eco engineers

Methodology: Carbon Dioxide Removal Through Algal Biomass Burial

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1. Methodology Description

This methodology, drafted in alignment with International Organization for Standardization (ISO) 14064-2:2019, provides rules for eligibility, means of quantification, monitoring instructions, reporting requirements, and verification parameters.

This globally applicable methodology aims to provide criteria and procedures for the quantification of greenhouse gas (GHG) reductions following the adoption of a nature-based biological carbon capture and sequestration (CCS) method using marine microalgal blooms. Credits generated for carbon sequestration will represent one metric ton of CO_2 removed from the atmosphere through controlled algal blooms and sequestered in dry tomb landfills for long-duration storage. The carbon content of the biomass is taken on a dry metric ton-basis and all credits issued are net of all identified project emissions. CO_2, CO, CH_4, and N_2O are the only GHGs considered for sources, sinks, and reservoirs (SSRs) and only biomass that is measured and buried as carbon dioxide removal (CDR) are credited.

This methodology encourages the enduring and low-cost storage of purpose-grown and waste biomass. It provides requirements to minimize leakage of fugitive gases, environmental impacts, remineralization of CO_2, and to anticipate future environmental changes.

The project activity must install and operate a new marine microalgal production facility where the associated GHG benefits are credited only for the CO_2 content that is sequestered within the algal biomass. The start date of the project is defined as the first instance of sustained microalgal production. Project proponents must begin validation within 12 months of the start date.

At the time of harvest, the rapidly growing cells should be separated from the seawater and rapidly processed and dried to prevent any form of bacterial remineralization, predation, or other ecosystem recycling. Filtered biomass is available for carbon sequestration. The extra-dry (>92% dry), hypersaline (>40% salt) biomass is then consolidated and buried in a shallow landfill on or close to the project site that is in an elevated area and protected from groundwater intrusion. Certain thresholds are provided in the methodology for the percentage of carbon derived from the dried biomass-salt composite (along with moisture, ash, and salt content). Biomass is quantified optically at the time of harvest; at the time of collection and consolidation before burial.[1] After burial, all fugitive gases (if there were any) are tracked, measured, and deducted from the budget. The landfill is lined and capped with a geomembrane, or similar barrier, to create a 'dry tomb' design. The durability of storage must be designed and monitored to ensure 1,000-year minimum stability of buried biomass (see Permanence section and Monitoring section). Boundaries of the discharge water impact are assessed at the point where the average pH value is pH 8.21, similar to pre-industrial pH.

Additional removals from the discharged seawater, while likely 25%-30% of total removals generated by this approach, are conservatively omitted from crediting while the open ocean system undergoes further study.

[1] Raffael Jovine, Deniz Ezra Kaya, Dicle Tez, Guy Hardwick & Hannane Ourrat: Durability of microalgal biomass in laboratory and field trials over time.

Multiple studies have confirmed[2,3,4,5,6] that, in dry conditions, hypersaline biomass does not degrade, nor does it generate any secondary gases.[7,8,9,10] The potential for reversals due to biogenic generation of methane is addressed by a) hyper-salinity of biomass beyond limits of biological productivity, b) consistent monitoring both during and after the project's crediting life cycle, c) low ambient humidity of project locations, and d) by physical separation of stored biomass above the levels of anticipated sea level rise within the next 1,000 years.

The methodology is applicable for projects in coastal deserts. An example of the workflow of CDR through algal biomass burial is as follows:

- Grow a strong, rapidly dividing inoculum of dense cells of endemic marine microalgae.
- Inoculate a small pond and fill it with seawater.[7]
- When the cells have been depleted of nutrients, add more seawater.
- When the pond's desired algal density is reached, transfer to the next larger pond and repeat the process.
- When the final pond in the sequence has reached its required algal density, separate the spent seawater from the biomass on the harvesting screens or filters.
- Evacuate seawater for natural atmospheric CO2 re-equilibration.
- Store dried algal biomass in the dry-tomb bio landfill.

[2] S. Sallon et al., Germination, genetics, and growth of an ancient date seed. Science 320, 1464 (2008), 10.1126/science.1153600.

[3] Fahmy A. G., Friedman R. F. (2008) Archaeobotanical studies at Hierakonpolis Locality HK6: The Pre and Early Dynastic elite cemetery, Archeo-Nil, 18:169- 183. https://www.archeonil.com/images/revue%202008%202010/AN2008-11-Fahmy%20et%20al.pdf

[4] Wetterstrom W., 1984. The Plant Remains. [in:] Wenke, R.J. (ed.) Archaeological Investigations at El-Hibeh 1980; preliminary report. Undena Publications, Malibu: 50-79 Bornkam R. & Kiehl H. 1989.

[5] Landscape Ecology of the Western Desert of Egypt. Journal of Arid Environment 17. 271-277.

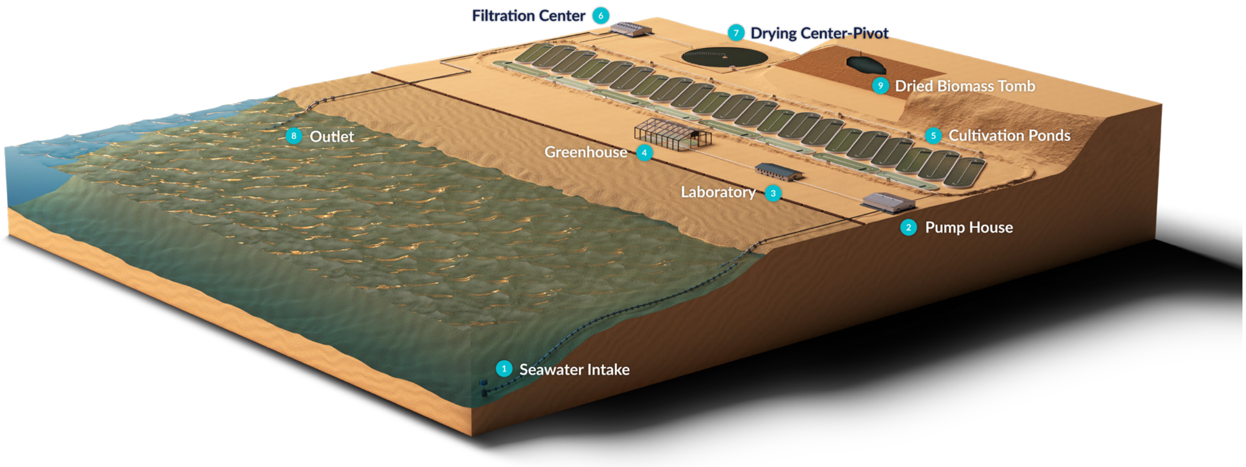
[6] Y. Yadin, The excavation of Masada–1963/64: Preliminary report. Israel Exploration J. 15, 1–120 (1965), https://www.jstor.org/stable/2792 5007.

[7] Yablonovitch, E., Deckman, H.W. (2023) Scalable, economical, and stable sequestration of agricultural fixed carbon, PNAS, 120(16) https://doi.org/10.1073/pnas.2217695120.

[8] Rezaei K., Jenab E., Temelli F. Effects of water on enzyme performance with an emphasis on the reactions in supercritical fluids. Crit Rev Biotechnol. 2007 Oct-Dec; 27(4):183-95. doi: 10.1080/07388550701775901. PMID: 18085461.

[9] Rupley, J. A., and G. Careri. 1991. Protein hydration and function. Adv. Protein Chem. 41:37–172.

[10] Finney, J. L. 1996. Hydration processes in biological and macromolecular systems. Faraday Discuss. 103:1–18.



The methodology draws on other aspects of currently available methodologies in the industry, as well as pilot CDR approaches that are not yet registered. Table 1 below provides an overview of those relationships and their relevance with regards to the specific phase of the technology used under this methodology.

