[Seaweed Generation]

Carbon Dioxide Removal Purchase Application

Fall 2022

General Application - Prepurchase

(The General Application applies to everyone; all applicants should complete this)

Company or organization name

Seaweed Generation

Company or organization location (we welcome applicants from anywhere in the world)

United Kingdom

Name(s) of primary point(s) of contact for this application

Paddy Estridge [redacted] Mike Allen [redacted]

Brief company or organization description

Ocean based CDR using macroalgae (seaweed): initially using problematic bloom material and then transitioning to cultivated material.

1. Project Overview[1]

a. Describe how the proposed technology removes CO_2 from the atmosphere, including as many details as possible. Discuss location(s) and scale. Please include figures and system schematics. Tell us why your system is best-in-class, and how you're differentiated from any other organization working on a similar technology.

[1] We use "project" throughout this template, but note that term is not intended to denote a single facility. The "project" being proposed to Frontier could include multiple facilities/locations or potentially all the CDR activities of your company.

<1500 words

Seaweed Generation (SeaGen) is developing two complementary technologies for large scale CDR with macroalgae. The first, the AlgaRay, is a robotic harvester, designed to intercept and sink large amounts of problematic macroalgae into the deep ocean. The second, which we call the AlgaVator (alternative name suggestions welcomed!), is a cultivation system designed to grow macroalgae offshore. This biomass would then be harvested, measured, transported (if necessary) and sunk by the AlgaRay.

Both technologies are designed to fully integrate with each other, are solar powered, and able to reach large scale through automation.

Carbon Dioxide Removal with seaweed

The best argument for CDR with macroalgae is the potential to scale cost effectively: it has a clear pathway to gigatonne scale, durable CDR, at a cost point that is projected to come below $100 a tonne of CDR.

Macroalgae absorb CO2 from the ocean as they grow, allowing the ocean to absorb more CO2 from the atmosphere in turn. Seaweed grows in the ocean without the need for fertilizer or freshwater, it increases biodiversity (when grown sustainably), and can absorb CO2 faster than terrestrial plants.

The size of the ocean offers ample space in which to grow, and the deep ocean is already the Earth's largest carbon sink, containing 16x more carbon than the upper ocean and terrestrial sphere.

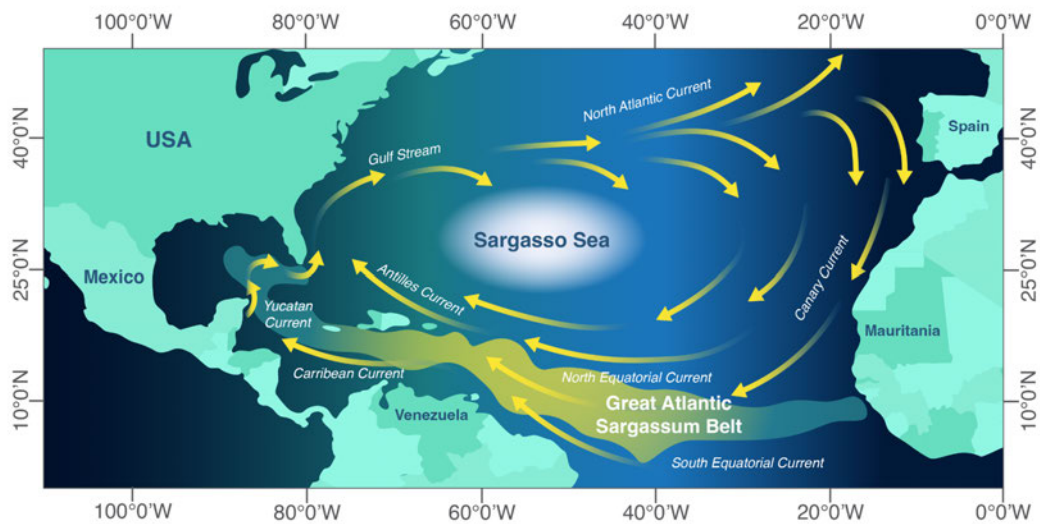
There are, however, important questions that must be answered before large scale CDR can be undertaken using seaweed. Some of these we will take part in answering with our pilot projects in the coming years, some of them will be the work of large scale modeling and monitoring by scientists in the space.

Lens1/Approach/Durability: Carbon sink not constrained by arable land or the terrestrial environment.

Lens1/Approach/Additionality/new carbon removed

The AlgaRay

SeaGen will lead initial CDR with the AlgaRay, focusing on the tens of millions of tonnes (up to 100 million tonnes) of problematic *Sargassum* that inundates the Caribbean every year. These influxes cause environmental degradation, loss of tourism and health threats (What are the environmental impacts of *Sargassum* inundations? - Seaweed Generation).



The Great Atlantic *Sargassum* Belt (What is the Great *Sargassum* Belt? - Seaweed Generation) is a recent phenomena (since around 2009) and is most likely a reaction to excessive nutrient and soil runoff into the oceans. Record amounts are now washing up on the shores of the West Coast of Africa, the Caribbean and more recently Florida and Louisiana, with detrimental environmental effects.

Sargassum, when dried, contains between 27.41% - 29.23% carbon (J. Mileage et al). Conservatively, 6 tonnes of wet *Sargassum* has absorbed 1 tonne of CO_2 from ocean waters.

The AlgaRay is a simple, solar powered, system, designed with automation and rapid scalability in mind. Traveling at around 3knts, it takes less than 1 minute to fill with *Sargassum* within a *Sargassum* mat. Once full, the AlgaRay drops to 200m (*Sargassum* becomes negatively buoyant at 135m), drops the biomass, and returns to the surface to refill. The *Sargassum* will reach 1000m in approximately 1.5 hours, at a rate of 10m a minute.

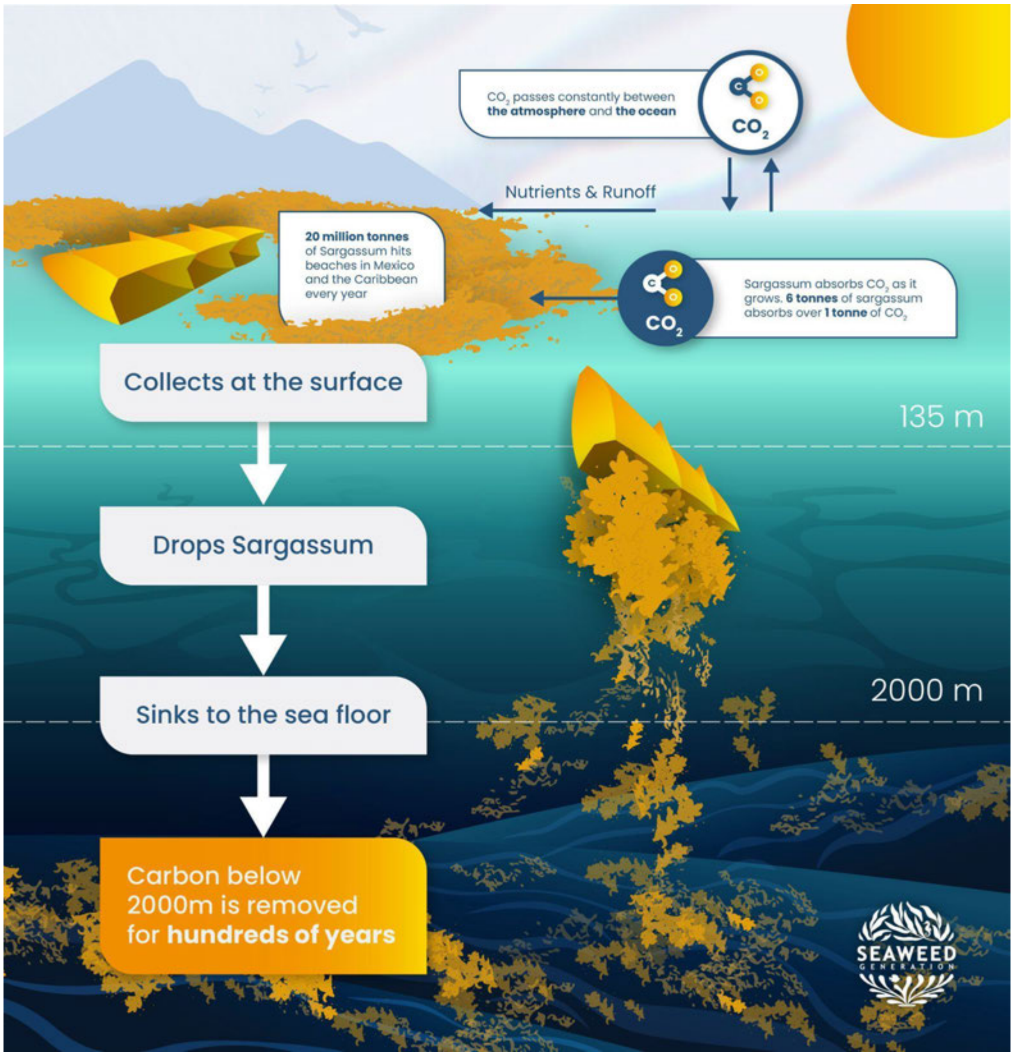
The whole sequence is captured on video and bundled with biomass measurement, timedate and GPS data for reporting purposes. The AlgaRay is an ideal vessel for data gathering, with capacity for multiple sensors on board, for further MRV capabilities.

