Mission Zero Technologies

Phase 1 Final Report

REDACTED REPORT - FAO Public Viewing

Date of issue: January 2022

Project Drive D4.8

BEIS Greenhouse Gas Removal Competition

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Abbreviations

APCr	Air Pollution Control residues
BEIS	Department for Business, Energy & Industrial Strategy
BoD	Basis of Design
CCUS	Carbon Capture, Utilisation and Storage
COMAH	Control of Major Accident Hazards
COSHH	Control of Substances Hazardous to Health
CS	Capture Solution
DAC	Direct Air Capture
DRIVE	Direct Removal through Innovative Valorisation of Emissions
EfW	Energy from Waste
EQU	Equinor New Energy
FEED	Front-End Engineering Design
FEL	Front-End Loading
GGR	Greenhouse Gas Removal
HAZOP	Hazard and Operability Analysis
HSE	Health and Safety Executive
IP	Intellectual Property
LCA	Life Cycle Analysis
MAQ	Material Assessment Questionnaire
MLS	Manufactured Limestone
MZT	Mission Zero Technologies
OCO	O.C.O Technology
OPT	Optimus Ltd.
PFD	Process Flow Diagram
PPE	Personal Protective Equipment
SDS	Safety Data Sheet
TDS	Technical Data Sheet
TEM	Techno-Economic Model
WEL	Workplace Exposure Limits
ZCH	Zero Carbon Humber

Introduction

This report is produced by the Project DRIVE (Direct Removal through Innovative Valorisation of Emissions) consortium as part of the Direct Air Capture (DAC) and Greenhouse Gas Removal (GGR) Programme run by BEIS. The project consortium consists of (see Annex A, pg. 17):

- Mission Zero Technologies (MZT) DAC technology development
- Optimus (OPT) DAC pilot plant engineering design
- O.C.O Technology (OCO) CCUS partner & future host for pilot plant

The core innovation involved lies in MZT's technology. MZT has developed a 2nd-generation DAC technology from first principles to tackle the 3 largest constraints of 1st-generation DAC: high energy requirements (>1500 kWh/tCO_2), high unit costs (>$300/t$CO_2$), and reliance on thermal energy either via waste heat or fossil fuel combustion.

MZT's 2-step approach producing high purity gaseous CO_2, when at scale, will eliminate the need for heat and will reduce overall energy requirements and capture costs by up to 3 times. This technology operates continuously and will leverage existing off-the-shelf equipment to scale up quickly beyond the pilot.

A high-level illustration of the DAC technology is in Figure 0.01 and involves three stages: solution-based air-contacting, an electrochemical separation method and depressurisation step within a release chamber to produce CO_2 gas at ambient temperature.

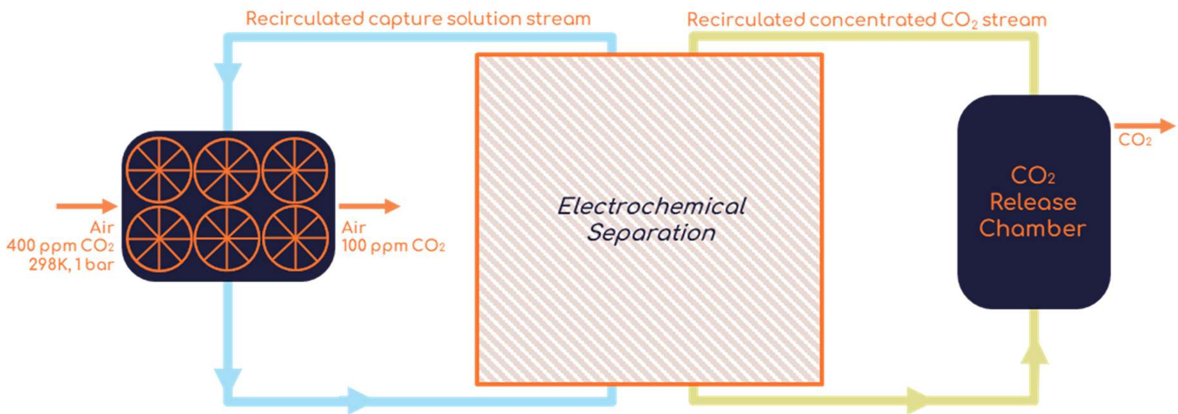

Figure 0.01 - Illustration of MZT's heat-free DAC technology [redacted]

Over 6 months, work has been underway to scale-up MZT's 2nd-generation DAC technology from TRL4 to a pilot plant. This involved experimental lab work undertaken to fully characterise and optimise CO_2 capture and recovery conditions, process flowrates, and solvent concentrations. In parallel, OPT has undertaken engineering work by applying the Front-End Loading (FEL) methodology (ref. Section 4).

Commercial development undertaken by MZT has scoped out future integration opportunities with sequestration projects at scale and built out the business case for co-locating the pilot within OCO's premises. This has maximised the mutual benefit to both parties and ensured that the CO_2 captured by the pilot will be permanently removed with very low environmental risks because of OCO's CO_2 to aggregates utilisation process.

1. Materials and Substances

The specific chemicals and substances supplied to the process are not disclosed within the public report. This section notes MZT's and OPT's engagement around supply, use, and disposal.

1.01 Supply and Usage

At the laboratory stage of testing, the chemicals have been sourced through Merck Life Science UK Ltd. For plant scale, BTC Europe has suggested a range of similar products, supplying relevant Safety Data Sheets (SDS) and Technical Data Sheets (TDS). BTC is a well-known speciality chemicals distributor.

Particular attention is drawn to MZT's choice of capture solution (CS) which recirculates within the contactor. As the contactor's fan pulls in and discharges air from one side to another, this route has the potential to aerosolise the solution; leading to a loss of chemicals.

EH40/2005 Workplace Exposure Limits (WELs) contains a list of substances that can be hazardous to the health of workers. These substances are not listed in WELs and the SDS provided from suppliers does not state exposure limits as known. The absence of substances from the WELs list does not indicate that it is safe. It is the responsibility of the employer to determine their in-house practices and standards for the control of exposure. [1]

The WELs list has been used as a guide to provide sensible limits based on similar substances, particularly for MZT's chosen CS. This WEL is initially set as 2 ppm and 4 ppm for long-term and short-term exposure limits respectively. This will be further reviewed as a part of a risk assessment required under COSHH.

1.02 Disposal

The chemicals within the system can be recycled and, on a laboratory scale, no waste is generated during operation. However, with scaled-up volumes and longer operating windows, waste management needs to be considered. The pilot phase will determine accurate volumes of waste produced but it is not expected to be significant.

MZT has considered appropriate disposal methods and engaged with Tradebe UK; a nationwide provider for the disposal of hazardous waste services. Activities such as Material Assessment Questionnaires (MAQ) and representative waste samples are required to inform Tradebe on how to best treat and dispose of any effluent. In accordance with the Environmental Agency (EA), hazardous consignment notes are provided upon collections to classify the waste before it leaves the premises. It is key that all substances will display the correct hazard label and correct PPE is used.

2. Energy Requirements

The operation of the Project DRIVE pilot plant, capturing 120 tCO_2/year, requires electricity taken from the grid with an approximate 42 kW rating requirement using a 400V 3ph 50Hz supply connected to a dedicated switchboard housed in the switch room container as part of the pilot plant.

Energy requirements listed in Table 2.01 include the core DAC elements of the MZT pilot plant. This excludes the compression and liquefaction packages which may vary across use cases due to CO_2 offtake requirements. This includes first-hand data for energy consumption of the air blower and solution pumps as provided by vendors and experimental data from MZT's electrochemical energy consumption experiments projected forward in consultation with the appropriate manufacturer.

In Table 2.01, the total estimated power requirement based on an operating time of 12 hours a day for 365 days, is 130 MWh. This equates to 2.18 MWh/tCO_2. These numbers do not provide for improvements in energy consumption which will likely result as a part of MZT's ongoing R&D program and thus represent a base case that is likely to improve. For an overview of all load calculations, see Annex B (pg. 18).

It should be noted that operational power draw will vary with external conditions. Summer and winter conditions will affect the requirements for heating and lighting. The power usage will be metered on-site and tracked to understand the power usage and operations effects on the demand.

Table 2.01 - Overview of Energy Requirements on Core DAC Items

ITEM	ABSORBED LOAD (kW)	POWER EFFICIENCY	RUN TIME TOTAL (hr/day)	kWh/day Operating
Ambient Air Blower	2.00	0.73	12.00	32.88
Pump Stream 1A	2.60	0.79	12.00	39.49
Pump Stream 1B*	2.60	0.79	12.00	
Electrochemical Separation Step	15.33	0.80	12.00	229.95
Pump Stream 2A	2.10	0.73	12.00	34.52
Pump Stream 2B*	2.10	0.73	12.00	
Trace Heating	2.00	1.00	7.00	14.00
Trace Heating Intermittent (BYPASS LOOP)	2.00	1.00	3.50	7.00
*STANDBY PUMP NOT INC. IN CALC.			TOTAL	357.84 kWh/day
				0.36 MWh/day
				130.6 MWh/year
				2.18 MWh/tCO_2

3. Environmental Impacts

A preliminary life cycle analysis (LCA) was conducted by MZT to estimate the CO_2 footprint of the designed plant at a high level. The inputs and outputs considered are illustrated in Figure 3.01. In this calculation, the overall emissions footprint of the plant was estimated to be ~0.19 tCO_2e/tCO_2, giving net negativity of 81%. This assessment assumes the use of grid electricity to operate the plant which currently has a significant emissions footprint. It is envisaged that in future pilots or commercial implementations, renewable electricity purchases will be agreed upon with utility providers to support the project and mitigate this. The energy consumption metric is split to identify the requirements of the core process and additional operations as distinguished in Section 2 and Annex B (pg. 18). As the process scales up, the energy consumption of (1) the electrochemical separation in the core process and (2) the additional operations are both likely to decrease, improving the net negativity in the future.

