

MCFS Technical report

March, 2026

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Intent of this document

The intent of this document is to address items and topics provided by the Ministry for the Environment in regard to the Microalgae Carbon Fixation and Sinking (MCFS) methodology and Gigablue's technology and activity. Highlighted colors throughout this document represent the prioritization as received from the MfE (green- high; yellow- medium; no color- low). All items have been addressed in this document, regardless of their priority.

Part 1. Quantification of Efficacy of the activity

1.1 Efficacy of CO₂ absorption from the atmosphere

Under the [Microalgae Carbon Fixation and Sinking \(MCFS\) methodology](#), atmospheric CO₂ removal is achieved through the ocean's natural air-sea gas exchange, which replenishes CO₂ drawn down by the MCFS activity. The methodology anchors efficacy to the efficiency of this air-sea exchange, requiring region-specific oceanographic modelling to quantify how much of the fixed carbon is balanced by net CO₂ uptake from the atmosphere over time (Rules 6.2, 9.3). Seasonal variability, circulation, and mixing are explicitly accounted for, and conservative efficiency factors are applied to ensure that credited removals do not exceed modeled atmospheric uptake (Rules 9.3.4, 9.5). This approach ensures that credited CO₂ removals reflect real, additional atmospheric drawdown consistent with observed and modeled ocean behavior.

In regions with strong upper ocean mixing and persistent wind forcing, such as the AOI, the equilibration between surface waters and the atmosphere is relatively rapid, contributing to high efficiency. The AOI is located in *Region 543* of the [\[C\]Worthy & \(carbon\)Plan DOR mapping tool](#). These values are used to quantify the C_{loss} parameter in the overall net removal equation. The modelled 10-year efficiencies for this region for deployments in the relevant season (austral summer) is 91%.

Seasonal variation across Region 543 reflects the dynamics of the Southern Hemisphere, where January is austral summer and July is austral winter. In summer, surface waters are stratified and the mixed layer is shallow. When CO₂ is removed from seawater under these conditions, the chemical perturbation remains concentrated in the thin near-surface layer where the ocean is directly exposed to the atmosphere. This amplifies the air-sea pCO₂ gradient and allows the atmosphere to replace the

removed CO₂ relatively efficiently. These conditions help explain why January shows the highest modeled 10 year DOR efficiency at around 91%.

By contrast, winter conditions (July) are marked by deep mixing and strong wind driven turbulence that extend far below the surface. Although winter waters can hold more CO₂ because they are colder, the removal signal is diluted throughout a much larger vertical volume. As a result, the difference between surface pCO₂ and atmospheric pCO₂ is smaller and re-equilibration with the atmosphere occurs more slowly, leading to the lowest seasonal efficiency (85%). Spring and autumn (October and April) represent transitional periods when stratification is either building or breaking down. Mixed layer depth, wind stress, and biological activity are all shifting, and none of the seasonal drivers dominate to the same degree as in mid-summer or mid-winter. Correspondingly, the efficiencies of 85-90% in these months fall between the two seasonal extremes.

Overall, the AOI sits in a region where atmospheric equilibration is generally strong over a 10-year horizon, but the degree of stratification, and therefore the thickness of the mixed layer in which the removal signal is expressed, largely determines why efficiency is highest in the austral summer and lowest in the winter.

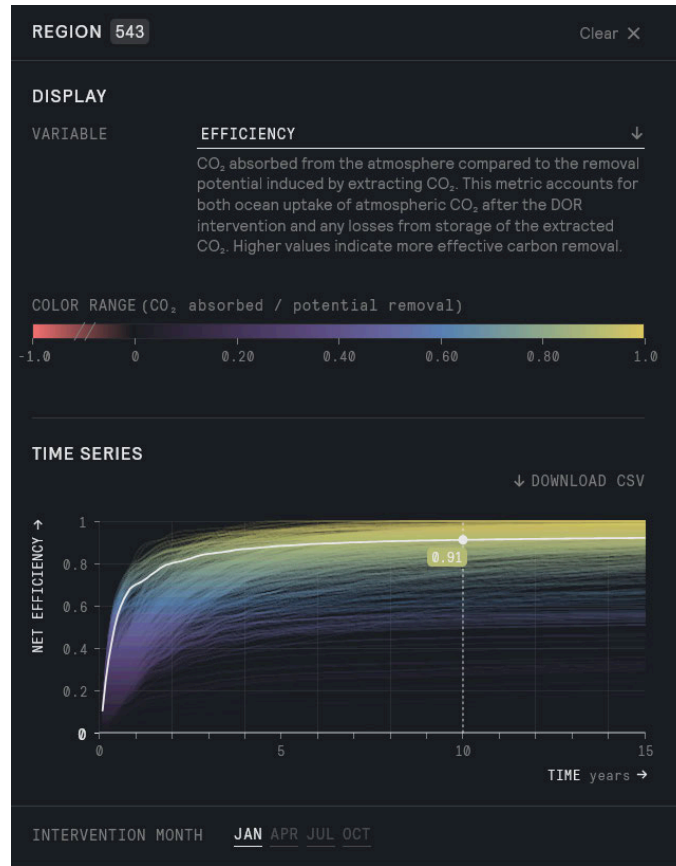


Fig. xx. Modeled Direct Ocean Removal (DOR) efficiency for a January deployment in Region 543, showing atmospheric CO₂ uptake relative to the induced removal potential. The curve illustrates rapid equilibration in the first decade, reaching approximately 91% efficiency after 10 years and stabilizing near 92% over the full 15-year model horizon. Source: CWorthy / CarbonPlan Direct Ocean Removal [Mapping Tool](#) (Region 543), based on the methodology described in CarbonPlan's [DOR Efficiency Explainer](#) (2024).

1.2 Efficacy of phytoplankton growth within the particle

The efficiency of growth within the substrate is strongly influenced by the porosity (ϕ) of the substrate, which represents the available space (volume) for growth inside it, and determined for a mass of unit. High porosity substrates are required to achieve high growth efficiency, and also allows for the exchange of masses (nutrients, oxygen, DIC, etc.) between the exterior of the substrate and the ocean waters. 9(2)(b)(ii)

The substrate efficiency is measured through a set of methods, both in the lab and ocean:

1. In the Gigablue R&D center there is a small mesocosm unit that uses simulated HNLC ocean waters with heterogeneous and local phytoplankton species from relevant Areas of Interest (AOI, i.e., NZ EEZ). It is used to test the growth efficiency of the local phytoplankton community within

the substrate and also learn about the dynamics of different masses (nutrients, oxygen, DIC, etc.) in the surrounding water.

2. In collaboration with ESNZ (NIWA) we conduct similar experiments using fresh HNLC waters from the NZ EEZ, which provides higher similarity of the natural biological diversity and water chemical composition into the R&D tests, although it has limited ability to simulate ongoing biological and chemical ocean dynamics.
3. In-situ ocean experiments provide the ideal set up for experimental work due to constant water mass turnover and real ocean hydrodynamics. Some experiments can be conducted using containment pens, which introduce the substrates to ambient conditions, such as light, and better water mass turnover and ocean hydrodynamics than those in the lab.

