Frontier

Buyers perspective
State of MRV for mCDR

Dr. Frauke Kracke | Science lead
September 2025

Topics

Frontier's approach to carbon removal

Our perspective on criteria for responsible mCDR

Our approach to MRV

Frontier

An advance market commitment to buy $1.25B+ of permanent carbon removal by 2030

stripe Alphabet shopify Meta McKinsey & Company

H&M Group JPMorgan Chase & Co. workday. salesforce AUTODESK

Watershed Partner Aledade Canva Match Group samsara

SKIMS Skyscanner WISE zendesk

From ‘22 - mid ‘25, Frontier facilitated 50 purchases

Dollars contracted

$626.7M

↗ $313.3M since Sep 2024

Tons contracted

1,667,624

↗ 920K since Sep 2024

Project locations

Projects by pathway

We're building a diverse portfolio to maximize the likelihood of meeting our global climate goals.

Direct air capture	13
Biomass carbon removal & storage	11
Mineralization	9
Field weathering	8
Ocean alkalinity enhancement	6
Direct ocean removal	3

Prepurchase: Early-stage suppliers piloting new technologies, prepaid, $500k

Offtake: Accelerated scaling of proven approaches, paid upon delivery, ~$20-60M

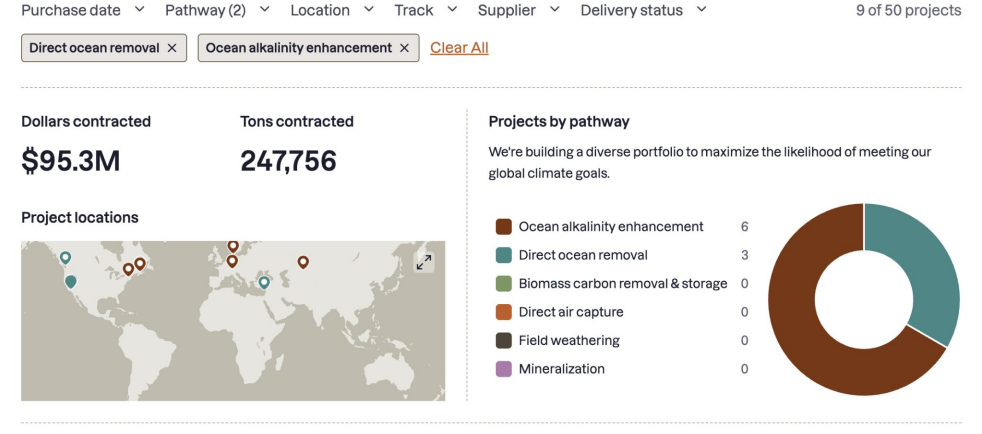
Buyers can support responsible innovation

As customers in a small market, buyers can influence the broader CDR ecosystem, including: a) suppliers; b) other buyers; c) governments; d) standard-setters

A snapshot of how we've supported responsible CDR innovation to-date:

- Driving alignment across buyers on principles for high-quality CDR
- Diligencing approaches and projects across target criteria (durability, capacity, cost, safety, etc.)
- Setting a high bar for standards for CDR measurement and community engagement
- Making applications & contracts publicly available to enable transparency & learning
- Requiring delivery criteria and/or milestones within contracts to motivate scientific deliverables
- Non-purchasing work: coalition-building, writing, policy development

First verified tons accepted, first OAE offtake contracts signed



- Purchased from 9 mCDR projects
- Including 3 pay-on-delivery offtakes

Frontier buyers sign $80M in offtake agreements with CO280 and CREW Carbon

December 17, 2024

- CO280 and CREW Carbon (Frontier members by 2030.
- Industrial retrofits alone cou

Frontier buyers sign world's first river liming carbon removal deal with CarbonRun

September 23, 2024

- Frontier buyer 2029.
- River liming br breakthroughs

Frontier buyers sign $31M deal with Planetary to advance ocean alkalinity enhancement

August 26, 2025

- Ocean alkalinity enhancement (OAE) could remove billions of tons of CO_2 annually at a price of ~$50-160/ton, emerging as one of the fastest and most affordable carbon removal solutions.
- Planetary's measurement, reporting, and verification (MRV) and safety protocols make them the ideal team to responsibly deliver on a field-first OAE offtake of this scale.
- OAE also helps reverse ocean acidification locally, benefiting coastal marine ecosystems.

