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Quantification Methodology (MRV)

Version 1.0

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01. Statement of Intent

This protocol outlines the carbon quantification and net removal achieved through Blusink's technology. It provides a comprehensive overview of the theoretical underpinnings of our approach, the deployment methodology, carbon emission and capture quantification, potential leakage calculations, and an assessment of the system's durability. The primary objective of this document is to ensure transparency and demonstrate the robustness of the processes employed.

Blusink's technique builds on years of peer-reviewed research on rhodoliths, meticulously adapted to support the deployment of Blusinkies. The methodology aligns with industry best practices and is designed to account for all carbon emissions and capture activities. Furthermore, it details the mechanisms by which Blusinkies establish permanent carbon sinks on ocean seafloors, effectively capturing and sequestering atmospheric CO2 through natural processes.

The MRV methodology described herein can be used to quantify carbon capture/emissions for projects deployed on the ocean sea bed using Blusinkies. The basic principles are:

- Adding Blusinkies to the ocean seafloor will create the perfect substrate for carbon capture and storage species, especially coralline algae. Carbon will be then captured by the metabolic processes of these species and will be fixed into their structure - storing carbon for geological time periods.
- DIC consumption is quantified through a combination of in situ environmental measurements, benthic chambers analysis of the carbonate system on water samples, laboratory incubations and calcification rates.
- Project emissions are then removed from the total amount of carbon sequestered.

02. Context and Background

The ocean's carbon capture mechanism is a complex process that involves a variety of biological and chemical elements working simultaneously. These processes in the marine environment differ significantly from their terrestrial counterparts, notably in terms of monitoring and quantification. Unlike terrestrial ecosystems, where direct CO_2 measurements can provide useful data, this strategy is insufficient for oceanic systems because carbon dioxide accounts for just a small portion of the total carbon contained in seawater. This distinction is important because seawater contains many types of dissolved carbon molecules.

As a result, marine Carbon Dioxide Removal (CDR) projects must adopt a more comprehensive approach, focused on measuring and removing total dissolved inorganic carbon (DIC), which offers a more accurate depiction of the ocean's carbon concentration and removal potential.

02.1 Dissolved Inorganic Carbon (DIC)

DIC consists of carbon in three forms: Carbon dioxide (CO_2), bicarbonate (HCO_3) and carbonate (CO_3). The sum of those forms is the total DIC. When atmospheric CO_2 is dissolved in sea water, it will react forming carbonic acid as it shown in the following equation:

$$H_2O + CO_2 = H_2CO_3$$

Carbonic acid is a very unstable acid that quickly transforms into bicarbonate ion (HCO_3) and a proton. Then, part of the bicarbonate dissociates to form the carbonate ion (CO_3), as shown in the following equations:

$$H_2CO_3 \leftrightarrow HCO_3^- + H^+$$

$$HCO_3^- \leftrightarrow CO_3^{-2} + H^+$$

The protons released as carbonic acid transforms play a crucial role in the ocean's pH. As the number of protons increases, the ocean becomes more acidic. This process of ocean acidification occurs because when more CO_2 dissolves in ocean water, it increases the concentration of protons, lowering the pH through the reactions shown above.

Ocean water pH plays a crucial role in determining the concentration of different DIC forms, as the distribution of these species varies with pH levels. This relationship is clearly illustrated in the Bjerrum plot below.

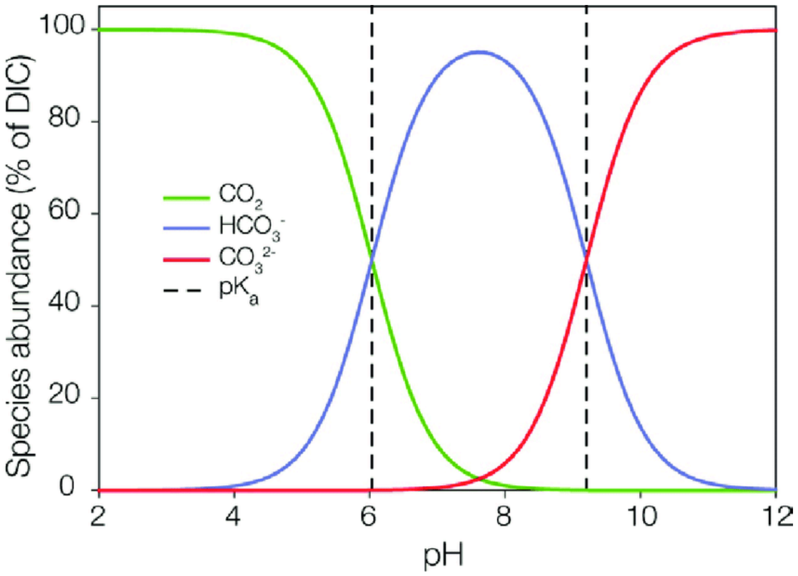

Figure 1. Bjerrum plot demonstrating the distribution of DIC species as function of pH

The Bjerrum plot shows that:

- pH values lower than 6 are dominated by the presence of carbon dioxide (CO_2) and some bicarbonates (HCO_3)
- pH values between 6 and 9 are dominated by bicarbonates (HCO_3)
- pH values greater than 9 are dominated by carbonates (CO_3)

Due to this variability, when analyzing CO_2 exchange between the atmosphere and ocean, it is important to measure total dissolved inorganic carbon rather than just CO_2 alone.

02.2 System Modelling

At Blusink, we employ a systems-based approach, viewing the ocean holistically as a system of interconnected reactions whose relationships must be evaluated as a whole. Our methodology measures the aggregate impact of these reactions to assess carbon dynamics, focusing on dissolved inorganic carbon (DIC). Our model encompasses four primary processes: photosynthesis, respiration, calcification, and dissolution.

Due to the complexity of marine ecosystems, we measure the total change in DIC through incubation chambers rather than attempting to measure individual reactions. This holistic analysis provides more meaningful results than examining isolated processes. The cumulative effect of these processes is the critical metric reflected in the change in DIC.