Planned research:

Future experiments will focus on onshore hybrid mesocosm systems that can use natural HNLC waters, that are introduced continuously with controlled light and hydrodynamic conditions. In-situ experiments will be conducted in dedicated pens or free plume, in accordance with the research question (e.g. functionality of the substrates, floating dynamics, carbon accumulation, etc.)

1.3 Carbon dioxide life cycle analysis

- Additionality of activity including manufacturing and transport
- Life cycle of material deposition over long term

The MCFS project offshore New Zealand deploys a floating substrate to stimulate biomass growth within it and then sinking to deep ocean waters, where carbon is durably sequestered for hundreds to thousands of years, and no less than 200 years. In the baseline scenario, only natural phytoplankton productivity occurs, with only a small fraction of biomass exported to depth while most carbon is consumed and remineralized in the euphotic zone and re-emitted; this natural export efficiency represents baseline removals. By contrast, the project increases both uptake and export, resulting in higher volumes of durable sequestration. The project is not required by law or regulation and is implemented voluntarily. It has no revenue streams or subsidies beyond carbon finance, and the sale of CORCs under the Puro Standard provides the sole mechanism enabling deployment, monitoring, and verification. Thus, the project meets baseline, regulatory, and financial additionality requirements and represents removals beyond what would occur naturally.

The Life Cycle Assessment (LCA) quantifies the greenhouse gas emissions associated with the production, transport, deployment, and monitoring of the substrates for each MCFS deployment. The LCA has been prepared in accordance with ISO 14040/14044 and the MCFS methodology and is submitted as part of the Production Facility Audit. The system boundary applied in this assessment is cradle-to-grave and includes all processes required to produce the substrate, transport it to the AOI, and perform the project-related Monitoring, Reporting, and Verification (MRV) activities. Raw-material generation, substrate manufacturing, inland transportation, maritime shipping to New Zealand (if needed), deployment vessel and MRV vessel operations. Activities occurring beyond the MRV window, such as long-term carbon storage and fate of the substrate in the deep ocean, are excluded from the LCA, as they are addressed separately in the MCFS carbon quantification framework.

Transport processes modeled in the LCA include multiple inland road-freight legs across Australia and deep-sea maritime shipping of finished substrate from Melbourne to Dunedin, New Zealand. Deployment activities involve a dedicated marine vessel operating between Dunedin and the AOI, while MRV activities involve a separate research vessel. Fuel consumption estimates for both vessels reflect anticipated operational patterns during the initial deployment.

The LCA results show that substrate manufacturing and raw-material production are the largest contributors to supply-chain emissions. Marine vessel operations (fuel consumption) contribute the next largest share of total emissions, with MRV operations contributing more than deployment activities because of their longer operational duration. Inland trucking and maritime shipping contribute relatively small shares.

Overall, the emissions profile of this deployment is shaped by three main components: raw materials, manufacturing energy use, and marine vessel fuel consumption. These findings provide a baseline against which future deployments, which may use different substrate inputs, use of recycled materials, alternative production techniques, or refined vessel operations, can.

1.4 Sinking and shear force

- Retention of phytoplankton as the particle sinks

The retention of carbon during the substrates sinking phase tested in-lab using a sinking simulator (SinkS). SinkS setup construct of a vertical velocity-controlled column with controlled seawater upflow. It is placed inside a controlled temperature incubator to illustrate relevant ambient temperature.

Carbon compacted substrates (after fixation stage) are introduced into the SinkS and upflow water circulation is applied while maintaining the substrates units under a fixed vertical location inside the column, which introduce an even force/flow upward - simulating the substrates sinking velocity. The exposure time of substrates under certain sinking velocity represent the different target depth according to pre-assessed seafloor depth at the relevant site (see figure 1). Then, the biomass is tested before and after the exposure to specific sinking depth and the difference is calculated for the retention.

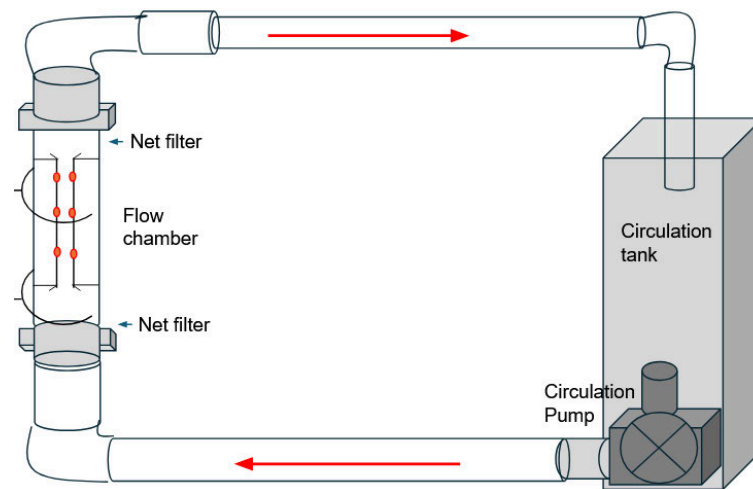


Figure 1. Schematic illustration of the sinking simulator (SinkS). Red spheres are the substrates.

Planned research:

Future research will focus on the variability of mass loss during sinking with different substrate types and varying organic loads. Moreover, the loss fraction with respect to depth will allow us to assess the sensitivity of specific substrates to release mass and optimize the substrate design and sinking timing.

In-situ experiments which include sampling of sinking substrates will be conducted to test the variability compared to in-lab tests. Substrate sampling will be conducted across multiple water column strata using the Multiple Opening/Closing Net and Environmental Sensing System (MOCNESS). The collected samples will be analyzed for biomass and organic carbon content per substrate unit at each depth. By comparing these values across different depth samples, the amount of organic carbon loss during the sinking period can be evaluated.

- Remineralisation in the water column

Remineralization, the breakdown of organic matter by bacteria into dissolved inorganic carbon (DIC) and nutrients as it sinks, is critical for calculating the substrate's sinking efficiency and evaluating environmental impacts.

The Sinking Efficiency (SE) is the fraction of fixed carbon that reaches a "durability depth" (a depth at which dissolved carbon will not reach the surface for at least 200 years) after being progressively reduced by remineralization in the water column. This process is quantified using a mathematical function (derived from Cram et al., 2018¹) that integrates several in situ and laboratory-measured variables. These include the surface remineralization rate (d_0), measured by on-board lab incubations of bacterial respiration; the sinking speed (w), which limits remineralization time and is quantified by hydroacoustic tracking or ROV; temperature (T_z), which promotes remineralization and is measured with CTD profiles; and dissolved oxygen (DO_z), whose concentration limits the extent of remineralization and is also measured with CTD profiles.