The assumed carbon intensities for the chemicals and equipment materials will be further updated in Phase 2 with vendor quotes; however, they currently contribute <<1% of the overall carbon footprint and so are not a major consideration. The key area of uncertainty here is the true electricity consumption that will take place during pilot operations; as discussed in Section 2 this has been conservatively estimated for the core process components as these technologies have not been previously used for carbon capture; a key objective of the pilot is to improve the confidence in these figures. MZT estimates that the emissions footprint in practice is likely to be in the range of 0.15-0.23 tCO_2e/tCO_2 giving a ±20% uncertainty.

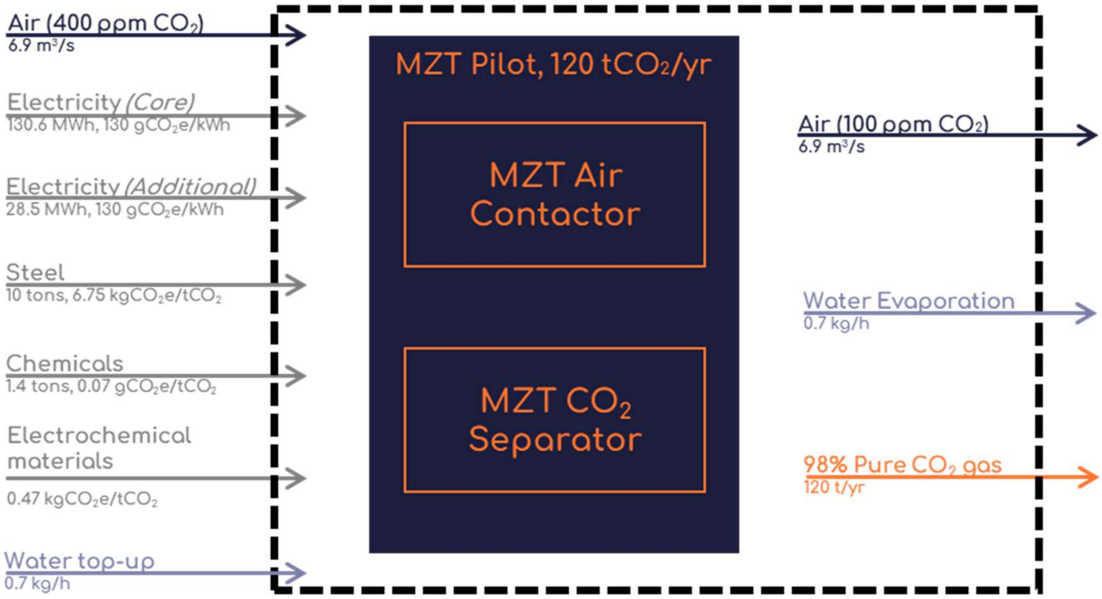

Figure 3.01 - LCA identifying embedded emissions for plant commissioning

As no waste materials or emissions are generated, at this point it is expected that monitoring of the CO_2 content of the air inlet and outlet as well as the high purity CO_2 output streams will be sufficient to verify the rate of CO_2 recovery from the air.

Refer to Section 5.03 for details on environmental and planning permits.

4. Detailed Engineering Design

The engineering to date has been performed by a multi-disciplined engineering team who have followed the OPT project and quality procedures alongside the FEL methodology. This approach, as shown in Figure 4.01, provides a governing framework that allows uncertainties to be systematically eliminated by the engineering team as a design matures. The stages FEL 1 (Concept Engineering), FEL 2 (Preliminary Engineering) and FEL 3 (Front End Engineering Design) stages have been carried out within series with a "gated" progression to ensure a robust solution is developed. This approach allows engineering development to first build on process understanding and basis definition before discipline detail is introduced and developed.

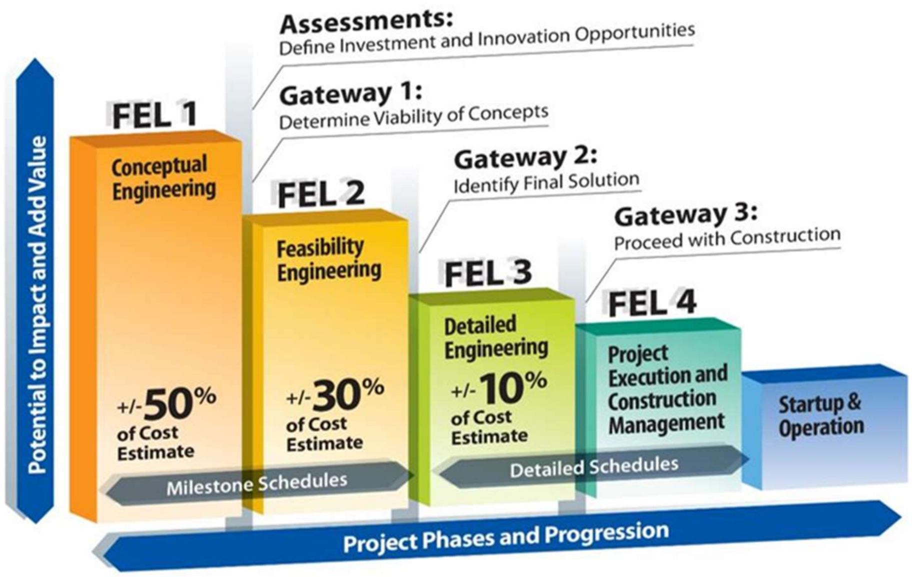

Figure 4.01 - Illustration of FEL Methodology [2]

The evolution of the design through these FEL stages can be seen pictorially in Figure 4.02; it is noted that in FEL 2 the design basis was at 365 tCO_2/year and then scaled down to the final 120 tCO_2/year size due to budgetary concerns.

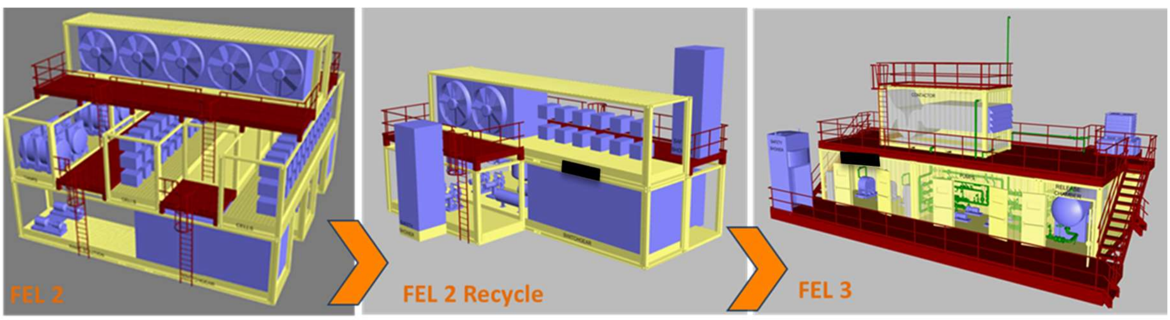

Figure 4.02 - Pilot Plant Design Evolution through Phase 1 [redacted]

4.01 Design Summary

Through Phase 1 the engineering team has developed the technology concept through stages of technical understanding and concluded in a FEED level design. FEL 3 summary and next steps can be found in Annex C (pg. 20). All engineering disciplines have been involved to best understand and challenge the Project DRIVE concept. The current pilot plant design is shown in Figure 4.01.01.

Using the parameters of the BEIS competition and the theory of the technology concept, the engineering team defined the governing parameters for the Project DRIVE pilot plant. Key parameters were:

- Target capture capacity of 120 tonnes of CO_2 per year
- Minimise energy consumption
- Design for simple operation and handling
- Manned by a minimum of two operators
- Continuous process running 12 hours a day
- Safeguard impacts of chemicals
- Steady operating temperature of 20°C
- System design life of 3 years

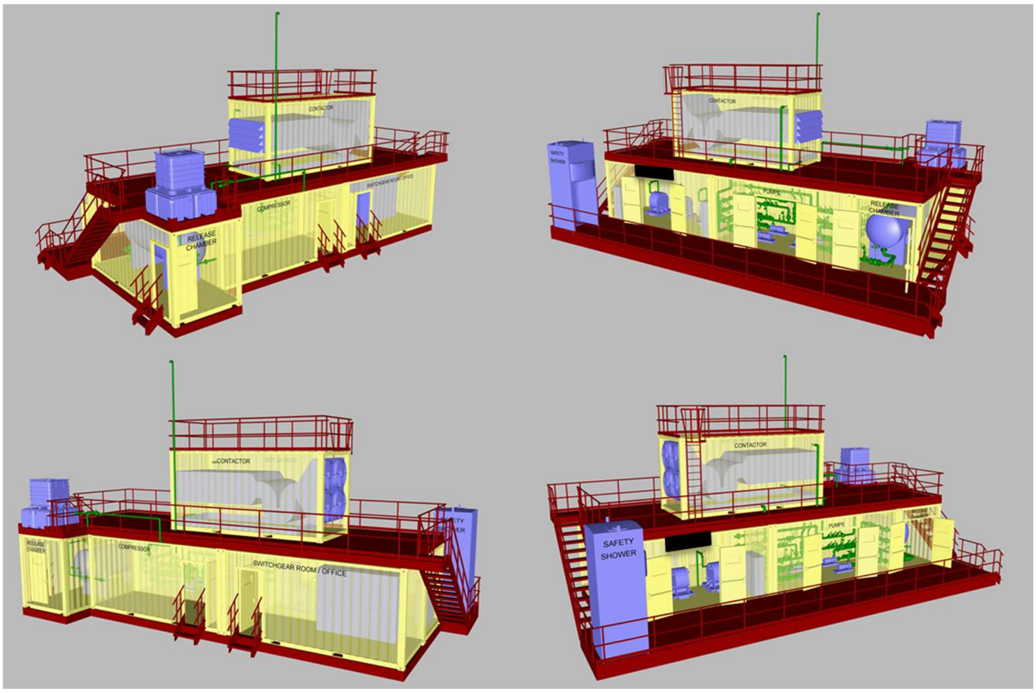

Figure 4.01.01 - Project DRIVE Pilot Plant FEED model [redacted]

For the Process Flow Diagrams (PFD) see Annex C (pg. 22). These figures give a process summary of the design.

It should be noted the CO_2 treatment package has been included in the system process documentation but has not been included in the project costs. The competition guidance states that the system needs only produce 98 mol% CO_2 gas at ambient conditions and so this package would have to be funded separately.