02.3 Calculating Net DIC Production/Consumption

We integrate system modeling outcomes, informed by our direct monitoring, with the principles of partial pressure to analyse the dynamics of CO_2 exchange between the atmosphere and the ocean. Partial pressure governs the diffusion of gases—specifically CO_2—across the air-sea interface, driving the system toward equilibrium by equalising CO_2 concentrations between the two mediums. This equilibrium underpins the continuous bidirectional exchange of CO_2 between atmospheric and oceanic reservoirs.

The integration of system modeling with partial pressure dynamics produces two key outcomes:

1. **Net Dissolved Inorganic Carbon (DIC) Production:** When system processes result in a net increase in DIC, the partial pressure of CO_2 in seawater surpasses that of the atmosphere. This imbalance drives CO_2 outgassing from the ocean to the atmosphere to restore equilibrium.
2. **Net Dissolved Inorganic Carbon (DIC) Consumption:** Conversely, when system processes lead to net DIC reduction, the partial pressure of CO_2 in seawater falls below atmospheric levels. This creates a gradient that facilitates CO_2 absorption from the atmosphere into the ocean, thereby reducing atmospheric CO_2 concentrations.

Blusink's strategy focuses on improving and optimising natural DIC sequestration processes through careful engineering and reconstruction of seabed habitats. We accomplish this by strategically and systematically planning optimal colonization of our Blusinkies by carbon capture and storage species, specially coralline algae which will later form rhodolith beds. **The Blusink system has consistently demonstrated the second outcome above, effectively removing CO_2 from the atmosphere.**

03. Our System

Blusink creates oceanic carbon sinks by leveraging targeted interventions in natural processes to enhance carbon sequestration. By understanding and optimising the natural behaviors of marine organisms, we amplify their capacity for carbon capture and storage, focusing primarily on the ocean seabed.

03.1 System Overview

Our approach involves the use of **Blusinkies**, small, bioengineered rock pebbles produced from construction industry debris and other responsibly sourced materials. These pebbles act as settlement substrates for benthic organisms on the ocean floor, particularly species that play a significant role in carbon capture and storage. Blusinkies facilitate carbon sequestration through two primary mechanisms:

1. **Carbonate Mineral Chemistry**:
   Blusinkies contain carbonate minerals that interact with seawater to capture carbon via a chemical liming process. This reaction lowers DIC through a decrease in bicarbonate, a decrease in CO_2 and an increase in carbonate. This results in an increase in the pH of the surrounding water, enhancing the ocean's buffering capacity and promoting the uptake of dissolved inorganic carbon (DIC).
2. **Biological Carbon Capture**:
   Coralline algae are especially attracted to the Blusinkies' surface, where they act as effective CO_2 sinks. Coralline algae are a unique group of red algae (Rhodophyta) that differ significantly from the typical perception of algae as slimy, free-floating organisms. Instead, coralline algae are hard, calcareous, and often encrusting, forming rigid structures that visually resemble coral more than traditional algae. They are widespread in marine environments, especially in shallow waters (though they exist from 0-300m), and play a critical role in reef ecosystems and ocean carbon cycling. Through their metabolic processes, these coralline algae capture carbon and store it within their calcareous structures, which remain stable over geological timescales. Their physical structure makes them resistant to change in their environment and unlike green algae, they do not degrade easily.

Blusinkies achieve nearly complete colonisation by benthic organisms within 8 to 10 months of underwater deployment. During this initial period, a diverse array of organisms establishes itself on the substrate, creating the conditions necessary for coralline algae colonisation. While carbon capture begins immediately through the mineral chemistry route, peak efficiency is achieved after the tenth month, when the abundant coralline algae transform Blusinkies into highly effective carbon capture units. This process reduces DIC in the surrounding seawater, stores carbon in the structures of the Rhodoliths and alters the ocean's partial pressure of CO_2, driving the absorption of atmospheric CO_2 to restore equilibrium.

Durability, or the duration for which carbon remains sequestered, is a critical aspect of Blusink's carbon removal solution. The carbon captured by Blusinkies is stored on geological timescales (thousands of years), ensuring minimal risk of re-emission into the atmosphere. This exceptional stability is achieved as carbon becomes permanently integrated into the calcareous structures of coralline algae. Over time, these structures transform into distinctive pink "living rocks," serving as long-term carbon repositories and providing a highly durable and reliable store for atmospheric CO_2 removal.

03.2 System Design and Operation

A Blusink project follows a structured lifecycle designed to ensure environmental integrity, effective carbon sequestration, and local community engagement. Each project progresses through the following key stages:

1. **Project Assessment & Definition** – We work with clients and project sponsors to assess the suitability of a potential project, defining objectives, scope, and expected outcomes.
2. **Feasibility Studies** – Small-scale test deployments (typically 200–400 Blusinkies) are conducted to evaluate site productivity and gather preliminary data.
3. **Baseline Assessment** – A comprehensive evaluation of environmental conditions is performed, establishing a reference point for measuring project impact.
4. **Site Selection** – Based on feasibility and baseline data, we determine the most suitable location for full-scale deployment, in collaboration with project stakeholders.
5. **Material Sourcing & Manufacturing** – Raw materials are sourced from sustainable waste streams, and Blusinkies are manufactured using local industrial infrastructure where possible.
6. **Local Employment & Community Engagement** – We prioritize hiring and training local workers to support project operations, fostering economic benefits within the deployment region.
7. **Transport & Logistics** – Blusinkies are transported to the deployment site via terrestrial, maritime, or aerial transport, depending on location constraints.
8. **Deployment** – Blusinkies are placed on the seafloor through diving teams for small-scale deployments and specialized vessels for large-scale projects.
9. **Monitoring & Quantification** – Post-deployment, we conduct in-situ environmental monitoring, regular site assessments, and Blusink incubations to track performance and validate carbon sequestration.

Below we detail our methodology for the main stages of this process, starting with the manufacturing process which is fairly project agnostic, before moving on to deployment, monitoring and quantification. We conclude this section with a discussion on how we assess durability of the carbon stored during our products and how we handle and quantify risk and uncertainty.