9(2)(b)(ii)

This evaluation incorporates temperature and oxygen profiles from the AOI, as well as the surface remineralisation rates of (0.015 d⁻¹). Therefore, it is anticipated that 1% of the total carbon fixed at the surface will be remineralized as the substrates sink to a depth of 1000 meters.

GB operation also involves monitoring the environmental impact. Intense remineralization can consume dissolved oxygen (DO), which is continuously monitored. Additionally, water is monitored for potent greenhouse gases: nitrous oxide (N₂O) and methane (CH₄) that may form under low-DO conditions.

- Confirmation of deposition beneath the thermocline

The engineered substrate sinks because its specific density, with or without the biomass addition fixed to it, is greater than that of seawater, ensuring it descends once its intended floating period is complete. To validate the substrate reaches below the thermocline, our monitoring plan, compliant with MCFS methodology, tracks the sinking substrates and measures their sinking rate. Furthermore, MOCNESS vertical tows are performed across multiple depth strata to evaluate the vertical distribution of the substrates in the water column during the sinking period. This provides evidence that the

¹ Cram, J. A., Weber, T., Leung, S. W., McDonnell, A. M. P., Liang, J., & Deutsch, C. (2018). The Role of Particle Size, Ballast, Temperature, and Oxygen in the Sinking Flux to the Deep Sea. *Global Biogeochemical Cycles*, 32(5), 858–876. <https://doi.org/10.1029/2017GB005710>

substrates have successfully reached the depths below the thermocline. Future company research will focus on testing and/or developing additional methods to assess the substrates' final actual distribution on the seabed.

- Confidence of retention at depth

Long-term sequestration permanence is fundamental for carbon removal to contribute effectively to climate mitigation. To demonstrate this, the MCFS methodology requires extensive modelling that verifies that the location in the deep ocean where the carbon is transported to is isolated from the atmosphere for hundreds to thousands of years, and for at least 200 years. This is achieved by combining regional models of ocean circulation patterns and water-mass dynamics with global ocean circulation frameworks that describe how deep waters migrate and exchange with the surface over time. For the Gigablue project, this modelling integrates data on local currents, stratification, and vertical mixing and was simulated specifically for the location where the substrate is expected to settle along the seafloor. The simulations show that the deep waters at the deposition site circulate and mix extremely slowly, on timescales of several centuries, ensuring that >97% of all carbon removed from surface waters and successfully sunk to abyssal depths will remain isolated from the atmosphere for more than 200 years, fully meeting the required durability threshold.

For further information on how durability was assessed and the results for the AOI, refer to the “Durability Assessment” report.

1.5 Efficacy of the activity in changing conditions

- Climate change implications – how long can the activity take place with increasing water temperatures-

Rising sea surface temperatures are expected to have a dual effect on ocean natural primary productivity. Reduction in productivity will happen because the warmer surface waters creates stronger stratification, acting as a "lid" that prevents vital, deep-ocean nutrients from mixing up to the sunlit surface layer, and can potentially lead to the expansion of "ocean deserts". Conversely, in some regions, warming can increase productivity. Polar areas are typically light-limited due to sea ice; melting ice allows more sunlight penetration, relieving this limitation. Furthermore, moderate stratification in these turbulent waters can be beneficial by keeping phytoplankton near the surface where light is maximized.

Regionally, the Equatorial Pacific is expected to experience sharp declines in nutrient supply and therefore primary productivity due to suppressed upwelling, the North Pacific expected to experience a shift away from large diatoms to smaller phytoplankton cells, and the Southern Ocean may see a net productivity increase initially, but will suffer from the unfavorable shift to smaller cell types. While warming increases stratification, intensifying winds (westerlies) in the Southern ocean may physically force more upwelling, potentially offsetting the decline in some zones.

Elevated ocean surface temperatures exert a demonstrable influence on metabolic processes (both carbon fixation and remineralization). Initially, a rise in temperature may augment carbon fixation rates, attributable to an acceleration in microalgae metabolic activity. However, if thermal tolerance thresholds are surpassed, this perturbation precipitates either significant microalgae mortality events or a shift in community composition toward less metabolically efficient taxa. The MCFS approach enhances the export efficiency during the sinking phase by ensuring carbon-loaded algae rapidly bypass bacterial remineralisation. This is achieved through high sinking velocities, which minimize the time the algae spend in the upper, warmer water column layers, thereby minimizing decay before they reach the sequestration horizon.

All that is described above is a scientific speculation as to how the future climate will affect the oceans, in a business as usual scenario, without industrial decarbonization and scalable CDR efforts such as MCFS.

- Efficacy with dispersion outside of HNLC (high nutrient low chlorophyll) waters-

Gigablue's operational approach complies with the MCFS methodology requirements and focuses on High-Nutrient, Low-Chlorophyll (HNLC) regions. Operational planning involves a detailed assessment of the AOI's physicochemical characteristics, including surface currents, nutrient concentrations, carbonate system properties, and microbiological characteristics. Deployment strategies are refined using a Lagrangian particle tracking model, which simulates the substrate's trajectory to statistically characterize sinking locations and densities, ensuring that project operations remain strictly confined within HNLC zones.

To assess and mitigate the risk of downstream effects beyond the immediate operation area, the project integrates oceanographic modelling and targeted monitoring of water column conditions. Physical circulation models are used to evaluate dispersion, residence times, and connectivity between

the AOI and adjacent regions, while biogeochemical simulations are used to assess nutrient redistribution. These analyses show that nutrient drawdown associated with the activity is rapidly replenished and does not propagate over large distances. Deployment location and timing and limited substrate floating time further limit the activity to the AOI, ensuring that if there are any localized effects, they remain transient, spatially constrained, and within the range of natural variability, consistent with the MCFS methodology requirements for environmental safety and impact containment.

- What is the time frame under which the technology is expected to be effective

The technology is expected to be effective as a mCDR solution, as long as there will be a need for carbon removal solutions to exist. According to the IPCC, until 2050 there will be an increasing need for that will reach to 10 Gigatonnes of CDR annually. Today all of the existing and developing solutions are able to support a limited amount tonnes annually, implying there is still a long way to go. As for the technology alone, its fundamentals are based on natural processes such as phytoplankton primary productivity, a mechanism that exists since the beginning of life.

1.6 Modelling

- Noting the challenges to baseline monitoring how Gigablue plans to overcome current issues relating to the maturity of modelling complex interactions between atmospheric, oceanographic, sediments, biogeochemistry models

Five numerical models are run to quantify, monitor, and validate the performance and environmental safety of the project under the MCFS methodology. These models collectively ensure that deployment and storage activities are conducted under characterized oceanographic conditions, and that the resulting carbon removals are durable, quantifiable, and environmentally safe.