- Approved one credit issuer and OAE protocol
- Accepted delivery of registered credits from one project so far

NEWS JUNE 16, 2025

World's first verified Ocean Alkalinity Enhancement credits

Credits issued for Planetary, certified by Isometric

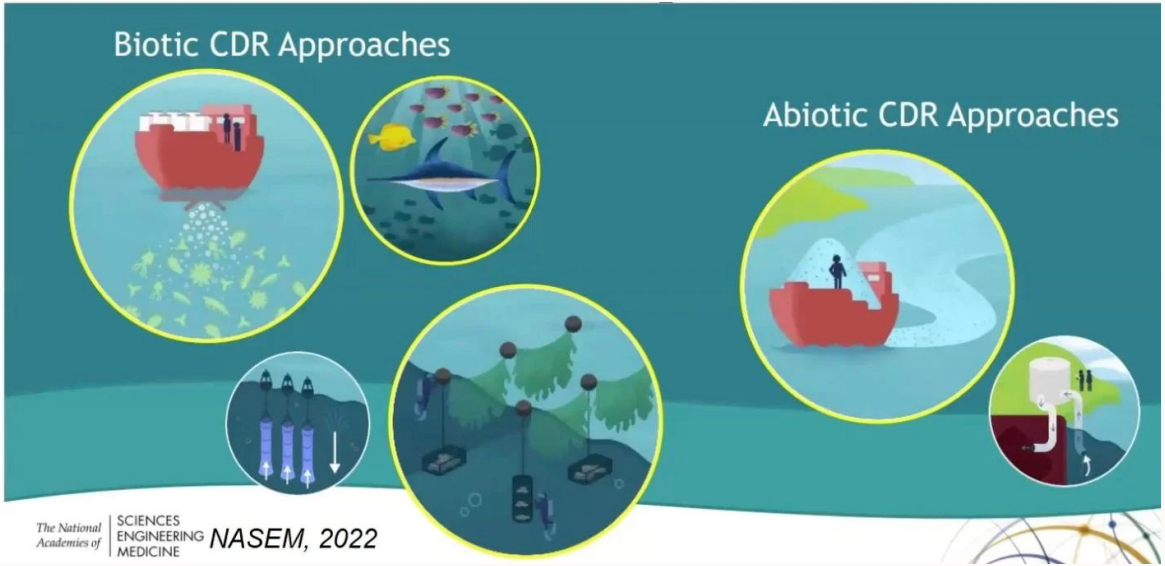
Stacy Kauk, P.Eng.
Chief Science Officer

Topics

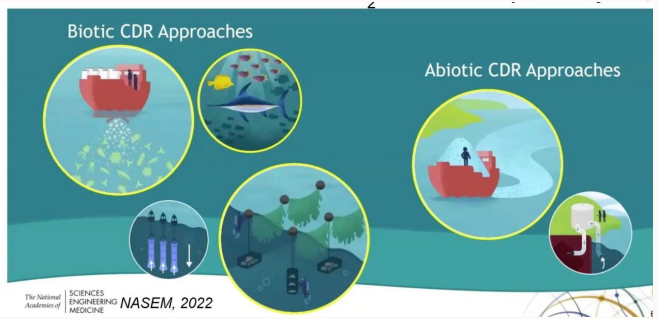
Frontier's approach to carbon removal

Our perspective on criteria for responsible mCDR

Our approach to MRV


Biotic CDR Approaches
Abiotic CDR Approaches
The National Academies of
SCIENCES
ENGINEERING
MEDICINE
NASEM, 2022

Abiotic approaches have clear path toward durable, scalable, and verifiable CDR



Pathway	Durability	Scale	Cost*	MRV	Env. Risk
Macroalgae cultivation	Low (10-100 yr)	Low (0.1 - 0.6 Gt/yr)	Low - Medium ($25-125)	Hard	Medium - High
Artificial upwelling & downwelling	Low (10-100 yr)	Medium (0.1 - 1 Gt/yr)	Medium ($100-150)	Hard	Medium - High
Ocean fertilization	Low (10-100 yr)	Medium (0.1 - 1 Gt/yr)	Low ($25-50)	Hard	Medium - High
Ocean alkalinity enhancement	High (>1,000 yr)	High (1-15+ Gt/yr)	Low - Medium ($25-160)	Medium	Low - Medium
Direct ocean capture	High (>1,000 yr)	Medium (0.1 - 1 Gt/yr)	High ($400 -$600)	Medium	Low

Sources: Carbon180, Additional Ventures, NASEM, NOAA;
*cost projections are based on public information only, and do not consider company-specific information at Frontier

We published buyer guidelines for mCDR including for MRV

Frontier

Buyer Principles for Responsible Procurement of Marine Carbon Dioxide Removal

Fall 2024

Context

Marine carbon dioxide removal (mCDR) represents a promising frontier in the fight agai
change. By leveraging the vast potential of our oceans, mCDR techniques aim to draw
atmospheric CO_2 at climate-relevant scales. However, with great potential comes great
responsibility.