03.2.1 Manufacturing

Through extensive research and development, we have engineered a biomaterial that replicates the complex chemical composition and physical characteristics of natural substrates where coralline algae achieve optimal settlement rates. Each component of our Blusinkies is purposefully selected and integrated to maximise the potential for species colonisation. To uphold our commitment to environmental sustainability, we source raw materials from construction industry waste streams as much as possible, eliminating the need for environmentally harmful extraction processes. By partnering with responsible local industries in deployment areas, we secure a stable supply of materials while aligning procurement and processing with project demands, thereby minimising waste and storage requirements.

Our manufacturing infrastructure is designed for flexibility, enabling operations to be established in locations with existing brick or ceramic industry facilities. This adaptable approach enhances production efficiency and fosters local economic development by creating sustainable employment opportunities, transforming traditional carbon-emitting industrial roles into environmentally conscious alternatives. At present, we have assumed that such factories are fossil-fuel burning and have factored this into our lifecycle impact assessment (LCA). Over time we hope to establish our own facilities which will be run on renewable energy and will therefore reduce our LCA ratio even further.

Through the implementation of standardised operating procedures and systematic quality evaluations, our production system ensures that Blusinkies are consistent in chemical and physical properties, allowing us to effectively control substrate variability during sampling. While biological factors such as colonization rates and the diversity of settling organisms are inherently variable, we have developed advanced methods to systematically analyze and categorize these variations. This rigorous approach ensures the reliability and scalability of our solution while maintaining its ecological integrity.

03.2.2 Deployment

03.2.2.1 Feasibility Assessments and Baselining

We work closely with our clients and project leads to determine the suitability of potential deployment sites through rigorous feasibility studies. These assessments are essential in ensuring that Blusink deployments are both effective and environmentally appropriate - and we will not deploy a project without first having quantified the site's suitability. When multiple site options are available, we conduct feasibility studies for each potential location to identify the most promising areas for successful carbon sequestration and/or marine habitat recovery.

As part of our feasibility study, we conduct a small-scale test deployment of Blusinkies, typically placing 200–400 units in the target area(s) and leaving them for a trial period of 3-6 months. This allows us to evaluate the site's productivity and assess how effectively the Blusinkies support carbon capture and storage species.

Additionally, we perform detailed environmental measurements of the wider area to establish a Baseline Scenario, providing a crucial reference point for future monitoring and impact assessment. Our scientific team conducts a detailed evaluation of the seabed characteristics where Blusinkies will be placed. Dependent on the scale of the project, this can include:

- **Large imaging analysis** to document the ocean seafloor's three-dimensional structure and composition
- **Biodiversity assessments** to record and quantify existing marine organisms in the area
- **Physical and chemical environmental measurements** to determine site suitability for the colonisation process. Key variables include:
    - **Temperature** – crucial for assessing which organisms are present and the metabolic activity of calcifying organisms, we take temperature measurements at different depths using calibrated sensors
    - **PAR (Photosynthetically Active Radiation)** – evaluates light availability, essential for photosynthetic marine species
    - **Salinity Levels** – using a refractometer, ensuring conditions are within the optimal range for Blusink's marine carbon sequestration process
    - **Total Alkalinity** - allows us to assess the ocean's buffering capacity and its ability to support calcification processes, as well as to track

    potential shifts in carbonate chemistry that influence long-term carbon sequestration
  - **Type of Substrate -** Identification and documentation of substrate types (e.g., sand, rock, coral gravel) by visual inspection
  - **Depth** - measurement of site depth
  - **Sedimentation** - visual assessment and/or if necessary measurement with sedimentation tramps

The Baseline Scenario is intended to be a comprehensive assessment of the environmental conditions in the deployment area before full project implementation. It serves as a critical benchmark, enabling us to quantify changes over time and accurately attribute them to project activities. To ensure consistency and reliability, the variables monitored during the baseline assessment precisely match those that will be tracked throughout the project's duration. Data is carefully collected and stored for further analysis.

03.2.2.2 Site Selection and Deployment Refinement

Following the feasibility studies, we select the preferred deployment site based on the findings from our test deployments and baseline assessments. We then collaborate closely with project stakeholders to conduct comprehensive environmental impact assessments (EIAs) and risk assessments, ensuring that our deployment aligns with ecological best practices and regulatory requirements.

Selecting an appropriate area for Blusink deployment is a crucial step for assuring maximum carbon capture. Because our target organisms, coralline algae, are photosynthetic, we prefer to work in areas that we know will optimise this process. We use the measurements taken during the feasibility study (detailed above) and determine the suitability of the site based off of these. The following points outline the optimal parameters for the colonisation, growth, and survival of Blusinkies, taking into account the characteristics of rhodoliths.

- Light availability: Rhodoliths are photosynthetic organisms and require sufficient light for their survival and growth.

  - *Ideal parameters*: Rhodoliths require moderate to high light intensities for optimal growth. The ideal light intensity may vary among species, but a range of 50 to 200 µmol photons $m^{-2}s^{-1}$ is often considered suitable.

- Low sedimentation: Rhodoliths thrive in environments with minimal sedimentation. High sediment levels can obstruct light penetration and create oxygen-depleted conditions, impeding gas exchange.

    - *Ideal parameters*: Moderate sedimentation rates of 0.1 to 1 cm/year or approximately 0.001 to 0.01 mm/day are often considered favorable for rhodolith growth.

