Summary of Public Feedback and Response to:

"Phytoplankton Carbon Solutions: A prioritized research framework to investigate carbon dioxide removal potential and inform decision making"

About This Document

Ocean Visions' "Phytoplankton Carbon Solutions" (PCS) report was commissioned to (i) assess the current state of knowledge and activities for open ocean phytoplankton-based carbon removal approaches (including ocean iron fertilization), (ii) identify remaining critical uncertainties and knowledge gaps about their efficacy and safety, and (iii) suggest key actions and research priorities to close knowledge gaps to facilitate future decision making.

Ocean Visions published a draft report on the project webpage[1] and solicited feedback via an open public comment period from 1 to 30 October 2025, via a Google Form (see Google Form Questions). The project team reviewed and consolidated public feedback and used that feedback to inform revisions to the report. The final report was published on 29 January 2026.

This document presents an overview of the feedback received and how the project team responded to the feedback and revised the report. The comments are summarized in aggregate by major themes and further illustrated with select quotes. Quotes are presented without attribution, as consent for attribution was not a requirement for submitting feedback.

This document was prepared by Eric Schwaab (Ocean Visions) and Dr. Lydia Kapsenberg (CEA Consulting) and published by Ocean Visions on 29 January 2026.

[1] https://oceanvisions.org/phytoplankton-carbon-solutions/

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Summary of Public Response

More than 50 individuals provided feedback to the draft Phytoplankton Carbon Solutions (PCS) report, the majority of whom were from North America. We received 45 response forms (Figure 1). Some responses represented perspectives of more than one individual and one response included the views of nine individuals affiliated with "other ocean industry". "Academic and/or government scientists" made up 62% of responses (n=28), the majority (n=18) of whom were from North America.

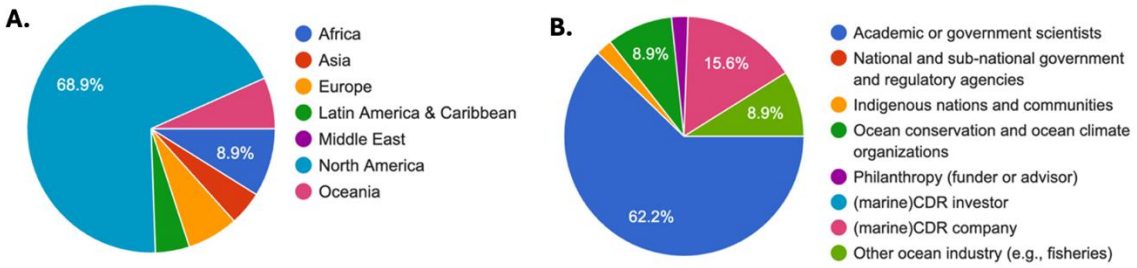

Figure 1. Geographic (A) and sectoral (B) representation of public comments submitted in the Google Form (n=45). Some comments represented feedback from more than one individual.

Overall, there was strong support for the basic framing, prioritization, and utility of the PCS report. The majority (62%) of comments indicated 'strong' or 'somewhat' agreement with the report priorities. This trend held true for scientific and non-scientific sectors. One representative comment of this perspective read:

- *"The proposed framework outlines a very thoughtful and reasonable action plan. The sequencing of investments is wise, prioritizing comprehensive modeling, sensitivity analysis, and a deeper understanding of the natural ocean carbon pump to establish a solid scientific baseline."*

Numerous comments that re-affirmed the importance of prioritizing **desirability** of PCS (alongside **feasibility**):

- *"There is a fear that if the question on feasibility is answered positively, the question of desirability will be forgotten."*
- *"As long as the risks are poorly understood and communicated, the whole enterprise will be too scary to attract capital, and progress will remain slow."*

Commenters also included recommendations for executing specific priorities. A few representative comments are shown below:

- **Reduce Uncertainty on Net Carbon Dioxide Removal –** *"It will be essential to consider in uncertainty analyses not only what the overall uncertainty is in estimating carbon transport below a given flux boundary, but also in estimating carbon sequestration on climate-relevant time scales."*

- **Improve Utility of Biogeochemical Models for PCS Evaluation (often stated in conjunction with the need for field data) –** *"In a nutshell, our current models lack sufficient skill to sufficiently capture the planktonic/ecological response to any of the mesoscale [ocean iron fertilization] experiments. We lack the parameterization necessary to get to this step. So how can the models provide any confidence that we can project the magnitude and durability of carbon export from these planktonic systems. [We need data to improve these models, so field trials are an essential early step that should be moving forward in conjunction with model development. We are wasting our time otherwise.]"*

- **Enable Coastal Communities and Fisheries Engagement** – *"For the fishing industry in general, few of us have the time to be as engaged as we need to be to understand all the issues. It's difficult for most of the fishermen to analyze this stuff. There are a lot of opportunities to provide data, provide real time info, etc. – and that's critical - but being engaged in the actual policy work is really tough. I hope that we can slow the process down and take a look at potential unintended consequences."*

A minority (20%, n=9) of comments indicated 'strong' or 'somewhat' disagreement with the report priorities. There were overarching dissenting perspectives, captured by comments like this one:

- *"The main uncertainties regarding the long-term ecological and socio-economic effects of these interventions do not provide sufficient confidence to justify the development of an implementation plan at this stage. Given the unresolved and multifaceted uncertainties, and potential transboundary impacts, prioritizing an implementation framework appears premature."*

Other disagreement was based on a range of factors including a desire for the report to prioritize field trials, disagreement on PCS priorities due to the current understanding of PCS environmental and socio-economic risks and uncertainties, and insufficient contextualization of PCS with respect to declining ocean health.

More detailed comments were sorted by theme and analyzed for consideration in completion of the final report. Responses included a wide range of thematic

suggestions, notable omissions, technical corrections, and prospective implementation recommendations.

The project team made report revisions according to this analysis. Feedback from all responses is summarized below, alongside a summary of the consequential revisions to the Phytoplankton Carbon Solutions final report. Feedback provided next-step suggestions for executing research priorities will be carried forward into implementation recommendations.

Summary of Thematic Commentary and Major Revisions

Major revisions to the report include two additional recommendations, one specific to field trials and one specific to the implementation of a PCS Research, Development & Demonstration (RD&D) program.

Some elements of the report were restructured to introduce, more clearly, recommended components including the PCS Research Framework, a RD&D Action Plan, and a PCS RD&D Program. The need for field trials and importance of co-benefits was enhanced throughout the report, and duplicative content was removed where relevant.

Feedback and Revisions by Major Theme

The PCS Role in Global Climate Action

Several commenters expressed support for stronger contextualization of PCS within the global climate challenge and also in comparison to a range of carbon dioxide removal (CDR) pathways.

There was significant support for characterizing PCS risks in comparison to other CDR options. Commenters expressed a strong desire to emphasize CDR as a complementary activity to global emissions abatement, without which CDR has limited utility.

Sample recommendations included:

- *"[situate] phytoplankton-based CDR more explicitly within the broader portfolio of marine and non-marine CDR approaches. Given that research funds and policy attention are finite, comparative prioritization is important."*
- *"[The report] needs to say up front, why PCS, among mCDR approaches, has great potential, with low energy needs (sunlight), often minimal structural needs (no factories/permanent structures), Gt scalability (know this from nature), and importantly in the case of iron, huge leveraging (Fe:C of >1:1000 in prior studies and 10-100x greater in nature."*
- *"All PCS pathways should be evaluated on a level playing field. The common risks and limitations should be stated for all PCS pathways.... Then what follows would be seen as a more nuanced analysis of PCS pathway specific challenges that can then be discussed within the framework of these common risks and challenges."*
- *"[Address] where PCS fits in a mitigation portfolio: The easiest thing for us to do is to consume less, yet there is no big push to do that. Nobody wants to tell people to buy less or use less electricity. For a lot of people, the ocean is out of sight, out of mind. It's complex, and people don't understand how it works. They think they've solved the issue by solving climate change through ocean-based solutions, but the burden is now on another ecosystem. Just like with offshore wind, we continue to trade one ecosystem for another."*

Response: PCS in context of other CDR options and baseline context was already included in the report. It is apparent from comments that this point needs to be strengthened in the final report.