The ocean is a complex and vital ecosystem, and any large-scale intervention must be
approached with the utmost caution and scientific rigor. As early buyers and supporters
emerging market, we recognize the responsibility we have to set the standard for care
stewardship of marine environments.

Marine carbon dioxide removal (mCDR) is a category encompassing a variety of differe
approaches to use riverine or ocean systems to draw down atmospheric CO_2. These in
are not limited to) ocean alkalinity enhancement (both mineral and electrochemical), riv
wastewater alkalinity enhancement, direct ocean removal, and terrestrial biomass sinki

It is important that buyers strike the right balance between enabling progress and mitig
We believe that carefully controlled, research-focused projects in lower risk approache
key to unlocking the potential of mCDR while safeguarding our oceans. By supporting
scientifically rigorous, transparently monitored, and responsibly scaled initiatives, we ai
catalyze the necessary R&D work that will determine whether mCDR can become a via
our climate mitigation toolkit.

The following principles outline our commitment to responsible procurement of marine
dioxide removal, ensuring that our support advances scientific understanding, prioritize
ecosystem safety, and engages local communities in a meaningful way.

Principles for Responsible Procurement of Marine Carbon Dioxide Removal

1. **Adopt a Research-Driven Approach**
   - Projects should be designed to help advance the science of mCDR and answer
     scientific questions about the efficacy and safety of mCDR techniques. This inclu
     investigating technical efficacy, ecosystem impacts, and long-term carbon storag
     potential. We also recognize that projects can fulfill scientific and commercial go
     same time.

Frontier

Summary of abiotic mCDR measurement requirements

In order to build confidence in the climate impact of abiotic mCDR activities, Frontier requires tha
suppliers have methods to effectively:

- **Measure alkalinity added** or carbon dioxide removed from ocean systems with a high level of accuracy.
- **Robustly account air sea gas exchange** dynamics specific to the site of the mCDR activity, and any resulting lags in effective carbon removal.
- Take steps to **minimize risks of secondary carbonate precipitation** that could re-release captured CO2, and ensure local conditions do not exceed thresholds under which precipitation might occur.
- **Account for any change in biotic calcification response** in the environment in which mCDR operations are occurring. Any increases in biotic calcification could effectively reverse a portion of carbon removal.
- **Account for any reduction in natural alkalinity release.** The addition of alkalinity can impact natural weathering of alkaline materials, particularly in sediments, and any change as a result of the project should be assessed.
- **Ensure minimal reversal risks of removed acid or CO2.** mCDR approaches that remove acidity or CO2 from the water must ensure they are not re-released.
- **Accurately assess ocean storage of bicarbonate from upstream interventions**. The addition of alkalinity or removal of carbon from freshwater systems can result in leakage during carbonate chemistry equilibration upon reaching the ocean.
- **Robust data sharing.** Developing robust empirical and modeling approaches hinges on transparency and openness in deployment data and model code. mCDR should not rely on black-box models developed using proprietary datasets.
- Robustly **monitor ecosystem impacts** and follow Frontier's ecosystem safeguards.

The rubric below outlines the practices for quantifying deliveries that Frontier expects to see fro
abiotic mCDR projects to be eligible for offtakes. As mCDR is still a relatively nascent approach,
Frontier will update the bar periodically as field learning evolves.

Frontier

Health & ecosystem impact assessment for abiotic marine carbon dioxide removal

Fall 2024

Context

Frontier aims to support promising carbon removal projects that can be done responsibly and maximize benefits to communities and ecosystems while minimizing potential harms. As a part of purchasing diligence, we assess the project's approach to legal and regulatory compliance, ecosystem safety and distribution of community benefits.

We have built mechanisms into Frontier's purchasing diligence and contracting to (1) minimize the potential known risks of projects; and (2) establish processes for adaptive management over time to ensure that projects stop if negative impacts are identified.

In some cases, existing regulations (OSHA, MSHA, EPA Controls, etc.) will be sufficient to manage project risks. For the specific safety risks where applicable regulatory regimes do not exist or do not fully retire the risks, Frontier uses the rubric below to inform whether to purchase from the project. This analysis also helps Frontier identify additional controls that should be added into the project contract to ensure safe, responsible deployment.