4.02 Design Basis

This section presents a summary of the pilot plant design at the end of Phase 1. Below is a summary of the key design basis used in FEED, extracted from Project DRIVE's Basis of Design (BoD). Reference Annex D (pg. 24), for further justification:

- The Air Contactor (C-100) capture efficiency is assumed to be 75%.
- The Air Contactor (C-100) has a 0.0005% CS loss from the drift eliminator.
- It is assumed that CO_2 is fully saturated in the capture/release solution and all CO_2 gas is released across the throttle valve on the inlet to V-100, near atmospheric pressure.
- Heat tracing is required to maintain an optimal temperature for the electrochemical step (20-25 °C).
- A bypass control loop is required for alternative operational routing during start-up. The bypass isolation valve is closed when the optimal temperature and CO_2 saturation have been achieved. The temperature and CO_2 inline sensors are positioned directly upstream of the bypass to inform the operator when to transition from start-up mode to normal operation.
- A peak flow of 27 m^3 has been used for line sizing based on scaled-up laboratory flows.
- CO_2 compression and liquefaction packages (A-101/102) are provided as a design option for injecting liquid CO_2 into OCO's aggregate manufacturing facility. Control and overprotection systems will be confirmed in a detailed design. The liquid CO_2 product conditions for the MZT – OCO boundary are:
    - 20 bar (max) pressure
    - 70°C (max) temperature

4.03 Equipment Summary

The main elements of the DAC pilot plant will include the following units:

- Air Contactor Package (C-100):
    - Shipping container size for ease of access and portability (2.3 m x 1 m x 3 m). Design to be further optimised in detailed design.
    - Air screen filters are positioned directly upstream of the air contactor packing contained within the package, on the air inlet side, to prevent dust and particles from entering the contactor.
    - Fans are positioned downstream of the contacting operation to pull air through the packing material on the air outlet side.
    - Drift eliminator required to capture entrained CS solution droplets in the air outlet stream. This is positioned directly between the packing material and fans.
    - Bund system to capture drainage.

- Electrochemical Separation Unit (M-100):

    - *[Confidential details have been removed for this public report]*

- CO_2 release chamber:
    - Horizontal separator (1.3 m ID x 3.25 T/T)
    - Required for CO_2 release at near atmospheric pressure
- Solution pumps:
    - 2 x 100% capture and release solution pumps
- Back-pressure regulator valves

More information on the two key packages is given below.

4.03.01 Air Contactor (C-100)

A wet scrubbing air contactor represents the first stage of the DAC process. This slab-geometry air contactor design uses gas scrubbing and cooling tower technologies.

Air fans are positioned on the air outlet side of the air contactor to draw airflow horizontally through the perforated contactor packing and the capture (diluate) solution is passed over the top of the air contactor and distributed throughout the structured packing via a spray nozzle system.

The capture solution chosen removes the CO_2 from the air stream and is used due to its high sorption capacity, low regeneration heat, high net efficiency, and low cost. CO_2 is captured as a carbonate ion and is then passed to the electrochemical separation step to liberate pure CO_2.

C-100 capture efficiency is assumed to be 75%. C-100 has a 0.0005% CS loss from the drift eliminator. Further methods to prevent the loss of CS from the contactor will be determined in the next design stage.

4.03.02 Electrochemical Separation Unit (M-100)

[Confidential details have been removed for this public report]

4.04 Costs & Vendor Engagement

In Phase 1 a complete project estimate has been developed. Vendors have been engaged for the key operating units; in particular, relationships have been established with potential suppliers. Annex E (pg. 26) shows a summary of technical information supplied by a variety of vendors. Learnings from all dialogues have been fed into the design and importantly have informed the project cost estimate.

A deterministic base estimate for the costs expected in Phase 2 is presented in Table 4.04.01. It is key to note, the deterministic base estimates do not incorporate any uncertainty or “contingency”. Alongside the deterministic estimate in Table 4.04.01 is a risked P10, P50, and P90 cost range. This adds a layer of risk and uncertainty consideration to the project cost estimate, given the project maturity. Reviewing the analysis of the project risk costs, the anticipated project costs range from around £2.2MM to £2.6MM. Further explanation is given in Annex E (pg. 27).

Table 4.04.01 - Deterministic Base Estimate Phase 2 and Pilot Plant

Cost Item	Deterministic	P10	P50	P90
CAPEX	£1,864,121	£1,834,110	£1,971,190	£2,150,650
OPEX	£333,000	£299,876	£330,194	£365,607
Decom	£93,206	£91,705	£98,560	£107,533
TOTAL	£2,290,327	£2,225,691	£2,399,944	£2,623,790

4.04.01 Exclusive Development Contracts

Regarding the interpretation of cost savings compared to exclusive development contracts, the budget and costs quoted to BEIS are lower than other commercial options for OCO. This pilot project as a part of the GGR competition does not include profit margins, where other companies would. Moreover, after completion of the GGR competition, MZT does not intend to sell the technology to BEIS.

4.05 Capture Rate Evidence

The following project strategy takes on an incremental approach towards the operation of the pilot plant. The initial plan is to establish steady operations for 12 hours a day. Once this is achieved, and requested permission is approved, the plant's operation will extend to the full 24 hour period. The pilot plant will need to achieve a steady capture rate of 0.014 tCO_2/hr (rounded to 2 significant figures), which equates to 120 tCO_2/year of capture steady-state operation for 24 hours for a year (Annex F, pg. 30).

Initial operations (set at 12 hours a day) aiming for 0.014 tCO_2/hr does not target a direct cumulative capture of 120 tCO_2/year. It more importantly and realistically sets out to pilot, establish, and measure a steady-state capture rate achievable of the yearly target. These lessons learnt will be carried forward to ensure an effective steady-state running over a longer period.

The CO_2 captured is to be measured by CO_2 sensors placed on the inlet and outlet of the air contactor gas stream. These sensors provide data for the CO_2 content upon entry into the contactor (before gas scrubbing) and CO_2 content exiting the contactor (post gas scrubbing). This differential can provide live recordings for measuring successful performance and establishing any trends during a shift or post-analysis. For accuracy and reliability, the sensors are to be routinely managed on a preventative maintenance plan and calibration schedule.

4.06 CO_2 Treatment

The CO_2 from the pilot plant needs to be treated prior to tie-in to the onsite storage tanks. This involves liquefaction and compression.

CO_2 compression will initially be achieved by package A-101, comprising of electrically driven two-stage diaphragm compressor, liquid removal vessels, coolers, valves, internal recycle line, etc. packaged in a modified 20ft shipping container. Integrated air blast coolers shall be utilised to avoid the requirement for an external cooling medium.

Liquefaction will be achieved by package A-102; the project is currently investigating available technology for the liquefaction of the CO_2 quantities produced by the pilot plant. One design of the liquefaction package commonly used involves compressing the CO_2 to a high pressure and then cooling and expanding it to the delivery pressure. The non-liquefied CO_2 is recirculated to the inlet of the compressor and recompressed.

Alternatively, it is understood that power consumption can be reduced by performing compression and depressurisation in several steps. The power consumption is reduced compared to the simple process because the non-liquefied gas is generally only recirculated to the inlet of the last stage of compression.

5. Project Plan

5.01 The Site: Benefits and Risks

OCO takes the alkali waste fly ash from Energy from Waste (EfW) incineration processes and by combining it with CO_2 produces a synthetic manufactured limestone (MLS) which is made into concrete blocks. OCO has made enough MLS in the UK to make 10,000 3-bedroom houses. By incorporating CO_2 from the atmosphere, instead of from fossil fuel-derived CO_2 sources, MZT can help align the economic imperative of building homes and fighting climate change. A full overview of OCO's business, active sites, and future plans are given in Annex G (pg. 31).

OCO is currently developing plans for a new Accelerated Carbon Technology (ACT) site in Wretham (Norfolk, IP24 1QY, UK) to begin operation by Q1 2023 with MZT's DAC pilot plant co-located onsite. This site was selected for DAC operations as OCO will have control over their CO_2 supply which is not typical at their current ACT sites elsewhere in the UK. The consortium explored other sequestration partners and engaged with EQU about integration with the Zero Carbon Humber project. However, this will not be online in time for the CO_2 offtake required for Phase 2 (2026 vs 2023).

In terms of risks, the close proximity of facilities producing pet food and meat for human consumption has been highlighted. These other parties will have an understandable interest in the close proximity of chemicals that can be harmful to people, animals, and the water table in the area.

5.02 GGR Interaction with Site

The overall process onsite will involve scrubbing CO_2 directly from the atmosphere using DAC and sequestering it permanently in synthetic limestone aggregates. Reference Annex G (pg. 31) for illustrative DAC interactions with the site. Site development requires 4500 tCO_2/year.

As the pilot plant is being designed to a capacity of 120 tCO_2/year, this can contribute up to 8% of their overall supply to the Wretham processing plant. This means the CO_2 captured by the DAC pilot plant, once treated and liquefied to reach target specification, needs to be mixed and stored with their existing incoming supply of CO_2.

MZT's DAC systems are designed for future scalability. After successful demonstration of the pilot plant, upon scale-up MZT can compete with CO_2 from fossil fuel sources and pave a greener pathway for OCO from source to usage. The DAC plant location will be directly situated next to the OCO's processing plant reducing the need for transportation and the number of gas deliveries to the site.

Figure 5.02.01 – A planned timeline for Phase 2

Figure 5.02.01 provides a highly conservative timeline for Phase 2 with the activities in the first half taking place off-site at vendor locations and OPT's premises while OCO's site is under development. Thereafter, commissioning, testing, operations, and eventual decommissioning activities will take place on OCO's premises.

OCO's site is expected to be available from Q1 2023. Prior to Phase 2, the consortium may consider bringing forward the initial tasks to better align the commissioning activities with Q1 2023.

5.03 Environmental and Planning Permits

A review of the Control of Major Accident Hazards (COMAH) Regulations 2015, undertaken by OPT, states that the pilot plant site is not a storage facility and does not contain any chemicals considered to be Schedule 1 dangerous substances. In conclusion, COMAH Regulations do not apply. [3]

The project consortium has proposed the pathway in Figure 5.03.01 to engage with the local council and the EA regarding planning and permitting pilot operations. As part of OCO's planned permitting application to the EA, there will be a conditional addition to the core activities planned for the site. In Detailed Design, all permits, licensing requirements, and certification of process and plant will be reviewed by OPT in conjunction with MZT and OCO to ensure all permit requirements, independent validation, and associated time frames are better understood.