Summary of Revisions: We have strengthened the following points, particularly in the introduction:

- Tightened and emphasized Report language to make both the role of CDR as a part of the global climate response and potential consideration of PCS as a CDR pathway context clearer.
- Improved equal treatment of introducing new PCS pathways and also acknowledging that ocean iron fertilization benefits from a more substantial pre-existing knowledge base.
- Improved introduction and treatment of environmental impacts
- Introduced a new framing that considers both feasibility and desirability considerations.

PCS Pathway Prioritization

Prioritization of ocean iron fertilization pathways received wide support. These included both high nutrient, low chlorophyll (HNLC) regions and low nutrient, low chlorophyll (LNLC) zones.

Feedback collectively indicated a broad desire for the PCS strategy to retain immediate focus on iron-based fertilization pathways. There were also comments in favor of inclusion of macronutrient and integrated nutrient interventions. Support for artificial upwelling was present in two responses. Finally, biotechnology and engineered particles were brought up in several responses.

- *"I am in agreement with the report that [ocean iron fertilization] and [ocean nutrient fertilization] (with some clear framework) is the path to focus onto. All the other approaches do not scale up."*
- *"Different nutrient combinations, including and beyond iron, should be considered rather than a narrow focus on iron."*
- *"Nitrogen fixation in the surface ocean tied to [ocean iron fertilization] is given greater emphasis than macronutrient fertilization alone, and this comes with a higher degree of uncertainty. I would like to see macronutrient fertilization represented and some consideration given to a field trial."*
- *"Iron & aluminum fertilization together in iron-limited oceans have been proposed as a potential novel CDR strategy.... Aluminum can enhance carbon fixation in the upper ocean by increasing the use efficiencies of dissolved organic phosphorus (DOP), iron (Fe), and dinitrogen (N2) by marine phytoplankton, including nitrogen-*

fixing cyanobacteria. Aluminum increases carbon export to the deep ocean and carbon sequestration by decreasing carbon decomposition rate.…Ocean aluminum fertilization could be both a production-based approach and an export-based approach."

- *"More attention to the Southern Ocean and innovations that enhance export. Nitrogen fixation in the tropics we think is less important given it will be extremely difficult to export carbon in those phytoplankton communities."*

Several comments called for better framing of shared and distinct challenges per pathway and maturity of scientific knowledge.

One representative comment discusses this in detail:

- *"The report considers [ocean iron fertilization] in the subarctic Pacific, subtropical waters, and Southern Ocean as individual topics, but they are not…. the major concerns are identical (durable carbon export, deoxygenation, nutrient "robbing", ecological shifts that impact higher trophic levels). They all face similar issues on how to achieve reasonable MRV… readers are left with the misconception that [ocean iron fertilization] has different POTENTIAL effects in different regions (highlighted here to reflect our rudimentary understanding at present). In this description of the different regions for [ocean iron fertilization], it would be valuable to give the reader a sense of the degree of understanding. For example, there is much more known about [ocean iron fertilization] impacts in the subarctic Pacific and Southern Ocean (HNLC regions) than in subtropical waters (LNLC)….That does not rule out the need to study [ocean iron fertilization] in these [LNLC] environments (I fully agree with this), but it gives the readers a more balanced sense of where the science stands."*

Response: The PCS pathway prioritizations in the draft remain unchanged, but we added language to be more open-ended and inclusive of other and more integrated nutrient and engineered approaches. This is a recommendation that will be highlighted for further emphasis moving into the Program implementation phase. We also agree with the need to better understand both shared and distinct challenges of iron-based approaches in different regions.