This assessment rubric

This rubric was developed by environmental, safety and health sciences firm Ramboll to help reviewers for Frontier's offtake purchasing program assess whether a project removing CO2 through abiotic marine carbon dioxide removal (mCDR) with a specific focus on alkalinity enhancement (electrochemical or mineral addition in oceans or rivers) (1) is set up for safe deployment and (2) has a best-in-class approach to monitor and mitigate any potential ecosystem and health and safety risks.

We do this by selecting for projects with low substantive risk and strong procedural controls across key risk categories:

- Low substantive risk - Risks are inherently lower because of the nature of the approach and the way the company has designed a deployment. For example, a project that uses a particularly well-characterized biomass feedstock.
- Strong procedural controls - A project has appropriate instrumentation and processes in place to monitor ecosystem interactions along with governance controls that trigger deployment shifts if any negative impacts are observed. For example, a project has a comprehensive plan to monitor local ecosystem impact parameters and a process to halt the intervention if variation is observed.

Pre-Deployment assessment rubric

Assessment Category		Assessment Type	Assessment Description	Relevant Pathway	Assessment Rubric			Guidelines for advanced monitoring & mitigation
					High pass	Low pass	Needs improvement	
1 - Overall Project Governance								
a	Regulatory compliance	Procedural	Project complies with local, state, and federal regulations	All projects	• Proponent has a regulatory compliance expert and has a plan for compliance. Client has a mechanism for tracking compliance. • Planning prioritizes hazard elimination where practical	Proponent has a regulatory compliance expert and has a plan for compliance and tracking	No regulatory compliance expert engaged and no plan for compliance or tracking	In the U.S., potentially applicable regulations include: • Local, State and federal permitting for CO2 transport and disposal (incling injection wells if applicable). • Local, State and federal environmental regulations associated with water and waste. • OSHA worker exposure, safety data sheet requirements • Federal or state permitting for potential releases to water (plant wastewater discharge, storm runoff if applicable) or waste disposal (depending on wastes generated and materials used for alkalization)
b	Compliance with ongoing, transparent environmental health & safety monitoring and reporting	Procedural	Project has established requirements for project reporting and auditing	All projects	• Proponent will receive regular, independent audits of environmental and safety outcomes for this project • Proponent plans to transparently report audit findings and safety data to relevant project stakeholders, including communities	• Proponent will receive regular, independent audits of environmental and safety outcomes for this project	• No plans for third party review or transparent reporting	Require monitoring and reporting on environmental health and safety metrics within purchase contract and project measurement & monitoring Protocol
c	Compliance with project-specific plans & objectives	Substantive and procedural	Project activity will result in atmospheric carbon reoval (establish CDR efficacy) Project has a clear plan for third party verification of project's carbon removal data and claims, and intends intends to report outcomes transparently	Primarily electrochemical alkalinity enhancement	• Proponent robustly demonstrates estimated carbon dioxide removal (CDR) benefit compared to counterfactual scenario. • Proponent sources electricity sourced entirely from renewable sources and processes optimized for energy efficiency	• Proponent robustly demonstrates estimated carbon dioxide removal (CDR) benefit compared to counterfactual scenario. • Proponent sources electricity from a combination of renewable energy and fossil fuels, but ensures energy sourcing emissions are fully accounted for within the project lifecycle assessment, including accounting for instances in which clean energy used would otherwise reduce fossil emissions. When using fossil fuels, electrochemical processes are primarily performed during times of the day where the demands on the electrical grids are the lowest.	Proponent does not accurately assess additionality or determine impact. Electricity sourcing not optimized based on environmental/social impacts, or environmental tradeoffs have not been adequately assessed and accounted for in measurement protocol	1. Determine electricity use and demonstrate processes are optimized for energy efficiency. 2. Source electricity from renewable sources; locate facilities where renewable energy structures are in place or possible to construct. 3. Energy sources must not impose negative impacts on Indigenous Peoples, workers, or communities. Natural resource rights are clearly demarcated and the project will not disrupt utilization by local communities. Specific project objectives will vary

After diligence, contracts enable us to continue to mandate responsible deployment

OAE projects should...	Contract requirements
...rigorously measure and **quantify CDR**	• Rigorous measurement, verification and reporting standards upheld and verified by two third parties: registry sets measurement standard, verifier performs physical verification *and we pay for these activities* • Registry's methodology must use conservative assumptions on uncertainty factors in order to be approved by Frontier
...minimize any harmful **ecosystem impacts** and rigorously monitor for unexpected outcomes	• Projects must be permitted and in good standing with local regulators • Must have a robust monitoring network and stop-trigger plans for operation in order to receive payment
...have strong **community support**	• Concrete community benefits plan is a pre-requirement for delivery
...have **transparent data** collection & sharing	• All data must be made available to researchers, NGOs, and local stakeholders