Table 1: Relationship to other methodologies

Methodology	Overview	Relevance
Puro.earth - Woody Biomass Burial	Burying woody biomass under conditions that inhibit biomass decomposition and capable of maintaining those conditions for containment of stored carbon over at least 100 years.	Biomass storage. Not applicable to marine algal cultivation and burial.
Verra - In-situ Phytoremediation of Eutrophic River-estuary Systems (PENDING)	Biological carbon sequestration using microalgal technology. The idea is to emulate natural seasonal microalgal blooms with fast growth rates and high nutrient uptake, contributing to microalgal biomass production and accumulation.	Fast growth of microalgal blooms and high nutrient uptake. Not applicable to marine algal cultivation and burial.
Climate Action Reserve - U.S. Landfill Protocol	The installation of a system for capturing and destroying methane gas emitted from a landfill.	Landfill management, monitoring, leakage risks. Not applicable to marine algal cultivation and burial.
Planetary Technologies – MRV Protocol for OAE Carbon Removals	CDR via ocean alkalinity enhancement.	Under saturating seawater in CO_2 relative to air, thus forcing a CO_2 flux from the air to the ocean. Not applicable to marine algal cultivation and burial.

Clean Development Mechanism (2007) Small-Scale Methodology AMS-III.L:	Avoidance of methane production from biomass decay through controlled pyrolysis, version 2.0.	Methods for assessing biomass decay. Not applicable to marine algal cultivation and burial.
Clean Development Mechanism (2014) Small-Scale Methodology AMS-III.E:	Avoidance of methane production from decay of biomass through controlled combustion, gasification or mechanical/ thermal treatment, version 17.0.	Landfill monitoring and leakage addressing approaches. Not applicable to marine algal cultivation and burial.

The following has also informed the development of the methodology:

- Intergovernmental Panel on Climate Change (IPCC) Special Report on Carbon Dioxide Capture and Storage: Chapter 6-1 Ocean Storage.[11]

This methodology uses the latest versions of the following Clean Development Mechanism (CDM) tools:

- CDM (2017) Methodological Tool 03: Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion, version 03.0.
- CDM (2017) Methodological Tool 16: Project and leakage emissions from biomass, version 04.0.

All projects will receive independent verification following procedures outlined under ISO 14064-3:2019.

[11] https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_chapter6-1.pdf.

2. Definitions & Acronyms

Definitions applied:

Additionality	-	Additionality is used to distinguish the net benefits associated with an activity or project by comparison with what would have happened in the absence of the intervention.
Algal cultivation ponds	-	Raceway ponds with a central divider and with a paddlewheel or other propeller that maintains the algal cells in suspension and prevent settling.
Deep seawater	-	Seawater from below the mixed layer depth that has been brought to the surface or near-surface because of upwelling.
Drying facility	-	Solar drying facility is a simple collection surface, with a sprayer/mister, to spray the algal slurry onto the prepared surface. The algae dry while suspended in the air as a mist and may further dry when settled on the ground.
Embedded emissions	-	Emissions that are associated with the entire lifecycle of a system within a defined scope. This includes scope 1, 2 and 3 emissions for the construction of a system facility, its operation, and finally its decommissioning.
Greenhouse	-	Clean algal cultivation environment with small ponds, protecting the daily seed culture while it transitions from laboratory to outdoor ponds.
Harvesting facility	-	Filters or other mechanisms that separate the microalgal biomass from the pond cultivation water.
Laboratory	-	Cultivates small quantities of microalgal organisms locally isolated ‘production strains’ to prepare a fresh unialgal inoculum of the growth system.
Biolandfill	-	Appropriately designed facilities designed to receive and store dry biomass, also meaning biomass-salt composite storage site or desert burial system.
Remote audit/ assessment	-	Remote audit refers to the use of Information and Communication Technology to gather information, interview an auditee, etc., when ‘face-to-face’ methods are not possible or desired (ISO 19011).
Seawater deacidification	-	Since the microalgae consume acidic CO_2 and bicarbonate (HCO^3) and bind this in their biomass they de-acidify the seawater and increase the pH of the discharge water.
Seawater discharge	-	Deacidified, oxygen-rich effluent with low biological oxygen demand
Seawater intake	-	The seawater intake pipe placed on seafloor with an intake riser system or other appropriately designed high throughput seawater intake system.
Upwelling		Process of deep, cold water rising toward the surface of the ocean.

Acronyms applied:

CDR		Carbon dioxide removal
CO_2e	-	Carbon dioxide equivalent
EIA	-	Environmental impact assessment
GWP	-	Global warming potential
CDM	-	Clean Development Mechanism
ISO	-	International Standard Organization
E&S	-	Environmental and social
ESIA	-	Environmental and social impact assessment
GHG	-	Greenhouse gas
HDPE	-	High density polyethylene
IFC	-	International Finance Corporation
I&AP	i	Interested and affected parties
KPI	-	Key performance indicator
LCA	-	Life-cycle assessment
MRV	-	Monitoring, reporting and verification
NPP	-	Net primary productivity
SSR		Sources, sinks and reservoirs

3. Applicability Conditions

The project activity will install and operate a new marine microalgal production facility where the associated GHG benefits are credited only for the CO_2 content that is sequestered within the algal biomass permanently stored on land. The project may involve systems exclusively tailored for biomass burial, or systems that include beneficial use or commercial products from the cultivated biomass.

The project activities for this methodology are only applicable under the following conditions:

1. Project makes use of seawater (this would normally be in a coastal area).
2. Project cultivates marine microalgae only (not macroalgae or freshwater microalgae).
3. Biomass production uses seawater from below the mixed layer depth as feedstock.
4. Deacidified effluent is discharged into an appropriate coastal location for CO_2 re-uptake.
5. Only endemic or independently certified, non-invasive species (species that do not cause ecological harm in a new environment where they are not native) of algae are cultivated.
6. Dried biomass is stored in a lined, dry tomb bio landfill, meeting all siting, construction, and monitoring requirements of this methodology.
7. Evidence must be provided that nutrient removals do not negatively impact local ecosystems (reduction of nitrogen to be less than 0.3% of the average standing stock per year).
8. The project provides sufficient documentation to prove adherence to all monitoring, reporting, and verification requirements to characterize energy inputs throughout the process and any decomposition of stored biomass.
9. To ensure net removals, the emissions from the project's activity must not exceed the embedded carbon in the sequestered biomass (i.e., net CO_2 removals are greater than GHG emissions caused by the system).
10. Discharged water complies with all local laws and regulations and international best practice. The discharge water must not include industrial effluent at any concentration.
11. The Project must comply with all host country laws and regulations and international standards for environmental protection.
12. The project must not make use of supplemental or artificial CO_2 sources for CO_2 supplementation (e.g., flue gas may not be injected into the water).

4. Project Proponent Description

Project initiator should provide detailed information about:

- Developer.
- Project ownership, including details of any ultimate beneficial owners holding over 20% economic interest or control.
- Governance overview, including details of board of directors at each entity level through to parent company.
- Details of key executives responsible for operating the Project.
- Partner organizations and stakeholders of the project with brief description on their rights to influence project's vital activities, if any.
- Description of any commercial products being generated.
- Key customers and users, if any.
- Regulatory bodies relevant to the project activities.
- Any operating standards complied with; for example, ISO standards or IFC performance standards.
- Overview of systems implemented in relation to a) environmental management, b) I&AP management, c) legal & regulatory compliance, d) health and safety.
- Utilities used by the project (electricity, natural gas, water, wastewater, garbage, etc.).
- Launch date of projects activities, including start of construction and commissioning.
- Project's anticipated time frame for biomass production and monitoring.
- Monitoring frequency in each phase of the process and associated reporting for regulatory bodies.
- If monitoring or part of it is being implemented by the third-party service provider, please provide a brief breakdown (what entity, what services, how frequent).

5. Crediting Period

The project crediting period is the time for which GHG emission removals generated by the project are eligible for issuance. Project proponents are eligible to register GHG reductions under this methodology for a period of 10 years following the project's start date. All projects that initially pass the eligibility requirements set forth in this methodology are eligible to register GHG removals for the duration of the project's first crediting period (10 years).

Project crediting periods will be renewed at least every 10 years to ensure that changes to a project's baseline scenario and eligibility conditions are taken into consideration throughout the lifetime of the project. Project developers may apply for eligibility for renewal of the crediting period twice up to 30 years in total and they must begin validation within the final six months of each crediting period.

The project reporting period is 12 months with the option of undergoing sub-annual, desktop audits for interim issuance of credits.

6. Stakeholder Engagement

Stakeholder engagement is the basis for building strong, constructive, and responsive relationships that are essential for the successful management of an operation's environmental and social (E&S) impacts. It is a continuous dialogue between a project proponent and its Interested and Affected Parties (I&AP's) throughout the life of the project.