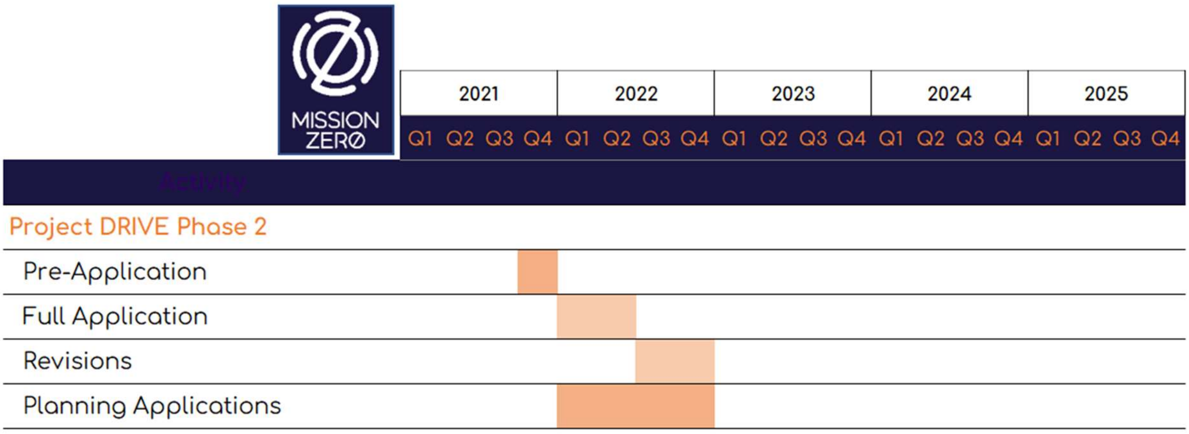

Figure 5.03.01 – A planned timeline for project permitting and Phase 2 delivery

MZT's pilot plant will sit within OCO's permit, which will enable OCO to operate its Wretham plant with no risk incurred from MZT's planned operations. However, the permit will be contingent on MZT demonstrating plant operation within the stipulated parameters, such as permitted noise levels.

The control of noise has been captured in the consortium risk register: from the fan on the contactor and other equipment noise (from the motor and gearbox). The vendor information on typical sound levels and mitigating engineering design features provides confidence that permitted noise levels will not be exceeded. See Annex H (pg. 33).

6. Programme and Business Plan Beyond Pilot Phase

This section looks at the GGR technology beyond the end of the MZT's DAC pilot plant phase. This is discussed in terms of the future proposed plan, learnings gained from the pilot stage to further scale-up, and dependencies affecting future developments.

6.01 Next Stage of GGR Development

MZT's product roadmap set outs to develop and commercialise increasing scales of GGR technology via its novel DAC product. The use of off-the-shelf components adapted from tangential industries allows for quicker scale-up and reduced technological risks.

Running up to 2025, MZT will develop and build 3 classes of DAC devices operating at differing capture scales. MZT's products are categorised as Device 1, 2, and 3 which incrementally increases up to 1000 tCO_2/year. The learnings of each device acquired in detailed design, operation, and build will feed-forward into the design of the next sequential device.

6.01.01 Use

Installation of MZT's scaled-up Device 3 (supplying 1000 tCO_2/year) and OCO's Wretham processing site (requiring 4500 tCO_2/year), increases OCO's CO_2 supply from DAC to 22% of their total supply. This increasingly competes with their current fossil fuel sources, enabling OCO to access the carbon credit markets (by demonstrating their LCA of synthetic aggregate has a minimised level of embodied emissions). Not only that, following the recent CO_2 supply crisis, having a DAC plant located on their site increases supply reliability (ref. Annex G, pg. 31).

6.01.02 Sequestration

MZT's DAC plant is designed for various off-take applications; accessing the breadth of the CCUS infrastructure. Phase 1 of Project DRIVE is already supported externally by EQU to identify how MZT's technology could be integrated effectively at the Zero Carbon Humber project. However, EQU's Zero Carbon Humber project is planned to come online in 2026 demonstrating misalignment for integration with MZT's pilot project from 2022 - 2025.

MZT held preliminary conversations with other sequesters. Similar to EQU, other storage projects (Project Acorn and Project Longship) plan to operate in the mid-2020s. Project Acorn and Longship aim to store CO_2 offshore within the northeast of Scotland and the west coast of Norway respectively. Storegga (a part of Project Acorn) has mentioned the possibility of another location in the UK that may be more suitable in terms of production scale/timeline.

Moreover, discussions with CCB Holding (landowner of the Energy Park for Project Longship), have confirmed the land space available for DAC and potential use for DAC captured CO_2 for algae and protein feed production. Further specifics cannot be disclosed at this stage but this demonstrates variety within CCUS.

6.02 Phase 2 Information & Learnings

This section discusses the expected key information that can be taken from the pilot phase of the project and applied to the next scale-up phase.

During the pilot phase of the project, MZT can contextualise the assumptions made with the Techno-economic Model (TEM). For example, the operation of the pilot-scale can provide accurate volumes of the usage of chemicals and disposal of waste. It will also identify key components that need to be secured within the supply chain.

While asset management is an important activity for older plants (where the design life of the facility may have been exceeded), MZT's pilot plant operation will still ensure practices are in place to record signs of deterioration and any observations of significance. This starts to build an audit trail of the technology to feed into future operating plants. The benefits provide: (1) a justification for safe continuation of the plant to regulators and stakeholders, (2) strategic business planning process for assets, and (3) understanding the ageing of equipment and measures required to sustain ongoing operations of the asset (e.g. a stock of critical equipment spares).

Lean Six Sigma, which is commonly used within manufacturing industries, will be applied. It is a methodological approach to reduce or eliminate steps within the process that does not add value. The operation of the pilot will unveil activities on a higher level of detail by observing actual tasks rather than those perceived. These integral observations will feed into the scale-up DAC for streamlined operations.

The plant is to initially operate 12 hrs/day which will involve regular start-up and shut-down of the DAC system. It is not expected that this intermittent operation will cause significant operational downtime but is to be determined in the pilot phase. This can evaluate the effect of the intermittent renewable energy supplied to DAC.

6.03 Phase 2 Dependencies

This section scopes out what the future plan is dependent on for delivery of the MZT's future DAC; once the piloting stage is complete. The next GGR development after piloting is MZT's Device 3 at 1000 tCO_2/year (ref. Section 6.01).

6.03.01 Supply Chain

Despite many industries experiencing supply chain constraints on materials across the breadth of the economy, this is not seen as a dependency. OPT have already taken conservative assumptions into the financial model and applied appropriate contingency (refer to Annex E, pg. 27). This will equally apply to future MZT's scaled-up devices.

Equipment availability and on-time delivery are key for timely plant commissioning. To mitigate delays to MZT's timeline, OPT is actively engaging with suppliers at an early stage and throughout the project's progress to understand the risks as and when they arise.

6.03.02 Project Consortium and Internal Recruitment

The consortium must be established for delivery of the DAC construction ahead of the Phase 2 application and for future GGR developments. The first round of internal recruitment has onboarded two process engineers and an electrochemist to join MZT's founding members. Recruitment to hire a senior design engineer and a project manager is also underway. From a social value perspective, this project has created roles within the green technology sector and will continue to do so as the company grows. Learnings gathered from the lead-up to and operation of the pilot plant will inform of any further recruitment required to progress to future devices.

Summary

This report summarises the totality of work taken by the Project DRIVE consortium in Phase 1 of the BEIS GGR Competition. It aims to deliver a FEED study for a DAC pilot plant utilising MZT's proprietary technology with a minimum capacity of 120 tCO_2/year, at an industrial site owned and operated by consortium partner OCO.

The consortium intends to submit a Phase 2 application to build and operate the proposed pilot plant. The consortium intends to add members, as subcontractors, who are responsible for 3rd party verification, supply of key materials where required, and for the manufacture of the pilot device. The evolution from Phase 1 to Phase 2 consortium has been formed from MZT's network, internal scoping exercises, and progression of OPT's engineering design work.

The DRIVE consortium has taken efforts to contextualise the operation of its pilot plant within the larger decarbonisation ecosystem which is currently evolving within the UK, at the time of writing. This is with a view of pure sequestration, dual sequestration, and utilisation. The unique sequestration pathway chosen by the DRIVE consortium represents a new and growing pathway to enable the decarbonisation of multiple industries through the incorporation of Scope 3 emissions within everyday products that we use to build our world and improve the human condition.

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Mission Zero Technologies

Phase 1 Final Report

ANNEX

REDACTED REPORT - FAO Public Viewing

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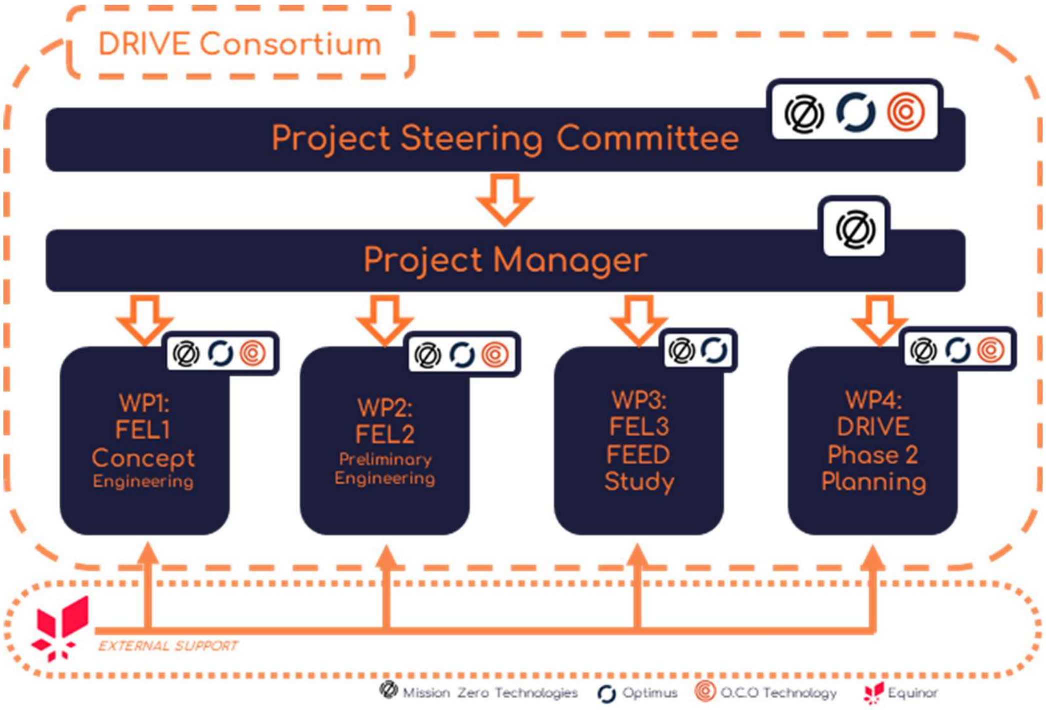
Annex A

Project Consortium & Governance

The project consortium is illustrated in Figure A.01. The project is supported externally with 40 hours of in-kind contributions from Equinor New Energy (EQU).