Projected Capacity rates of the AlgaRay

Version	Capacity	Tonnage of *Sargassum*	Max drops per day	Capacity Factor	Annual CO_2 sunk*
Surface infrastructure (2 x 3m)	8m3	2.6 tonnes	60 (8 hrs)	12%	1000
Glider (6m)	8m3	2.6 tonnes	72 (18 hrs)	20%	2200
Glider (10m)	48m3	16 tonnes	72 (18 hrs)	20%	14000

*Note: this calculation has not had LCA, air-sea flux or additionality baked in yet, hence 'sunk' rather than removal

Initially tethered and pulled by a support vessel, the first iteration of AlgaRay has been tested in 2022 at our R&D site in Scotland and on site in Antigua. The AlgaRay will be remotely operated in 2023 as we work towards full automation and an independent glider (i.e. no surface infrastructure) system in the future.



Lens2/Execution/all major elements are at least TRL3

Early Pilots (2023-25)

Our initial activities will take place off the coast of Antigua & Barbuda at our two pilot areas: Area 1: Lat17.14861, Lon-60.86138, Lat17.27694, Lon-60.96666, Lat17.25666, Lon-60.68305 (202m2)l . Area 2: Lat17.28861, Lon-61.16583, Lat17.30777, -Lon60.99916, Lat17.39722, -61.11972 (102m2). These areas have been selected for a combination of close proximity to the coast, positioning to intercept *Sargassum* before it makes it to the coasts (in these areas, it would hit Antigua or St Kitts and Nevis), for the depths available (>4,000m), and for the ability of the government to guarantee that the areas will remain undisturbed long term (which is also highly likely even without a guarantee, given the depths).

Current modeling of selected pilot areas suggest no upwelling currents, which will be confirmed using turbidity sensors prior to and throughout the pilots. Distribution will be spaced out to limit effects and to monitor different deposition loadings on the sea bed.

We are working with the local environmental and fishing groups to ensure a fair, stable and sustainable bioeconomy, as well as providing assurances for all parties on environmental impact, safety of operations, legal compliance and longevity.

Lens1/Approach/Safety&Legality/highest standards of safety, compliance, local environment. Actively mitigate risks and negative environmental consequences.

AlgaVator

To achieve gigatonne scale CDR, cultivation is required. We are sharing privately the designs for our patent pending cultivation system, which couples simple structures, with robotic seeding, maintenance and harvesting.

The system is designed to be suitable for offshore conditions so as to exploit the open ocean space, and potential co-use areas, such as wind farms. It is suitable for cultivating multiple species, which will allow greater biodiversity benefits in growing areas, and makes it suitable for deployment in tropical, subtropical and cooler areas.

We are in early discussions with members of the Small Island Developing States, which account for 30% of the world's ocean and seas, and will enable rapid expansion and scale up of activities.

Lens1/Approach/NetNegativity/Results in net reduction in atmospheric carbon dioxide.

Capacity Projections with Cultivation

Year	Systems	Area for cultivation	Tonnage of biomass	Max annual CO2 absorbed*
2024	4	1 ha	3,200	532
2027	250	1 km2	200,000	33,000
2030	16,000	40km2	12.8 million	2.1 million

*Note: the calculation has not had LCA, air-sea flux or additionality baked in yet. Not has the biomass been sunk (which it would need to be for any removal to be durable) yet hence absorbed rather than removal

Following cultivation, seaweed will be sunk to specific places in the deep ocean by the AlgaRay, in the same way (and with the same reporting) as *Sargassum*.

We are entering our second year of cultivation in 2022 in Scotland, and are in early talks with several SIDs countries for trials in 2023. We are offering 8 tonnes of CDR from cultivation at the end of our proposed timeline as a proof of concept.

For large scale, seaweed cultivation has huge potential as a mitigation factor for the 359 billion tonnes of sewage, the 75 million tonnes of nitrogen / 14 million tonnes of phosphorus, and / or the 36 billion tonnes of soil erosion that occur each year (and cause problematic algal blooms).

Lens1/Approach/Cost/<$100tonne

Lens1/Approach/Capacity/meaningful solution (0.5Gt)

Air-sea flux in the subtropics (*Sargassum* and cultivated seaweed)

Air-sea flux with macroalgae will need to be measured on a regional basis as part of our pilot, and broader global modeling will need to be further developed. Having consulted with Professor Andy Watson, FRS, a member of our Science Advisory Board, we estimate the combination of tropical waters and air-sea mixing produces air-sea flux of 90% in 6-7 months (What is the Air-Sea Flux with *Sargassum* - Andy Watson).

We are working with our Science Advisory Board, and other members of the scientific and CDR communities for guidance on best practices for measurements. Any scientists reading this, please get in touch!

Lens1/Approach/NetNegativity/Results in net reduction in atmospheric carbon dioxide.

CDR in the deep ocean

The deep ocean carbon cycle touches on the surface carbon cycle, but is substantially and remotely disconnected from it. It is slower, and significantly larger than the terrestrial environment and contains an estimated 37 trillion tonnes of carbon. All human emissions since industrial times (around 1.5 trillion tonnes), if added to the deep ocean (below 1000m), would be an equivalent addition of just 4%.

Once seaweed is sent to the deep ocean seabed (at depths of 2000m or more), it is essentially removed from the surface carbon cycle for 1000s of years at least. (See durability).

b. What is the current technology readiness level (TRL)? Please include performance and stability data that you've already generated (including at what scale) to substantiate the status of your tech.

<500 words

AlgaRay: Current TRL for AlgaRay is 4-5 (Technology validated in a relevant environment), we have tested prototypes of the operation in Antiguan waters. Collection has been proven, as has the ability to operate at 200m depth, and the inversion 'flip' movement required to empty *Sargassum* completed. We have sunk 100kg of *Sargassum* to > 700m evidenced with depth sensor data.

What remains is to complete the full process in order, which we will undertake in early 2023, taking it to TRL 6-7.

Cultivation Rig: We have successfully cultivated 2 tonnes of seaweed in the 2021/22 season. The latest AlgaVator system is about to reach TRL6: a prototype is in the final stages of construction and will be deployed at our Scottish testing area in late October 2022.

c. What are the key performance parameters that differentiate your technology (e.g. energy intensity, reaction kinetics, cycle time, volume per X, quality of Y output)? What is your current measured value and what value are you assuming in your nth-of-a-kind (NOAK) TEA?

Key performance parameter	Current observed value (units)	Value assumed in NOAK TEA (units)	Why is it feasible to reach the NOAK value?
Energy Intensity	1kwh/per hour	2kwh/ per hour	Larger AlgaRays will need more energy - all activities are solar driven
Biomass per drop	0.3 metric tonnes	2 metric tonnes	Additional modules added as we test and increase confidence
Operational Capacity factor	15%	20%	As we scale operations we will be able to optimize for operational conditions, positioning and collection efficiency

d. Who are the key people at your company who will be working on this? What experience do they have with relevant technology and project development? What skills do you not yet have on the team today that you are most urgently looking to recruit?

<300 words

SeaGen's team comprises Paddy Estridge, Prof Mike Allen, Dr Duncan Smallman, Paul Gray,

Dan Schaub and Jeremy Wiltshire.

Paddy, CEO, a software engineer with a past life with Google and Betterment, Paddy is our guiding compass and keeps us focused on the task at hand.

Mike, CSO, a Professor at Exeter University and marine biotechnologist. Mike's published research (>100 papers) includes work on environmental genomics, algal physiology, biorefinery development and more.

Duncan, Chief Cultivator, a marine biologist with 9 years of experience in cultivating seaweed. He is an avid seafarer, with over a decade of commercial marine and health and safety experience, a qualified diver and has experience conducting underwater monitoring.

Dan, Head of Engineering, is a programming aficionado and software engineer of great renown. With over 12 years experience at New York startups like Betterment and Wellsheet. He's also diving into our machine learning and automation challenges.

Paul, Head of Mechanical Engineering, with 15 years of experience in defense systems, nuclear submarines and water management. He has years of experience in coming up with innovative, scalable, durable and robust solutions for systems that come under immense pressure and complications due to the presence of water.

Jeremy is a Senior Mechanical Engineer, with 30 years of experience in the nuclear, oil and gas industries.

We have assembled a Science Advisory Board to help guide and steer us:

Prof Andy Watson FRS (marine & atmospheric scientist and arguably the world's most renowned expert in processes affecting atmospheric carbon dioxide and oxygen concentrations).

Prof Tom Scott (remote sensing, automation, robotics and environmental monitoring)

Prof Willie Wilson (marine microbiology).

Prof Bess Ward (biological oceanographer).

Prof Dan Mayor (marine biogeochemist).

Dr Giorgio Dall'Olmo (Earth observation scientist).

Ms Arica Hill (environmentalist and advocate).

Lens2/Execution/Expertise & experience of team

e. Are there other organizations you're partnering with on this project (or need to partner with in order to be successful)? If so, list who they are, what their role in the project is, and their level of commitment (e.g., confirmed project partner, discussing potential collaboration, yet to be approached, etc.).