This methodology requires the following process to be undertaken to ensure thorough and transparent engagement with local communities, regulators, other relevant stakeholders:

1. Undertake an ESIA

The first consideration should be to undertake a full Environmental and Social Impact Assessment (ESIA) during the feasibility and assessment phase of the project. This will allow the project proponent to fully understand the baseline scope of the environment and the social context of the project, identify potential E&S impacts, and ensure that the project will be implemented in a socially and environmentally responsible manner.

By undertaking an ESIA the company can:

- Avoid or mitigate potential negative impacts and enhance positive impacts on the environment and society.
- Many countries require companies to conduct an ESIA as part of their regulatory requirements before a project can be approved. The ESIA will provide the basis for the local laws and regulations that should be adhered to and ensures that the project follows a fair and just process.

- The ESIA provides an opportunity for Stakeholder Engagement and consultation, where affected stakeholders can provide input into the project design and potential impacts. This helps the company build trust and increase transparency and accountability.
- Consultation with stakeholders provides valuable information that can be used to inform a projects design and planning. This often includes identifying potential risks and mitigation measures, selecting appropriate technologies and methods, and considering alternatives that may have fewer negative impacts.

2. Apply Best Practice

This methodology also subscribes to the International Finance Corporations (IFC) World Bank Best Practice - IFC Performance Standards, 2012 and the IFC Performance Standards Guidance Notes for Environmental and Social Sustainability Standards and other Good International Industry Practice (GIIP).

Among other aspects, Best Practice states that project proponent will implement a Stakeholder Engagement Plan as this would be helpful to build positive relationships with its stakeholders, make better informed decisions, enhance reputation, reduce risk, and create long-term value for all stakeholders via periodic 'townhall' events where information is reported back to stakeholders, and it is an open forum for ongoing discussion regarding current and future operations.

It is an ongoing process that involves the following:

a. Stakeholder analysis and planning,

b. Disclosure and dissemination of information,

c. Consultation and participation,

d. Grievance Mechanism,

e. Continuous engagement with the project area community.

3. Implement a Management System

The most effective way to manage stakeholder engagement is by developing an Environmental & Social Management System (ESMS). This framework enables the project proponent to manage the identified risks and opportunities associated with its operations. The primary goal is to minimize the negative impact that the operations may have on local communities, environment, and other stakeholders, whilst maximizing the positive impacts.

The following tools and techniques should be implemented to reduce the project proponent's social risk:

- Develop and implement compliance monitoring tools to ensure relevant laws, regulations and international standards are adhered to. Continual monitoring of the system will ensure that any potential social risks or non-compliance issues are identified early.

- Implement a Social Performance Management System (SPMS) that includes policies, procedures, and tools to monitor and improve the company's social performance over time and ensure that the company operates in a socially responsible and sustainable manner while meeting business objectives.

  Important SPMS tools and techniques used include:

  - Developing KPIs (key performance indicators).
  - Audits and assessments.
  - Developing and implementing action plans to address any identified issues.
  - Annual sustainability report.

7. Public Consultation

For a new CCS project, the project proponent shall conduct a public consultation prior to breaking ground on the project. This is to ensure that public feedback is invited, and any concerns raised during the meeting are addressed appropriately by the time the project becomes operational.

1. Identify Stakeholders

To promote inclusivity, the project proponent must identify and invite all relevant stakeholders. Relevant stakeholders are any person or party which is affected by or is involved in the project in any capacity. It is good practice to consult both directly and indirectly affected individuals or communities (e.g., representatives from local governing bodies, NGOs, residents from surrounding areas where the project will be located, indigenous community etc.).

2. Invitation for Consultation

The invitations should be sent out to the stakeholders (identified as above) at least one month in advance to allow enough time for participants to plan to attend the meeting. As well as organizing an in-person meeting, a virtual meeting link must be set up to encourage participation from those who are unable to attend the meeting in person. It is ideal to include the date and time of meeting, complete address of the venue for in-person attendance, and the reason for organizing the public consultation for in-person attendance, and the live link to online meet, in the invitation.

The invitations can be circulated via both print media (pamphlets, notices, newspaper advertisements, etc.) and digital media (email, company website, Facebook groups, etc.).

3. Documentation

The consultation must be documented. The documentation should include at least the following:

i. List of invitees

ii. Date(s) when each invitation is circulated/sent

iii. List of attendees

iv. Agenda of the meeting

v. Minutes of the meeting

vi. Questions/feedback from participants and responses by project developer to those questions

It is good practice to maintain a copy of invite, in each format used to invite stakeholders, as evidence for the verifier (e.g., picture of stakeholder advertisement printed in newspaper, email draft of the invitation, etc.). The project proponent shall demonstrate to the validation body what action, if any, it has taken because of local stakeholder consultation. The project proponent must document evidence on how they acquired consent from local stakeholders to implement the project.

4. Grievance Redressal Mechanism

Simultaneous to planning and organizing public consultation, the project proponent must create and implement grievance redressal mechanism. During the meeting, all stakeholders must be made aware of such a set-up and the time taken to address any queries/concerns through the system. The same information must be part of the project proponent's website.

Project proponent may have all or any of these options in place which will allow the affected party to reach out to the project proponent with their feedback/grievances at any time through the implementation and operation phases of the project:

i. a dedicated email address

ii. a help desk phoneline

iii. an in- person help desk at a local office of the project

The aim shall be to revert any concerns/complaints within 15 working days, informing the affected party of the decisions/solutions implemented to resolve the query. It is realistic that not all concerns may be addressed within 15 working days, for such queries, the project proponent must communicate the timeline by which the issue will be resolved and the reason for this delay.

A log shall be maintained of all the grievances received and the solution provided throughout the crediting period of the project. The resolution may be incorporated on the project website to ensure transparency with stakeholders and encourage public participation through the life of the project. These logs must be made available to the public upon request and to the VVB for each verification event.

The project proponent must address all the concerns and complaints received from the public. For any concerns that are not addressed, the reason for the same must be communicated to the party concerned. The log must also reflect all unsolved grievances with justification that was communicated.

8. Project Boundaries

Unlike direct air capture (DAC) or other Biological Carbon Removal and Storage (BiCRS), system boundaries under this methodology should be drawn very wide and include the intake seawater system and the coastal receiving water, where the discharge is dispersed offshore. All Scope 1, 2, and 3 emissions should be considered and be quantified.

To enable the full characterization of the entire production system, the mass balance of carbon should be available to be traced at every stage of production. All CO_2 absorbed by the algal biomass is absorbed either across the pond water-air interface or the discharge water-air interface. The single most limiting nutrient for algal biomass growth is CO_2, since carbon is the most abundant element in the algal biomass.[12,13,14] For this reason, the operations should be optimized to maximize atmospheric CO_2 to seawater transfer. Similarly, the dry biomass is also tracked to ensure that there are no or minimum fugitive emissions from the harvesting, drying, or sequestration process.

The coastal seawater receiving the de-acidified pond water should be included in the System Boundaries. The dispersion of the discharge water to be monitored via:

- A physical measurement system (e.g., moored buoys and platforms with water monitoring sensors, or similar alternatives, etc.).
- A surface sampling program to physically measure surface water pH.

Permanence and Monitoring sections provide guidance and parameters with acceptable ranges to facilitate project developers for monitoring and ensuring that all activities comply with the methodology requirements. System boundaries should include:

- All the seawater intake, pipeline, pumping, piping, and distribution systems.
- All the lab, incubators, greenhouse, inoculum preparation and seawater filtration systems associated with the production of a clean inoculum.

[12] Redfield, A.C. (1934) On the Proportions of Organic Derivatives in Sea Water and Their Relation to the Composition of Plankton. James Johnstone Memorial Volume, University Press of Liverpool, 176-192.

[13] Tett P, Droop M, Heaney S. 1985. The Redfield ratio and phytoplankton growth rate. Journal of the Marine Biological Association of the United Kingdom 65(2): 487-504.

[14] Geider R.J., La Roche J., Redfield revisited: variability of C:N:P in marine microalgae and its biochemical basis, Eur. J. Phycol. (2002), 37: 1-17.