1. The *physical oceanographic model* provides the baseline characterization of the marine environment in which the project operates. It integrates in-situ and remote sensing (satellite) data sources, including CTD profiles and mooring station time series. The model simulates hydrographic parameters such as temperature, salinity, current velocity, nutrient concentrations, carbonate system, plankton community, and stratification to characterize both the seasonal and interannual variability of the site. These outputs form the foundational dataset for all subsequent models.

2. The *Lagrangian particle tracking model* simulates the movement and sinking trajectories of the deployed substrate from release to seabed settlement. Using historical circulation data and multiple seasonal scenarios, the model evaluates dispersal pathways, potential sinking locations, substrate concentrations in the water, substrate density on the seafloor, final deposition coordinates and dimensions. Each simulation tracks virtual particles released within the operational polygon, enabling identification of optimal release points and validation that the majority of trajectories terminate within the predefined settlement polygon.

3. The *oxygen depletion model* evaluates the potential for oxygen depletion within bottom waters due to substrate-fixed biomass decomposition and remineralization. Using parameters such as diffusivity, bottom current velocity, and initial oxygen concentration, the model estimates expected oxygen consumption over time and the thickness of the affected water layer. Its primary objective is to ensure that oxygen levels remain above established ecological thresholds, thereby avoiding creating hypoxic or anoxic conditions in the local benthic environment.

4. The *nutrient robbing model* assesses whether biomass growth and subsequent export could lead to the local or regional depletion of essential nutrients. The approach follows a three-phase process: Phase I involves controlled laboratory experiments performed in collaboration with the NIWA, to determine substrate-specific nutrient uptake and phytoplankton growth rate kinetics. Phase II evaluates near-field nutrient gradients and potential short-term depletion effects around the plume footprint. Phase III extends the assessment to the far field, integrating regional circulation patterns to evaluate downstream redistribution and potential ecosystem impacts.

5. The *durability model* estimates how much of the carbon transferred from surface waters will remain sequestered in the deep ocean for at least 200 years (and defines the distribution between hundreds to thousands of years for each sequestration site). The model combines local hydrodynamic simulations of abyssal circulation with global ocean circulation frameworks to determine water mass isolation and ventilation timescales. By tracking the vertical and horizontal transport pathways of deep water masses at the specific settlement site, it assesses the probability that settled carbon will remain out of contact with the atmosphere over climate-relevant timescales.

Planned research:

The future research plan includes validating the models using real-world, in situ collected data from Gigablue's activity. These measurements will allow for the verification and improvement of the

models, specifically by quantifying the effects of currents and winds on floating particles, and quantifying surface nutrient depletion during the project's operation.

Additionally, laboratory incubation experiments are planned. These experiments will use deepwater-incubated substrates loaded with biomass to assess the rate of their degradation and the fate of the remineralized carbon. This evaluation will be performed in conjunction with dissolved oxygen (DO) consumption and nutrient release evaluations, which will help with the model validation.

In situ validation of the deepwater dissolved oxygen (DO) reduction model is scheduled for a later stage, once the project's operational scale is large enough to enable effective tracking of the sunk plume.

Part 2. Evidence/Research on the Following Environmental effects:

2.1 Chemical:

- **Leaching outside the particle – surface, water column and seabed**

All produced substrates are tested for their physical and chemical properties including mechanical stability and materials leaching. Under mechanical stability the retention of mass (suspended solids) is tested using intense conditions to ensure the substrate durability. Materials leaching is tested using conservative procedures to illustrate the surface and water column leaching, environmental oriented tests like heavy metals and organic contaminants. At the seabed, the substrates and the accumulated carbon are designed to biodegrade with relatively short time-scales (months).

- Deoxygenation at the surface due to phytoplankton growth

The open ocean surface water in the AOI is typically well oxygenated and has low organic matter (OM) export (baseline conditions). The introduction of the GB substrate to the AOI will add cellulose-based organic matter, and additional phytoplankton growth within it, increasing photosynthetic oxygen production; therefore, oxygen levels in surface waters are expected to increase during and shortly after the activity.

After the substrates sink below the photic zone, the organic matter is respired by bacteria, consuming oxygen. MCFS is designed to mitigate by design any creation of any oxygen minimum zones or localised hypoxia, through (1) rapid sinking of the substrates (2) controlled, low density of organic matter

per area. In any case, dissolved oxygen is being in-situ monitored in the surface ocean, and will be monitored in the seafloor when the activity reaches a sufficient scale.

- Effects on surface temperature and other chemical parameters

Gigablue's pulsed and controlled deployment has the potential to induce transient, localized changes in surface-water chemistry, and there are no effects expected on surface temperature. Enhanced photosynthetic carbon fixation temporarily reduces dissolved inorganic carbon (DIC) in surface waters, creating short-lived CO₂ undersaturation relative to the atmosphere. Over timescales of weeks to months, natural air–sea gas exchange re-equilibrates this deficit through atmospheric CO₂ uptake, during which a temporary, localized increase in surface-water pH may occur and potentially counter acidification effects caused by CO₂ excess in the ocean surface waters. This is the mechanism of atmospheric carbon dioxide removal and the essence of the science behind MCFS as a climate change mitigating technology.

Primary productivity stimulated by the substrate also consumes macronutrients such as nitrate and phosphate; however, in HNLC regions, these macronutrients are not the limiting factor for productivity, and nutrient drawdown remains spatially constrained and replenished by natural circulation and mixing. No direct effect on surface temperature is anticipated, as the activity does not alter physical heat fluxes or stratification; any long-term temperature effects would occur only indirectly through cumulative atmospheric CO₂ excess reduction at global scale of decarbonization and specifically CDR efforts (essence of CDR). Potential physical effects such as surface shading and light attenuation are minimized through controlled deployment densities and are addressed separately under surface light considerations.

- Effects on seabed chemical parameters

Potential effects on seabed chemical conditions are mainly linked to oxygen dynamics and changes in carbon chemistry following substrate deposition and biomass degradation. In line with the MCFS methodology, the project is required to demonstrate that benthic dissolved oxygen levels remain above thresholds that protect seabed ecosystems. For the Gigablue activity, oxygen depletion is assessed using a site-specific model (see sections 1.6), with conservative limits informed by ENSZ (NIWA) studies that define acceptable reductions in dissolved oxygen for deep-water basin environments (see section 2.3; third bullet). These thresholds, which suggest that MCFS operations should avoid DO drawdowns

exceeding 20–30% of background, are designed to ensure that oxygen concentrations remain well above hypoxic conditions and do not pose a risk to benthic communities.

As deposited biomass degrades, localized increases in dissolved inorganic carbon are expected at the sediment–water interface. Under the prevailing deep-water pressure, temperature, and buffering conditions, this process may also be associated with stable or slightly elevated alkalinity, which supports long-term carbon retention rather than release. No sulfide generation or harmful byproduct formation is anticipated, as oxygen levels remain above the defined thresholds, and the substrate composition does not contain heavy metals or other toxic materials. Overall, any chemical changes at the seabed are expected to be minimal, gradual, spatially limited, and within the range of natural variability, and are addressed through modelling and monitoring in accordance with the MCFS methodology requirements.