In relation to Section 1.02 Disposal, it is important to note OCO is a subsidiary of Grundon, a provider of waste management services. MZT have initially contacted Tradebe UK to advise on suitable disposal but OCO may provide more suitable waste options due to the connection with Grundon waste services and already established relationship through Project DRIVE Consortium.



A.01 - Working and governance structure of Project DRIVE Consortium

Annex B

Energy Load Calculations

Figure B.02 shows the full list of items for the pilot plant and their load calculations. Table 2.01 (Section 2) and Table B.01 divide this overview to show the core process-related items and peripherals respectively. Notes related to Figure B.02:

- Values for the blower and pumps are taken from industry standard motors.
- Trace heating values were calculated based on industry data and operational run time. The intermittent values are factored for operations expectations.
- Safety shower values are based on recent vendor information from a shower purchase and HSE legislation (water heating for 2.5 hrs a day).

Example Calculation on Ambient Air Blower item, accompanying Figure B.02:

1	$\text{Base Consumed Load [kW]} = \dfrac{\text{Absorbed Load [kW]}}{\text{Efficiency}}$ $\text{Base Consumed Load [kW]} = 2.00\text{ kW} \div 0.73 = 2.74\text{ kW (to 2 decimal places)}$
2	$\text{Operating Load}\left[\dfrac{\text{KWh}}{\text{day}}\right] = \text{Base Consumed Load [kW]} \times \text{Run Time}\left[\dfrac{\text{h}}{\text{day}}\right]$ $\text{Operating Load}\left[\dfrac{\text{KWh}}{\text{day}}\right] = 2.74\text{ kW} \times 12\dfrac{\text{h}}{\text{day}} = 32.88\dfrac{\text{kWh}}{\text{day}}\text{ (to 2 decimal places)}$

Table B.01 summarises energy requirements for additional items. The overall energy consumption of these items is not expected to increase considerably, during scale-up.

Table B.01 - Energy Requirements on Additional Items

ITEM	ABSORBED LOAD (kW)	EFFICIENCY	RUN TIME TOTAL (hr/day)	kWh/day
Internal/External Lighting Intermittent	3.00	1	3.50	10.50
Safety Shower Heater	3.00	1	2.50	7.50
Fire Protection	1.00	1	24.00	24.00
Metering	1.00	1	12.00	12.00
Instrument	2.00	1	12.00	24.00
			TOTAL	**78.00** kWh/day
				0.08 MWh/day
				28.5 MWh/year
				0.47 MWh/tCO_2

EQUIPMENT		OPERATIONAL DUTY				BASE CONSUMED LOAD						Run time per hour	Run time total per Day	kWh / day Operating	REMARKS
ITEM / TAG	DESCRIPTION	CONTINUOUS INTERMITTENT STAND-BY	Absorbed Load	Eff'ncy	pf	CONTINUOUS		INTERMITTENT		STAND-BY					
			A	B	C	D		E		F					
			kW	pu	COS φ	kW	kVAr	kW	kVAr	kW	kVAr				
B-100	Ambient Air Blower	C	2.00	0.73	0.80	2.74	2.05					1.00	12.00	32.88	
P-100A	[redacted]Pump A	C	2.60	0.79	0.82	3.29	2.30					1.00	12.00	39.49	
P-100B	[redacted]Pump B	S	2.60	0.79	0.82					3.29	2.30				Standby Load is not calculated as duty will be the same
M-100	[redacted]	C	15.33	0.80	0.90	19.16	9.28					1.00	12.00	229.95	
P-102A	[redacted]Pump A	C	2.10	0.73	0.80	2.88	2.16					1.00	12.00	34.52	
P-102B	[redacted]Pump B	S	2.10	0.73	0.80					2.88	2.16				Standby Load is not calculated as duty will be the same
THDB-1 (A)	Trace Heating	C	2.00	1.00	1.00	2.00						0.30	7.00	14.00	Load is on 24hrs to prevent freezing and maintain temp for start up
THDB-1 (B)	Trace Heating	I	2.00	1.00	1.00			2.00				0.15	3.50	7.00	
DB-L-101	Internal / External Lighting	I	4.00	1.00	0.85			3.00	1.86			0.15	3.50	10.50	Based on 24hrs for safety
Shower-1	Safety Shower Heater	I	3.00	1.00	1.00			3.00				0.10	2.50	7.50	
	Control Panels														
TBA	Fire Protection	C	1.00	1.00	0.90	1.00	0.48					1.00	24.00	24.00	
TBA	Metering	C	1.00	1.00	0.90	1.00	0.48					1.00	12.00	12.00	
TBA	Instrument	C	2.00	1.00	0.90	2.00	0.97					1.00	12.00	24.00	
						34.07	**17.73**	**8.00**	**1.86**	**6.17**	**4.45**			435.84	**kWh / Per Day**
						Totals								0.44	**MWh / Per Day**
														159	**MWh / Per Year**

Figure B.02 - Load calculations on all plant items [redacted]

Annex C

In this project, FEL 1 identified multiple process implementation options, while FEL 2 carried out initial design work for the most viable process implementation. This is followed by FEL 3 where detailed engineering design was conducted to produce flowsheets, energy & mass balances, instrumentation diagrams, structural drawings, a hazard and operability analysis (HAZOP) and statistical cost projections for procurement and construction activities in Phase 2.

Overview Summary in FEL 3 Report

“The work relating to FEL 3 began in early September following a recycle of the FEL 2 design through August.

FEL 2 was completed at the end of July 2021 at this point it was agreed within the consortium that the concept design was not suitable for the BEIS GGR competition. The design was targeting a capture rate of 365te/year which had led to the physical design being too large for the pilot plant host and deemed too expensive for the BEIS phase 2 budget.

A period of 3 weeks was taken to recycle the FEL 2 design to review the system assumptions of the process design. The process design, equipment selection and an updated design was presented and reviewed during a 2 day workshop held in Aberdeen on the 1st and 2nd September 2021.

FEL 3 commenced with a period of process documentation being updated to reflect the recycled and updated Project DRIVE design. Following the update in mid-September all engineering disciplines (including process, mechanical, electrical, piping, instrumentation, controls, structural and technical safety) were engaged to commence Front End Engineering and Design (FEED).

The results of the FEED work carried out is presented in this report and an illustration of the design is given.”

Next Steps Summary in FEL 3 Report

“The following will be addressed in Detailed Design:

1. The Environmental Permitting Regulations (England and Wales) 2010 consider the pilot plant to be a regulated activity. All permits, licensing requirements and certification of process and plant will be reviewed by OPT in conjunction with MZT and OCO to ensure all permits requirements, independent validation and associated time frames are understood.

2. A final review of the FEL 3 plant layout for all plant and equipment will be completed, this will include personnel access and egress for operations, desk space, maintenance and escape routes. The layout review will include consideration of safe areas and for venting, drainage and bunding. Also included will be Hazardous Area requirements with regard to any loss of containment from the electrochemical separation equipment into the container in which it is located.

3. The HAZOP raised a total of 53 actions. Where appropriate, these output FEL 3 actions have been addressed and incorporated into the pilot plant design. Ongoing actions will be finalised in Detailed Design.

The Design Review considered the following, and these will be finalised during Detailed Design:

- impact assessment of process inputs and outputs,
- chemical degradation and top up with regards to storage and handling,
- Environment Agency permitting,
- process control, and
- high level chemical safety review (MSDS) ”

The following Figures C.01 – C.02 are PFDs constructed during the FEED design. The ones selected within this annex are considered as core elements of MZT’s pilot plant.