Summary of Revisions:

- Enhanced language on PCS challenges that are shared across multiple pathways or distinct to a particular pathway
- Revised PCS taxonomy figure under Export pathways to include two categories: one on enhancing sinking and the other on avoiding degradation (in light of feedback on the iron-aluminum hypothesis)

- Improved language on the potential to supplement iron fertilization with other nutrients, including aluminum
- Assigned PCS pathways to specific stages within the stage-gate approach
- Updated Appendix table content detailing PCS pathway knowledge
- Clarified text to avoid insinuating that ocean iron fertilization in LNLC resolves all nutrient robbing issues.

Stage-Gate Approach

Many respondents expressed strong support for the stage-gate approach, with some conflicting perspectives on the structure and offramp criteria.

There were requests for stage gates to be more specific, especially when it comes to more subjective determinations (e.g., environmental risk, social support, how much information is "enough" for decision-making and who makes the decisions).

- *"The draft's requirement for governance, monitoring, and science-based decision gates aligns with community priorities for balanced ocean management."*
- *"There is a fear that if the question on feasibility is answered positively, the question of desirability will be forgotten."*

Stage gating classifications were also addressed, with many commenters expressing a need to elevate the importance of field data in all stages.

- *"The stage gates are clear and the sequence, in my opinion is correct"*
- *"The stages are clear, and the gating criteria are sensible. But I wonder if it wouldn't be more efficient to pursue most of the objectives and deliverables in parallel."*
- *"Stage gates seemed to be based on model efforts and not empirical, experimental data. I am not convinced that we can move through stage gates without manipulation experiments that confirm some of the principles of the PCS solutions."*
- *"I think the inclusion of off-ramp indicators is a very important and valuable part of this report. At the same time, they are difficult to evaluate objectively in their current form. For example, what constitutes an "insurmountable" environmental risk? Without further definition, this type of criterion risks becoming highly subjective."*
- *"Clear expressions of public support might be hard to achieve. The CCS sector has advanced to deployment optimisation without visible public support."*
- *"Societal support is difficult to quantify, and it is built over time, it's not an 'on/off' switch. It evolves, and it is essential to keep working on it, but there is rarely a way to*

measure whether you have 'achieved it.' Moreover, satisfying everyone is not necessarily a limiting factor if legal requirements are met."

- *I wouldn't support off ramping a technique that was less that 1 gt co2 per year, particularly if there were other benefits to ecosystem health, biodiversity and climate adaptation benefits.*
- *"We also support the stage-gate approach, noting that the 1+ Gt $GtCO_2e$ per year is a high bar but one that is appropriate given the necessary monetary investment and the potential for environmental risk. Response: we agree and keep this."*
- *"I would de-emphasize scalability as a strict imperative for advancing from stage to stage, and would add co-benefits. In short, I think there's room for more nuanced, multi-objective thinking in the stage gates framework."*
- *"Include infrastructure mapping and capacity assessment as part of the early "stage-gate" process recommended for field trials."*

Response: We keep the main stage gate structure and quantitative metrics on scalability and uncertainty. We believe 1 GtCO2 is still the right target threshold for PCS implementation at scale because of the need for scalable solutions and inherently greater risks associated with PCS interventions. We note that this threshold could potentially shrink if the risk-benefit framing changes (e.g., with the emergence of co-benefits or better definition of risks).

Summary of Revisions:

- Expanded the description of the stage-gate approach and assigned PCS pathways to specific stages.
- Added a section 'Key Activities' to the stage gate figure and included field data/trials in each stage.
- Provided more detail on the need to track social and regulatory support over time in order to inform offramp decisions.
- Maintained the 1 GtCO2 scalability metric but acknowledged that this metric could change over time, especially if there is strong evidence for co-benefits.