Planned research:

The future water column environmental research program is structured around three key areas: baseline characterization, the carbonate system and gas exchange, and nutrient dynamics. Baseline characterization emphasizes the essential requirement of establishing baseline chemical characteristics, specifically surface water chemistry, which is necessary to accurately detect and measure any perturbations relative to the natural state. The carbonate system and gas exchange component focuses on monitoring the carbonate system, including $p\text{CO}_2$ (partial pressure of CO_2), tracking the reduction of Dissolved Inorganic Carbon (DIC), and will incorporate Eddy Covariance in a later research stage to study the link between vertical mixing and CO_2 gas-exchange rates. The nutrient dynamics area involves tracking macronutrient depletion near the operational site, modeling the movement of nutrient-depleted water to assess far-field nutrient robbing, and modeling the consumption's impact to stay within maximum permissible reduction thresholds. The in situ monitoring will also sample and measure the concentrations of trace elements, to test for leached micronutrients during the operation.

The future research on seafloor phenomena focuses on understanding the chemical fate of sinking carbon and the ecological consequences of its breakdown, with key areas centered on Dissolved Oxygen (DO) dynamics and carbon remineralization. Regarding DO, the study will further refine preventative deposition thresholds, measure consumption rates via laboratory incubations, and implement long-term, in-situ monitoring to quantify depletion intensity and replenishment rates. For

carbon, the research will quantify the final fate of the sunken biomass at the sediment-water interface by measuring the release of Dissolved Inorganic Carbon (DIC) and nutrients, and will assess the potential for interaction with calcium carbonate (CaCO_3) to enhance long-term sequestration durability. The research methodology involves establishing a lab-based chemical baseline using sediment cores, followed by continuous, scaled in-situ chemical monitoring on the seafloor for operations at a sufficient scale that will allow the detection of those elements.

2.2 Biological:

- Impact of consumption on marine animals, seabirds and plants (particularly fisheries stocks)

Marine animals: From the “Environmental Impact Assessment” report (section 6.5)

“...The likelihood of ingestion is expected to be related to feeding methods. Filter feeders (e.g. Blue, Bryde’s, Humpback, Southern Right whales) may incidentally consume particles mistaken for plankton, and dolphins may visually investigate particles resembling prey. Based on the relatively small size of the particles combined with their biodegradability and relatively rapid dispersion to low concentrations, if incidentally ingested, particles are likely to pass through the digestive systems of marine mammals without adverse effects. Additionally, the offshore location of the selected trial area avoids the distribution of many of the smaller dolphin species which might be more at risk.

Seabirds: From the “Environmental Impact Assessment” report (section 6.6)

“Ingestion of pumice or gastroliths is common across many seabird species (e.g. penguins, albatrosses, petrels, storm-petrels, skuas, auks) to aid in the mechanical digestion of food (Lavers & Bond 2023). Thompson (2025) notes that given the propensity of seabirds to ingest non-food items, and given the spatial overlap between the AOI and the wide range of taxa utilising the area, it is likely that seabirds will ingest particles...

...Petrels, shearwaters, and fairy prion are likely to be at the greatest risk of ingesting particles due to their surface feeding behaviour and/or their diets targeted to crustaceans and plankton (Roman et al., 2019). Birds which typically feed on larger fish and squid prey such as albatross are less likely to target the relatively small particles (Van der Reis et al., 2024). As such, the proximity of 'Threatened' albatross hotspots to the likely trajectory of surface particles is unlikely to notably increase their risk of ingestion. Birds which forage using diving methods are also less likely to incidentally ingest particles compared to those which filter at the surface, as they would likely exhibit avoidance behaviour due to visibility limitations (Darby et al., 2022).

Thompson (2025) does note considerable uncertainty surrounding the interaction between the seabirds and the released particles, however, Gigablue have video evidence from their smaller scale trial in October 2024 showing seabirds avoiding the particles and only resting in waters well clear from the plume.

Where ingestion could occur, the stomach acid of some seabirds (i.e. wandering albatross) may be concentrated enough to aid in particle digestion (Grémillet et al., 2012), but, whilst considered unlikely, the consumption of large volumes of particles could cause intestinal blockages and nutrient absorption impairment (Thompson, 2025). In smaller volumes, cellulose is unlikely to result in abrasion damage in the digestive tract and would likely pass through the digestive tract or be regurgitated, particularly considering the ability of seabirds to excrete harder materials such as bones, otoliths, and shells (Barrett et al., 2007).

Though the likelihood of seabirds ingesting particles at volumes sufficient to cause adverse health effects is expected to be low, the consequence of the loss of an individual from a vulnerable taxon within the AOI would be significant. Consequently, the proposed release site in the western extent of the AOI has been selected to avoid known bird hotspots for the most vulnerable species, thereby reducing the overall risk of birds encountering and ingesting large numbers of particles in these areas. The western release site also reduces the likelihood of Chatham Island tāiko encountering the plume when it is at its densest, with species observations limited to eastern areas of the AOI (eBird, 2025).

As such, the overall magnitude of effect (i.e. likelihood + effect) from direct particle ingestion is expected to be low."

Plants: From the "Environmental Impact Assessment" report (section 4.2.5; 6.2)

Ingestion is unlikely as the substrates are too large to ingest for most zooplankton.

Fisheries stock: From the “Environmental Impact Assessment” report (section 6.4)

“Fish may try to eat entire particles or pieces of particles, particularly when coated in phytoplankton, presenting some potential health risks. Herman et al. (2021) found that the transfer of iron from zooplankton to fish through direct ingestion resulted in lower uptake compared to the uptake directly from water to fish, suggesting this pathway presents a lower toxicological risk for fish than directly from the water. The size of the particles may also present a digestive issue for fish of a certain size where many particles are ingested whole...

...However, the favourable physical properties of the particles (i.e. soft, compressible, and hydrophilic) suggest that they are relatively unlikely to result in significant adverse health effects unless consumed in very high quantities. Additionally, the fish species most likely to ingest particles are also the algal-feeding fish most likely to be able to digest cellulose material (Augustine & Joseph, 2018). There is also some evidence that the inclusion of cellulose in fish diets can have health benefits (e.g. improved intestinal health) (Zhang et al., 2022).

The reviewed information suggests that while there is a moderate risk of ingestion, adverse effects are anticipated to be low to negligible.”