- Mixed substrates: Preferably mixed rocky/sandy substrates, although they can also inhabit soft substrates.
    - *Ideal parameters*: We´ve seen that the closest they are to a coral reef, the faster they get colonized. But this does not mean that it is exclusive of other habitats.
- Moderate water movement: Adequate water movement is crucial for rhodoliths. It helps remove particles from the surface layer, preventing excessive sediment deposition. Water movement also facilitates occasional rotation of the thalli, preventing sediment accumulation and ensuring light reaches all surfaces.
    - *Ideal Parameters*: Limited or low currents. Strong currents can make deployment more difficult and there is a higher probability of losing Blusinkies over time.
- Full submersion: Rhodoliths cannot tolerate extended periods of emersion and require a consistently submerged habitat as they are highly sensitive to desiccation. Low tides or exposure to air can be detrimental to their survival.
    - *Ideal Parameters*: Fully submerged underwater
- No organic input and heavy metal pollution from sewage discharges: Rhodoliths are highly susceptible to the negative effects of organic pollution and heavy metals present in sewage discharges. These pollutants can be toxic to the organisms and can result in mortality and a decline in maerl beds.
    - *Ideal Parameters*: Low organic input specially from sewage discharge
- Avoidance of muddy sand containing hydrogen sulfide: Rhodoliths cannot survive in muddy sand environments that contain hydrogen sulfide. Exposure to such conditions can lead to their death within two weeks.
    - *Ideal parameters*: No hydrogen sulfide

As a general rule, areas with high temperatures, low depth and a lot of light availability are preferred.

Using the data collected during baseline monitoring, we refine our projected carbon sequestration estimates, incorporating site-specific environmental variables to enhance the accuracy of our forecasts. We also use the data to determine the appropriate density of Blusinkies. We have standardised specific quantities of Blusinkies for different substrate types to avoid interfering with organisms that already capture carbon and maintain their natural ecological roles. While Blusinkies can be placed on any substrate, the required quantity varies by location. Here is our placement guide by substrate type:

Density Blusinkies	Amount in a square meter	Types of substrate
High	80-100	> 60% of Sand Coverage > 50% Damaged sea floor > 40% Coral Rubble Rocky substrate
Medium	75-100	> 60% Presence of coral reefs
Low	25-70	Seagrasses > 80% Presence of coral reefs

Table 1. Calculation of required density of Blusinkies

03.2.2.3 Deployment Operations

Our deployments are carefully planned and executed to ensure maximum efficiency and environmental sustainability. We classify our deployments into two categories based on scale:

- **Small-Scale Deployments** (under 5,000 sqm / 0.5 ha)
- **Large-Scale Deployments** (over 5,000 sqm / 0.5 ha)

Small-Scale Deployments

For smaller sites, our deployments are conducted using diving teams who strategically place Blusinkies on the ocean seafloor. This hands-on approach utilises skilled diving teams to systematically place Blusinkies across designated sections of the ocean seabed. The complexity and scope of these deployments necessitates varying levels of time commitment and resource allocation, which are directly proportional to the total area being covered. The deployment process demands meticulous planning and execution, with resource requirements scaling according to the specific dimensions of each project area.

Large-Scale Deployments

For larger sites exceeding 5,000 sqm, we utilise specialised equipment to efficiently distribute Blusinkies across the designated area. This may include vessel-based deployment systems or customised underwater dispersal techniques, ensuring even coverage while minimizing disturbance to the marine environment. These larger deployments are carefully coordinated with project stakeholders to align with site-specific environmental conditions and logistical constraints. Following the initial deployment, qualified diving teams conduct strategic spot-checks to verify proper placement and distribution patterns. This hybrid approach combines the efficiency of mechanized deployment with quality assurance through expert verification. The complexity and scope of these operations require careful coordination between vessel operations and diving teams, with resource allocation scaling according to the total area being covered.

Regardless of scale, all deployments are guided by data-driven site selection, rigorous environmental assessments, and ongoing monitoring to ensure long-term carbon sequestration success.

03.2.3 Monitoring

To ensure the success and long-term effectiveness of Blusink deployments, we implement a comprehensive monitoring strategy that integrates in-situ environmental monitoring, periodic site assessments, and structured data collection protocols. This strategy enables us to track key environmental variables, validate carbon sequestration performance, and ensure the continued functionality of deployed sensors.

Initial Monitoring Phase (First 4–6 Months)

Immediately following deployment, we conduct continuous in-situ monitoring of environmental variables using high-precision sensors strategically placed at the deployment site. These sensors measure critical parameters that influence calcification and carbon sequestration processes.

The required number of sensors for any given deployment is determined through the analysis of two critical factors: first, the degree of environmental heterogeneity within the monitored area, which includes variations in topography, vegetation density, and microclimate conditions; and second, the total spatial extent of the deployment area, which influences the coverage requirements and spatial resolution of the monitoring network.

To maintain data integrity and sensor performance, our team performs regular maintenance checks at predetermined intervals throughout this initial phase. These checks involve:

- Calibration verification to ensure sensor accuracy
- Physical inspections to assess potential biofouling or mechanical issues
- Data integrity assessments to confirm proper recording and transmission

We have carefully selected the sensors that we specify use of through a rigorous evaluation process that considered multiple key performance factors. The primary selection criteria included their high degree of measurement accuracy for reliable data collection and extended battery autonomy for prolonged deployment periods. These technical specifications were balanced against cost considerations to ensure the sensors remained within a moderate price range, making them a practical choice for large-scale deployment while maintaining high quality standards.

Sensor	**Specifications**
PAR	Odyssey XTREEM PAR Data Logger with Wiper
Temperature Data Logger	Odyssey Xtreme Temperature Logger ● Resolution: +/-0.01°C ● Accuracy: +/-0.1°C

Table 2. Specifications for in-situ monitoring sensors

Ongoing Monitoring and Long-Term Assessment

After the initial monitoring phase, we return to the site at a minimum of once per year, with an ideal frequency of every six months, to conduct further assessments. These visits include:

- Blusink incubations to quantify carbon sequestration performance (see Quantification section below)
- Sensor maintenance and recalibration to ensure continued data collection
- Environmental assessments to track changes in key variables over time
- Large imaging analysis to document restoration efforts - change in the three-dimensionality of the seafloor

This structured approach ensures that our monitoring efforts remain consistent, reliable, and adaptable, allowing us to refine our models and improve future deployments based on real-world data.