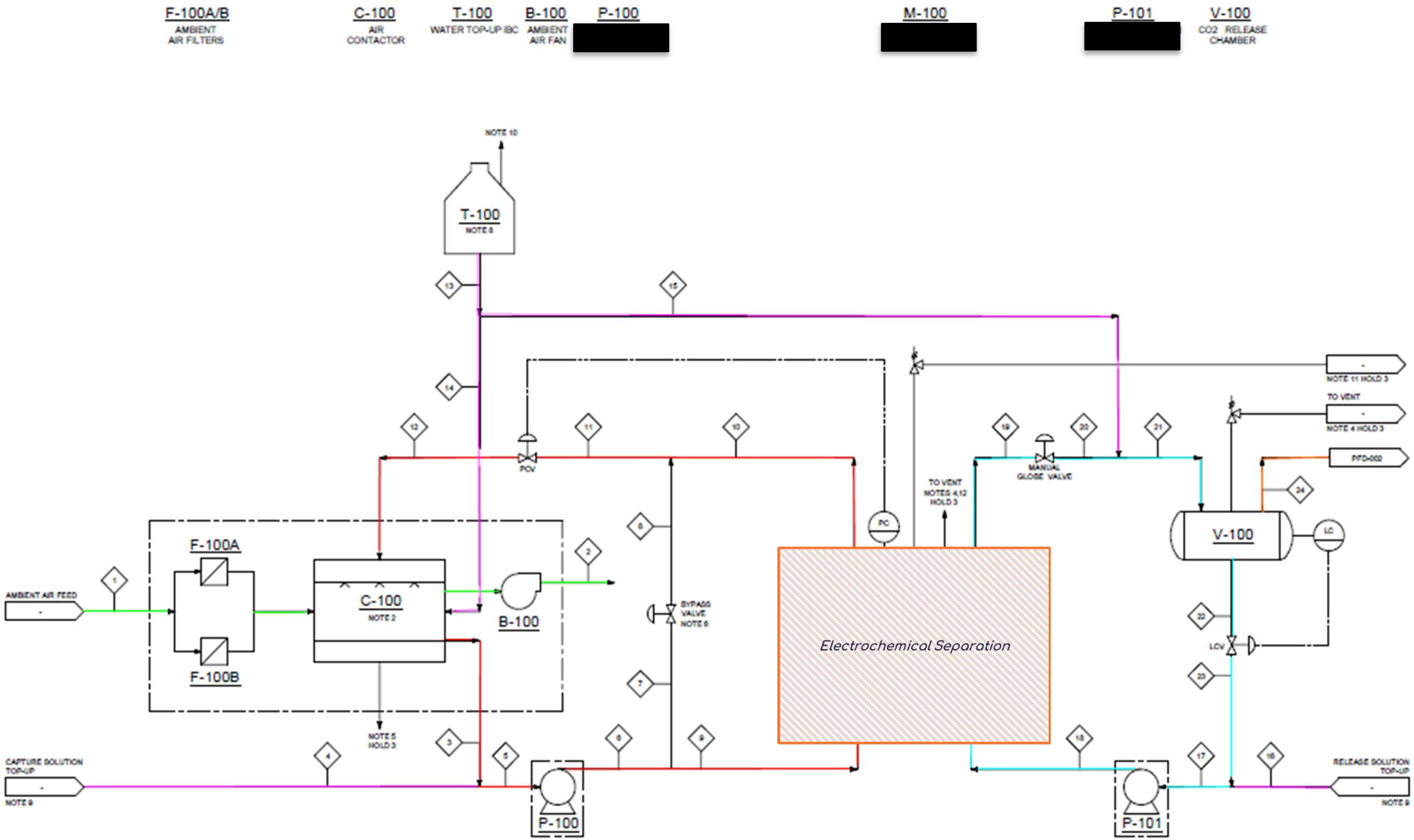


Figure C.01 - DAC Pilot Plant PFD – CO_2 Capture & Release [redacted]

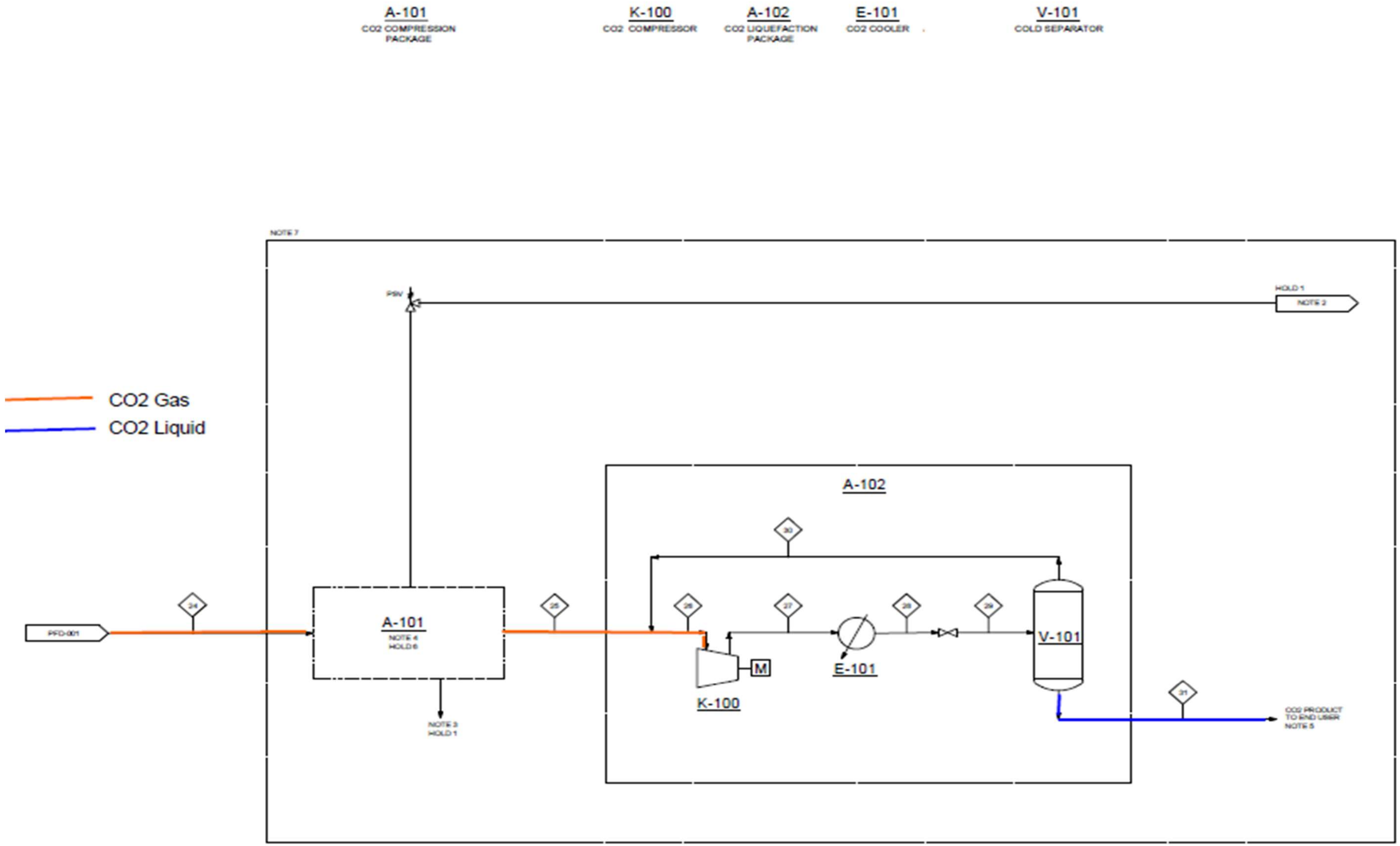


Figure C.02 - DAC Pilot Plant PFD – CO_2 Compression & Liquefaction

Annex D

Summary of Basis of Design Key Assumptions

Parameter	Assumption	Justification
Design Life	3 years	Pilot plant operation for 1 year and provides the options for a follow-up test without exceptional costs.
Capture rate	120 Tonnes CO_2/year	Provided a 20% margin above BEIS target of 100 Tonnes CO_2/year.
CO_2 concentration	98 mol%	BEIS target.
Daily Operations	12 hrs/day	Based on OCO site operation permits.
Steady State Operational Temperature	20 – 25 °C	Optimal temperature based on laboratory experiments.
AIR CONTACTOR		
Capture Efficiency: Air Contactor (C-100)	75 %	Based on supplier data..
Air Contactor (C-100) – Drift	0.0005% capture solution (CS) loss	Based on Brentwood (an industry leader) data and drift elimination in this type of equipment. The best possible configuration would give a drift of 0.0005%, with the normal design.
CO_2 Concentration at Inlet	400 ppm	Assumed based on average CO_2 concentration in the air
Single-pass CO_2 uptake into capture solution	0.07 gCO_2/L	Calculated based on a cumulative scaling factor considering the packing surface area, air velocity, and mixing regime. Assumed CO_2 is fully absorbed in carbonic acid.
Air Contactor module depth	2 m	Assumed 2 m to allow for varying operating parameters during the pilot.
Mass transfer coefficient	0.0013 m/s	Assumed 50% lower than the lab measurement to yield conservative capture solution flow rates.
Temperature	Ambient conditions	Air flow temperature based on ambient conditions. Capture solution flow will remain constant at 20-25 °C.
Pressure	Atmospheric	Air Contactor is open at both ends and will be designed for atmospheric pressure.
Dosing strategy	Continuous CS flow	Alternative dosing strategies (such as intermittent dosing of the capture solution) to be reviewed in detailed design.

Air Velocity	3 m/s	Optimal velocity based on Brentwood's XF75 velocity range (2.3-3.5 m/s). Velocities selected out of this range increases solution drift through the drift eliminator.
Air Flowrate	Minimum 6.9 m³/s	Minimum airflow required based on 120 Tonnes CO_2/year at 75% capture efficiency.
Air Fan Efficiency	55%	Based on existing supplier data.
Electrochem. separation unit circuit flowrates	28 m^3/h	Based on calculated scaled-up flows.
ELECTROCHEMICAL SEPARATION UNIT		
[Confidential information removed for the public report]		
SOLUTIONS		
Capture/Release Solution Flow Rate	27-28 m^3/hr	Based on scale-up flowrates, assuming 120 Tonnes CO_2/year is fixed.
Additional water/chemical injection top up flows	-	To be determined in detailed design and pilot operation.
OUTPUT		
CO_2 Release Pressure	Atmospheric	Assumed CO_2 is fully released at atmospheric pressure.
Export Max Pressure	20 barg	OCO tie-in requirement
Export Max Temperature	70 °C	OCO tie-in requirement

Annex E

Vendor Engagement

To provide confidence in the cost estimate, vendors for all key pilot plant equipment were contacted and quotations sought. The following documents the technical data shared with Vendors on check quotations.