Planned research:

The future research plan includes the establishment of in-vitro protocols to assess the ecological risks, specifically bio-obstruction and bio-fragmentation associated with the ingestion of GB particles by marine macrofauna. The study aims to quantify digestibility, mechanical resilience, and chemical fate using four distinct simulation models: the "Gizzard Model" for seabirds (testing micro-fragmentation), the "Standard Shake Flask" for predatory fish (testing false satiation), the "Stomacher Simulation" for cetaceans (testing bio-obstruction), and the "Cold Enzyme Reactor" for cephalopods (testing caecal clogging). Following exposure to biologically accurate simulated gastric and intestinal fluids, the research involves post-digestion filtration, gravimetric analysis, microscopy, and density checks to produce a comprehensive risk matrix and fate report. In addition, behavioral studies will be undertaken during field activities.

- Bioaccumulation of materials used in animal/plant tissue -

From the “Environmental Impact Assessment” report (section 6.2-6):

- *Seabirds*: “As for other marine fauna, iron is an essential trace metal for seabirds which are typically regulated through feather moult and excretion (Roman et al., 2023). However, bioaccumulation can occur where concentrations exceed an organism’s regulation capacity, particularly for seabirds which are generally at the top of the food web. Food web accumulation is, however, expected to be relatively limited given the baseline deficiency of iron in the trial area and the relatively small scale and duration of the trial. No evidence exists for accumulation of cellulose based material in seabirds, and cellulose material is hydrophilic, less likely to penetrate lipid membranes or accumulate in fatty tissue (Zantis et al., 2020; Egan & Salmon, 2022).”
- *Marine mammals*: “As for marine fish and invertebrates, iron is an essential trace metal for marine mammals which can be regulated through various mechanisms including hepatic metabolism, biotransformation, and excretion (Page et al., 2024). However, bioaccumulation can occur where concentrations exceed an organism’s regulation capacity, particularly for marine mammals which are generally at the top of the food web. Food web accumulation is, however, expected to be limited given the baseline deficiency of iron in the trial area and the relatively small scale and duration of the trial. No evidence exists for accumulation of cellulose in marine mammals, and its hydrophilic nature means it is less likely to penetrate lipid membranes or accumulate in fatty tissue (Zantis et al., 2020; Egan & Salmon, 2022).”
- *Fish*: “As for marine invertebrates, iron is an essential trace metals for marine fish (Chandrapalan & Kwong, 2021). As such, fish have evolved specific physiological mechanisms (i.e. involving intestine and gills) to regulate metal absorption, and there is even evidence that fish can modulate trace metal uptake at the gill (Chandrapalan & Kwong, 2021). However, bioaccumulation can occur where concentrations exceed an organism’s regulation capacity.

The main ecological issue for fish is more a lack of bioaccumulation owing to low environmental iron concentrations, resulting in deficiencies for marine phytoplankton and fish (ANZG, 2025). Similarly, iron deficiencies in lower trophic levels have been reported to limit the growth of marine fish, suggesting that increasing bioaccumulation is generally desirable (Galbraith et al., 2019).

Ingested cotton and viscose material is hydrophilic (water-attracting), making it less likely to cross lipid membranes when ingested (i.e. gut and blood vessel). This reduces its potential to

accumulate in fatty tissues, unlike hydrophobic microplastics which are consequently more resistant to environmental degradation (Egan & Salmon, 2022).

Given the above evidence, the very low concentration of metals in the GIGPA04 particles, and the high proportion of affected phytoplankton organic matter expected to sink to the ocean floor with the particles, bioaccumulation of iron is not expected to occur. If it were to occur, it would likely have a positive effect on fish communities.”

- *Marine invertebrates*: “Iron is an essential trace metal for many marine invertebrate species (Jeong et al., 2023; Oweson & Hernoth, 2009). As such, many species have evolved mechanisms to regulate the uptake of this metal (Chiarelli & Roccheri, 2014). However, bioaccumulation can occur where concentrations exceed an organism’s regulation capacity. Given the very low concentration of metals in the GIGPA04 particles and the high proportion of affected phytoplankton organic matter expected to sink to the ocean floor within the particles, bioaccumulation of particle materials is expected to be negligible.”
- *Phytoplankton*: “Due to the short lifecycles of plankton and their position as the primary consumers of the particle nutrients, bioaccumulation is not considered to pose a significant adverse effect.”

- Effects and extent of smothering and light reduction at the surface

Potential smothering effects are primarily associated with seabed deposition and are therefore addressed in the sections of this document dealing with benthic interactions and seabed impacts. In contrast, potential light reduction is a surface water consideration and addressed here. The MCFS methodology requires demonstration that project activities do not cause material or sustained reductions in light availability within the euphotic zone (Rules 4.4.3, 9.5). Substrate properties, deployment densities, and operational timing are designed such that any transient increase in suspended particles in surface waters remains short-lived and within the range of natural variability in suspended particulate matter.

A surface direct light attenuation experiment has been conducted using floating substrates using the standard method (for experiment setup, protocol and results see [this link](#)). Briefly, the experiment's outcomes showed no significant direct-light reduction (PAR) below 10% substrate coverage, which is about 14 gr/m². Substrate dispersion modelling shows maximum coverage of 19 gr/m² (mean = 6.5 gr/m²) in the first 24 hours after deployment. The experiment report can be provided upon request.

- **Impact on benthic communities**

See the “effects on the seabed” section below (2.3; third bullet)

2.3 Environmental:

- Environmental effects of manufacturing particles

Gigablue does not manufacture substrate materials “in house”. All substrate is procured from established, legitimate third-party suppliers operating under applicable host-country regulatory frameworks. Supplier selection prioritizes responsible and sustainable sourcing practices, including compliance with environmental regulations, labor rights, occupational health and safety standards, and relevant product and process certifications (where available). Manufacturing related environmental impacts, such as emissions, waste generation, and worker safety, are therefore governed and enforced at the supplier level under existing industrial and environmental oversight regimes. As part of project due diligence, Gigablue assesses supplier practices and documentation to confirm alignment with these requirements and to ensure that no novel or project-specific manufacturing processes are introduced as part of the MCFS activity.

- Regional oceanographic/climate monitoring and modelling

Section 1.6 above provides a detailed description of the models used

- Effects on the seabed -
 - **Coverage and smothering -**
 - **Impact on Biodiversity diversion from baseline**
 - **Species composition, diversity and population dynamics**
 - **Particle composition and how it breaks down**

Effects on the seabed: The MCFS methodology requires that project activities do not result in adverse effects on seabed environments (Rules 3.7.7-8, 4.5.19-21). Projects must demonstrate, through site selection, substrate design, modelling, and monitoring, that interactions with the seabed are spatially limited, predictable (via modelling), and remain within defined environmental safety thresholds over both short and long time timescales.

Coverage and smothering: Risks related to seabed coverage and smothering are explicitly addressed in the MCFS methodology by requiring demonstration that substrate deposition does not lead to continuous coverage or accumulation thick and dense enough to physically smother benthic habitats (Rules 4.5.19, 4.5.20, 4.5.21). The areal deposition at the seabed must be shown to result in deposition patterns, and does not form a consistent layer and remain below accepted tolerance limits for deep-sea epifauna. Threshold-based criteria, defined currently by ESNZ (previously NIWA) as “to levels below established taxon-specific sedimentation thresholds (typically 50–100 mg L⁻¹ suspended sediment pulses or <0.5 mm yr⁻¹ accumulation)”, are applied to prevent excessive accumulation, supported by modelling and seabed characterization and, when activities scale will be sufficient enough for detection, post-deployment verification (Rules 3.7.7, 3.7.8).