03.2.4 Quantification

To accurately assess the carbon sequestration potential of Blusinkies, we employ a rigorous, multi-tiered quantification approach that combines laboratory incubations, benthic chamber assessments, and statistical analyses. This methodology enables us to measure both individual and community-level carbon fluxes while ensuring robust and replicable results across all project sites.

3.2.4.1 Laboratory Incubations for Individual Blusinkies

During the first monitoring round post-deployment, we randomly collect a minimum of 10 colonised Blusinkies to assess their carbon capture behavior under controlled laboratory conditions. These incubations provide a proxy for consumed DIC and calcification rates and help establish baseline estimates of carbon uptake.

Incubation Procedure

- Blusinkies are cleaned with a soft brush to remove epiphytes while preserving their calcified structure.
- Incubations are conducted using filtered seawater (0.45 µm) in custom-made, water-jacketed plexiglass chambers (V = 150 mL) with internal mixing via magnetic stirrers.
- Temperature control is maintained at the field-recorded temperature using a circulating water bath.
- Dark respiration rates (R) are first measured under dark conditions, followed by incubations at incrementally increasing light intensities to assess photosynthetic calcification.
- Water samples are collected at the beginning and end of each incubation, preserved with $HgCl_2$, and stored in borosilicate tubes (V = 25 mL each) for Total Alkalinity (TA) analysis.

Calcification Rate Determination

The calcification rate (G) on each Blusinky are determined using TA measurements of seawater samples before and after each incubation. For TA measurements, duplicate analyses of each sample will be performed, using the Gran titration method. This experimental proxy aims to illuminate the behavior of the data, revealing insights into their mean, variability, and standard deviation.

$$G\ (\mu Mol\ CaCO_3\ g^{-1}\ DW\ h^{-1}) = (\Delta TA * V) / (2 * DW * t)$$

Where:

- **DW** = Dry Weight (g)
- **V** = Chamber Volume (L)
- **t** = Incubation Time (h)
- **TA** = Change in Total Alkalinity (meq. L^{-1})

Dry Weight Determination

To standardize calcification rates, an additional minimum of 10 Blusinkies are dried at 60°C for 48 hours and weighed to determine dry weight (DW), ensuring consistency in comparative analyses.

Total Dissolved Inorganic Carbon (DIC) Flux for Individual Blusinkies

DIC concentrations are estimated using the CO_2SYS macro in Excel, with pH, TA, temperature, and salinity as inputs.

$$DIC\ Flux\ individual\ Blusinky\ (\mu Mol\ C\ g^{-1}\ DW\ h^{-1})\ =\ [(\Delta DIC\ *\ V)\ /\ (DW\ *\ t)]$$

Where:

- **DIC** = Change in DIC concentration during incubation (Mol L^{-1})
- **DW** = Dry Weight (g)
- **V** = Chamber Volume (L)
- **t** = Incubation Time (h)

Power Analysis for Sample Size Optimisation

To ensure statistical robustness, we conduct a power analysis with the results from the 10 blusinkies used to determine alkalinisation to determine the minimum sample size required to detect significant carbon capture on a site-by-site basis. The analysis is performed with:

- Power = 0.8
- Significance threshold = 0.05
- Effect size derived from initial laboratory incubations

This prevents resource inefficiencies by avoiding over-sampling while ensuring sufficient data for meaningful comparisons over time.

3.2.4.2 Benthic Incubation Chambers for Community-Level DIC Flux

To quantify the broader ecosystem impact of Blusink deployments, we conduct benthic chamber incubations to measure DIC fluxes in the surrounding community of the Blusinkies (e.g. not just the species directly anchored to the Blusinkies).

Benthic Chamber Incubation Procedure

- Chambers (V = X mL) with internal circulation are deployed over areas containing Blusinkies.
- Incubations occur at different times of the day, with varying light intensities controlled by mesh layers, in order to create light dependent curves..
- Dark incubations are conducted to capture respiration rates over a full 24-hour cycle.
- Water samples (X mL) are collected post-incubation, immediately analyzed for temperature, dissolved oxygen, and salinity, and stored in borosilicate bottles fixed with $HgCl_2$.

Total DIC Flux for the Community

DIC concentrations are estimated using **CO_2SYS**, with the following formula:

$$DIC\ Flux\ Community\ (\mu Mol\ C\ g^{-1}\ DW\ h^{-1})\ =\ [(\Delta DIC\ *\ V)\ /\ (DW\ *\ t)]$$

Where:

- **DIC** = Change in DIC concentration (Mol L^{-1})
- **DW** = Dry Weight (g)
- **V** = Chamber Volume (L)
- **t** = Incubation Time (h)

3.2.4.3 Estimating Total DIC Flux for the Project Area

To scale up individual and community measurements to the entire deployment site, we use a multi-step extrapolation process:

Estimating DIC Flux in the Baseline Scenario

We first calculate the DIC flux contribution from non-Blusinky organisms in the community:

$$DIC\ Flux\ (baseline\ scenario)\ =\ DIC\ Flux\ (Community)\ -\ n\ *\ DIC\ Flux\ (individual\ Blusinky)$$

Where:

- n = Number of Blusinkies in the incubation area

Estimating Total DIC Flux for the Incubation Area

$$Total\ DIC\ Flux\ (incubation\ area)\ =\ n\ \ *\ DIC\ Flux\ (individual\ Blusinky)\ \ +\ DIC\ Flux\ (baseline\ scenarios)$$

Scaling to the Full Project Area

Finally, we extrapolate results to the **entire deployment site**:

$$Total\ DIC\ Flux\ (project)\ =\ a\ \ *\ \ Total\ DIC\ flux\ (incubation\ area)$$

Where:

- a = Total project area

This comprehensive quantification approach ensures that we accurately measure and validate the carbon sequestration potential of Blusinkies. By integrating laboratory incubations, benthic chamber studies, and rigorous statistical analyses, we create a scientifically robust framework for assessing and verifying carbon uptake across all Blusink projects.