- All pond operations, maintenance, repair and management.
- All harvesting, biomass extraction from the seawater, channeling of the filtrate (de-acidified seawater) back to the ocean.
- All inputs, such as seasonal nutrient supplements, materials, and their associated logistics.
- All biomass dewatering, solar drying, and preservation activities.
- All dry biomass storage, burial, and monitoring activities.
- The electric power consumption and resource consumption with their associated emissions.
- Embedded emissions from development of renewable energy equipment on site/nearby.
- For both operational planning and MRV, the boundaries also should include the characterization of the deep intake seawater, before it is used to cultivate algae in the land-based ponds, as well as tracking the discharge water as it is released back to the environment again.

The boundaries of the project will be limited to the geographical limits of the project site including all water intake, water discharge, pools, basins, landfill, greenhouses, pumping drying, conveyance, on-site offices, engines, equipment, on site transportation of biomass and materials, and the discharge distances in the ocean required for CDR generation from oceanic uptake of carbon. All energy requirements of equipment used on site or primarily used for project activities are to be accounted for.

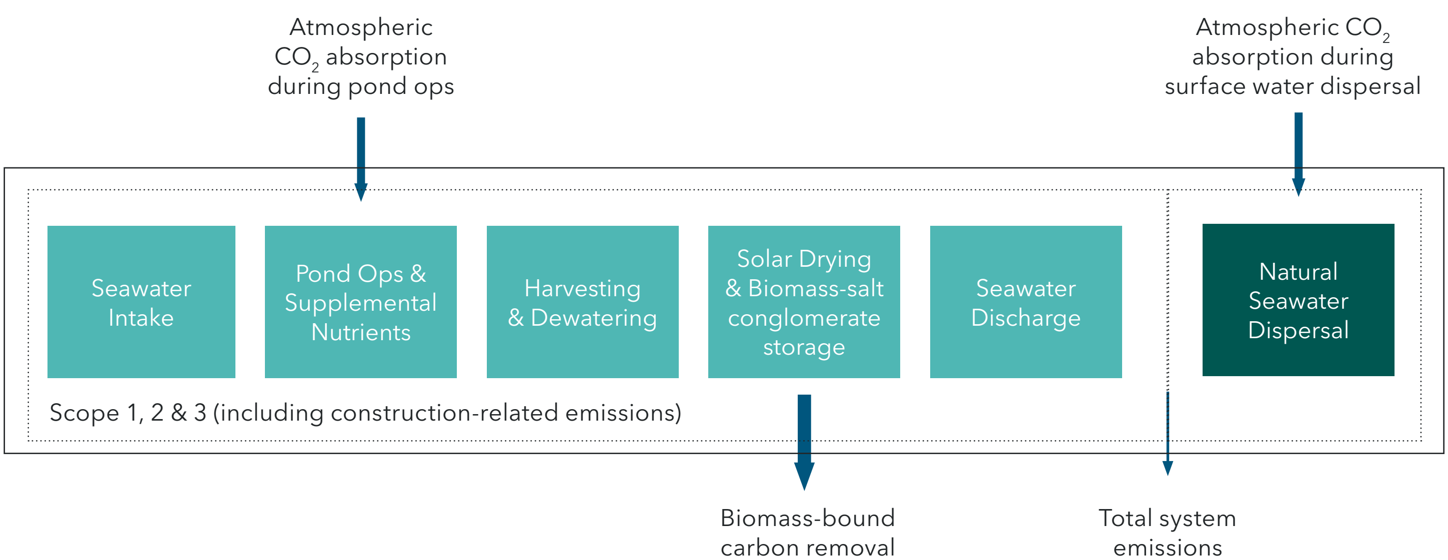


Figure 1.
System boundaries of all operation and system components

The project proponents should provide detailed information on the following items:

- Location of the project site, including address, coordinates.
- Description of the land area regarding:
    - Soil type
    - Vegetation type (if any)
    - Previous long-term geological history of landscape (i.e., earthquakes)
    - Climate and sea level rise history, if possible, extreme events
    - Offshore bathymetry and ocean currents
    - Description of topography or topographical map including altitude relative to mean-sea-level distance from the water
    - NPP
- Description of surrounding area of project site that will be monitored including landfill locations (directions, distance, active and passive monitoring boundaries).
- Description of locations in the sea and surrounding area where any equipment is located.

9. GHG Boundaries

In addition to project boundaries, GHG/LCA boundaries are defined under the methodology. In the context of the LCA the functional unit for the system boundaries is the sequestration of 1,000 kg of CO_2 from the atmosphere for a minimum of 1,000 years. The 'Cradle to Grave' system boundaries with the allocation procedures should be applied where appropriate. To assemble the LCA, carbon content of all materials should be identified.

In alignment with ISO 14064-2, construction of the site facilities, transportation to and from the facilities for operations, development of renewable energy equipment on site (or nearby), secondary activities (commercial, residential) due to site operations, and others are conservatively omitted from calculations unless a LCA approach is adopted (ISO 14040-14044). Project proponents should consider measures and opportunities to reduce project emissions by using low-carbon materials and methods.

Activity LCA boundary includes all activities existing solely for the purpose of CO_2 removals. Projects incorporating secondary revenue streams from algal by-products or related activities are permitted but must clearly define and segregate:

a. The process/activities that are CDR purposed,

b. Intermediate processes/activities/facilities that are not associated with the CDR and are only for co-product purposes, i.e., they do not contribute to CDR.

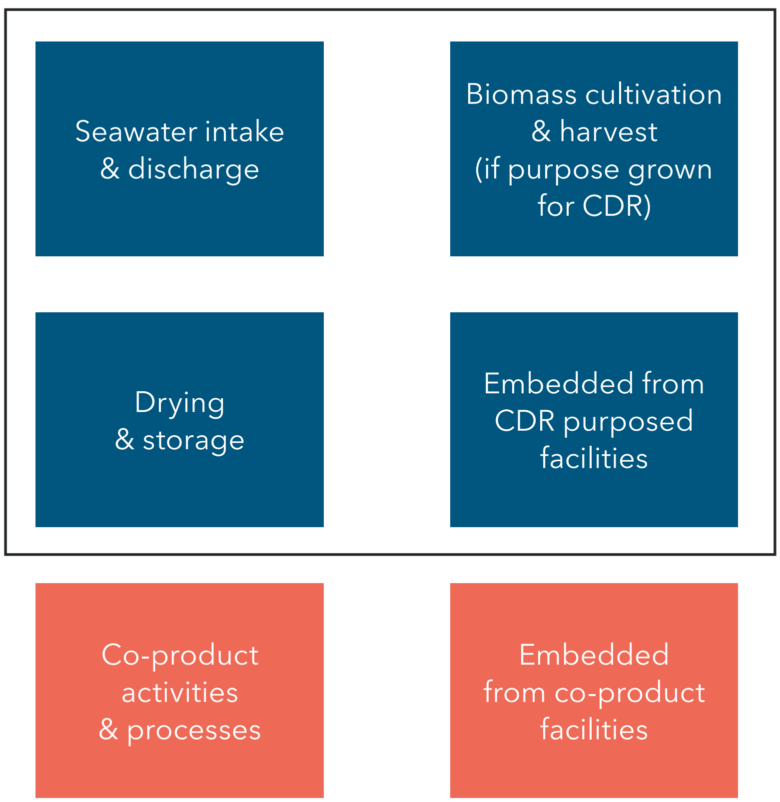
LCA boundary includes all emissions from processes that are directly related to CDR activities including but not limited to seawater intake and discharge, biomass cultivation and harvesting, drying and storage, etc.

All the emissions associated with intermediate or secondary processes should be excluded from the LCA boundary in line with similar approaches.[15]

Any use of biomass that is not related to the CDR, should be excluded from removals quantification, and credits should be generated only based on the quantity of buried biomass/CO_2, without accounting for any co-product utilization that might lead to carbon credits for substitution of fossil/synthetic products.

In summary, this methodology excludes from LCA boundary carbon 'credits' and 'debits' that are not purposed or directly associated with CDR activities.

The diagram below illustrates the relevant emissions boundaries. All blue shaded boxes are included, and the orange boxes are excluded from the LCA boundary.



[15] BECCS activities credited under the Puro Geologic Storage Methodology do not incorporate emissions from the production facility. Similarly, biogas credits generated under CAR Organic Waste Digestion protocol are not generated by net of livestock or processing facility emissions.