Impact on biodiversity relative to baseline: The methodology requires establishment of baseline seabed conditions and assessment of whether the potential project induced changes to benthic biodiversity exceed natural spatial or temporal variability (Rules 3.7.7) and ensure "no net harm" to the environment. Any impacts must be limited in extent, reversible, and must not result in long-term degradation of benthic ecosystem structure or function (Rules 3.7.8). In all cases, the activity is intentionally designed to operate within conservative environmental thresholds. Its low-density signature, combined with its controlled and adjustable implementation, enables the system to be tailored to meet any defined threshold requirements.

Species composition, diversity, and population dynamics: MCFS requires that project activities do not cause sustained or material changes in benthic species composition, diversity, or population dynamics relative to baseline conditions. Monitoring parameters and indicators must be capable of detecting shifts in community structure or dominance patterns, with predefined thresholds and response actions where observed changes exceed acceptable limits.

To characterize benthic habitats and identify protected species or sensitive communities, an assessment must be conducted using existing biological datasets. These datasets include habitat maps, photographic/video evidence, and specifically, macrofauna surveys (Rule 3.7.8). A Vulnerability Analysis is mandatory (Rule 4.5.19). This analysis requires reviewing available scientific literature to pinpoint specific organisms in the area known to be susceptible to particulate smothering. Furthermore, to safeguard population dynamics, the impact on Dissolved Oxygen (DO) depletion in the deep ocean water overlying the sediments must be evaluated (Rule 4.5.6). This necessitates employing a multi-box model

to simulate oxygen consumption at the sediment-water interface. Operations are strictly prohibited from causing hypoxic conditions ($\text{DO} < 60 \mu\text{mol/kg}$) or reducing deep-water oxygen by more than 30%, as such changes would critically compromise species survival and diversity (Rule 4.5.8).

Particle composition and breakdown behavior: The methodology requires full characterization of substrate particle composition, including material type, density, size distribution, and degradation pathways (Rules 3.6.1-3.6.6). Projects must demonstrate that particles degrade through natural biological and physicochemical processes without generating pollutants or toxic byproducts, and that degradation products are environmentally benign and consistent with naturally occurring organic matter fluxes to the seabed (Rules 9.4.12).

In depth Benthic Assessment: NIWA was commissioned to provide a desktop review of available and relevant benthic data and identify benthic species thresholds (e.g., to depleted dissolved oxygen or sedimentation/deposition of particulates), where they can be established, for Gigablue's area of interest (AOI) in the Bounty Trough. Their two reports, which are provided together with this document, cover the following:

1. Benthic data discovery
2. Review of international literature
3. Addressing specific questions
4. Predictive benthic species distribution modelling
5. Xenophyophore still image analysis

These reports further review peer reviewed scientific literature for limits on bottom-water dissolved oxygen (DO) drawdown and particulate deposition within the AOI. Their report establishes taxon-specific environmental thresholds based on the best available evidence for deep-water basin settings relevant to the AOI. The assessment evaluates the magnitude of dissolved oxygen reduction from background levels at which benthic impacts are likely to occur, alongside the rates of particle accumulation at which physical smothering may affect benthic communities. On this basis, the report concludes that a conservative dissolved oxygen threshold corresponding to a <20–30% reduction from background concentrations (i.e. avoiding dissolved oxygen levels below approximately $100\text{--}120 \mu\text{mol kg}^{-1}$, is appropriate), aligns with identified ecological sensitivities while remaining well above commonly used hypoxia thresholds ($\sim 60 \mu\text{mol kg}^{-1}$).

Oxygen Depletion modelling: To estimate the oxygen depletion caused by any potential (substrate fixed) biomass decomposition, we utilized a dissolved oxygen consumption model on sediment - water interface. This is a multi-box model that simulates the decay of fresh organic matter. The model tracks DO changes in a series of horizontally aligned boxes as water flows from upstream to downstream, where downstream DO concentrations depend on oxygen consumption in the preceding (upstream) boxes. The rate of DO consumption is governed by a differential equation that incorporates current velocity (through the box), incoming and ambient DO concentrations, organic matter degradation rate, and a half-saturation constant for oxygen uptake. The modeling results indicate that the worst-case deployment scenario does not pose a risk of generating any hypoxic conditions or causing detrimental damage to benthic ecosystems. Under an optimistic assumption of a 10:1 CO₂-to-substrate removal ratio, a modeled deployment of 10,000 tons of substrate was evaluated along a transect following the organic matter plume. In the baseline scenario, mixing within a 100m bottom boundary layer prevents significant dissolved oxygen (DO) depletion, maintaining concentrations close to background levels (~200 µM).

A more conservative scenario assuming slower water movement results in higher localized deoxygenation. However, even at the point of maximum impact, ~0.1 years after deployment, DO concentrations 150 km downstream do not fall below 198.9 µM, indicating only minimal deviation from background conditions. The modeled DO drawdown remains within acceptable limits, confirming that the proposed project activity is compliant with environmental safety objectives regarding dissolved oxygen depletion.

Planned research:

Future research aims to characterize the fate of exported substrates and associated carbon reaching the sediment and evaluate the changes in biogeochemical dynamics at the deep ocean water-sediment interface induced by MCFS substrate deposition. This will involve lab incubation experiments using deepwater from the AOI to study remineralization processes, including measuring DO consumption, DIC, and nutrient release, and remineralization rates.

In February 2026 a lab experiment, in collaboration with ESNZ, began to assess the effects of substrate that could potentially land on deep water corals. The experiment is evaluating whether the corals have the ability to disengage from the substrate (e.g. “shake it off”), and if not, how that would affect respiration and vitality. The experiment will also examine various oxygen threshold levels and their effect on coral vitality.

An in situ benthic chamber study will also be considered once the scale allows for effective tracking. To monitor DO changes, an in situ deep-sea long term monitoring experimental setup with a sensor array will be repeatedly deployed in the sunken plume area in a larger-scale operation to measure the effects of DO concentration changes over time, until replenishment, and any possible cumulative effects. Additionally, a desktop study will evaluate the possibility of a chemical reaction between the substrate and CaCO_3 in the sediment during remineralization that might lead to greater durability of carbon sequestration. Finally, a seabed study utilizing an observation system like the Deep Towed Imaging System will be used to confirm that the substrate reaches the sediments in the sunken plume area and facilitate macrofauna observation, with the images used to evaluate substrate density and additional carbon load on the sediments, comparing the results to model and lab estimations once the operational scale is sufficient for effective plume tracking.