Partner	Role in the Project	Level of Commitment
EcoEngineers	Independent 3rd Party MRV development	Confirmed partner

College of Life and Environmental Sciences, University of Exeter	Development of environmental monitoring program	Confirmed partner
Center for Climate Change	*Sargassum* sinking modeling	Discussing collaboration
Global Systems Institute, University of Exeter	MRV development, Carbon accounting	Confirmed partner
Global Carbon Budget	Carbon budgeting	Discussing collaboration
Government of Antigua & Barbuda	Cabinet approval for operation in dedicated intercept and sinking areas	Confirmed partner
National Parks Authority, Antigua & Barbuda	Preservation, protection, management and development of ecological resources	Confirmed partner
Environmental Awareness Group, Antigua & Barbuda	Sustainable use and management of natural resources.	Discussing collaboration
The University of the West Indies	Long term monitoring program, data processing, seaweed ecology	Confirmed Partner
Department of Marine Services, Antigua and Barbuda	Licensing and registration of vessels, hydrography, maritime affairs, surveys and inspections.	Discussing collaboration
Department of the Environment, Antigua and Barbuda	Environmental management	Discussing collaboration

f. What is the total timeline of your proposal from start of development to end of CDR delivery? If you're building a facility that will be decommissioned, when will that happen?

<30 words

March 1 2023 - April 2025

March 2023 - Baseline measurements begin

May 2023 - First removal

April 2025 - Completion

Beyond April 2025 - continued measurements/monitoring

g. When will CDR occur (start and end dates)? If CDR does not occur uniformly over that time period, describe the distribution of CDR over time. Please include the academic publications, field trial data, or other materials you use to substantiate this distribution.

<100 words

Sargassum is somewhat seasonal (March - September), with high spatial and temporal variability. Satellite observations and models can be used to predict *Sargassum* volumes and locations based on wind speed and direction, sea surface currents, growth rates, mortality and sinking.

Taken from Figure 5, Trinanes et al 2021

We plan to scale slowly, baking in the time to take robust data readings and monitoring activities as we go.

May-23: 1t

June-23: 10t

July-23: 40t

August-23: 40t

March-24: 50t

April-24: 60t

May-24: 100t

June-24: 200t

July-24: 200t

August-24: 200t / 1t cultivation

March-25: 250t / 3t cultivation

April-25: 130t / 5t cultivation

h. Please estimate your gross CDR capacity over the coming years (your total capacity, not just for this proposal).

Year	Estimated gross CDR capacity (tonnes)
2023	600 per AlgaRay unit - initial capacity would be dictated by recommendations for progressive monitoring and MRV
2024	10,000 - 1,300 per AlgaRay unit
2025	100,000 - 8,000 per AlgaRay unit, 40 per AlgaVator
2026	200,000
2027	500,000
2028	1,000,000
2029	2,000,000
2030	4,000,000

i. List and describe at least three key milestones for this project (including prior to when CDR starts), that are needed to achieve the amount of CDR over the proposed timeline.

	Milestone description	Target completion date (eg Q4 2024)
1	First remotely driven voyage	Q4 2022
2	Completion of monitoring and MRV module	Q1 2023
3	Confidence gained to widen AlgaRay with surface infrastructure (faster gathering and sinking)	Q2 2023

j. What is your IP strategy? Please link to relevant patents, pending or granted, that are available publicly (if applicable).

<200 words Patents pending: A METHOD AND SYSTEM FOR CARBON SEQUESTRATION, GB2204699.9 A METHOD AND VESSEL FOR CARBON SEQUESTRATION GB2208514.6 A RIG FOR USE IN GROWING SEAWEED AND A METHOD OF OPERATING SUCH A RIG

GB2214031.3

k. How are you going to finance this project?

<300 words

Seaweed Generation has raised [$1M from VC sources] to finance the 2023 pilot. We will raise a further round in 2023, and will be offering pre-sales to CDR pioneers like Frontier.

l. Do you have other CDR buyers for this project? If so, please describe the anticipated purchase volume and level of commitment (e.g., contract signed, in active discussions, to be approached, etc.).

<200 words

We are in active discussions with potential early purchasers. We are looking for the correct combination of positioning (being clear about the early nature but high potential of mCDR, and the co benefits of our approach) and pricing (around $400 a tonne).

m. What other revenue streams are you expecting from this project (if applicable)? Include the source of revenue and anticipated amount. Examples could include tax credits and co-products.

<200 words

There are no other revenue streams expected from this project.

In the future we may be able to co-sell *Sargassum* removal as a tourism and coastal protection (especially mangroves, reefs and seagrass) product. Currently governmental margins in the Caribbean region are incredibly tight, and tourism (which doesn't tend to flourish on the windward sides of Caribbean Islands) has already been limited by weather and *Sargassum* innundations.

For cultivation, biomass could be used for other industrial processes, to qualify for CDR it would need to be sunk into the deep ocean in an appropriate (>1000m, no upwelling, legally and socially acceptable) location.

n. Identify risks for this project and how you will mitigate them. Include technical, project execution, ecosystem, financial, and any other risks.

Risk	Mitigation Strategy
Push back arising from uncertainty around ocean based CDR	Ensure we keep ahead of the science, become proactive and part of the scientific debate. Guidance from world leading scientists on our Science Advisory Board.
MRV delays accreditation.	Work with stakeholders in the verification and academic communities to establish a robust, future-proof monitoring, recording and verification program.
Run out of money whilst still pre-revenue for CDR.	Actively seeking pre-purchases, planning another round in 2023
Cultivation cost too high for viable CDR use.	Seaweed biomass sold into established food/feed markets until cost per tonne is viable with CDR market.
Weather risks	Use weather prediction tools to ensure seaweed sinking can occur safely and efficiently when safe to do so. Pause operations accordingly.
Ecological disruption at surface of ocean (*Sargassum*)	Early evidence suggests that macrofauna disassociates with extensive *Sargassum* mats as they become enlarged. In addition to a technology that will 'eat' the *Sargassum*, and would thereby scare away most marine life, we are adding further mitigation measures to repel creatures (see supplement)
Ecological disruption at surface of ocean (Cultivation)	Regular monitoring prior to and during cultivation for plankton and macro fauna. Increase in macrofauna is expected in growth areas, which may in turn increase plankton. Needs further MRV, species grown and areas for cultivation need to be selected thoughtfully
Ecological disruption in deep ocean	Early evidence suggests the addition of seaweed material will have negligible impact on seabed ecology, however if ongoing monitoring detects any perturbations, sinking zones can be enlarged or new ones identified to allow material to be distributed over larger regions.

2. Durability

a. Describe how your approach results in permanent CDR (> 1,000 years). Include citations to scientific/technical literature supporting your argument. What are the upper and lower bounds on your durability estimate?

< 300 words, including number/range of durability estimate

Primary production and fixation of CO2 in the surface ocean by seaweeds will cause more CO2 to enter the surface ocean to replace it, this will become long term if the seaweed (and the carbon contained in it) is subsequently stored durably.

Ocean based CDR is so effective that around 80% of any carbon dioxide entering the deep oceans from the atmosphere is permanently stored. This remains the case even at 550ppm (double pre-industrial levels). The remaining 20% will leak back into the atmosphere at a rate determined by location and depth. The deeper it moves, the longer the time to return. It is accepted that CO2 directly placed in the deep ocean will equilibrate with the atmosphere over a period ranging from 300-1000 years. This process will be considerably longer for organic carbon comprising seaweed biomass, which would need to be respired and remineralised first before any return to the atmosphere could take place. This is known as the biological pump.

Seaweed Generation will accelerate the biological pump by enhancing seaweed deposition to the seabed >2500m deep, taking advantage of gravitational pull exerted below 200m (our release depth) following the negative buoyancy induced in *Sargassum* at depths below 135m.

Seaweed material which becomes incorporated into the seabed and sedimented will be sequestered indefinitely on geological timescales (see Figure 3 in Hain et al). The rest could subsequently return to the surface by two possible mechanisms: mixing and migrant induced.

Movement of material to depths below 1000m (roughly the bottom of the thermocline, where the oceans become stably stratified by temperature/density gradients inhibits vertical mixing further), enhances longevity by reducing mixing.

Diel vertical migration of zooplankton and nekton only occurs in the euphotic zone (upper 200m of ocean) and will not impact on deep ocean material.

b. What durability risks does your project face? Are there physical risks (e.g. leakage, decomposition and decay, damage, etc.)? Are there socioeconomic risks (e.g. mismanagement of storage, decision to consume or combust derived products, etc.)? What fundamental uncertainties exist about the underlying technological or biological process?

<200 words

In the depths of the ocean, undisturbed seaweed will decompose on the seabed and become remineralised over thousands of years. Unplanned disturbance will only happen due to a natural disaster such as an earthquake or deep sea volcanic activity. Some minor, but planned, disturbance will occur through our monitoring program as we remove samples to ensure that the environmental and ecological consequences (or lack of) are measured appropriately.

Working with local governments, we will ensure that sinking zones will be ‘ring-fenced’ indefinitely and industrial activities such as deep sea metal ore mining and oil drilling are prevented. We have recently signed an agreement with Antigua & Barbuda to this effect; and plan to sink in two dedicated regions for our initial pilots with monitoring and MRV.

The largest point of uncertainty, that we cannot answer without conducting pilots and field trials, is if there will be any effect on the deep ocean, under what circumstances, and what we can do to prevent it. We have spoken to a host of scientists and communities in the field of CDR, with differing opinions. The largest point of consensus is that we need more information, more data and more monitoring.

3. Gross Removal & Life Cycle Analysis (LCA)

a. How much GROSS CDR will occur over this project's timeline? All tonnage should be described in metric tonnes of CO_2 here and throughout the application. Tell us how you calculated this value (i.e., show your work). If you have uncertainties in the amount of gross CDR, tell us where they come from.