Topics

Frontier's approach to carbon removal

Our perspective on criteria for responsible mCDR

Our approach to MRV

Frontier's Target Criteria

Focus on scalable, permanent carbon removal

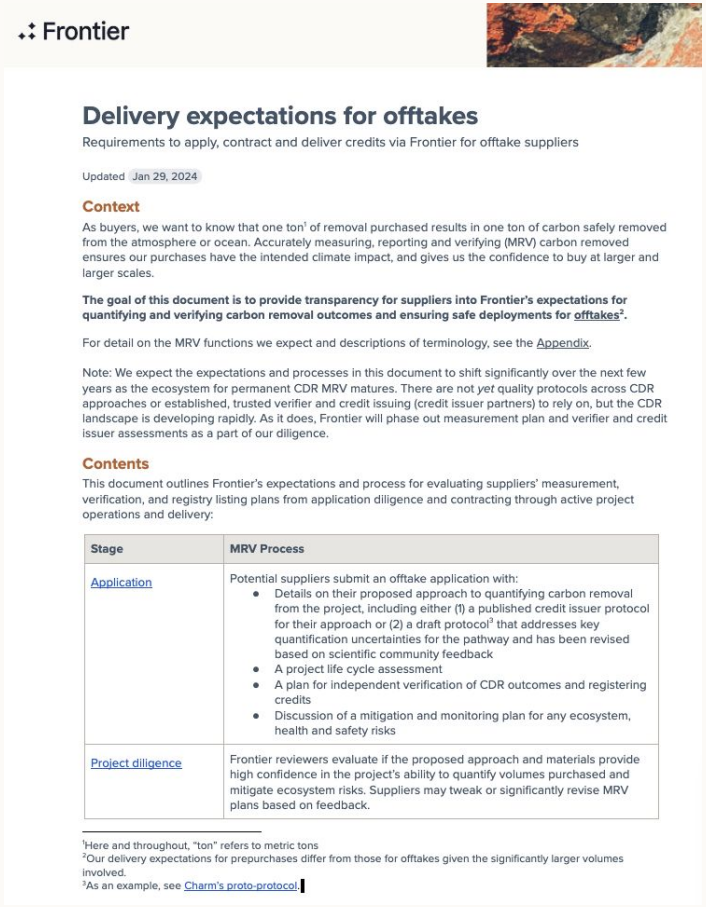
Durability	Stores carbon permanently (>1,
Physical footprint	Takes advantage of carbon sin
Cost	Has a path to being affordable
Capacity	Has a path to being a meaning (>0.5 gigatons per year)
Net negativity	Maximizes net re
Additionality	Results i bon rem alr g to occur
Verifiability	Has a path to using scientifically rigorous and transparent methods for monitoring and verification.
Safety and legality	Is working towards the highest standards of safety, compliance and local environmental outcomes; actively mitigates risks and negative externalities on an ongoing basis

Some measurement uncertainty is ok–as long as we can account for it

Our confidence in verifiability should be a precondition for larger purchases, but **not a barrier to early innovation**

Early **purchases can help accelerate field learning** and reduce open questions

MRV playbook



Frontier

Delivery expectations for offtakes

Requirements to apply, contract and deliver credits via Frontier for offtake suppliers

Updated Jan 29, 2024

Context

As buyers, we want to know that one ton[1] of removal purchased results in one ton of carbon safely removed from the atmosphere or ocean. Accurately measuring, reporting and verifying (MRV) carbon removed ensures our purchases have the intended climate impact, and gives us the confidence to buy at larger and larger scales.

The goal of this document is to provide transparency for suppliers into Frontier's expectations for quantifying and verifying carbon removal outcomes and ensuring safe deployments for offtakes[2].

For detail on the MRV functions we expect and descriptions of terminology, see the Appendix.

Note: We expect the expectations and processes in this document to shift significantly over the next few years as the ecosystem for permanent CDR MRV matures. There are not *yet* quality protocols across CDR approaches or established, trusted verifier and credit issuing (credit issuer partners) to rely on, but the CDR landscape is developing rapidly. As it does, Frontier will phase out measurement plan and verifier and credit issuer assessments as a part of our diligence.