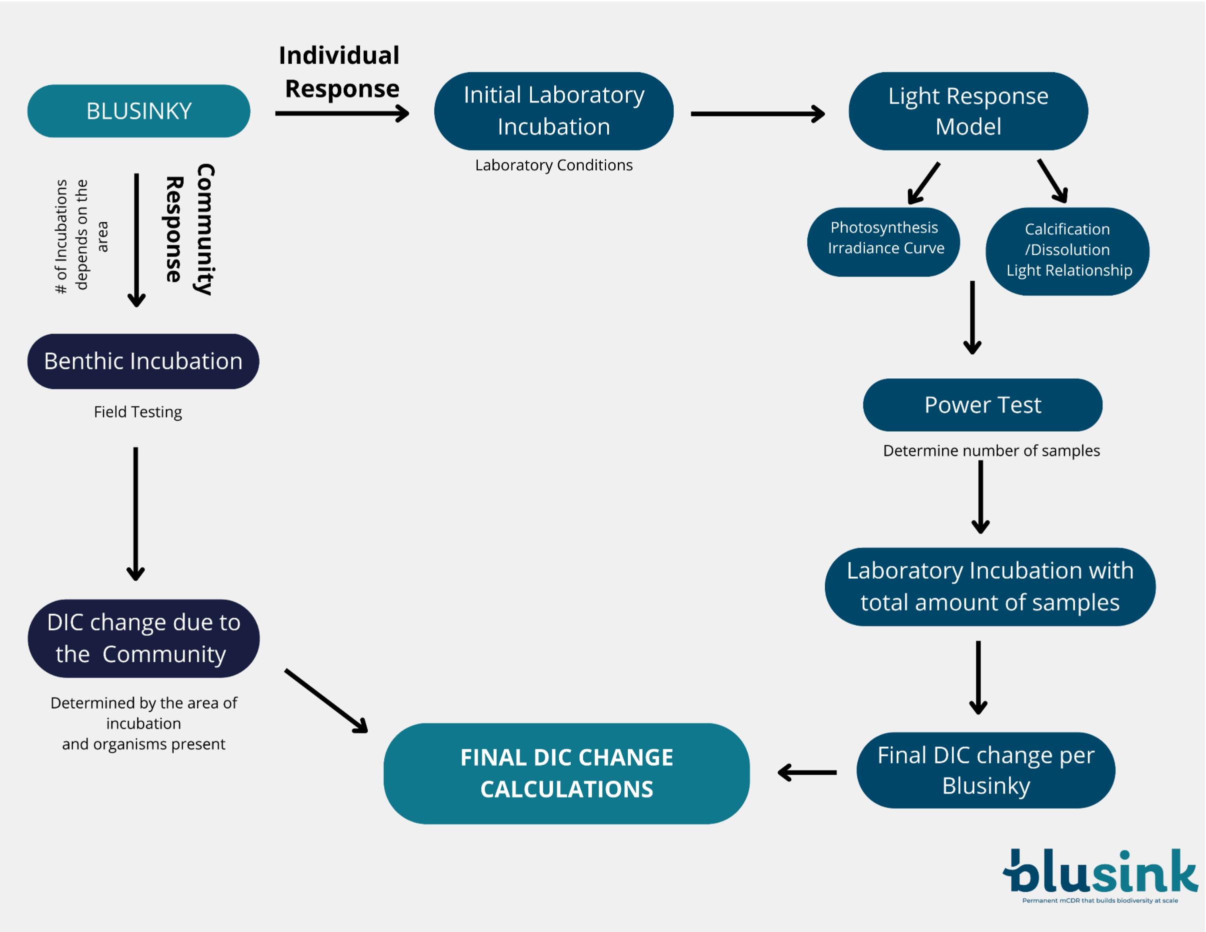

Figure 2. Carbon quantification overview

03.3 System Durability

Durability refers to the length of time carbon remains stored and continues to deliver its reduction benefits. For Blusink's projects, the durability of carbon storage is directly tied to the calcium carbonate structures created by Blusinkies, which ultimately transform into rhodoliths. Based on existing research and geological records, we believe the carbon stored through Blusink's technology remains sequestered for, at minimum, centuries and could be stored for several millennia, as outlined below:

Long-Term Storage Potential

- Rhodolith Longevity: Rhodoliths are long-lived organisms. Some individuals have been documented to survive for over a century, with fossil evidence revealing rhodoliths as old as 8,000 years in Scotland (Costa et al., 2023).
- Slow Growth Rates: Rhodoliths incorporate carbon into their calcium carbonate structures gradually over time, ensuring carbon is sequestered in a stable form for extended periods.

Geological Evidence of Stability

- Geological records indicate that rhodolith deposits have been stable for thousands of years, further supporting the idea that these structures can serve as long-term carbon sinks (Aguirre et al., 2017). This durability is enhanced by the chemical and physical stability of calcium carbonate under typical oceanic conditions.

Resistance to Extreme Conditions

- The coralline algae producing the calcium carbonate structures, such as those contributing to rhodolith formation, are notably more stable and resistant to extreme environmental conditions (e.g., elevated temperatures) compared to other algal types, such as Laminariales (kelp and seaweed). This resilience reduces the likelihood of carbon reversal due to environmental changes, enhancing the durability of the storage.

Currently, we rely on existing research to estimate the durability of carbon sequestration in our system. Once larger Blusink deployments are available for observation, we plan to validate these assumptions through comprehensive monitoring of dissolution rates under varying environmental conditions on a project-by-project basis. Additionally, we will employ ocean chemistry modeling to account for saturation states relative to calcium carbonate, ensuring a robust assessment of long-term carbon storage durability.

03.4 System Uncertainty

Blusink is committed to transparent and rigorous uncertainty reporting in accordance with best practices for carbon removal projects. Our approach ensures that all key variables used in the net CO_2e removal calculation are systematically measured, analyzed, and reported, with a detailed uncertainty analysis to enhance the credibility and reproducibility of our results.