Gross tonnes of CDR over project lifetime	1,290 tonnes
Describe how you calculated that value	AlgaRay & *Sargassum* Gross CDR Initial AlgaRay can harvest and sink 2.6 tonnes of *Sargassum* up to 60x a day = 156 tonnes 365 days a year = 56,940 tonnes of *Sargassum* Capacity factor is 12% = 6,832 tonnes of *Sargassum* Dry *Sargassum* is 15.68% of wet weight = 1,024 tonnes 27.41% - 29.23% (say 28%) of dry *Sargassum* is carbon = 286.72kg of carbon 286.72 X 3.667 = 1,051 tonnes of CO2 a year Minus 10% for air-sea flux (*uncertainty* / needs further research) Minus 10% for natural deep-sea sinking (D. Krause-Jensen, et. al) (*uncertainty* / needs further research) Minus 19% for further *uncertainty* and buffer (deep sea sequestration, drifting) = 631 tonnes of CO2 removal a year maximum

	AlgaVator & AlgaRay Gross CDR Initial (full sized) AlgaVator can grow up to 800 tonnes over a 12 month period (multiple harvests) Estimated initial capacity factor is 50% (or 50% success rate of growth) = 400 tonnes of wet seaweed Assuming a similar wet to dry weight % of 16% = 64 tonnes dry Species selected for >29% dried carbon content = 18.56 tonnes 18.56 x 3.667 = 68 tonnes of CO2 per unit Minus 10% for air-sea flux (*uncertainty* / needs further research) Minus 10% for potential plankton displacement (*uncertainty* / needs further research, and thoughtful placement to avoid this) Minus 19.09% for further *uncertainty* and buffer (deep sea sequestration, drifting) = 40 tonnes of CO2 removal a year per unit maximum Project calculation over time Y1 - Starting slowly, allowing time for data gathering and monitoring 91 tonnes gross removal Y2 - Increasing efficiency 811 tonnes gross removal Y3 - Delivery buffer 380 tonnes gross removal

b. How many tonnes of CO_2 have you captured and stored to date? If relevant to your technology (e.g., DAC), please list captured and stored tons separately.

100kg of *Sargassum* sunk in piecemeal amounts, approximately 69.9kg of CO2 equivalent (see section 4d below), during initial small scale, informal buoyancy and sinking trials as proof-of-concept.

c. If applicable, list any avoided emissions that result from your project. For carbon mineralization in concrete production, for example, removal would be the CO_2 utilized in concrete production and avoided emissions would be the emissions reductions associated with traditional concrete production.

Do not include this number in your gross or net CDR calculations; it's just to help us understand potential co-benefits of your approach.

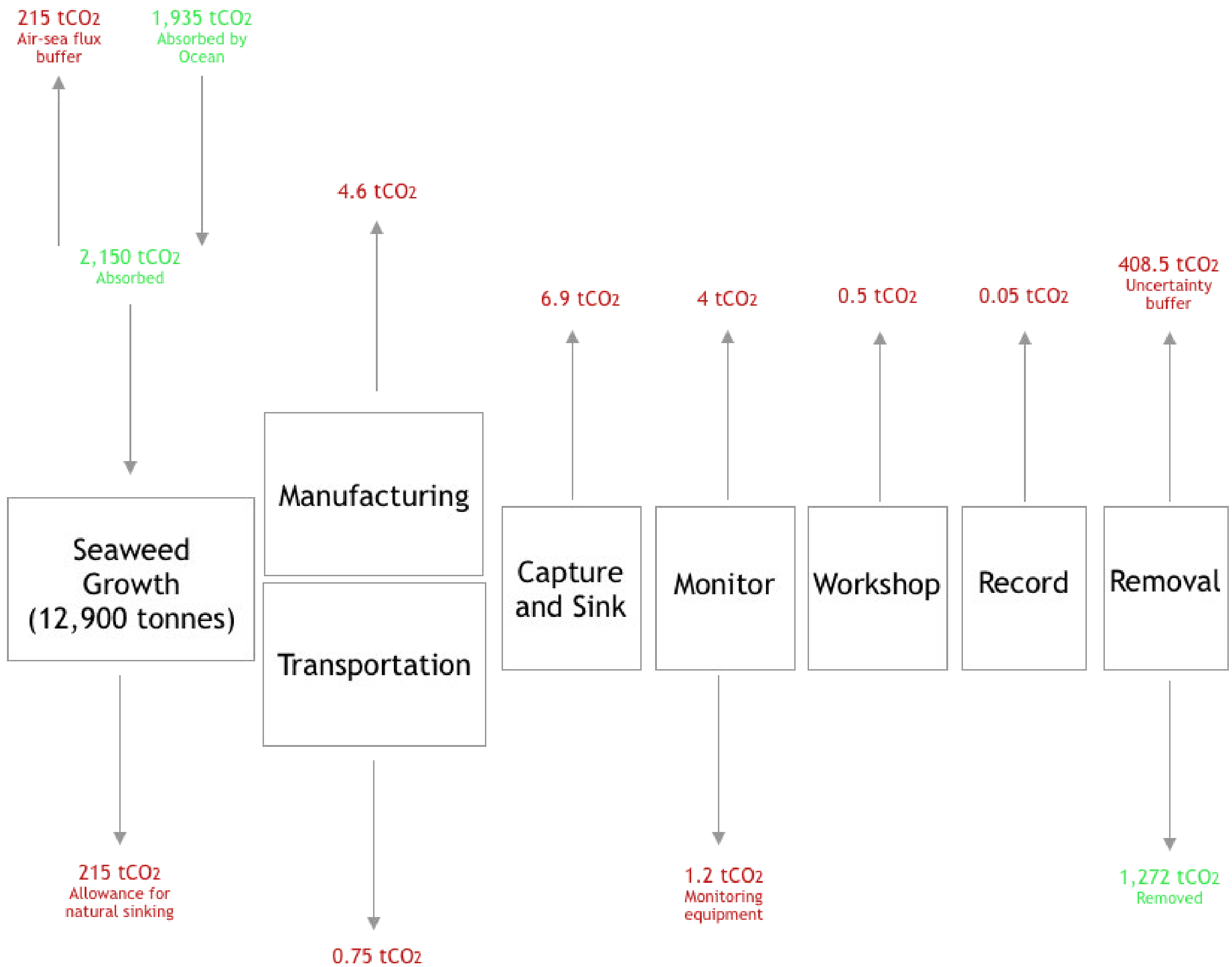
Sargassum material which is not intercepted offshore, rots when it becomes beached and releases the CO2 that it has previously absorbed back into the atmosphere and surface waters. Under anaerobic conditions (which occurs when oxygen cannot penetrate, both on land and in water), methane gas will be produced. This will occur on the beaches, as well as in landfill sites where *Sargassum* is most commonly disposed of. Mangroves, under pressure from anoxic conditions or the arsenic released by the *Sargassum,* may also produce large amounts of methane (Rosentreter, J et al). Measurements and analysis of these emissions would need further investigation to quantify. There is also the CO2 cost of the heavy machinery required to remove material from beaches to consider, as well as the associated environmental cost of beach degradation and coastal erosion through loss of sand material.

d. How many GROSS EMISSIONS will occur over the project lifetime? Divide that value by the gross CDR to get the emissions / removal ratio. Subtract it from the gross CDR to get the net CDR for this project.

Gross project emissions over the project timeline *(should correspond to the boundary conditions described below this table)*	18
Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)*	0.0139
Net CDR over the project timeline *(gross CDR - gross project emissions)*	1,272

e. Provide a process flow diagram (PFD) for your CDR solution, visualizing the project emissions numbers above. This diagram provides the basis for your life cycle analysis (LCA). Some notes:

- The LCA scope should be cradle-to-grave
- For each step in the PFD, include all Scope 1-3 greenhouse gas emissions on a CO_2 equivalent basis
- Do not include CDR claimed by another entity (no double counting)
- For assistance, please:
  - Review the diagram below from the CDR Primer, Charm's application from 2020 for a simple example, or CarbonCure's for a more complex example
  - See University of Michigan's Global CO_2 Initiative resource guide
- If you've had a third-party LCA performed, please link to it.



f. Please articulate and justify the boundary conditions you assumed above: why do your calculations and diagram include or exclude different components of your system?

<100 words

A full LCA is being undertaken by EcoEngineers.

We include manufacturing, parts, transport and operations expected over the course of the project, for the production of 2 AlgaRays and 1 trial sized AlgaVator, with a (simple) AUV.

We are including buffers for ocean operations. In time these operations will become unnecessary as we increase automation.

We are including a generous allowances for computation needs for the storage / processing

and publication of CDR evidence and data sharing. We are including allowances and buffers for natural sinking rates of *Sargassum*, uncertainties around air-sea flux, and a 19% buffer for further uncertainties.

g. Please justify all numbers used to assign emissions to each process step depicted in your diagram above. Are they solely modeled or have you measured them directly? Have they been independently measured? Your answers can include references to peer-reviewed publications, e.g. Climeworks' LCA paper.