Contents

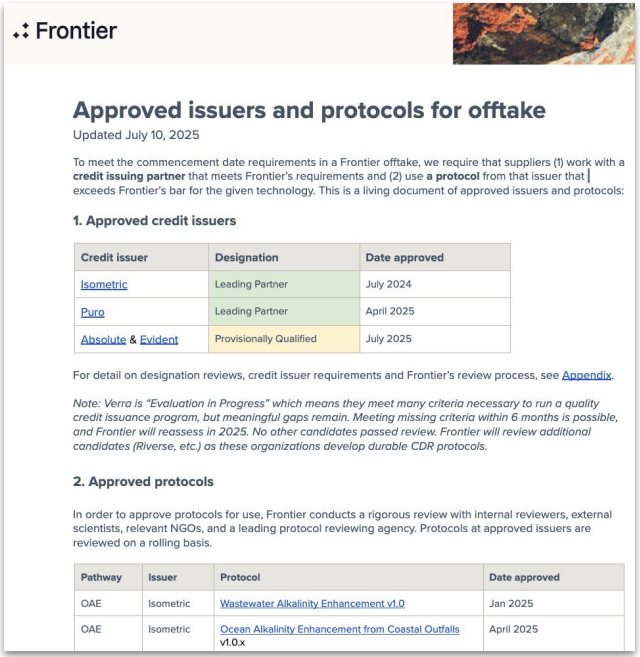
This document outlines Frontier's expectations and process for evaluating suppliers' measurement, verification, and registry listing plans from application diligence and contracting through active project operations and delivery:

Stage	MRV Process
Application	Potential suppliers submit an offtake application with: • Details on their proposed approach to quantifying carbon removal from the project, including either (1) a published credit issuer protocol for their approach or (2) a draft protocol[3] that addresses key quantification uncertainties for the pathway and has been revised based on scientific community feedback • A project life cycle assessment • A plan for independent verification of CDR outcomes and registering credits • Discussion of a mitigation and monitoring plan for any ecosystem, health and safety risks
Project diligence	Frontier reviewers evaluate if the proposed approach and materials provide high confidence in the project's ability to quantify volumes purchased and mitigate ecosystem risks. Suppliers may tweak or significantly revise MRV plans based on feedback.

[1]Here and throughout, "ton" refers to metric tons
[2]Our delivery expectations for prepurchases differ from those for offtakes given the significantly larger volumes involved.
[3]As an example, see Charm's proto-protocol.

- **Application + project diligence**
  - Frontier reviews and approves a draft protocol and draft verification and credit issuer plan
  - Assign verification confidence levels to pathways & suppliers
  - Take conservative discount for each uncertainty factor
- **Verification of CDR**
  - Prior to delivery, a supplier must meet set conditions, including approval of PDD, methodology and verifier
  - We require plans (and we pay) for third party auditing to verify delivery against a protocol,
  - We require transparent, public listing of tons on an independent registry
- **Our work outside of offtakes to advance the field**
  - We have ongoing partnerships with the academic community to create buying standards for new pathways
  - We support research designed to improve the measurement accuracy across new approaches
  - Actively incentivize field-wide tools like registry protocols and data sharing tools

How Frontier maintains requirements for high quality MRV



Frontier

Approved issuers and protocols for offtake

Updated July 10, 2025

To meet the commencement date requirements in a Frontier offtake, we require that suppliers (1) work with a **credit issuing partner** that meets Frontier's requirements and (2) use **a protocol** from that issuer that exceeds Frontier's bar for the given technology. This is a living document of approved issuers and protocols:

1. Approved credit issuers

Credit issuer	Designation	Date approved
Isometric	Leading Partner	July 2024
Puro	Leading Partner	April 2025
Absolute & Evident	Provisionally Qualified	July 2025

For detail on designation reviews, credit issuer requirements and Frontier's review process, see Appendix.

Note: Verra is "Evaluation in Progress" which means they meet many criteria necessary to run a quality credit issuance program, but meaningful gaps remain. Meeting missing criteria within 6 months is possible, and Frontier will reassess in 2025. No other candidates passed review. Frontier will review additional candidates (Riverse, etc.) as these organizations develop durable CDR protocols.

2. Approved protocols

In order to approve protocols for use, Frontier conducts a rigorous review with internal reviewers, external scientists, relevant NGOs, and a leading protocol reviewing agency. Protocols at approved issuers are reviewed on a rolling basis.