10. Baseline Determination and Quantification

Baseline is determined as a business-as-usual scenario prior to project implementation. The following options provide a description of baseline.

Option A – In the absence of this project activity, the baseline scenario would consist of the absence of biomass burial, and no carbon removal through algae based GHG emissions removals.

Baseline scenario is to be considered zero and all actions are additional.

Option B – (optional) Amount of CDR potential from alternative land uses, e.g., using project property for development of renewable energy infrastructure. Net atmospheric benefit must be greater during course-of-project period for project activities than alternative scenarios.

11. Permanence/Durability

The anticipated duration of carbon storage must be at least 1,000 years and is expected to be significantly longer than that. As such the project developer must ensure that this expectation is met and monitored for this duration. To achieve this the project developer must provide details regarding the burial site and management procedures to ensure durability of sequestered biomass. The information will include at a minimum:

- Biolandfill's description within the project area and dimensions, landscape map with coordinates or .kml file to be included.
- Landfill soil type.
- Intended depth of the landfill and altitude of the floor level.
- Projected active period of landfill (how many years will take the landfill to reach its full capacity).
- Landfill's geological isolation description.
- Procedures to be implemented once the landfill is full.
- Description of the materials to be used and construction technologies to be applied to ensure durability of storage.
- Description of the measures to be considered after the project's active phase completion to ensure storage stability.
- Monitoring procedures and equipment for fugitive gases present in the landfill and measures to mitigate and prevent any reversals emerging from the landfill.

Effective long-term storage of biomass must comply with the following requirements:

- Physical stability of the storage environment for millennia.

- The exclusion of water.
- Ready sampling and quantification of decay products such as fugitive gases or leakage.
- Access to the stored biomass for long-term monitoring, reporting and verification (MRV).
- Large volume capacity, near the site for biomass production to minimize transportation and logistics-related emissions.

The bio landfill must be:

1. Properly located and constructed to be free from surface water incursion.
2. Physically protected from erosion, resistant to earthquakes if sited in prone areas, and not vulnerable to groundwater incursion.

Before storing dried biomass, an analysis of its composition should be performed at regular intervals, and each time that a new species, breed, or algal manipulation has occurred. The table below can be used to present the results of this analysis. In the case of secondary products, sampling must occur prior to burial of all waste biomass from the process and separately from all other biomass if simultaneous streams are being buried from CDR purpose-grown and commercially intended algae.

The biomass salt composite is typically composed of:

Microalgal biomass	68% - 48%
C:N ratio	32:1 - 8:1
C content	44% - 38% of biomass
Salt	20% - 40%
Water	6% -12%
Ash	0.5% – 7%
Density	0.96 - 1.12 g / cm^3

The following thresholds apply to ensure stability of the buried biomass:

C:N ratio	8:1
Salt (minimum)	20%
Water (maximum)	12%
Ash	0.5% – 7%
pH	3.6

Project developers will provide a description for all measures taken to prevent physical and chemical decay of stored biomass. It is recommended that multiple complementary and independent microbial and physical methods are applied to all stored biomass, in addition to those required by this methodology. The biomass should be buried in arid regions under dry conditions.

Though no CDR credits are generated directly from open ocean activities, there is an additional and unquantified environmental restoration co-benefit in de-acidifying the seawater.

Potential alternative

During the cultivation process, the microalgae will deplete the bicarbonate and dissolved CO_2 pool of the intake seawater, incorporating that carbon into the algal biomass that is dried and buried. The project must demonstrate that upon discharge of the seawater, equilibrium at the previous levels of bicarbonate and dissolved CO_2 is reached again. Full re-equilibration must be validated using direct pH measurements to a precision of 0.1 pH units and validated oceanographic modeling for pH changes that are not measurable. Model re-validation must take place at least every six months. Project developers should track discharged water with an array of moorings, ship-board measurements, or actual, physical dye-release, etc.

12. Conservativeness

The CDR calculations in this methodology are designed in a conservative way to minimize the possibility of overestimation and over-crediting of CO_2 removals.

As described above, additional CO_2 removals occur once processed seawater is discharged back into the ocean. CO_2 re-absorption by the discharged seawater is happening due to discharged water characteristics.[16,17,18,19]

Those removals (i.e. re-absorbed CO_2 from the atmosphere) sum up 25%-30% through this methodology.

However, **for the sake of conservativeness, those 25%-30% carbon dioxide removals are omitted from crediting while the open ocean system undergoes further research.**

In addition to the 25%-30% conservative reduction, this methodology applied a 'buffer pool' for each generated credit. Having said that, a portion of carbon credits generated by the projects under this methodology is set aside and placed in a buffer pool instead of being sold. Buffer credits can be canceled from the pool if a 'reversal' takes place, with the aim to ensure the integrity of previously issued credits.

Buffer pool makes up to 10% of total accounted CDRs.

16. Dickson, A. G., & Millero, F. J. (1987). A comparison of the equilibrium constants for the dissociation of carbonic acid in seawater media. Deep-Sea Research, 34, 1733-1743.

17. Williams, R. G., & Follows, M. J. (2011). Ocean dynamics and the carbon cycle. Cambridge University Press. doi: 10.1017/CBO9780511977817.

18. Bakker, D. C., et al. (2016). A multi-decade record of high-quality fco2 data in version 3 of the surface ocean co2 atlas (socat). Earth System Science Data, 8, 383-413, doi:10.5194/essd-8-383-2016.

19. Friedlingstein, P., et al. (2022). Global carbon budget 2021. Earth System Science Data, 14, 1917-2005, doi:10.5194/essd-14-1917-2022.

Withheld Buffer, %	Description
4.7	Possible methanogenesis from the bio landfill.
0.3	Nutrient removal negative impacts.
5	Possible reversal due to force majeure.

Buffer pool amount conservatively shall be taken as maximum for new projects, that are lacking research and historical data on functional stability of the storage.

The quantity of withheld buffer credits can be reviewed once the project has been operating for five years and absence or minimum methanogenesis can be proved. In case project developer is launching additional projects, obtained data and experience from pilot project can be used to justify reduction of buffer credits amount.

Carbon credit insurance shall be permitted to compensate for any potential reversal in lieu of buffer pool if it can be proven to have sufficiently similar safeguards for retirement of equivalent quality carbon credits. Project developers are responsible for communicating the insurance mechanisms with specific registries and buyers, and shall transparently report the details in their PDD, including but not limited to:

- Amount of insurance required in $ and type.
- Type of credits purchased in the case of reversal.
- The timing of the replacement credits being applied after a reversal.
- Envisaged mechanisms to be applied in case of claim rejection.
- Type/form of reversals covered.

13. Additionality

In a climate change mitigation context, additionality is generally used to mean net GHG emissions savings or sequestration benefits in excess of those that would have arisen anyway in the absence of a given activity or project (i.e., compared to a 'baseline'). Carbon removals are considered additional if they are surplus to what would have occurred in the absence of a carbon offset market. In order to be additional, the project activities must:

- Not be required by any regulation.
- Not be financially viable in the absence of a carbon credits market.
- Satisfy applicability conditions stated above.
- Bury microalgae that would not otherwise have been buried.

- Not displace or reduce algal productivity in the source water or the discharge water.
- Account for the primary productivity displaced on land.
- Have zero baseline emissions capture.
- Illustrate alternative land-use options to increase the project's value (see baseline option b).

If the above mechanisms are implemented, projects are assumed to be additional.

Additional requirements should be reviewed within the final six months of each crediting period if the project proponent decides to apply for crediting period renewal.

14. Leakage

Potential sources of leakage in this context are primarily physical, except for electricity demand leakage concomitant with many energy-intensive, engineered CDR activities.

Leakage from the limited means is the loss of CO_2 from the biomass-salt composite after the harvest and burial of the biomass. It represents volatilization or other pathways to melting or deteriorating with liquid loss, or fugitive gas formation. For example, the formation of leachate in the burial chamber that becomes mobile and deteriorates elsewhere (within or outside of project boundaries) would be considered leakage. Leakage also implies loss of revenue and bears the potential risk of producing gases such as methane and nitrous oxide that have a high GWPs in terms of atmospheric heating capacity.

There are several physical leakage risks from the burial site, including:

- Physical damages in the chamber structure.
- Meteorological critical conditions.
- Creation and leakage of various GHGs in the chamber.
- Rising sea levels.
- Changing groundwater levels.
- Physical erosion of the top cover layer.