Process Step	CO_2(eq) emissions over the project lifetime (metric tonnes)	Describe how you calculated that number. Include references where appropriate.
Manufacturing and parts **AlgaRay**	4.2 tonnes over 5 years Project timeline of 3 years = 2.5 tonnes	Batteries 14kwh - 73kg x 14 = 1,460kg Fiberglass hull - 200kg @ 2.5 tonnes CO2 a tonne - 500kg AlgaRay shells - 50kg per module x 16 - 800kg Computer system (2 laptop equivalent) - 600kg Drive system (1 laptop equivalent) - 300kg Solar panels - 50kg x 8 - 400kg Winches / cables - 100kg @ 1.9 tonnes CO2 a tonne - 190kg
AlgaVator (Trial size)	3.7 tonnes over 10 years Project timeline of 2 years = 0.4 tonnes 1.7 tonnes Total = 4.6 tonnes	Batteries 6kwh - 73kg x 6 = 438kg Central structure - 50kg PVC (0.014kg/CH4 + 1.2kg CO2 a kg) = 77.5kg Growing structure - 200kg PVC (0.014kg/CH4 + 1.2kg CO2 a kg) = 300kg Lab and transport of spores (estimate, 2 years seeding) - 1,000kg Data monitoring - (1 laptop equivalent) - 300kg Seeding / harvesting AUV (4 laptops equivalent) - 1,200kg Solar panels - 50kg x 8 - 400kg Both: Shipping of parts - 1 container China - UK - 1,200kg Workshop and buffer - 550kg
Shipping	0.75 tonnes	UK - Antigua - 1 container - 750kg
Operations	6.9 tonnes	Backup fuel for marine operations (research and monitoring vessel is sail and electric powered)

Monitoring	4 tonnes	Backup fuel for marine operations (research and monitoring vessel is sail and electric powered)
Workshop for maintenance	0.5 tonnes	Power (parts accounted for in Manufacturing)
Central computing	0.05 tonnes	Data processing and storage for this project
Manufacturing and sensors for MRV	1.2 tonnes	Equivalent to 4 laptops - 1,200kg

4. Measurement, Reporting, and Verification (MRV)

Section 3 above captures a project's lifecycle emissions, which is one of a number of MRV considerations. In this section, we are looking for additional details on your MRV approach, with a particular focus on the ongoing quantification of carbon removal outcomes and associated uncertainties.

a. Describe your ongoing approach to quantifying the CDR of your project, including methodology, what data is measured vs modeled, monitoring frequency, and key assumptions. If you plan to use an existing protocol, please link to it. Please see Charm's bio-oil sequestration protocol for reference, though note we do not expect proposals to have a protocol at this depth at the prepurchase stage.

<300 words

This is the most challenging aspect of ocean based CDR.

Our process locks away carbon by accelerating the biological pump. The reason it is so effective and simultaneously so difficult to monitor, record and verify is because it is so well locked away. This is not a good reason to avoid ocean based CDR.

We are working with EcoEngineers, our Science Board, and industry experts to develop a reliable MRV system. With *Sargassum*, no cultivation occurs, removal occurs in the open ocean, with one species of seaweed which is in an active growth phase, in one regional location. This initial MRV will help form a foundation for ongoing MRV development, needed for ocean CDR: we can later layer in variations for cultivation impacts, coastal implications, multiple species, growth cycle impacts, multiple locations.

AlgaRays generate positional (GPS, time) and physical data (weight) which can be used to correlate seasonal biomass variation to carbon composition (time-location-weight). Every removal event is visually recorded, as well as associated chemical and physical conditions (pH, temp, dO2, salinity, depth, shading). This will generate substantial data.

Seaweed is being tested throughout the season on a monthly basis for carbon content. Buoyancy and sinking rate data will be gathered, to assess if any seasonal variation exists. As a rapidly growing biomass it is expected that variation will be minimal. Drops will be followed on a monthly basis with video footage confirming sinking/timing/current measurements.

Seaweed deposition will be monitored by monthly sampling at the seafloor where we have sunk biomass (>4000m) to assess longevity, as well as long term ecological impact (pH, DOC, DIC, POC, Nutrients, O2, microbial communities, eDNA, trophic exchanges, visual monitoring and seabed samples). Turbidity sensors will be used to verify expected absence of upwelling and speed of deep sea currents for leakage verification.

b. How will you quantify the durability of the carbon sequestered by your project discussed in 2(b)? If direct measurement is difficult or impossible, how will you rely on models or assumptions, and how will you validate those assumptions? *(E.g. monitoring of injection sites, tracking biomass state and location, estimating decay rates, etc.)*

<200 words

80% of carbon that reaches the deep (>1000m) ocean is removed permanently.

Offshore, where this project is active, from the moment the AlgaRay releases the seaweed it has three potential destinations, with three different durabilities.

The first is that the seaweed fails to sink and/or sinks at such a slow rate that it is remineralised before reaching the deep ocean (in this instance the durability would be months to years and uncertain). Dropping at 200m (past the eutrophic zone), the biomass will reach 1000m in under 1.5 hours. This can be verified by visually tracking sinking biomass.

The second is the seaweed can reach the seabed where it joins the deep ocean carbon cycle (1000+ years, high certainty) , which the monitoring program will be able to watch the degradation of through visual inspection, monitoring trophic impacts and tracking through stable isotope probing.

The third is that the seaweed becomes sedimented (approximately 1.25% is expected) and is effectively removed indefinitely (hundreds of millions of years), this will be monitored by seabed grabs or cores.

c. This tool diagrams components that we anticipate should be measured or modeled to quantify CDR and durability outcomes, along with high-level characterizations of the uncertainty type and magnitude for each element. We are asking the net CDR volume to be discounted in order to account for uncertainty and reflect the actual net CDR as accurately as possible. Please complete the table below. Some notes:

- In the first column, list the quantification components from the Quantification Tool relevant to your project (e.g., risk of secondary mineral formation for enhanced weathering, uncertainty in the mass of kelp grown, variability in air-sea gas exchange efficiency for ocean alkalinity enhancement, etc.).
- In the second column, please discuss the magnitude of this uncertainty related to your project and what percentage of the net CDR should be discounted to appropriately reflect these uncertainties. Your estimates should be based on field measurements, modeling, or scientific literature. The magnitude for some of these factors relies on your operational choices (i.e.,

methodology, deployment site), while others stem from broader field questions, and in some cases, may not be well constrained. We are not looking for precise figures at this stage, but rather to understand how your project is thinking about these questions.

- See this post for details on Frontier's MRV approach and a sample uncertainty discount calculation and this Supplier Measurement & Verification Q&A document for additional guidance.

Quantification component Include each component from the Quantification Tool relevant to your project	Discuss the uncertainty impact related to your project Estimate the impact of this component as a percentage of net CDR. Include assumptions and scientific references if possible.
Macroalgae Biomass Generation (*Sargassum*) (Cultivated)	Natural phenomena. Material in the rapid growth phase will exhibit less physiological variability in biomass carbon. *Sargassum* mats composed predominantly of single, floating, homogeneous species. Mass of material measured for every sinking event, converted to carbon using carbon calculator. Observational composition data to confirm. Uncertainty: low. Impact: Negligible (<1%) Seaweed growth monitored throughout growth cycle for accurate yield and productivity data. Carbon content of specific seaweed species seeded can be calculated. Mass of material measured for every sinking event, converted to carbon using carbon calculator.Observational composition data to confirm. Uncertainty: low. Impact: Negligible (<1%)
Leakage (*Sargassum*) (Cultivated)	Release below 200m will ensure biomass is sunk to depth. Visual field recordings to confirm. Uncertainty: Negligible to low Impact: 1% Not floating seaweed biomass will sink effectively when removed from SeaTree tether and sunk using the AlgaRay Visual field recordings to confirm. Uncertainty: Negligible to low Impact: 1%
Surface Composition Effects (*Sargassum*) (Cultivated)	Naturally grown biomass: has already naturally displaced phytoplankton primary productivity. Uncertainty: Negligible to low Impact: 1% Seaweed growth could have secondary effects on phytoplankton carbon uptake, including via nutrient depletion or canopy shading. Uncertainty: Low to medium Impact: 5%

Air-Sea Gas Exchange (*Sargassum*) (Cultivated)	Floating biomass growth occurs at the very surface of the ocean reducing surface contact with atmosphere, Air-sea flux across ocean CDR is in need of further scientific investigation, research and modeling. DIC-depleted water directly below biomass could increase contact with the atmosphere following its removal thereby improving atmospheric drawdown. Observational data to confirm. Uncertainty: Medium - High Impact: 10% (Andy Watson) - 40% Location-specific air-sea gas exchange dynamics based on observational data to be modeled. Uncertainty: Medium - High Impact: 10% (Andy Watson) - 40%
Energy (*Sargassum*) (Cultivated)	Solar powered systems. AlgaRay - 6.5MWh - 40MWh (size dependent) AlgaVator - 10MWh Largest impact of energy and material needs is battery manufacturing. Long term use makes this impact negligible. Uncertainty: Low Impact: <1%
Materials	Material needs comparatively low, and easily quantified. Uncertainty: Low Impact: <1%
Deepwater Recirculation	1.25% will be buried indefinitely. 98.75% will remineralise over 1000+ year time scales. Sinking to occur in specified regions >2500m in depth. 80% of deep water carbon is permanently removed. Locations verified for absence of upwelling, chosen for deep water. Uncertainty: Low - Medium Impact: 2%

d. Based on your responses to 4(c), what percentage of the net CDR do you think should be discounted for each of these factors above and in aggregate to appropriately reflect these uncertainties?

<50 words

AlgaRay
Biomass Generation <1%
Leakage 1%
Surface Composition <1%
Air-Sea Flux 10-20%
Energy <1%
Materials 1%
Deepwater Recirculation 2%

Total 20-25% (plus buffer/natural sinking rate)

AlgaVator
Biomass Generation <1%
Leakage 1%
Surface Composition 5%
Air-Sea Flux 15-25%
Energy <1%
Materials 1%
Deepwater Recirculation 2%

Total 25-30% (plus buffer)

e. Will this project help advance quantification approaches or reduce uncertainty for this CDR pathway? If yes, describe what new tools, models or approaches you are developing, what new data will be generated, etc.?