Key Variables and Required Measurements

We provide a comprehensive list of key variables used in our net CO_2e removal calculations, including:

- **Direct measurements from laboratory incubations and field monitoring**
    - Total alkalinity (TA) changes
    - Dissolved Inorganic Carbon (DIC) flux
    - Dry weight (DW) of Blusinkies
    - Temperature, salinity, and pH levels
    - Light intensity and respiration rates
- **Model-derived parameters**
    - Carbon flux extrapolations from small-scale incubations to full deployment sites
    - Sensitivity studies on environmental factors affecting calcification
- **Process instrumentation measurements**
    - Material weights from transportation and deployment logistics
    - Energy consumption from deployment operations
    - Any emissions associated with material processing and transport
- **Laboratory analyses**
    - TA and DIC analysis via titration and CO_2SYS calculations
    - Biomass composition assessments
    - Analysis of feedstocks for any synthetic materials used in Blusinkie production

For each of these variables, measurements will be taken in triplicate and average will be used. In addition minimum and maximum values will be reported as potential variance, along with associated measurement uncertainties.

Uncertainty Analysis Approach

To quantify uncertainty in our net CO_2e removal estimates, we apply a multi-layered uncertainty analysis:

- **Measurement Uncertainty:**
    - For all laboratory and field measurements, we report instrument precision, calibration errors, and standard deviations.
    - For TA and DIC analyses, we include uncertainty estimates from titration and CO_2SYS modeling.
- **Model Uncertainty:**
    - We conduct ensemble simulations and alternative sensitivity studies to evaluate variability in model outputs.
    - Model skill is quantified through data-model comparisons, using field data from incubations to validate modeled carbon fluxes.
- **Emission Factors:**
    - Any emission factors used in our calculations (e.g., transport emissions, energy use) will be sourced from publicly available databases and reported with their respective uncertainty ranges.
- **Process Instrumentation Data:**
    - We integrate measured operational data (e.g., transport weights, energy use) into uncertainty calculations to ensure accuracy in net CO_2e removal estimates.

Sensitivity Analysis

To assess the impact of input parameter uncertainty on the final net CO_2e removal estimate, we conduct a sensitivity analysis that:

- **Quantifies the contribution of each variable's uncertainty** to the overall removal uncertainty.
- **Excludes input variables contributing <1% change** to net CO_2e removal, in accordance with best practices.
- **Provides details of the sensitivity analysis method**, ensuring full reproducibility by third parties.

03.6 Project Risk Mitigation

Blusink conducts comprehensive environmental risk assessments tailored to each project site to ensure responsible deployment of its carbon sequestration technology. These assessments address potential risks associated with sourcing, production, preparation, storage, and distribution of materials, including impacts such as land degradation, deforestation, watershed contamination, and other land-use concerns. To minimise these risks, we ensure that all materials used in the production of Blusinkies adhere to our environmental and sustainability standards.

For marine environmental risks, we evaluate site-specific conditions to account for potential impacts of its deployment on ocean chemistry and ecosystems, using data gathered during our site feasibility and selection process. This includes monitoring for changes in carbonate chemistry that may influence other calcifying organisms, shifts in pH, and nutrient availability. The risk of ecosystem disruptions, such as altered biological productivity or community composition, is carefully assessed, and the suitability for deployment of Blusinkies (including whether their expected productivity in the area) is decided.

Our environmental risk assessments are conducted within the broader context of dynamic ocean environments, recognising the challenges of defining baselines and attributing causation for observed changes. Our evaluations typically consider the necessity of carbon sequestration to address climate change, ensuring that potential impacts are minimised and contributions to ecological benefits are maximised.

In addition to the feasibility risk assessment, we also develop a plan for each project that addresses:
- Information sharing protocols and strategy for stakeholder engagement - which should be ongoing for the duration of the project
- Emergency response for example if monitoring shows that a Blusink deployment is disrupted by a storm
- Conditions for stopping or pausing monitoring of a deployment.

03.7 System Reporting Period

The reporting period for Blusink projects is defined as the interval during which carbon removals are calculated, monitored, and reported for verification. For all deployments, the reporting period begins one year after deployment and extends to four years post-deployment. This timeframe applies consistently across all projects, as each deployment is treated as a discrete unit with clearly defined boundaries.

Our solution is inherently self-sustaining, meaning carbon capture will continue well beyond the designated reporting period without requiring additional intervention. However, this defined interval ensures the reliability of carbon capture forecasts by focusing on the early, most measurable stages of sequestration.

During the reporting period, all greenhouse gas (GHG) emissions associated with project activities are accounted for. This includes:

1. Emissions related to the establishment and deployment of Blusinkies allocated to the reporting period.

2. Emissions occurring directly within the reporting period from any operations or monitoring.
3. Anticipated emissions post-reporting period, allocated to the reporting period as necessary.
4. Leakage emissions that occur outside the project boundary but are attributable to project activities.

Carbon removal is calculated using a combination of direct measurements and calculations (CO_2SYS), ensuring accurate and transparent reporting. In future we hope to incorporate an adapted ocean-carbon flux model into our methodology to validate the chemical and biological carbon capture on a greater scale.

We expect the majority of removal credits to be issued ex-post, after verified carbon sequestration has been achieved.

04 Project lifecycle carbon assessment

04.1 Scope

This methodology is intended to cover all the activities that are in scope of a Blusink project deployment, specifically the fabrication of Blusinkies, their transport to the deployment area, deployment and monitoring activities. For consistency, carbon emissions are calculated for the production of 1,000,000 Blusinkies—the approximate quantity needed to cover 1 hectare.

Activity	**Category**	**Justification**
Sourcing of raw materials for creating the Blusinkies	Manufacture	Activity is a direct result of project
Transportation of the raw materials to Blusink´s factory	Manufacture	Activity is a direct result of project

Production of Blusinkies	Manufacture	Activity is a direct result of project
Transportation of Blusinkies into Deployment Area	Deployment	Activity is a direct result of project
Deployment activities	Deployment	Activity is a direct result of project
Monitoring	Monitoring	Activity is a direct result of project
Data processing	Monitoring	Activity is a direct result of project

Table 3. Blusink Processes in Scope of LCA

04.2 Calculations

04.2.1 Emissions from Manufacturing

In the production of Blusinkies, half of the raw materials come from industrial by-products that would otherwise end up in landfills. The other half consists of metamorphic and sedimentary minerals. These minerals are readily available, abundant in Earth's crust, and contain minimal levels of heavy metals.