Modeling

We received supportive and constructive feedback on model-based recommendations.

Some commenters emphasized the need to pair model-based improvements with lab and field data, including field trials. Others requested and recommended additional specificity in the proposed activities.

"The stage gates are clear and the sequence, in my opinion is correct. The first proposed standard, regarding uncertainties, should be approached with caution, as reducing these uncertainties requires considering the dynamics of an oceanic system not only from a physical perspective but with substantial effort to **the structure and off-ramp criteria.**

There were requests for stage gates to be more specific, especially when it comes to more subjective determinations (e.g., environmental risk, social support, and how much information is enough.

- *"incorporate biotic interactions in production and consumption. The major challenge in achieving this is to prioritize studies on the spatio-temporal variability of the biological pump and the implementation of efficient and standardized models."*
- *"Studies of CDR rate over downwelling eddies, non-eddy, and upwelling eddies should be prioritized and done."*
- *"All mCDR activities have a single objective: remove CO2 from the atmosphere and sequester it into the deep ocean. There is a surprising lack of emphasis on the initial pathways i.e. air-sea gas exchange (ASGE). I would suggest that you prioritise ASGE as a process that should be quantified for any PCS activity. The other pathway is the export of carbon from the mixed layer into the deep ocean. This is a well-recognised problem within the biological carbon pump (BCP) community, but remains within the realm of fundamental science."*
- *"In a nutshell, our current models lack sufficient skill to sufficiently capture the planktonic/ecological response to any of the mesoscale [ocean iron fertilization] experiments. We lack the parameterization necessary to get to this step. So how can the models provide any confidence that we can project the magnitude and durability of carbon export from these planktonic systems. We need data to improve these models, so field trials are an essential early step that should be moving forward in conjunction with model development. We are wasting our time otherwise."*
- *"The model-based priorities need further detailing and clarification. Improve Utility of Biogeochemical Models for PCS Evaluation [should be prioritized]. While model intercomparisons can be useful exercises, a real test of model skill is direct comparison with observations. For example, we need to assess how well the various models represent the background physical-biogeochemical-ecological ocean state compared to data to yield accurate counterfactual simulations, and determine if models exhibit substantial spin-up or bias issues. Also, the statement " improved*

ecosystem inputs to better characterize and assess biological trends under natural and perturbed conditions" could use additional clarification. What is meant by "ecosystem inputs" here? Do you mean the representation of model ecosystem and associate complexity/realism? There should also be a focus on developing data-assimilative models instead of forward-only simulations that are not constrained by observations."

- *"The emphasis on model development is good, but a bit general. Specifically developing models that are focused on regions of interest for [ocean iron fertilization] will be important, e.g some portion of the SO, or N Pacific where EXOIS has proposed an experiment. Ideally models that can directly feedback to how an [ocean iron fertilization] application could be both monitored and improved for efficiency."*
- *"I agree that biogeochemical models must be improved, including the inclusion of more biological processes, such as grazing and vertical migration and aggregation processes. However, these advances should be developed in partnership with new laboratory and field experimentation. Continued refining of models on previous mesoscale experiment data – which lacked much of the biological data needed to constrain model developments – will be incremental at best. In particular, improved model representation of zooplankton grazing and Fe recycling (for sustaining blooms) is needed – these are some of the least-constrained components of Fe biogeochemical models. Small scale models would also be useful to apply to evaluate mechanisms for enhancing export. Findings of initial lab studies should be scaled up in silico to understand the feasibility and cost of large-scale deployment."*
- *"Our current models lack sufficient skill to sufficiently capture the planktonic/ecological response to any of the mesoscale [ocean iron fertilization] experiments. We lack the parameterization necessary to get to this step. So how can the models provide any confidence that we can project the magnitude and durability of carbon export from these planktonic systems. We need data to improve these models, so field trials are an essential early step that should be moving forward in conjunction with model development. We are wasting our time otherwise."*
- *"Modelling is necessary in the long term but you cannot model what you do not know and knowledge will only come via process studies. Clearly this is more expensive at the outset but it is a necessity for understanding the feasibility of PCS. So less emphasis on modelling and more on process studies."*

Response: We agree to provide greater emphasis on the role of field trials and the need for integration of experimental and model-based advances. Further, many of the specific recommendations can both be added into Report language on a limited basis and captured for consideration in future Program implementation.