<200 words

This project is an early pioneer for seaweed based CDR approaches. The *Sargassum* angle in particular provides us with an opportunity which is immediately scalable and can generate baseline data and methodology for other sinking approaches. With a single target species (*Sargassum*), and control over interception, measuring and sinking location, our initial approach is the simplest method envisageable for seaweed CDR.

All other approaches will include additional complications (such as cultivation, harvesting, multiple species, seasonal variation, location), we can help form a foundation on which the industry can develop the models that others can utilize.

f. Describe your intended plan and partners for verifying delivery and registering credits, if known. If a protocol doesn't yet exist for your technology, who will develop it? Will there be a third party auditor to verify delivery against that protocol or the protocol discussed in 4(a)?

<200 words

We are currently developing our concept note, methodology, LCA and 3rd party verification with EcoEngineers, and hope to work with Ocean Visions to help implement their framework for 'Macroalgae Cultivation & Sinking for Carbon Sequestration'. We are in early talks with registries (Patch, Puro.Earth, C-Capsule) and certification bodies (VERRA, Puro.Earth, C-Capsule) to develop protocols around seaweed based CDR.

5. Cost

We are open to purchasing high-cost CDR today with the expectation the cost per tonne will rapidly decline over time. The questions below are meant to capture some of the key numbers and assumptions that you are entering into the separate techno-economic analysis (TEA) spreadsheet (see step 4 in Applicant Instructions). There are no right or wrong answers, but we would prefer high and conservative estimates to low and optimistic. If we select you for purchase, we'll work with you to understand your milestones and their verification in more depth.

a. What is the levelized price per net metric tonne of CO_2 removed for the project you're proposing Frontier purchase from? This does not need to exactly match the cost calculated for "This Project" in the TEA spreadsheet (e.g., it's expected to include a margin), but we will be using the data in that spreadsheet to consider your offer. Please specify whether the price per tonne below includes the uncertainty discount in the net removal volume proposed in response to question 4(d).

$/tonne CO_2 $393 (inclusive of uncertainty discounting)

b. Please break out the components of this levelized price per metric tonne.

Component	Levelized price of net CDR for this project ($/tonne)
Capex	$74
Opex (excluding measurement)	$225
Quantification of net removal (field measurements, modeling, etc.)[2]	$71
Third party verification and registry fees (if applicable)	$23
Total	(should match 5(a)) $393

[2] This and the following line item is not included in the TEA spreadsheet because we want to consider MRV and registry costs separately from traditional capex and opex.

c. Describe the parameters that have the greatest sensitivity to cost (e.g., manufacturing efficiencies, material cost, material lifetime, etc.). For each parameter you identify, tell us what the current value is, and what value you are assuming for your NOAK commercial-scale TEA. If this includes parameters you already identified in 1(c), please repeat them here (if applicable). Broadly, what would need to be true for your approach to achieve a cost of $100/tonne?

Parameter with high impact on cost	Current value (units)	Value assumed in NOAK TEA (units)	Why is it feasible to reach the NOAK value?
Operational efficiency (OPEX)	$225	$180	Increase in scale and decrease in numbers of personnel needed at sea as we increase automation
Manufacturing / materials	$74	$59	Increase in capacity of AlgaRay, brings down cost per tonne for materials dramatically
Quantification / MRV	$71	$57	Monitoring needs likely to decrease over time, and / or cheaper solutions developed in house or in the market. Also, economies of scale

d. What aspects of your cost analysis are you least confident in?

<100 words

Operational efficiency / OPEX is our greatest unknown. Our process relies on the efficient interception of a moving biomass which is variable in location, speed, shape and size. The ability to monitor using satellite technology is a major advantage and opportunity to help mitigate this, but is nullified by cloud cover. To this end, we intend to mitigate by use of UAV gliders and drones. As we increase in operational scale our local mapping, coverage and understanding of the real time spatial and temporal situation will increase; as well as our modeling and prediction capabilities.

e. How do the CDR costs calculated in the TEA spreadsheet compare with your own models? If there are large differences, please describe why that might be (e.g., you're assuming different learning rates, different multipliers to get from Bare Erected Cost to Total Overnight Cost, favorable contract terms, etc.).

<200 words

They are fairly consistent with our assumptions / expectations.

For cultivation, we believe that the overall costs will reduce further over larger scale.

f. What is one thing that doesn't exist today that would make it easier for you to commercialize your technology? (e.g., improved sensing technologies, increased access to X, etc.)

<50 words

MRV sensors and tooling!!

Seriously that. Affordable ocean sensors and deployment systems. We are and hope to build some potential solutions (i.e. using the AlgaRay) inhouse, but there's much there to do.

6. Public Engagement

In alignment with Frontier's Safety & Legality criteria, Frontier requires projects to consider and address potential social, political, and ecosystem risks associated with their deployments. Projects with effective public engagement tend to:

- Identify key stakeholders in the area they'll be deploying
- Have mechanisms in place to engage and gather opinions from those stakeholders, take those opinions seriously, and develop active partnerships, iterating the project as necessary

The following questions help us gain an understanding of your public engagement strategy and how your project is working to follow best practices for responsible CDR project development. We recognize that, for early projects, this work may be quite nascent, but we are looking to understand your early approach.

a. Who have you identified as relevant external stakeholders, where are they located, and what process did you use to identify them? Please include discussion of the communities potentially engaging in or impacted by your project's deployment.

<300 words

We have engaged with the Government of Antigua and Barbuda as we identified their EEZ as being perfectly positioned for the development and deployment of the AlgaRay. Official approval has been granted (4th October 2022) and Seaweed Generation now has access to dedicated drop zones with assurance of longevity. Our interactions with the Antiguan Government progressed on to discussions with their Maritime Department, Environment Agency, as well local NGOs, fishing communities and conservation societies.

Other locations impacted, and governments with whom we have either engaged, or plan to engage, include, Mexico, Belize, Ghana, St Martens, Guadeloupe, Barbados, Jamaica, and others in the Caribbean region.

The global scientific community is a vital stakeholder. We have engaged with Exeter University, the Global Systems Institute and The University of West Indies Five Islands in Antigua, and Ocean Visions.

We are involved with or members of [The Sargasso Sea Commission], the [ICOS] [Integrated Carbon Observation System] for Necessities of Integrated Global Observations' ([RINGO]) Oceans Interest Group, and [Safe Seaweed Coalition].

To gage support from the next generation of environmental researchers for our concept, our CSO recently gave a seminar to final year undergraduates at Exeter University, who provided overwhelmingly positive feedback on the approach being taken.

b. If applicable, how have you engaged with these stakeholders and communities? Has this work been performed in-house, with external consultants, or with independent advisors? If you do have any reports on public engagement that your team has prepared, please provide. *See Project Vesta's community engagement and governance approach as an example and Arnestein's Ladder of Citizen Participation for a framework on community input.*

<300 words

In recent months, our attention has been focused in and around Antigua & Barbuda. We have held many meetings with The Honorable Dean Jonas, MP, Cabinet Minister, Antigua & Barbuda, Minister of Blue Economy and Her Excellency Karen-Mae Hill, High Commissioner of Antigua & Barbuda, which culminated in a presentation to the full cabinet, chaired by Prime Minister, The Right Honorable Gastone Browne this summer.

We have met with Amb. Dwight Gardiner (Director/Registrar General Antigua & Barbuda Department of Marine Services), representatives (Mr Ruleo Camacho and Dr Chris Waters) from the Environmental Unit of the National Parks Authority, representatives at the Department of the Environment, as well as Ms Arica Hill, Executive Director of Environmental Awareness Group.

Arica now serves on our Science Advisory Board, while we have engaged with Ruleo to help undertake our field work in the region. Our ethos and approach is to identify the right people with the right attitude and the right knowledge and work with them to achieve our goals.

Local Caribbean (Antiguan) press has covered our approach and process.

We have also reached out to many members of the ocean monitoring and CDR focused scientific community and continue to engage with major stake-holders.

c. If applicable, what have you learned from these engagements? What modifications have you already made to your project based on this feedback, if any?

<100 words

There's a strong initial feeling that sinking seaweed is a 'waste of resource', followed by a grudging realization that there are currently no economically or environmentally viable uses for *Sargassum* biomass.
CDR in response to the climate emergency is not always regarded as a valuable activity because the income stream is not a physical product to be sold. We have modified our approach to emphasize that island nations can not only provide a valuable contribution to the climate problem, but they can actually take a global lead in providing a solution. This change of emphasis is opening doors for us.

d. Going forward, do you have changes to your processes for (a) and (b) planned that you have not yet implemented? How do you envision your public engagement strategy at the megaton or gigaton scale?

<100 words

We will be working closely with local communities and governments to measure any effects that our activities have on *Sargassum* beachings. We plan to complete monitoring and to share data with local and international scientists, in addition to working closely with local communities.

At Mt/Gt scale, we would continue to be transparent (publishing data, monitoring and reporting, enabling searches of removals) as we are planning to be at this early stage. We would plan to engage with local and global press, environmental groups and populations, ensuring that jobs and investment from our activities benefit the coastal communities that enable large scale blue CDR.