The project proponent should state the level of risk of those leakages happening on their project, as well as provide detailed plan for avoidance of consequences and procedures to maintain credit value in case of leakage.

Potential sources of leakage considered under this methodology are provided in the table 2.

Table 2: List of operations and associated leakages

Operation	Potential Leakage	Mitigation Measure
Harvesting on screens	The screens do not have perfect efficiency and some of the cells harvested might be washed out with the discharge.	Measurement of cell loses maintenance and replacement of filter screen fabric.
Spray and solar drying	Strong wind blows the drying biomass particles off the drying field.	Cover drying field to prevent losses carried by excess wind during storms and wind breaks at a distance to trap wind-borne biomass.
Blowing biomass into the burial chamber	Pneumatic pipe that moves the biomass from the drying field loses biomass on the way.	Maintain piping and disk chains that move biomass and/or spray directly into storage pit.
Biomass in the burial chamber gets wet while uncovered	If the biomass is uncovered, and it were to rain, it could potentially get wet and less stable.	Provide rocky aggregate cover material for at least 1.5 m cover over geomembrane to prevent wind erosion of surface cover.
Once the chamber is shut, biomass becomes stable for a prolonged period	Perform subterranean environmental measures to monitor the burial chamber conditions and actively monitor the formation of any biological activity (temp, moisture) or fugitive gases.	Provide complementary and independent measures such as free gas analysis, temperature measurements, or biomass sensor measurements (such as electric conductivity or moisture content) to ensure that if any one of the probe fails, there are redundant and independent measures available.
Formation of fugitive gasses	Catalytically break these down at the sampling ports convert them into CO_2 and N_2O, to prevent the release of high GWP gasses.	If any fugitive gas traces are detected, these can be an independent signal that the biomass has become wet, then the bio landfill can be forcibly aerated with desert-heated, dry air, to dry it out again, through the same ports that are used for the gas sampling.
Leachate that runs into the ground and becomes difficult to track	Monitor environmental conditions underground with sensors for EC and moisture, and periodically sample adjacent test well to monitor any moisture movement.	Measurements of the biomass include moisture sensors as well as electric conductivity sensors. When there is sufficient liquid to solubilize salt, the electric conductivity rises rapidly as does the moisture level. At this point forcible aeration as outlined above can be performed to dry the bio landfill.

Rationale for Fugitive Gas Measures

It is difficult to anticipate burial conditions for 1,000+ years and decay of the biomass cannot be measured in the lab setting across thousands of measurements and across a broad range of burial conditions. For this reason, project developers should conduct a deliberate and active underground research program to bury biomass under a range of conditions, including wet, low salt biomass and low acid biomass to measure any decay (see Monitoring section).

In addition, the measurement of fugitive gases is provided to monitor what organisms may be deteriorating the biomass. The gases themselves are indicative of what form of deterioration is happening or what type of organisms are growing, enabling more targeted interventions.

Table 3: List of fugitive gases to be monitored

Gas	Purpose	Indicates
Oxygen (O_2)	A drop in oxygen indicates that it is being consumed. Aerobic respiration results in oxidative phosphorylation and the consumption of oxygen.	Indicates aerobic respiration, metals corrosion or other oxidation that consumes oxygen. Can be a sign for eukaryotic organisms such as mould.
Carbon Dioxide (CO_2)	Obviously, CO_2 emissions need to be quantified and an increase in CO_2 above atmospheric levels confirms that there is aerobic respiration happening.	Unlike rusting, or other oxidative processes, the combination of oxygen drop with CO_2 increase indicates biological activity.
Methane (CH_4)	Methane has a greenhouse gas potential 84 times that of CO_2 over a 20-year period – it co-occurs with increased CO_2 production under anaerobic fermentation.	Methanogenic conditions require lack of oxygen, moisture and fermenting bacteria and methanogenic archaea.
Nitrous oxide (N_2O)	Nitrous oxide has a greenhouse gas warming potential 298 times that of CO_2 – it forms naturally when nitrogen rich anaerobic soils become wet and hot.	Nitrous oxide production by soils results when denitrifying bacteria and nitrifying bacteria consume amines (proteins or fertilizers) as an energy source.
Hydrogen Sulphide (H_2S)	Hydrogen sulphide is not a greenhouse gas and is converted into sulphates in the atmosphere contributing to cloud brightening – it produces the familiar marsh gas smell.	A large variety of bacteria can use the sulphide in protein, amino acids and reduced sulphur compounds as an energy source and produce the characteristic marsh gas smell.

Carbon Monoxide (CO)	Carbon monoxide is a weak greenhouse gas and rapidly oxidizes to CO_2 – however, it consumes atmospheric hydroxyl radicals that could otherwise break down other greenhouse gasses.	CO forms in combination with H_2S or methanogenesis indicating the activity of sulphate-reducing, acetogenic or methanogenic bacteria.
Volatile Organic Carbon (VOC)	VOC is a broad group of volatile carbon compounds – smells and vapors. The quantity of VOC matters since in the environment they break down into CO_2 over time	VOC (smells) can be traced readily and are highly temperature dependent.

The combination of these measurements, including the temperature, humidity, and oxygen content in the air spaces of the burial chamber, enables interpretation of what changes are happening underground (e.g., if oxidation happens this would consume some O_2 but not release greenhouse gases).

The underground testing system should be designed to be able to be unearthed again and to independently re-weigh the biomass on an annual basis to measure changes to the biomass-salt composite to ensure stability. The project developer shall take measures to prevent/minimize biomass blown by the wind.

In addition, project proponents should describe measures taken to prevent removal of biomass by outside parties, such as labeling and education to ensure no accidental or intentional intrusion on site. Project proponent will provide a plan ensuring permanence of the storage after the project's completion (see permanence section).

Another form of leakage (not physical, indirect) happens when some effects of an environmental action occur outside the project's carbon accounting boundary (e.g., an action causing emissions reductions in one place may also cause increases emissions elsewhere). The associated increase in emissions is known as emissions leakage.

Electricity leakage is considered within this methodology. This refers to the increment of emissions resulting from meeting the additional electricity demand caused by the project.

Electricity leakage must be considered for alternative usages of grid-based renewable power sources. If the net usage of power on site exceeds 1% of total renewable power in the gird whereby the project drives up electricity demand of the grid such that existing energy requirements must be met by traditional fossil sources, all electricity must be considered as coming from the grid and combined/averaged grid emission factor should be applied in project emissions calculations.

The approach above is true, if the project proponent can demonstrate that additional capacity has been added to the grid, or availability of power currently exceeds the demand on the grid.

Otherwise, if the facility causes an increased production of the marginal (fossil-based) power plant in the grid, the additional emissions should be accounted for based on the marginal emissions rate (emissions of marginal power plant), rather than average grid emission factor. This approach leaves other grid users unaffected, i.e., average grid emission rate/factor will not be changed for other users. Therefore, project/user causing the marginal increase in emissions will be accountable for such emissions.

Similarly, if the project includes the installation of its own renewable power plant, the benefits of the renewable energy will be directed exclusively to the owner/proponent, leaving the rest of the grid users with the same emissions.

If the latter case occurs, project proponents should demonstrate how marginal emissions are assessed for certain projects and justify the reason for the selection of a specific mechanism. There are some mechanisms that allow assessment/forecasts of the marginal emissions in the grid (e.g., Watttime) to which the project proponent can refer.

15. Additional Risks

To ensure that project activities do not harm the environment, an EIA must be conducted (by independent party), including but not limited to the following studies:

- Terrestrial ecology.
- Soils.
- Land use.
- Geohydrology.
- Ocean (seawater intake and discharge areas).
- Nutrient removal effects – must not adversely deplete natural resources that other biologically productive systems use, e.g., nutrient mining the coastal ocean where local coastal organismal growth would be reduced.
- Landfill siting.
- Marine ecology.
- Coastal processes/sedimentation transportation.
- Cultural and heritage resources.

- Maritime heritage.
- Socioeconomic.
- Noise.
- Traffic.
- Landfill rehabilitation and closure.
- Catastrophic impacts from containment failures of storage tanks, landfill.
- Local human impacts.
- Indigenous/cultural relevance of project site or vicinity.
- Other site-specific considerations.