- Potential farfield effects

The MCFS methodology requires evaluation of potential far-field effects to ensure that project-induced perturbations do not propagate beyond the AOI in a manner that could cause adverse environmental and/or economic impacts. For the MCFS activity, far-field effects are assessed using coupled physical and biogeochemical oceanographic modelling, supported by targeted monitoring, to evaluate downstream transport, dilution, and recovery timescales. These analyses show that changes in carbon chemistry, nutrient concentrations, or biological activity associated with the deployment are rapidly attenuated by advection, vertical mixing, and air–sea exchange, and remain spatially limited. In HNLC regions, macronutrient drawdown is quickly replenished by natural circulation and does not result in sustained nutrient redistribution or productivity changes at regional scales (see section 2.1 above for further details).

Our examination of various scenarios revealed that even in the worst-case scenario of a shallow Mixed Layer Depth (MLD) of ~20m, the reduction in macronutrient percentages from ambient values was minimal, less than 1% for all macronutrients. Given that the MLD in the AOI during October-February ranges from 20-60m, an even smaller relative reduction in macronutrient concentration is anticipated. It is also important to note that these low values are obtained after an unrealistic, instantaneous deployment of 10,000 tons of substrate (at once, as opposed to gradual). In practice, the deployment will be spaced out, temporally and spatially, allowing for the nutrient replenishment in (partially) depleted locations

The controlled nature of MCFS enables the implementation of deployment strategies (e.g. spatial and temporal spacing between deployments) designed to further minimize connectivity with sensitive downstream environments, ensuring that any effects remain transient, localized, and within the range of natural variability. A far field nutrient depletion assessment report that summarizes the modelling done can be provided upon request.

The operational planning approach for each deployment will incorporate a nutrient depletion model. This model will be used to adjust the deployment frequency, density and strategy, ensuring that environmental thresholds, including far-field nutrient depletion, are not exceeded.

Part 3. Social/Cultural impact:

- Economic impact analysis
 - Includes impact of manufacturing the particles
- Social impact analysis
 - Social licence to operate
 - Effects on existing interests
- Cultural impact analysis

The items specified in Part 3 are addressed in dedicated documents, provided together with this document.

Part 4. Monitoring:

- General short- and long-term monitoring of the activity and effects
 - Beyond general water sampling – including monitoring of marine communities and the seabed
- Seabed monitoring parameters
- In situ monitoring of effects at scale
- Inputs for modelling of effects

The following section provides a concise overview of the monitoring and sampling framework applied to the MCFS activity, covering both short and long term monitoring of project operations and environmental effects. The overview provided below addresses, at a high level, water-column monitoring beyond routine physico-chemical sampling, including observations of marine communities; in situ monitoring of effects at operational and spatial scales relevant to deployment; and the data streams used as inputs for modelling environmental effects. Full details of monitoring objectives, parameters, methods, frequencies, QA/QC procedures, and thresholds are provided in the “Monitoring plan” report and in the monitoring requirements specified in the MCFS methodology. Longer term developments and research driven monitoring enhancements are described in the attached “Research Plan”. Additional detail on the use of oceanographic modelling to support environmental monitoring and impact assessment is provided in Section 2.3 above.

The monitoring plan ensures the safety, eligibility, and precise quantification of carbon dioxide removals achieved under the MCFS methodology. Its objectives are to:

- i) maintain environmental and operational safety throughout all phases;
- ii) demonstrate that the project meets eligibility requirements;
- iii) quantify the amount of durable carbon removal with high precision through continuous measurement, sampling, and model validation.

Monitoring spans all stages from pre-deployment to post-deposition. The substrate is analyzed and characterized in the laboratory. Before loading, substrate is weighed and sampled to determine moisture content, providing an accurate dry-mass estimate. At sea, operations are coordinated between two vessels, one responsible for deployment and the other for measuring and monitoring the free-floating plume, sinking area, and control site.

The program uses a suite of oceanographic and environmental instruments to capture physical, chemical, and biological processes throughout the operation. A *CTD rosette* provides vertical profiles of temperature, salinity, oxygen, chlorophyll fluorescence, turbidity, and light penetration while collecting discrete water samples for laboratory analysis. *Plankton nets* and a *Multiple Opening/Closing Net and Environmental Sensing System (MOCNESS)* collect suspended and sinking particles to assess biomass composition, particle size, and export efficiency. A *scientific echosounder* tracks the distribution and vertical movement of the plume, complemented by *GPS drifters* that record surface currents and dispersion in real time. *Remotely operated vehicles (ROVs)* observe and measure the substrate’s sinking

velocity, while aerial drones capture surface imagery and document deployment and monitoring activities.

Sampling is conducted across multiple spatial and temporal scales at the control site, deployment site, plume area, and sinking site. These stations represent distinct zones for assessing baseline conditions, carbon fixation and export processes, and long-term storage in deep water. Temporal coverage includes background measurements before deployment, repeated sampling every 2–3 days during the fixation and export phases, and post-sinking sampling from in situ platforms and variation pens. A dedicated control (reference) site sampling establishes an *in-situ* baseline to ensure that observed carbon fixation and sinking are attributable to real-time project activities.

Water column and substrate monitoring combine in-situ instrumentation with discrete sampling. Sampling is conducted in adherence to standard oceanographic procedures. Vertical profiles from CTD casts are collected at each site and stage, with water samples analyzed for dissolved inorganic carbon, alkalinity, nutrients, and organic matter. Biological and substrate samples are analyzed to evaluate carbon content, biomass composition, and sinking dynamics. Biomass fixed samples will undergo analysis by third-party laboratories post deployment. Each analyzing laboratory will be accountable for the quality control (QC) of its respective analysis to ensure the precision of each method. Optical and acoustic measurements record plume structure and particle fluxes, with ROV and drone observations documenting spatial distribution and plume evolution.

All data, including sensor outputs, geolocation, sample metadata, and visual documentation, are uploaded daily to a centralized data management system shared by the operations and science teams. Laboratory analyses conducted onshore undergo the same QC process, comparing analytical and field results to maintain accuracy and internal consistency.

When the operation achieves a sufficient spatial scale, the seabed conditions and specific parameters will be examined (as outlined in the company's Research plan). The post-operation monitoring plan will include integration of a sediment in situ observation system. Furthermore, a long-term, deepwater monitoring setup will be implemented to monitor the dissolved oxygen (DO) dynamics of the plume generated by the sunk substrates.

Additional provided documentation

The following documents are provided together with this document:

- MCFS methodology by Puro.Earth
- Environmental Impact Assessment (prepared by Tonkin & Taylor)
- Monitoring plan
- Benthic data summary (prepared by ESNZ (NIWA))
- Review study of benthic thresholds for dissolved oxygen and particle deposition (prepared by ESNZ (NIWA))
- Oxygen depletion modelling report
- Durability report
- Research plan