7. Environmental Justice[3]

As a part of Frontier's Safety & Legality criteria, Frontier seeks projects that proactively integrate environmental and social justice considerations into their deployment strategy and decision-making on an ongoing basis.

a. What are the potential environmental justice considerations, if any, that you have identified associated with your project? Who are the key stakeholders? Consider supply chain impacts, worker compensation and safety, plant siting, distribution of impacts, restorative justice/activities, job creation in marginalized communities, etc.

<200 words

Sargassum beachings are a massive scale environmental disaster for the local populations of West Africa, the Caribbean and Mexico. More often than not, these communities are reliant on tourism or fishing income, both of which are being negatively affected by these influxes.

[3] For helpful content regarding environmental justice and CDR, please see these resources: C180 and XPRIZE's Environmental Justice Reading Materials, AirMiners Environmental and Social Justice Resource Repository, and the Foundation for Climate Restoration's Resource Database

The poorer the location affected by *Sargassum*, the less likely their governments are to have the resources be able to clear the issue. The cleanup cost in the Caribbean was $120M in 2018 alone, a devastating economic bill in addition to the loss of revenue from tourism.

This project offers the opportunity to create climate positive jobs in island states and coastal areas, where climate change will have outsized effects on coastal regions, and *Sargassum* is already having terrible side effects (Environmental and Human).

b. How do you intend to address any identified environmental justice concerns and / or take advantage of opportunities for positive impact?

<300 words

We estimate that the effects of our activities would be largely positive. The same Island nations suffering from *Sargassum* influxes also face high impacts from rising sea levels and increases in extreme weather. Our activities would directly alleviate the *Sargassum*, and offer the local population a chance to take part in activities that could slow the increase in broader climate change.

Our project will use local labor where possible (the vast majority of new roles created by this project will be for local populations who will operate the project) therefore providing alternative, safe and longer term employment. We will keep up the dialogue we have already started with other seafarers and actively work with fisheries and tourism businesses to ensure fair use and fair access.
Only near coastal *Sargassum* is being removed, none from the Sargasso Sea or immediately adjacent to the Sargasso Sea and therefore the impact as a fish nursery will be limited.
Removal of *Sargassum* will solve a major environmental justice issue of access to beaches and the sea for island communities.

8. Legal and Regulatory Compliance

a. What legal opinions, if any, have you received regarding deployment of your solution?

<100 words

As we are working directly with governments and have received permission to operate in their waters, we are not anticipating the need for further legal opinions above and beyond adhering to local employment, safety and maritime laws.

b. What permits or other forms of formal permission do you require, if any, to engage in the research or deployment of your project? What else might be required in the future as you scale? Please clearly differentiate between what you have already obtained, what you are currently in the process of obtaining, and what you know you'll need to obtain in the future but have not yet begun the process to do so.

<100 words We have obtained permission, and designated areas of our operations, from the Government of Antigua and Barbuda.

c. Is your solution potentially subject to regulation under any international legal regimes? If yes, please specify. Have you engaged with these regimes to date?

<100 words Not that we are aware of currently. We anticipate (and indeed, hope) that CDR and marine CDR will become regulated in the future.

d. In what areas are you uncertain about the legal or regulatory frameworks you'll need to comply with? This could include anything from local governance to international treaties. For some types of projects, we recognize that clear regulatory guidance may not yet exist.

<100 words Our activities will take place near shore where clear 'ownership' of the free floating seaweed can be ascertained. In the future, as we expand our scale of operation we will move into international waters, in which case we expect that the rules of the London Convention would apply. As we are capturing and sinking naturally occurring local biomass, we have been advised that the activity would not be considered dumping. For cultivation activities, we plan to operate within Exclusive Economic Zones for the foreseeable future, and will be seeking agreements similar to the one that we have with Antigua and Barbuda.

e. Do you intend to receive any tax credits during the proposed delivery window for Frontier's purchase? If so, please explain how you will avoid double counting.

<50 words N/A

9. Offer to Frontier

This table constitutes your offer to Frontier, and will form the basis of contract discussions if you are selected for purchase.

Proposed CDR over the project lifetime (tonnes) *(should be net volume after taking into account the uncertainty discount proposed in 4(c))*	1,272 tCO2
Delivery window *(at what point should Frontier consider your contract complete? Should match 1(f))*	May 1 2023 - April 2025
Levelized Price ($/metric tonne CO_2) *(This is the price per tonne of your offer to us for the tonnage described above)*	$393 (Ex. VAT)

Application Supplement: Biomass

(Only fill out this supplement if it applies to you)

Feedstock and Physical Footprint

1. What type(s) of biomass does your project rely on?

<100 words

Naturally occurring *Sargassum* (seaweed) growth and cultivated macroalgae.

2. How is the biomass grown (e.g., kelp) or sourced (e.g., waste corn stover)? Do you have supply agreements established?

<200 words

Initially, we are capturing naturally grown, problematic *Sargassum* material from the Great Atlantic *Sargassum* Belt ourselves. We have no requirement to grow it and its removal by the AlgaRay is deemed an important ecosystem service to all countries impacted by its relentless inundations. We have established an agreement with the government of Antigua & Barbuda for exclusive access to their waters (and *Sargassum* material) and the right to sink in dedicated regions of their EEZ.

Our AlgaVator systems for cultivating macroalgae in the future are designed to be versatile and automated to allow their deployment globally. We have applied for licenses in Scotland for our R&D trials, and are in discussions with Antigua & Barbuda and SIDs member states about establishing a global roll out program.

3. Describe the logistics of collecting your waste biomass, including transport. How much carbon emissions are associated with these logistics, and how much does it cost? How do you envision this to evolve with scale?

<200 words

The most elegant part of the AlgaRay approach is that it intercepts *Sargassum* material in situ and simply moves it in the vertical direction to induce its permanent removal from the surface CO2 cycle. Driven by photovoltaic power, there are no transport or processing costs per se, only the collection and sinking costs which are already factored into our calculations.

For cultivation, depending on which areas we cultivate in, there may be a need to move biomass to appropriate sinking areas (chosen for distribution, monitoring, deeps, longevity parameters, etc). For this, the AlgaRay will be reused. Costs are broadly baked in for this - 1 AlgaRay will be able to transport 16 tonnes at a time, and by the time we are cultivating at a meaningful scale, will be largely automated.

4. Please fill out the table below regarding your feedstock's physical footprint. If you don't know (e.g. you procure your biomass from a seller who doesn't communicate their land use), indicate that in the table.

	Area of land or sea (km^2) in 2022	Competing/existing project area use (if applicable)
Feedstock cultivation ***Sargassum***	*0km2 (already growing)*	*Sargassum* causing issues for fishing vessels and sailing boats. Disruption to habitats will be mitigated by repelling marine life, leaving small rafts. Biomass heading towards land will be disrupted shortly after our interception point when it beaches / becomes denser.
Cultivation	0.01km2	Cultivation area < 1ha for testing of trial system. Licensing an existing seaweed farm to test our structures. No additional displacement created by our project. Longer term, licensing of appropriate sites near to deep water, and in offshore areas, will also need to include allowances for fishing lanes and shipping activities.
Processing ***Sargassum***	0km2 (no processing)	Workshop on a boat yard - 10m x 5m
Cultivation	0km2 (no processing)	Same workshop used for cultivation
Long-term Storage ***Sargassum***	1km2 (dropping area)	No current competition for sea bed >4000m down. Ecological impact needs to be closely monitored, and the amount of biomass that can be safely sunk needs to be established.
Cultivation	0km2 (no storage intended for 2022 crop)	

Capacity

5. How much CDR is feasible globally per year using the biomass you identified in question 1 above? Please include a reference to support this potential capacity.

<100 words

Sargassum material in the Great Atlantic *Sargassum* Belt is conservatively estimated to number in excess of a 20 million tonne standing stock, grows rapidly throughout the summer months in particular and makes landfall in substantial amounts over a 6-8 month period.

SeaGen estimates *Sargassum* biomass provides capacity for 5-10 million tonnes of AlgaRay induced CDR comfortably annually by 2030, and crucially, provides the opportunity to establish the baseline MRV methodologies for future cultivation activities. By 2030, we predict cultivated material CDR will have overtaken natural *Sargassum* harvest (2.1 million), continuing to expand to reach > 2 gigatonnes per annum by 2050.

Additionality and Ecosystem Impacts

6. What are applications/sectors your biomass feedstock could be used for other than CDR? (i.e., what is the counterfactual fate of the biomass feedstock)

<100 words

We have investigated uses for *Sargassum* including biofuel, fertilizer, biostimulants, omega-3, pigments, amino acids, sugars, even remediation of metals and plastic. *Sargassum* is a poor and unreliable feedstock, and is a nuisance that causes economic and ecological harm. Its saving grace: it is perfect for CDR as it utilizes nutrients incredibly efficiently and grows rapidly.

Cultivated seaweed will find a plethora of uses (mentioned above), and could feed into supply chains for niche markets. At megatonne to gigatonne production scales, supply to such low volume/high value markets will become saturated, providing justification and impetus for its use in CDR.

7. There are many potential uses for waste biomass, including avoiding emissions and various other approaches to CDR. What are the merits and advantages of your proposed approach in comparison to the alternatives?

<200 words

For *Sargassum* there is little in the way of an alternative approach. Once *Sargassum* has made landfall it is already too late, it becomes about damage limitation (ecological, environmental, health, economic). Our approach prevents this happening: by intercepting and sinking it before it becomes damaging and dangerous.