Pathway	Issuer	Protocol	Date approved
OAE	Isometric	Wastewater Alkalinity Enhancement v1.0	Jan 2025
OAE	Isometric	Ocean Alkalinity Enhancement from Coastal Outfalls v1.0.x	April 2025

Credit issuer & verifier requirements

In order to qualify as a credit issuing partner, at an organizational level, we expect compliance with many IC-VCM[2] and Calyx criteria, as well Frontier-specific criteria:

Category	Key criteria summary
Governance & transparency	• **Avoids financial conflicts of interest** (e.g., selling credits, CDR project development, fees tied to issued volume) • **Follows robust governance policies** to guard against bribery, corruption, money laundering • **Corporate structure, decision-making procedures**, standards & protocols are available to the public
Stakeholder consultation	• **Expert and public stakeholders are involved** in the review and approval of the standard, protocols, and projects • **Clear, transparent, and accessible grievance processes** are in place to collect and address public feedback
Credit issuer	• **Controls exist to prevent double-counting** within the credit issuer and across other credit issuers • **Clear and public accounting** of retired, transferred, and canceled credits • **Sufficient information is provided for public accountability** of credits issued
Standard & protocols	• **Independent scientific experts are involved** in protocol review • **Methodologies address key criteria** (e.g., accounting boundary, additionality, counterfactuals, process emissions, monitoring, reversal risk) • **Willingness to incorporate ecosystem-level standards** developed or endorsed by Frontier
3rd party validation	• **Quality controls and required accreditations** for verifiers to ensure they can rigorously audit a given project and technology • **Controls to manage conflicts of interest between verifiers and suppliers** (e.g., payment structures, assignment by credit issuer, regular rotation)
Durable CDR expertise	• **Sufficient durable CDR expertise in-house** (e.g., to assign verifiers, support protocol development, organize scientific panels) • **Clear labeling or differentiation of projects** by durability, and between carbon removal and avoided emissions

Credit issuer designations

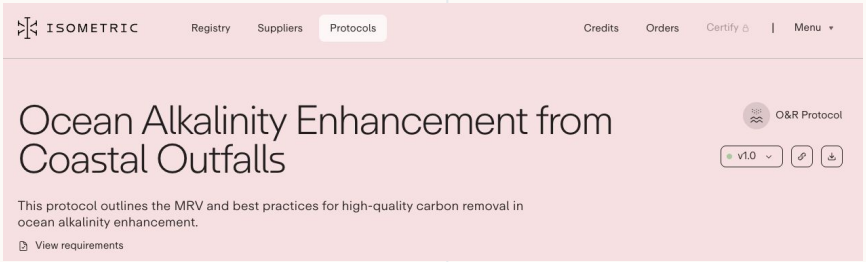
Credit issuers are classified into one of five designations according to how well they meet the above criteria:

Designation	Assessment performance
Leading	**Approved for offtakes** • Industry-best partner, laser-focused on quality, scientific rigor and governance • Meets or exceeds all criteria, including Nice-to-haves
Qualified	**Approved for offtakes** • Meets all criteria to run a quality credit issuance program • Meets all Dealbreakers and all Important elements criteria
Provisionally Qualified	**Conditionally approved for offtakes** • Meets most criteria (Dealbreakers and Important elements) to run a quality credit issuance program • Has a concrete plan to meet any missing criteria within 6 months
Evaluation in Progress	**Not approved for offtakes** • Meets many criteria (Dealbreakers and Important elements) to run a quality credit issuance program, but meaningful gaps remain • Meeting missing criteria within 6 months is possible
Not qualified	**Not approved for offtakes** • Doesn't meet bare-minimum criteria (Dealbreakers), *or* • Doesn't have a path to achieve Important elements, *or* • Has not been formally assessed.

Criteria for Protocol Evaluation

- System boundaries for the removal activity
- System lifetime & crediting period
- Gross carbon removal measurement
- Net carbon removal formula
- Estimation of removal losses and reversals
- Accounting method for each emissions source
- Embodied emissions allocation
- Energy emissions accounting protocol
- Storage durability
- Scientific & community best-practice
- Removals baseline
- Additionality
- Third-party verifier
- Double counting controls
- Pre-deployment safety screening
- Ongoing safety monitoring
- Data sharing principles