It is also required that project developers demonstrate that their project design does not substantially decrease baseline albedo.

EIA must be conducted by an independent third party.

Results and process for each EIA are to be made available to the VVB, as needed.

Project proponents must provide detailed plan regarding how identified risks would be identified, measured, and mitigated.

Legally obligated environmental studies may be used to fulfill this requirement but will not be considered independently sufficient unless all parameters are included and is broad and rigorous enough to establish a comprehensive risk mitigation plan.

Project developers should provide predictions of the likelihood of sea-level-rise change and change in weather patterns (over 1,000 years) for the project area that might cause precipitation/flood events.

The table below may be used by project proponents to identify and characterize project risks.

Risk Category	Description	Likelihood*	Magnitude* (Optional)	Evidence	Procedures/ Response plans

(Likelihood and Impact should be rated as either Low, Medium, or High.)

16. GHG Removal/Reduction Quantification

Project activities should result in durable CO_2 sequestration, therefore the main GHG considered for removals quantification is CO_2. Scope 1, 2, and 3 emissions from project activities should be assessed in CO_2e or obtained from suppliers. Project emissions should preferentially be quantified via LCA but may be quantified via scope reporting where invoices, metering, and electricity/power usage are traceable.

SSRs (Sources Sinks and Reservoirs) to be considered are:

Sources:

- Project energy demand – Electricity and/or fossil fuels used to operate CDR facility.
- Fugitive emissions from biomass decay through processing and storage of biomass.
- Emissions from added nutrients.
- Embedded emissions associated with facility construction.

Sinks:

- Carbon pools in products made from algae prior to burial.

Reservoirs:

- Carbon stored in bio landfill.
- Carbon removed from atmosphere and reabsorbed into ocean waters.
- Once the 'de-acidified' seawater is reduced of bicarbonate by the stimulated algal bloom it is discharged into the sea. After the microalgae have consumed a portion of the Dissolved Inorganic Carbon (DIC) in the seawater, the de-acidified seawater is returned to the environment. Nothing is added to the seawater, nothing is stored in the seawater, and no CO_2 is sequestered in the seawater. Rather, the discharge water has had carbonic acid removed from it, which was formed when atmospheric CO_2 dissolved in the original intake seawater. This bicarbonate-depleted seawater then returns to normal as it rapidly re-equilibrates with the atmosphere at the surface of the open ocean.

CDR for the project activities will be determined by Equation 1:

- $CDR = CDR_{alg} - PE - Leakage$.

Quantification for each SSR will be determined by the following:

$CDR_{Alg} = \sum PR - \sum PE - Leak - Unc$	
CDR_{Alg}	Carbon dioxide removals by algae, tCO_2.
$\sum PE$	All the emissions of the project, tCO_2e.
$\sum PR$	Total removals due to the project, t CO_2e.
Leak	Emissions from leakage, t CO_2e (expressed as % from total).
$\sum PE = E_{Cult} + E_{Harv} + E_{Dis} + E_{Dry} + E_{Bur} + E_{Cons}$	
E_{Cult}	Emissions from biomass cultivation, including electricity emissions, nitrate, and phosphate emissions, etc., t CO_2e.
E_{Harv}	Emissions from biomass harvesting operations, t CO_2e.
E_{Dis}	Emissions from discharge operations, t CO_2e.
E_{Dry}	Emissions from biomass drying, t CO_2e.
E_{Bur}	Emissions from dried biomass burial, t CO_2e.
E_{Cons}	Emissions from construction activities of the project, including embedded emissions in intake pipeline, ponds, concrete channels, pumping station, pipe network, buildings, civil works, emissions from labor, etc., t CO_2e.
$\sum PR = R_{land}$	
R_{land}	Removals on land due to biomass storage, tCO_2.
$R_{land} = W_{biomass} * CC * 44/12$	
$W_{biomass}$	Weight of dried biomass, ton.
CC	The carbon content of the dried biomass, %.
44/12	Carbon to CO_2 conversion factor.
U	Total uncertainties related to the sampling, extrapolation, etc. (typically 0.1%).

Net CDR amount to be credited will include the deduction of buffer pool fraction, as described in the Permanence / Durability section, and uncertainties.

$CDR_{Net} = CDR_{Alg} \cdot (1 - BP - U)$

17. Managing Data

Data collection will be implemented and deliberately managed during all the phases of the process. Measurement data records should be stored safely during project operations and 10 years after the completion of final verification.

To enable this, where feasible, all key processes on site are to be controlled and recorded by a centralized Supervisory Control and Data Acquisition (SCADA) system accessible on-site and off-site. The system must have best-practice security management and audit trail functionality. For measurements that are not feasible to be gathered by a SCADA-based system, a protocol is to be developed for all manual records and those records are to be stored digitally. Such records are also to be subject to best practice security and digital audit trail functionality, by using, for example, Microsoft SharePoint or its equivalents.

Project developers should provide details on their data management systems. Adherence with ISO/IEC 27000, or similarly refined standard, is encouraged.

18. Project Monitoring and Documentation

The main objective of the monitoring is to prove net carbon removals from the final stage of dry-tomb bio landfill burial of the salt-biomass composite and to quantify the emissions resulting from the project scenario during the project crediting period, before each verification. The project proponent must establish high-quality procedures to manage all relevant data, documentation, and applicable information. Thorough written procedures must be established for each measurement stage detailing all relevant requirements and responsibilities.

The 1,000-year durability is based on extrapolation of active measurement (established over the 10-year initial monitoring period). The 10-year active monitoring period is intended to create a baseline. In addition, monitoring should continue as long as there is an operating company, and a fund to continue monitoring after project completion should be set up.

This methodology uses a comprehensive monitoring and documentation framework that captures the GHG impact in each stage of the microalgal biomass value chain. Monitoring and detailed accounting practices must be conducted throughout the entire project as well as to ensure the continuous integrity of the carbon removals and crediting. The project proponent must develop and apply a monitoring plan according to ISO 14064-2 principles of transparency and accuracy that allows the quantification and proof of GHG emissions removals.

The table below provides a list of the parameters needed to be monitored, to ensure proper operation under this methodology.

Table 4: List of measurements

Measurement	Purpose
pH	Determine marine Dissolved Inorganic Carbon (DIC).
Temperature	Determine marine Dissolved Inorganic Carbon (DIC).
Electrical Conductivity (EC)	Determine marine Dissolved Inorganic Carbon (DIC) and Salinity.
Total Alkalinity	Determine marine Dissolved Inorganic Carbon (DIC).
Scattering NTU	Determine biomass in ponds.
Pond depth	Determine dilution rate and volume.
Baseline Fluorescence F_0	Determine biomass in ponds.
Total Organic Carbon	Determine the carbon content of dry biomass.
Total cellular absorption	Determine the productivity of algae.
Moisture content of biomass	Harvesting, drying, burial.
Water Activity Meter	Buried biomass water absorption.
Buried biomass stability	Independent biomass stability measurement.
Subsurface temp	Biomass stability.
Subsurface humidity	Biomass stability.
Fugitive gases	Measure CO_2, CH_4, O_2, H_2S, CO, N_2O, VOC.
Seawater intake volume	Define system throughput.
Seawater outflow volume	Define system throughput.
Algal slurry volume	Determine biomass produced..
Algal slurry water content	Determine biomass produced.

Water content after drying	Define biomass.
Final moisture, salt, ash content	Define biomass.
Tide height	Pumping energy optimization.

To perform biological growth modeling and operations, the developer should use meteorological stations and perform oceanographic monitoring that measures the impact of the discharge water pH and nutrient content on the environment. In addition, a suite of measurements should be automated on-site to track the carbon mass flow from the intake seawater, to monitor the final biomass once it has been buried. It will also be tracked in the seawater discharge until that discharge has re-equilibrated in the environment. These measurements must be recorded and tracked throughout the seasons to develop an annual baseline against which to track further process improvements.

To ensure the safety of the environment, discharge water parameters must be within the ranges shown below.

