailed design phase • By-product analysis and optimisation of process parameters during pilot trials in support of WP5

- Trouble shooting and general scientific support
- Process plant design improvements and innovation
- Generation of new IP
- Summarise the results and findings of the project
- Secure any IP created during the project
- Prepare dissemination materials
- Plan dissemination activities

Description of work

Task 1: Confirmation of key process parameters and other reactor design input in detailed design phase (WP2)
Task 2: Scientific support for the trial
Task 3: Process development and innovation
Task 4: Capture of new IP
Task 5: Preparation of materials and planning of dissemination of project outcomes

Milestones:

MS6.1 – Conclusion of DAC pilot research activity and research summary report and dissemination materials and plan available

Equipment and Facilities

- CCC/University of Chester lab facilities and scientific services

Summary of Deliverables: Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External /Internal (E/I)	Responsibility	Due Date	Comments / Notes
D6.1	Research summary report	I	CCC	M22	

Dependencies

Items which must be available for this Work Package	Responsibility
WP2,3,4,5	OSL/CCC
Work Packages dependent on this Work Package	Responsibility
WP7 & 8	CCC

Work Package 7: 50kt Plant planning

Start date : M5
End date : M24
Work Package Leader: CCC
Contributing Partners: OSL

Work Package Objectives:

- More detailed design of a future 50kt CO2LOC DAC plant based on learning from the pilot plant
- Construction plan and costing it support business planning and consortium building (WP8)

Description of work

Task 1: Review of previous Phase 1 FEED study
Task 2: Detailed design of key reactor components based on pilot data
Task 3: Identification and exploitation of heat recycling and other efficiency improvements between the various process steps
Task 4: Detailed FEED study and costing
Task 5: Prepare costing and construction plan

Milestones:

MS7.1 – 50kt Plant FEED study report available
MS7.2 – 50kt Plant costing and construction plan available

Equipment and Facilities

- N/A

Summary of Deliverables: Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External /Internal (E/I)	Responsibility	Due Date	Comments / Notes
D7.1	50kt Plant FEED study report	I	OSL	M19	
D7.2	50kt Plant costing and construction plan report	I	CCC	M25	

Dependencies

Items which must be available for this Work Package	Responsibility
WP2-6	OSL/CCC
Work Packages dependent on this Work Package	**Responsibility**
WP8	CCC

Work Package 8: Business and Commercial Planning

Start date : M13
End date : M25
Work Package Leader: CCC
Contributing Partners: OSL/UoC

Work Package Objectives:

- Development of a business plan to attract investment and partners to deliver the 50kt DAC plant
- Bring together interested parties to form a consortium to deliver the 50kt DAC project
- Secure seed investment to support the business team focused on the development of the 50kt DAC plant and delivery of the business plan
- Management of PR about the pilot project and future plans

Description of work

Task 1: Preparation of DAC business plan
Task 2: Identify and recruit key stakeholders
Task 3: Local market analysis for CO_2LOC by-products
Task 4: Agree scope for the 50kt DAC project with key stakeholders, secure commitment to the consortia
Task 5: Secure seed investment to take the 50kt DAC plant project forward
Task 6: Manage PR activities around the pilot project

Milestones: **MS8.1** – Business and commercial plan available
Equipment and Facilities • N/A
Summary of Deliverables: Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External /Internal (E/I)	Responsibility	Due Date	Comments / Notes
D8.1	Business and commercial plan	E	CCC	M24	

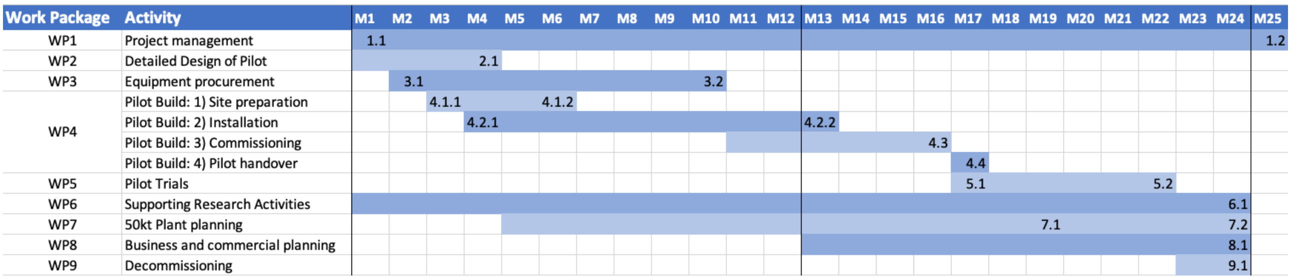
Dependencies	
Items which must be available for this Work Package	Responsibility
WP1-7	CCC/OSL
Work Packages dependent on this Work Package	Responsibility
N/A	

Work Package 9: Pilot Plant Decommissioning
Start date : M23 End date : M24 Work Package Leader: OSL Contributing Partners: CCC
Work Package Objectives: • Decommissioning the pilot plant • Return of site to landlord
Description of work **Task 1:** Removal of plant from site and make good **Milestones:** **MS9** – Pilot site cleared and returned to landlord
Equipment and Facilities • Pilot site
Summary of Deliverables: Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External /Internal (E/I)	Responsibility	Due Date	Comments / Notes
D9.1	Site decommissioned	I	OSL	M24	

Dependencies	
Items which must be available for this Work Package	Responsibility
WP1-5	CCC/OSL
Work Packages dependent on this Work Package	Responsibility
N/A	

Project Gantt Chart



Milestones

WP.MS	Milestone	Deliverable	Date
1.1	Project Start	Kick-off meeting report	M1
1.2	Project Completed	Close Out meeting report	M25
2.1	Pilot design completed	Full design documentation available	M4
3.1	Long lead-time equipment procured	Delivery schedule, purchase orders	M2
3.2	Equipment delivered to site	Equipment delivered to site	M10
4.1.1	Site work started	Work schedule available	M3
4.1.2	Site ready for pilot build	Site ready for pilot build	M6
4.2.1	Plant installation started	Work schedule available	M4
4.2.2	Plant Installed on site	Pilot plant on site	M13
4.3	Pilot commissioned	Operational pilot plant	M16
4.4	Pilot handed over to demo team	Demo team on site	M17
5.1	Pilot trials begin	Trial plan available	M17
5.2	Pilot trial completed	Pilot performance report	M22
6.1	Research summary reports available	Research summary report	M22
7.1	Outline FEED study for a 50kt plant	Design Report/FEED	M19

7.2	Costing and construction plan for 50kt plant	Costing and construction plan	M25
8.1	Business plan for 50kt plant completed	Business Plan	M25
9.1	Decommissioning	Pilot site cleared	M24

Project Management

Regular technical review meetings with the CCC team and quarterly meetings with our Monitoring Officer during the 25-month project will provide the backbone for project progress monitoring and reporting. Measurable, significant and timed key milestones have been included in our plan for each work package task. This structure is also intended to help manage technical risk, as it provides frequent opportunities to identify and correct any shortcomings in pilot equipment or methodology and any timeline slippage.

As a further risk management strategy, the process of stakeholder consultation and experimental review through the project provides the opportunity and time to make changes to the detail of experiments & data collection if feedback from stakeholders warrants it.

Despite CCC having management of the overall project, management of the pilot design and construction will be under the direct control of Otto-Simon Ltd, this will leverage their experience and expertise, ensuring successful delivery of the pilot plant.