Summary of Revisions:

- Emphasized the specific need to improve biogeochemical model inputs to explicitly address questions unique to biological pump-based interventions.
- Improved the linkages between model-based improvements and field data to test and refine model outputs.
- Emphasized the benefit of reconciliation of multiple model outputs through an intercomparison process.
- Added specificity on the ways that emerging data and AI capacities could explicitly enable model advances.
- Targeted finer-scale modeling efforts to better predict specific regional CDR benefits.

Field Trials

There were a number of recommendations to prioritize field data, across all research stages, including through support of field trials of varying scales. Concurrently, there was feedback in opposition to large scale field trials based on socioeconomic and environmental concerns, and remaining uncertainties of PCS viability.

The most common points expressed a need for data that could not be replicated at all or efficiently through other means. Commenters noted the need for data to enhance models and to test intervention mechanisms. They also pointed to the value of demonstrating science-based experiments that would build critical understanding of PCS pathways, build public confidence in science-based experiments, and help unlock additional funding.

- *"An endorsement of field studies here will lead to leveraging of other funding sources."*
- *"Field trials must be significant and this is where combining resources will be essential."*

Proponents also noted that past field trials for ocean iron fertilization had not, for the most part, been designed to test for CDR additionality and durability. And they further noted that advances in methodologies coupled with modern observation and measurement technologies offered significant new opportunities.

Field trial proponents also noted the likelihood of commercially supported activities advancing in ways that would leave academic-based efforts behind (*"Given the private sector activity in this space, an academic-led field trial is fully warranted"*).

These proponent perspectives were tempered by comments against field trials as an immediate priority. These concerns were generally based on risk considerations and social license challenges.

There were also voices in support of natural analog opportunities as a prelude to field trials. It was noted that most field trial references were specific to ocean iron fertilization and that trials for other PCS pathways should be acknowledged.

Additionally, many comments addressed preferred locations for field trials. These included both geographic focus areas and the distinction between HNLC and LNLC zones. With many commentors specifically supporting or being vocally against a northeast Pacific (NEP) ocean iron fertilization trial.

- *"This report, and its recommendations, are missing one ultra-critical thing: the extreme need for 21st century data from 21st century experiments at sea."*
- *"I fully agree that improving the 'Utility of Biogeochemical Models for PCS Evaluation' is a high priority, as is 'Reducing Levels of CDR Uncertainty'. But neither of these can be accomplished without field-scale studies … real data will be needed to accomplish these goals."*
- *"We are looking for a confirmation that field studies are essential in the next 2-3 years … if [the report] is read as a call to delay field trials i.e. no explicit recommendation for field trials, it will … stall research and leave open the field for commercial and rogue geoengineers."*
- *"in situ experiments and continuous observations are indispensable to test responses of primary productivity, carbon sequestration, and phytoplankton community shifts driven by natural and experimental forcings."*
- *"It is vital to comprehend the possibilities for mCDR at scale. That needs to be understood before you can move onto understanding the socioeconomic risks and concerns, or to the prioritization of pathways. The experiments to-date have been small scale. Without greater research into the scalability of these solutions, why bother?"*
- *"in regions with fishing-dependent communities, field studies allow for simultaneous evaluation of ecological and socioeconomic impacts — information necessary for governance decisions and public acceptance."*

Response: We concur that the report can position the general need for field trials more prominently but also recognize specific concerns that must be addressed in considering large field trials as the immediate next step in PCS research.