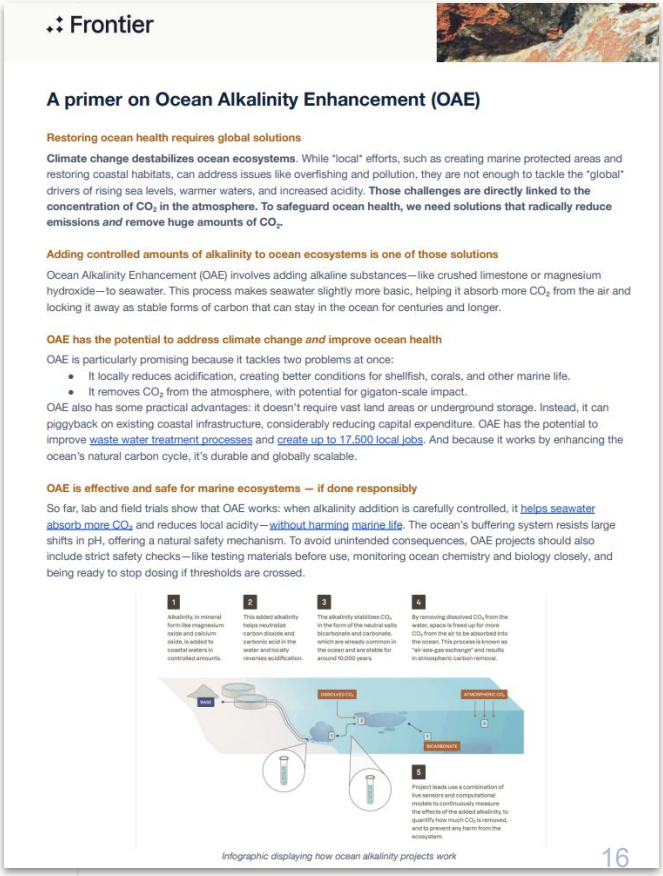
MRV for abiotic pathways most advanced



Rigorous MRV standards upheld and verified by a third party

Conservative assumptions on uncertainty factors identified by the scientific community

- Feedstock dissolution
- ASGE
- Secondary precipitation
- Interaction w/ sediments
- Biotic calcification response



Infographic displaying how ocean alkalinity projects work

Building trust in OAE by continuously iterating and improving

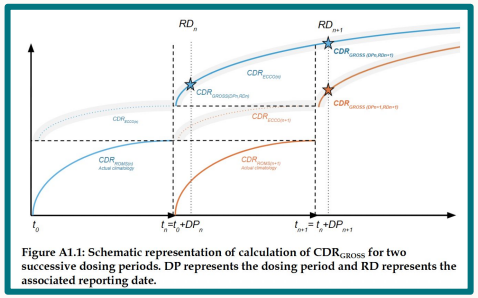


Figure A1.1: Schematic representation of calculation of CDR_{GROSS} for two successive dosing periods. DP represents the dosing period and RD represents the associated reporting date.

Dosing period	Carbon intensity (kg CO_2e/t feed)
TC24	0.136
TC25.1	0.112

Improved Outcomes & New learnings

Credit Delivery

Presentations, Webinars, Reports

Continuous Iteration & Improvement

Improved MRV

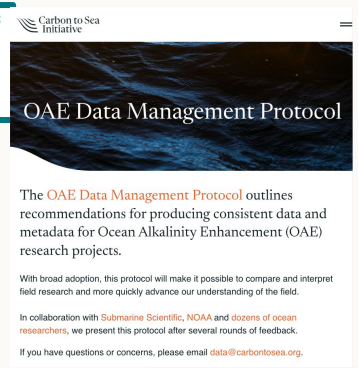
Novel surveys, Experiments, Analyses

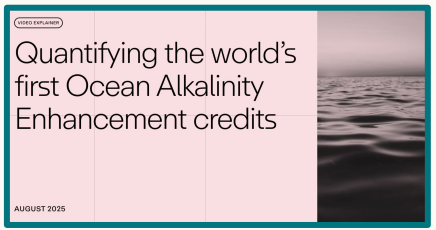
Feedback

Tufts Cove Ocean Alkalinity Enhancement Project
Operations and Monitoring Report

Operational Period
January 1st 2024 - January 31st 2025

May 2025





Outlook: Building Confidence in OAE

Growing evidence base will strengthen confidence in efficacy & best practices

- **Field trials** already underway in multiple environments
- **Commercial projects** generating open-access data through sharing requirements
- **Ecosystem impact and co-benefit studies** advancing understanding of impacts and potential co-benefits

Immediate R&D needs

Field priorities	*MRV priorities*
• Scalable, fast-dissolving, safe alkalinity sources • Clear thresholds for key parameters (pH, TA, Ω, TSS, etc.) • Proof points for ecosystem & climate co-benefits	• Better tracking of near field • High resolution ROMS models for regions of interest and intermodel comparison • High sensitivity sensors for alkalinity and other key parameters • Advanced dissolution models for feedstocks/deployment modes

Thank you

fkracke@stripe.com