Socially, ecologically and economically, we believe that our project will have a very positive effect on the areas that we are operating in. At full operational scale, we will be able to offer a large impact on the *Sargassum* influxes, allowing the return of economic activities that were present before they occured.

Our approach prevents the *Sargassum* beaching events which lead to the re-emission of captured CO2 (as well as methane production) and re-introduction of nutrients into the surface ocean as it degrades, the very processes contributing to its uncontrollable growth over the past decade.

For cultivation, scale at the size needed for meaningful CDR would flood existing markets. We believe that it is possible (and sensible) to strike a balance between using biomass for appropriate markets where there is demand and infrastructure (location, market, and facility specific), and for CDR.

8. We recognize that both biomass production (i.e., growing kelp) and biomass storage (i.e., sinking in the ocean) can have complex interactions with ecological, social, and economic systems. What are the specific, potential negative impacts (or important unknowns) you have identified, and what are your specific plans for mitigating those impacts (or resolving the unknowns)?

<300 words

We have given much thought to production and storage impacts: the geoengineering of the planet to mitigate climate change will undoubtedly have knock-on effects and implications.

We believe our approach will have minimal impact: we are adding gigatonnes of carbon to a system that already contains tens of thousands of gigatonnes. Nevertheless, this may have an ecological impact which we intend to measure and monitor. We will regularly check the impact of our sinking events on the deep sea ecosystems that receive our biomass by taking visual footage, physical and chemical measurements, as well as samples for biological analysis. We will be looking for changes in chemistry (such as oxygen, pH), biology (trophic interactions), as well as physical processes. If we identify an *unwanted* perturbations (we may find unexpected positive perturbations e.g. if sedimentation rates increase with increased deposition rates, an outcome which improves permanence and durability from thousands to millions of years), we can mitigate against this by changing intensity of activity in that region, cycling activity (much like crop rotations in agriculture), or changing location.

Socially and economically, offshore *Sargassum* removal is unlikely to have any negative impacts beyond the overwhelmed commercial operators who currently remove seaweed material from beaches or try to prevent it reaching the shores with barriers.

Mass automated cultivation offshore may have an impact on access to waters for fishing communities and maritime shipping activity. For the former, we will engage with local communities to ensure that positive benefits are reaped by all parties: seaweed forests are likely to provide breeding grounds for fish stocks, but will need to be left uninterrupted at certain times of the year. For the latter, our technological approach provides the data and tools we need to ensure activities remain safe, efficient and effective for all parties.

Application Supplement: Ocean

(Only fill out this supplement if it applies to you)

Physical Footprint

1. Describe the geography of your deployment, its relationship to coastlines, shipping channels, other human or animal activity, etc.

<200 words

Our deployment area has been determined through consultation with and approval from the relevant local authorities. It takes advantage of the unique tectonic geology of the Caribbean islands which run along plate boundaries creating deep sea conditions relatively close to a safe harbor. It is away from the immediate coastline and occurs where the ocean depth is greater than 1000m. The deployment areas are away from major navigation and shipping channels.

Animal activity within the excess and large *Sargassum* aggregates is still an active area of research which we will continue to support and feed into. Our project aims to protect that which calls *Sargassum* home by dealing with only problematic biomass, in areas where the *Sargassum* is about to reach coastal areas (an event that would kill marine life within the mat, and anything coastal that gets trapped in it as it reaches the coast).

We have built deterrents and easy escapes into our system, such as bright colors, shallow nets, and wide net gauges. In addition to the noise from our activities, we believe effects on animals will be low. We can add further deterrents if necessary.

2. Please describe your physical footprint in detail. Consider surface area, depth, expected interaction with ocean currents and upwelling/downwelling processes, etc.
    a. If you've also filled out the Biomass supplement and fully articulated these details there, simply write N/A.

<200 words

2023
Sargassum
Feedstock Cultivation - already growing, no additional impact. If anything, we create more space by freeing up coastal areas (by a very small amount at first) from *Sargassum* that takes up space when it hits shores.

Processing - workshops in Antigua and Scotland. 2x 50m2 facilities approximately.

Long term Storage - Deep ocean in designated sinking areas. > 4000m down, no upwelling currents are modeled (confirmation will be undertaken with turbidity sensors), sinking occurs using gravity after deposit at 200m by AlgaRay

Cultivation
Feedstock Cultivation - 1ha / 0.01km2 testing area. See Biomass supplement for short term cultivation displacements.

Processing - workshop space used for cultivation development as well. No processing necessary for biomass to be sunk (cultivated biomass will not be sunk in 2023, in 2024 we will cultivate in the Caribbean, close to deep water, where the biomass can be sunk in our existing sinking areas)

Long term Storage - as above.

3. Imagine, hypothetically, that you've scaled up and are sequestering 100Mt of CO_2/yr. Please project your footprint at that scale, considering the same attributes you did above (we recognize this has significant uncertainty, feel free to provide ranges and a brief description).
    a. If you've also filled out the Biomass supplement and fully articulated these details there, simply write N/A.

<200 words

***Sargassum* / Problematic Algal blooms**

Feedstock Cultivation - problematic algal blooms are increasing worldwide. This year has been record breaking (24 million tonnes recorded in the Gulf of Mexico and Caribbean region in June alone), with other algal blooms causing issues in Gibraltar and Fiji.

Problematic seaweed will cap out at about 5-10 million tCDR a year. Further scale will need cultivation.

Processing & Long term Storage - see below

Cultivation
Feedstock Cultivation
Area Needed **-** Between 2,500 - 5,000km2. Positioning in areas where co benefits can be established (excess nutrients, prevention of anoxic zones, additional biodiversity benefits)

Competing Used Cases **-** Fishing, maritime shipping. Cultivation of an excellent natural habitat is very likely to increase fish breeding and therefore yields around cultivation areas.

Processing
Area Needed **-** 0.5km2 for equipment manufacture, boat yards and seaweed nursery globally

Competing Used Cases - Distributed in multiple locations - warehouse style workshops close to coasts. These facilities are already in existence all over the world, we don't foresee any changes to current land use.

Long term Storage
Area Needed **-** The ocean is 361 million square kilometers, and 90% of that is below 1000m.

Competing Used Cases - Deep sea mining. Mitigated with government agreements and dropping in very remote areas.

Potential to Scale

4. Building large systems on or in the ocean is hard. What are your core engineering challenges and constraints (not covered already within 1(n)? Is there any historical precedent for the work you propose?

<200 words

Both the fishing industry, and the shipping industry, are relevant in terms of historical precedent. Certainly in terms of scale and logistical complexity.

Getting to that scale is a tremendous engineering and logistical challenge. To begin with, we are operating within the waters of countries suffering from too much biomass. Our initial pilots are small in scale, will be conducted relatively close to shore, will enable us to develop and optimize the processes that we have, and develop the existing marine expertise on our team.

Our biggest engineering challenges are likely to occur due to extreme weather, which at first we will avoid. As we develop our equipment, we will design and build components that are designed specifically to handle extreme marine weather.

Over time, we will streamline our processes, optimize our efficiency, and add automated components and machinery to increase efficiencies. Our process is specifically developed to allow gradual integration of automation.

Externalities and Ecosystem Impacts

5. What are potential negative impacts of your approach on ocean ecosystems?

<200 words

The Great Atlantic *Sargassum* Belt is a recent phenomena resulting from an imbalance in the ocean ecosystem. Unlike the Sargasso Sea which has a stable and established ecosystem formed over millennia, the GASB is young and developing. The removal of this biomass therefore has the potential to disrupt any macrofauna that is beginning to interact and take advantage of it.

In the deep ocean, the addition of organic material (above and beyond the natural biological pump) has the potential to disrupt ecosystems. We do not believe this will result in substantial disruption: the addition of all anthropogenic CO2 emissions to the deep sea would result in an increase in 4% in the overall carbon content. Nevertheless, localized, intense addition of seaweed biomass may cause some disruption in the short term.

The activity of a fleet of AlgaRays moving up and down regularly in the top 200m of the ocean may cause some disruption to animals such as rays, turtles, dolphins and whales. To put this into context, America currently has 289 million motor vehicles (1.3 million of which are electric). We project the need for 800,000 AlgaRays in operation, to remove 1 GT of CO2 a year.

6. How will you mitigate the potential for negative ecosystem impacts (e.g., eutrophication and alkalinity/pH)? How will you quantify and monitor the impact of your solution on ocean ecosystems and organisms?

<200 words

AlgaRays will be constantly generating a visual record of what is going on around them; if we see disruption or unwanted interaction of sea life, we can adapt accordingly by changing location, operational parameters (such as speed, angle of descent etc) or include 'avoidance' measures (such as the use of light or sound).

Physical and chemical parameters will be monitored: pH, salinity, temperature, light penetration (at the surface), nutrients (N, P), oxygen, CO2. These will provide top level information on how the oceanic regions are responding and functioning.

To assess ecosystem impacts we will undertake biological monitoring of the planktonic communities (surface waters) and planktonic/benthic communities (deep sea) to assess dynamics at all trophic levels. Microbial communities will be measured through metagenomic analysis: 16S and 18S ribosomal genes will be analyzed using next generation sequencing technologies to study the prokaryotic and eukaryotic community response to the addition of seaweed biomass. This will provide vital information on both community composition and function.

Similar approaches will be used in coastal regions to monitor where *Sargassum* no longer naturally lands; to determine if there are any unintended negative impacts at the coast associated with our bioremediation 'byproduct' activity.