Table E.01 - Excerpt on Vendor Engagement Spreadsheet [redacted]

Supplier for Budget Quotes	Model	Manufacturer	Quotation Status	Last Contact with Supplier	Weight (kg)	Dimensions (L x B x H) (mm) (Diam x T/T) (mm)	Est Lead Time	Price
[redacted] (M-100)								
[redacted]								
AIR CONTACTOR (C-100)								
Aqua Cooling Ltd	Custom Build	TBC	Declined to bid	Request for quotation issued 22nd Oct 21. Supplier pulled out 27th Oct 21	-	Available space 6m x 2.35m x 2.39m based on 20ft container internal dimns	-	-
Watermiser (HOLD)	Custom Build			Request for quotation issued 3rd Nov 21				
PUMPS - CAPTURE SOLUTION (P-100A/B)								
Kinder Janes	K3156 Mag-Drive	Sundyne	Budget Quote	Quote Received 21st Oct 21	Pump - 53kg Motor - 45kg	627 x 300 x 298	8-12 wks	£5745 per unit
ITT Industrial Process	IC 65-40-160 24	Goulds	Budget Quote	Quote Received 4th Oct 21 (Superceded) Revised Quote Received 25th Oct 21	Pump - 44kg Motor - 46 Baseplate - 44kg	946 x 390 x 397	12wks	£6164.91 per unit
ITT Industrial Process	ICM-B 24 65-40-160	Goulds	Budget Quote	Mag Drive Quote Received 27th Oct	119kg total pump / motor	840 x 250 x 292	12wks	£5626.72 per unit
PUMPS - RELEASE SOLUTION (P-102A/B)								
Kinder Janes	K3156 Mag-Drive	Sundyne	Budget Quote	Quote Received 21st Oct 21	Pump - 53kg Motor - 33kg	627 x 300 x 298	8-12 wks	£5710 per unit
ITT Industrial Process	IC 65-40-160 24	Goulds	Budget Quote	Request for quotation issued 23rd Sept 21	Pump - 44kg Motor - 30kg Baseplate - 45kg	946 x 390 x 397	12wks	£6104.77 per unit
ITT Industrial Process	ICM-B 24 65-40-160	Goulds	Budget Quote	Mag Drive Quote Received 27th Oct	98kg total pump / motor	840 x 250 x 292	12wks	£5469.50 per unit
SAFETY SHOWERS								
Hughes Safety Showers	EXP-MH-14KS/1500(F2)	Hughes Safety Showers	WIP	Quote Received 22nd Sept 21 Revised Quote Received 26th Sept 21	500 per unit	Length1420, Depth 1495, Height 3912	8 - 10 wks	£26,359.06 for two
STORAGE TANKS (T-100 / T-101 / T-102)								
Direct Water Tanks	IBC-1250-NEW-SP-2	Direct Water Tanks	Budget Quote	Quote Received 17th Sept 21	65.5	1200 X 1000 X 1350	From Stock	£269.99 Unit Price
Chemical Support Systems (CSS)	ECOBULK RMX 1250	Schutz	Budget Quote	Quote Received 20th Sept 21	65.5	1200 X 1000 X 1350	From Stock	£297 unit price
CO2 Release Vessel (V-100)								
Internal sizing and estimate at this stage	Custom Build	TBC			Internally Estimated weight 4500 - 5000kg	1500 x 4000	30 wks	£45000 - 50,000

Cost Estimate & Analysis

Pilot Plant Risked Cost Summary

A key part of the Phase 1 scope was to develop a robust estimate for project DRIVE. The details of the estimate and the results of the analysis are captured in this section. The overall costs estimate includes capital, operating, and decommissioning costs.

This annex presents an executive summary of the key information extracted from Phase 1's commercial and economic assessments undertaken by OPT.

Deterministic Base Estimate

In the body of this report, the expected most expensive case was presented, however, in this annex, two equipment configurations are presented. A key driver of the overall procurement costs for Phase 2 will be the selection of the electrochemical separation unit which will be dependent on the specific operating conditions.

Configuration 1	*[Confidential details have been removed for this public report]*
Configuration 2	*[Confidential details have been removed for this public report]*

In detailed design, the configuration will be selected following lab experiments and further discussion and testing with the supplier.

The costs for two configurations were included in the Phase 1 cost estimate and modeling. This included; £486K for Configuration 1 and £752K for Configuration 2. Vendor engagement and equipment testing are planned to inform the selection.

NOTE: The deterministic base estimates do not incorporate any uncertainty or "contingency".

Table E.02 – Summary of Costs Comparing Configuration 1 and 2

Cost Item	Base Estimate Configuration 1	Base Estimate Configuration 2
CAPEX Total	£1,598,121	£1,864,121
Detailed Design	£224,000	£224,000
Procurement	£1,145,300	£1,411,300
Fabrication	£107,801	£107,801
Hook-up & Commissioning	£121,020	£121,020
OPEX	£330,000	£330,000
Decommissioning	£79,906	£93,206
PROJECT TOTAL	£2,008,027	£2,287,327

Risked Project Cost

To reflect the level of uncertainty inherent within the design at this stage, the maturity of estimates from vendors, and uncertainty with respect to market forces the project has taken a risk-based approach to its cost estimate. To determine the cost uncertainty of a project, ranges are introduced to cost elements based on inputs from the risk register, vendors, discipline knowledge, and market predictions. A probabilistic cost model has then been run using Monte Carlo methods and a range of outcomes is produced.

Introducing uncertainty is not difficult or time-consuming, aids the decision-making process and by incorporating uncertainty into the analysis the decision-maker can see the impact of the uncertainties on the choices they make.

The histogram in Figure E.01 predicts the probability of achieving a certain cost value for the project scenarios and demonstrates the spread of the possible outcomes and the most likely value (the location of the peak on the x-axis). The single bars represent the base cost estimates for the two configurations.

As can be seen from the bar graph the predicted Project Costs range from around £1.9MM to £2.8MM.

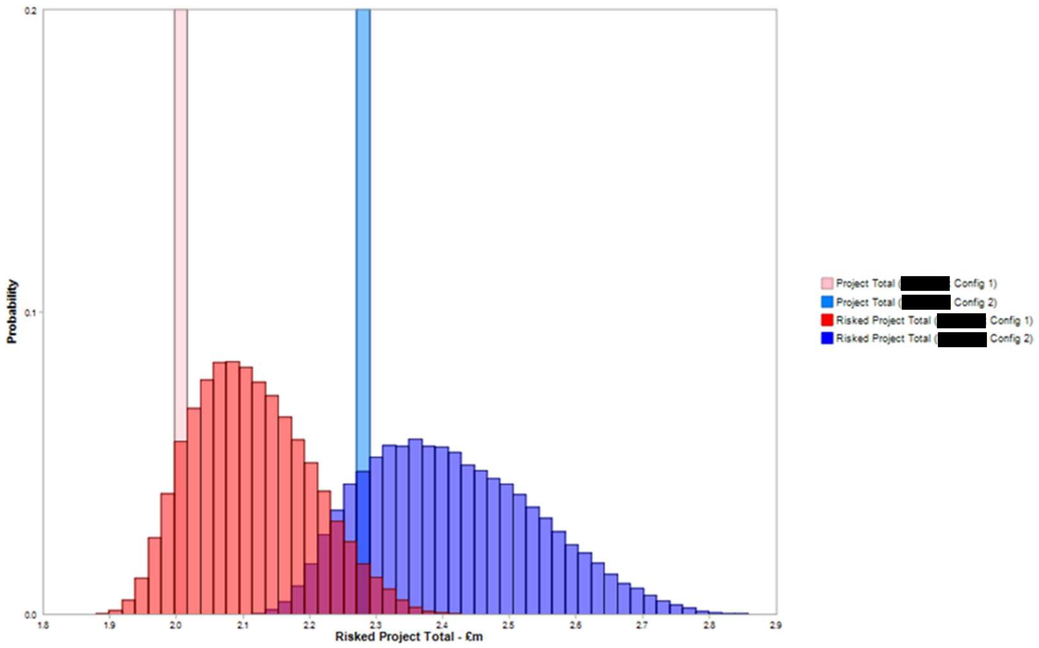


Figure E.01 – Histogram on risked total project cost vs base estimate [redacted]

Data points on the curves highlight P10, P50 and P90 data points. The horizontal axis shows the possible value of the variables (£MM), and the vertical axis shows the probability of being less than or equal to that value.

In comparing the two scenarios we can see that there is only a less than 10% chance of achieving the equivalent P90 cost of the lower-cost unit if we have to select the higher specification unit in Configuration 2. We can use this information for example in Phase 2 to focus on exploring possible solutions to use the lower specification units.

The procurement cost is the biggest influencer on the overall project cost so choices that are made in this area have the biggest impact. To help analyse this we can produce a Tornado plot of all the cost elements for procurement.

The Tornado plot provides a summary of the degree of influence each input variable has on the amount of uncertainty on the procurement cost. The bars are ordered top to bottom according to the degree of influence they have, the horizontal axis shows the possible value of the output variable.

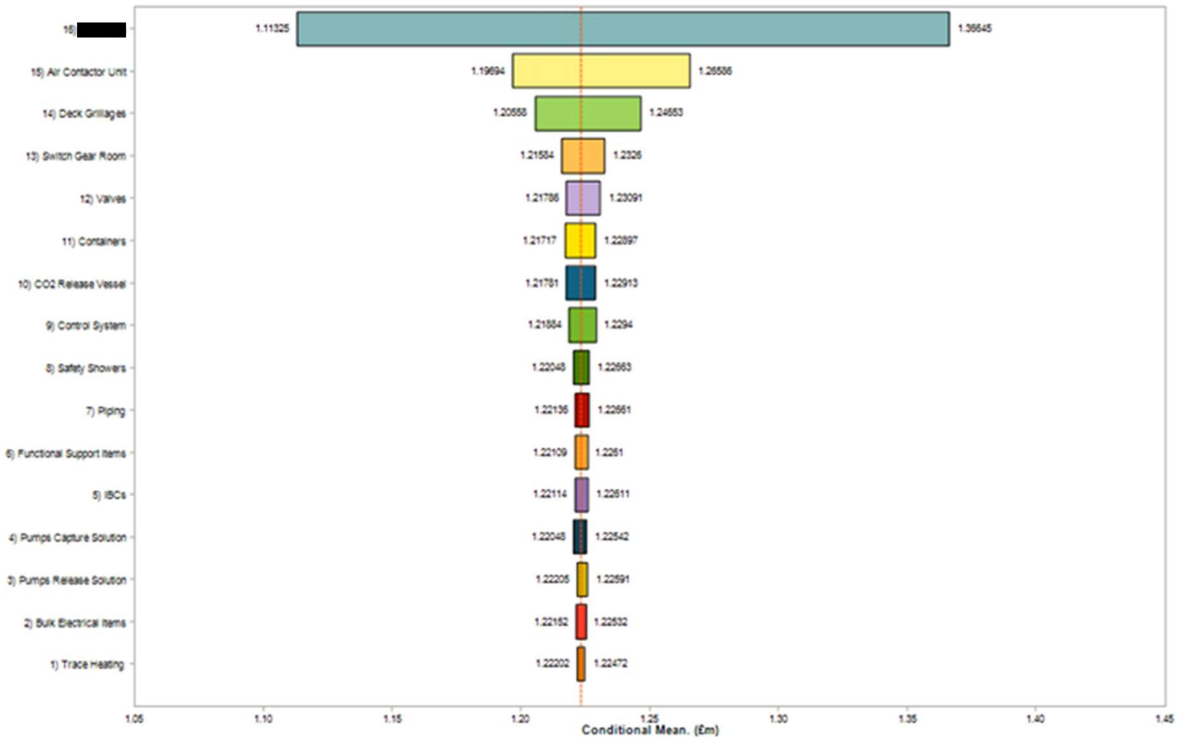


Figure E.02 – Tornado plot for risked procurement [redacted]

From the model output the top three procurement items that have the greatest impact on procurement uncertainty are the electrochemical separation units, the air contactor units and the deck grillages.