Blusink's production process starts with sourcing raw materials that meet strict technical, mining, and environmental standards. The materials then go through dosing, mixing and homogenization, moistening, shaping, drying, firing, and classification. The table below represents the emissions of CO_2 at our current manufacturing facility. These calculations, specifically the natural gas requirement, will be adjusted for new manufacturing facilities, taking into account the number of Blusinkies produced (and therefore the tonne/production efficiency ratio).

Process	**Emissions CO_2 (tn)**
Transport of materials to manufacturing facility	Depends on where the manufacturing facility will be
CO_2 emitted by the natural gas combustion process	54.60 tn CO_2
CO_2 emitted by the decomposition of ingredient X	13.20 tn CO_2
CO_2 emitted by the decomposition of ingredient Y	14.32 tn CO_2
CO_2 emitted by the decomposition ingredient Z	7.17 tn CO_2
TOTAL CO_2/hectare	**89.29 tn CO_2**

Table 4. Current Manufacturing Carbon Emissions

$$CO_2\, released\ (manufacture) = 89,29\ tonnes\ CO_2 + CO_2\ emitted\ Transport\ Materials$$

04.2.2 Emissions from Transportation

Blusink minimizes CO_2 emissions by shipping Blusinkies from the manufacturing facility to deployment areas by terrestrial transport and/or boat. However, some deployment sites are on islands that can only be reached by airplane or boat. All these transportation methods are included in our transport carbon emissions calculations.

$$CO_2\, released\ (transport) = CO_2\ (terrestrial\ transport) + CO_2\ (boat) + CO_2\ (airplane)$$

04.2.3 Emissions from Deployment

Deployment carbon emissions include emissions from both internal terrestrial transport at the deployment site and type boat used for deployment.

$$CO_2\, released\, (deployment) \;=\; CO_2\, (\, terrestrial\, transport) \;+\, d \;\; * \;\; CO_2\, (\, deployment\; boat)$$

Where:

d = days required for deployment

04.2.4 Emissions from Monitoring

Monitoring carbon emissions include emissions from both internal terrestrial transport at the site and type boat used for monitoring

$$CO_2\, released\, (monitoring) \;=\; CO_2\, (\, terrestrial\, transport) \;+\, d \;\; * \;\; CO_2\, (\, monitoring\; boat)$$

Where:

d = days required for monitoring

04.2.5 Total Project Carbon Emissions

Total emissions are calculated by summing the CO_2 released from manufacturing, transport, deployment, and monitoring activities.

$$CO_2\, released\, (project) \;=\, h \;\; * \;\; (CO_2\, (manufacturing) \;+ CO_2\, (\, transport) \;\;+ CO_2\, (\, deployment)$$

Where:

h = number of hectares in the project

04.2.6 Project Net Carbon Emissions/

Net Carbon Emissions are calculated subtracting total project emissions from total DIC flux of the project:

$$Net\ carbon\ emission\ project\ = CO_2\ released\ (project)\ -\ Total\ DIC\ Flux\ (project)$$

4.3 Assessment of Leakage

Leakage, in the context of Blusink's methodology, refers to any unintended carbon dioxide (CO_2) emissions that are directly or indirectly caused by project activities but occur outside the defined project boundary. These emissions, while not part of the primary project scope, must still be carefully considered and monitored by Blusink as the responsible organisation.

The most significant leakage risk we are able to identify at present, which is not yet incorporated into our calculations, stems from the energy consumption and resulting emissions associated with data processing and storage for individual project reporting. This particular aspect of leakage remains unaddressed in our current framework, primarily because the computational power requirements remain minimal at our current scale and secondly because we are unable to track emissions associated with compute power due to the lack of granular emissions data provided by cloud service providers to organisations of our scale. This limitation arises from the providers' reporting practices, which typically aggregate energy usage and emissions data at a broader level, making it inaccessible for small-scale users like us.

We continue to advocate for greater transparency in emissions reporting and are exploring alternative approaches to estimate and account for these emissions in our assessments.

05. Conclusion

Blusink's Monitoring, Reporting, and Verification (MRV) framework has been designed to ensure scientific rigor, transparency, and accuracy in quantifying the carbon removal potential of our deployments. By implementing systematic monitoring, robust quantification methods, and comprehensive uncertainty analysis, we establish a credible foundation for evaluating the long-term impact of Blusinkies in marine ecosystems.

Our approach follows a structured project lifecycle, from feasibility assessments and baseline monitoring to deployment, long-term data collection, and carbon uptake quantification. We integrate in-situ environmental monitoring, laboratory incubations, and community-level assessments to generate precise carbon flux data, which is then used to extrapolate total net CO_2e removal at the project scale.

To uphold the integrity of our results, we apply rigorous uncertainty analysis, incorporating:

- Direct measurements from laboratory and field assessments.
- Model-derived calculations, validated through ensemble simulations and sensitivity studies.
- Process instrumentation data for tracking energy use, material transport, and deployment logistics.
- Statistical approaches, including power analysis and data-model comparisons, to ensure reliability.

Blusink's commitment to adaptive management and continuous improvement means that our MRV processes will evolve alongside technological advancements and scientific best practices. By maintaining transparent data reporting, reproducible methodologies, and third-party verifiability, we ensure that Blusink remains a trusted and effective nature-based carbon removal solution.

Through this MRV framework, we not only quantify the carbon benefits of Blusink deployments but also contribute to broader marine conservation efforts, habitat restoration, and sustainable economic opportunities for local communities. Our methodology provides a scalable and scientifically validated pathway for leveraging marine ecosystems in the fight against climate change.