Table 5: Discharge water parameters

Metric	Unit	Relative to Receiving Water
Temperature	°C	<2oC
Free pH	inverse log	<2 pH units
Salinity (EC)	‰	<4 part/thousands
Total Alkalinity	mM	<5%
Nitrogen	mM	0-15
Phosphorous	mM	0-2
Silicon	mM	0-1

Table 6: Required data on each measurement

Data / Parameter	Description
Data unit	
Equations	
Source of data	
Description of measurement methods and procedures to be applied	
Frequency of monitoring/recording	
QA/QC procedures to be applied	
Purpose of data	
Calculation method	
Comments	

Environmental conditions of the burial chamber as well as direct fugitive gas conditions should be properly measured and monitored using different sensors, as guided below:

1. Sensors are buried directly with the biomass in direct contact to measure the physical conditions of the biomass and provide lead indicators of environmental change underground. These sensors can be readily accessed via cables that are reachable at the surface.

2. Additional sensors should be used to measure the physical conditions underground to determine whether the physical conditions have changed. These include humidity and gas composition in the airspace above the biomass.

3. Surface-mounted sample ports should provide access to the gases emanating from the biomass and do not need to be in direct physical contact with the buried biomass. These should be accessible at the top of the landfill and the gas analyzers be connected to tubes that actively pump the gases to the surface and measure the relevant gases via the tubes that are embedded in the biomass underground.

The following table is an example of how each sensor used in the project should be described.

Sensor	Purpose	Features and update	Location	Frequency
Portable Gas Analyzer	Fugitive gas analysis	This analyzer can simultaneously measure up to five separate gas components CH_4, CO, CO_2, SO_2, O_2, CH_4, N_2O, and H_2S at ppm and ppb levels.	Tubing in biomass with dust filter.	Once a week and special conditions.*

*Special conditions example: *unless an anomaly is detected, at which time measurements should be taken twice daily until the anomaly is rectified.*

The project must be able to record data that can be processed to report on the contribution of each process stage by its impact factor and source or sink by each relevant GHG.

19. Reporting

All indicated and relevant project data shall be compiled and presented at validation in the form of a Project Design Document (PDD). The PDD will reflect the project proponent's plan for adherence to this methodology, encompassing all requirements herein. The monitoring report will be representative of the in-situ application of the PDD for each facility and operation within the project boundary and shall be updated for each annual or sub-annual monitoring period.

Table 7: Project Design Document and Monitoring, Verification and Reporting Requirements

Measurement	Purpose	Reporting Format
pH in intake and discharge seawater	Determine marine Dissolved Inorganic Carbon (DIC).	
Temperature in intake and discharge of seawater	Determine marine Dissolved Inorganic Carbon (DIC).	
Electrical conductivity (EC) in intake and discharge seawater	Determine marine Dissolved Inorganic Carbon (DIC) and seawater salinity.	
Total alkalinity in intake and discharge seawater	Determine marine Dissolved Inorganic Carbon (DIC).	
Scattering NTU in cultivation ponds	Determine biomass in ponds.	

Pond depth in cultivation ponds	Determine dilution rate and volume.	
Baseline fluorescence F_0 in cultivation ponds	Determine biomass in ponds.	
Total organic carbon in biomass	Determine the content of dry biomass.	
The moisture content of biomass	Harvesting, drying, burial.	
Water activity meter	Buried biomass water absorption.	
Buried biomass stability	Independent biomass stability measurement.	
Subsurface temp	Biomass weight over time.	
Subsurface humidity	Biomass stability.	
Fugitive gases	Measure CO_2, CH_4, O_2, H_2S, CO, N_2O, VOC.	
Seawater intake volume	Define system throughput.	
Seawater outflow volume	Define system throughput.	
Algal slurry volume	Determine biomass produced.	
Algal slurry water content	Determine biomass produced.	
Drying pad temperature	Determine biomass produced.	
Water content after drying	Define biomass.	
Final moisture, salt, ash content	Define biomass.	
Tide height	Pumping energy optimization.	

In addition, process description-specific information should be made available:

- Anticipated productivity of the functional unit of the process regarding the land area (CO_2/ha/year).
- Specifics regarding the species to be used and proof that they are endemic or non-invasive.
- Carbon content of the harvested biomass.
- The dryness level of biomass to be buried.
- The water activity level of biomass to be buried.
- Salt content of the biomass to be buried.
- The projected stability period of buried biomass.
- Carbon content of depleted seawater (specified as carbonate, bicarbonate, and dissolved CO_2).
- Modeled CO_2 re-uptake regime for depleted seawater.

The table below provides guidelines regarding basic assumptions and parameters to be provided to ensure the appropriate use of this methodology.

Table 8:

Parameter	Value	Unit
CO2 sequestered per annum		Tonnes
Total staff required		# Employees
Facility operating lifetime		Years
Annual operation days		days
By each phase (production, harvest, sequestration, monitoring, control)		
Water intake and distribution		KWh/day
Discharge pump		KWh/day
Paddle wheels		KWh/day
Harvest process		KWh/day

Drying		KWh/day
The volume of water requiring nutrients		m3/day
Nitrate requirement		umol/l
Phosphate requirement		umol/l
HDPE required		tonnes
Concrete required		tonnes
Steel required		tonnes
Earthworks required		m3
Emission factors		
Electricity (for each source)		kg CO_2e/kWh
Earthworks		kg CO_2e/m3
Concrete		kg CO_2e/kg cement
HDPE		kg CO_2e/kg PE
Pond liner membrane		kg CO_2e/kg
Steel		kg CO_2e/kg PE
Acrylic		tons CO_2e/kg

20. Verification/Validation

The project shall maintain a detailed monitoring and reporting plan that will be used for both validation and verification. The document is designed to be the guidance document that auditors shall use to develop a project-specific risk assessment and sampling plan.

Validation is required for the initial project design and initiation of a new project. Verification is required for each reporting period to assess ongoing conformance to the project design and confirmation of credits generated.

All validation/verification bodies (VVBs) must be able to demonstrate accreditation from An International Accreditation Forum (IAF) member against ISO 14065 against the ISO 14064-2 scope. All validation/verification activities are to be conducted according to this standard, and conflict of interest must be avoided according to ISO 14065 between Project Proponents, VVBs, and individuals involved with the project and verification teams. The level of assurance for each verification is to be reasonable, with a materiality threshold of +/-5%. All credits that are retired are to be on an ex-post basis following a positive project validation and subsequent positive verification report being issued. Any pre-sales of credits are to be based on adherence to this methodology and must be corroborated by VVBs during the process of verification.

At a minimum, a physical on-site visit will be required by VVBs:

1. Within two years of the project start date.
2. For the initial project validation or combined validation/verification.
3. Once every three years during the reporting period following the first physical site visit.

A physical site visit by VVBs is not mandatory at the time of credit period renewal but can be required by VVBs if determined to be necessary through the risk assessment.

The first physical site visit may combine both validation and verification audits if the project developer and VVBs combine these events.

Due to the remote nature of these installations, remote audit site visits can be conducted utilizing Information and Communication Technology (ICT) Technologies – including, but not limited to, software and hardware such as smartphones, handheld devices, laptop computers, desktop computers, drones, video cameras, wearable technology, artificial intelligence, and other remote site visit equipment.
The use of ICT may be appropriate for auditing/assessment both locally and remotely. Examples of the use of ICT during audits/assessments may include but are not limited to meetings; by means of teleconference facilities, including audio, video,and data sharing – audit/assessment of documents and records by means of remote access, either in real-time or asynchronously – recording of information and evidence by means of still video, video or audio recordings – providing visual/audio access to a remote location.

The virtual site visit must meet the requirements of the International Accreditation Forum Mandatory Document for the Use of Information and Communication Technology for Auditing/Assessment Purposes: Issue 2 (IAF MD4:2018) or the most recently updated version. Remote audit site visits may occur for intermediate years (years one and two following physical site visit) and may be conducted at the verifier's discretion for any verification event.

For projects undergoing sub-annual audits for more frequent credit issuance, desktop audits may be conducted semi-annually, or more frequently. These audits may not require a virtual or physical site visit but will require verifiers to conduct sufficiently rigorous inspections of data systems and data streams to reach the required level of assurance and materiality. The risk of error is assumed to be lower for these events since the frequency of audits is greater and there has been a complete verification within the previous 6 months.

Verification will require confirmation of constant monitoring of the facility. Reporting frequency requirements will be checked for conformance according to Table 7 in the reporting section. Accepted evidence includes photographic evidence, direct metering, direct measurements, modeling, and corroborating sampling of ocean carbon uptake. Any reasonable evidence requested by the VVB must be made available for each verification event.

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