These areas illustrate the areas for continued work and priority at the commencement of detailed design.

Annex F

Capture Rate Evidence

The plant and equipment have been designed based on achieving a capture rate of 120 tCO_2/yr, which equates to 0.014 tCO_2/hr.

$$120\ \frac{tCO_2}{yr} \times \frac{1}{8760}\ \frac{yr}{hr} = 0.013699\ \frac{tCO_2}{hr} = 0.014\ \frac{tCO_2}{hr}\ (to\ 2\ significant\ figures)$$

As mentioned previously, the pilot plant initially is to operate for 12 hours a day at 0.014 tCO_2/hr. Once this operating rate has been achieved, extending operations to the full 24 hours will be requested to further demonstrate effective capture rate over a longer period of time, while maintaining steady-state.

Annex G

Commercial and Operational Considerations

OCO technology operates a unique business model for the upcycling of APCr resulting from EfW plants where municipal and biogenic wastes are incinerated for the production of district heating and low-carbon electricity. They combine CO_2, cement, and APCr to form MLS aggregate which is made into concrete blocks for use in established construction industries. A schematic of OCO's operations is given in the figure below.

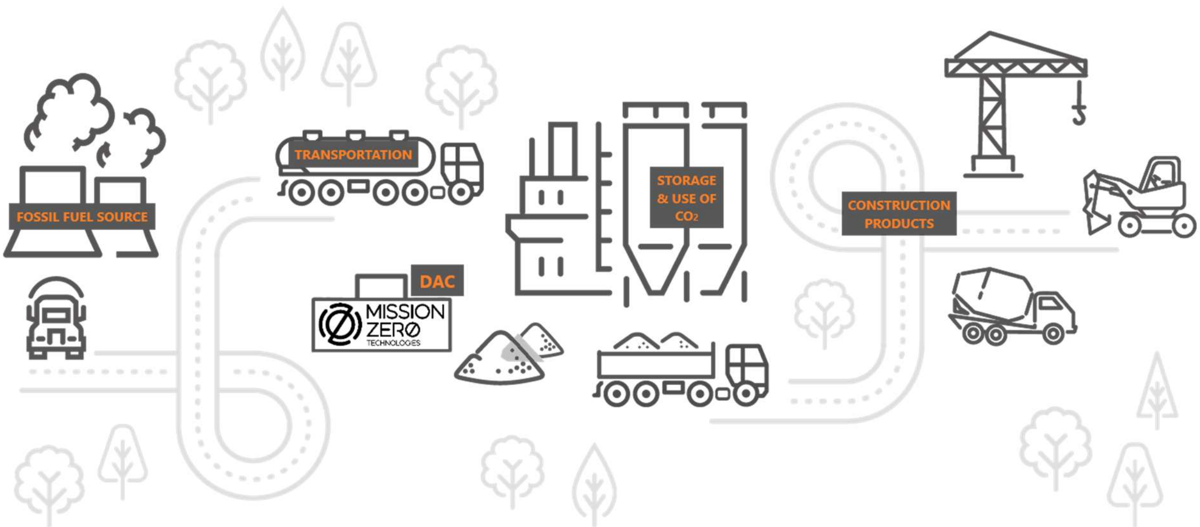


Figure G.01 – Illustration of DAC interaction on OCO premises

They have made enough MLS over the past decade to make 10,000 3-bedroom houses in the UK. With access to low carbon CO_2 sourced directly from the atmosphere, OCO's established business model can become a conduit for permanently locking away emissions from the atmosphere. In recognition of their technologies capability to sequester CO_2 they have been recognised as one of Mitsubishi's green construction consortium members and have projects underway internationally.

OCO operates 4 plants across the UK currently using ~15k tons of CO_2 every year across these sites. A map of their current locations and planned locations are given below, Figure G.02. As one of the largest users of CO_2 they are acutely sensitive to both supply and cost fluctuations resulting from participation in the current CO_2 commodity market. Hence their interest in securing a more stable long-term source of CO_2.

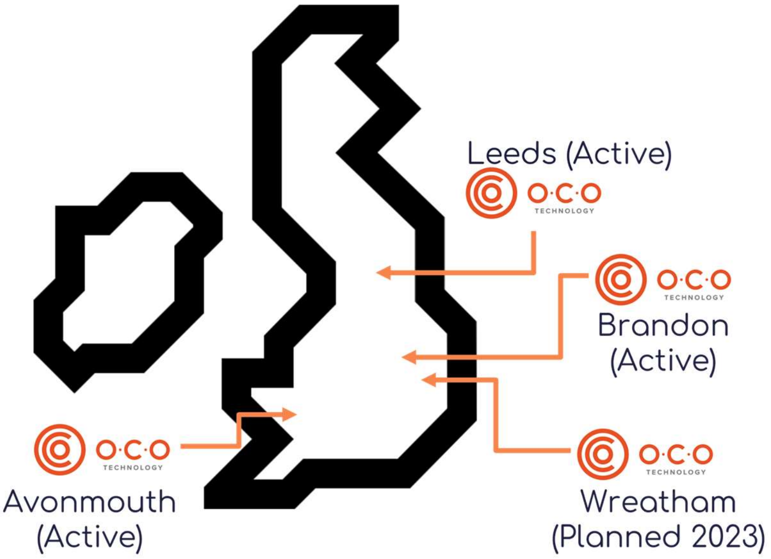


Figure G.02 – Map of OCO's UK operations both active and planned

MZT will be co-locating its DAC pilot plant at OCO's planned Wretham site from 2023 onwards as part of the BEIS GGR Competition Phase 2. As referenced in the main report OCO is opening a new ACT plant in Wretham, Norfolk, UK. For visualisation purposes, the DAC plant's co-location is shown in the figure below.

Figure G.03 – Visual representation of DAC pilot plant on OCO's premises

Annex H

Noise Mitigation

Upon engaging with contactor vendors, OPT have advised that a standard cooling tower provides approximately 75-80 dBA sound pressure 1.5 m from the skid edge, which is further reduced by 10-15 dBA by 15 m from the skid edge. These distances have been considered, as for standard practice, noise measurements are usually taken from 1.5 m and 15 m from all sides; with 1.5 m from the top.

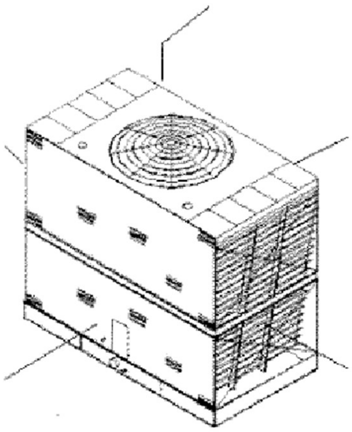
As the sound pressure is further reduced as the distance from the noise source is increased, it is likely that noise permit levels will not be breached. From an HSE and safety workplace perspective, the 75-80 dBA range of sound pressure sits below the lower exposure action value. Even though the sound pressure is compliant for a standard cooling tower, low noise fan designs and noise attenuators are still to be considered in detailed design to ensure noise pollution compliance. [4] [5]

No. of Fans: (1) 7.5 ft. Diameter Fan Per Cell
Fan Type: Standard
Motor HP: 20 HP per fan

Octave band and A-weighted sound pressure levels (L_p) are expressed in decibels (dB) reference 0.0002 microbar. Sound power levels (L_w) are expressed in decibels (dB) reference one picowatt. Octave band 1 has a center frequency of 63 Hertz.

Top L_p Sound Pressure (dB)		
Octave Band	Distance	
	5 ft	50 ft
1	60	51
2	78	57
3	85	63
4	79	65
5	81	68
6	82	68
7	79	65
8	75	66
A-wgtd	**87**	**74**

Air Inlet L_p Sound Pressure (dB)		
Octave Band	Distance	
	5 ft	50 ft
1	61	46
2	70	53
3	73	61
4	76	61
5	79	64
6	78	64
7	71	57
8	66	54
A-wgtd	**83**	**69**



End L_p Sound Pressure (dB)		
Octave Band	Distance	
	5 ft	50 ft
1	68	56
2	68	60
3	73	63
4	73	59
5	75	65
6	72	61
7	65	54
8	59	53
A-wgtd	**78**	**68**

End L_p Sound Pressure (dB)		
Octave Band	Distance	
	5 ft	50 ft
1	68	56
2	68	60
3	73	63
4	73	59
5	75	65
6	72	61
7	65	54
8	59	53
A-wgtd	**78**	**68**

Air Inlet L_p Sound Pressure (dB)		
Octave Band	Distance	
	5 ft	50 ft
1	61	46
2	70	53
3	73	61
4	76	61
5	79	64
6	78	64
7	71	57
8	66	54
A-wgtd	**83**	**69**

Sound Power (dB)		
Octave Band	Center Frequency (Hertz)	L_w
1	63	85
2	125	90
3	250	94
4	500	94
5	1000	97
6	2000	96
7	4000	92
8	8000	92

Figure H.01 - Typical Cooling Tower Sound Pressures