To balance these opposing recommendations, reframing of the value of field trials should be accompanied by the need for more comprehensive framing of the theory of impact of

any particular field trial. Field trials can serve multiple purposes in the search for PCS answers. It will be important to draw out those purposes and associated context to aid in justifying the most valuable field trials at the most appropriate time through use of specific criteria for highly catalytic impact.

Timelines could differ for different scale field trials and PCS pathways and in accordance with comprehensive experimental designs. We should clarify that field trials can be part of any stage in the stage gate approach, and field trials are valid at any point in pathways studies in accordance with a comprehensive study design and theory of impact, and with sufficient local collaboration and understandings of the scientific merit and risks.

Summary of Revisions:

- Expanded the discussion on the limitations of previous mCDR reports that call for large-scale field trials and clarified the purpose of the PCS report to advance near-term scientific priorities that will aid in unlocking the necessary resources to pursue field trials. Emphasized the role of field trials as an important component of any pathway evaluation, regardless of the research stage. Achieving viable CDR solutions will require field trials (alongside the clearing of hurdles of other priorities, such as models/uncertainty, acceptance of predicted and unknown env impacts, etc.)
- Noted the limited scope of past OIF field trails.
- Updated the Stage Gate figure to include more specificity around field work potential in each stage.
- Recommended that a PCS program fully evaluate field trial cost / benefit as part of a comprehensive pathway research program. This includes supporting field trials that present a clear theory of impact for pathway, location alternatives analysis, projected CDR benefits, and comprehensive social license development.
- Bolstered language on the importance of the need for comprehensive public engagement, regulatory support, and funds to execute them.
- Removed emphasis of specific projects (e.g., the NEP trial) in the executive summary but retained the specific focus on Southern Ocean iron fertilization as the currently understood most scalable PCS pathway.

Location of Field Trials

Feedback included both pros and cons on iron fertilization field trials in the northeast Pacific (NEP) Ocean and Southern Ocean and further identified opportunities in other

regions. Additionally, feedback noted the tension between nearshore and open ocean social and ecological dynamics and the need for local support for selected locations.

The draft report noted the NEP iron fertilization trial as a case study iron fertilization trial, and numerous comments addressed the NEP location and both its advantages and disadvantages. Advocates noted its well-developed concept, numerous locational benefits for both logistical and experimental purposes, and the need to develop methodologies and proofs of concept in structured, academically supported ways.

Opponents noted that conditions in the NEP were not representative physically or biologically of Southern Ocean conditions and that the Southern Ocean was the most likely place where iron fertilization-based PCS could scale.

While recognizing the likely future focus on the Southern Ocean, several commenters noted the extensive challenges associated with field work there.

Finally, there were numerous mentions of other possible locations and approaches to field trials. Field trial opportunities were highlighted for Southern Ocean, NEP, LNLC regions, Australia, and West Africa. The location of a field trial should consider the perspective of those potentially directly impacted by the trial and if they in fact want and welcome the trial in that location. This will look very different for different projects.

- *"Priorities should better include tropical and sub-tropical regions to improve global relevance and equity in PCS research and application. Field trials should start small and transparent, with strong MRV, governance, and community engagement. Priority should include tropical and West African regions to ensure equity and broader scientific relevance."*
- *"[Ocean iron fertilization] in the Southern Ocean is likely to be the most effective of all the regions considered in the report, but it is the least likely environment to get much of the necessary experimentation done. We have to take baby steps before we run, and the subarctic Pacific is the place to start. What is learned there will inform models, reduce uncertainties, and help develop the logistical and observational skills sets needed to test [ocean iron fertilization] in the Southern Ocean. The low priority given to this experimentation in your report will sharply curtail advancing our understanding beyond number juggling."*
- *"There should be priority in the North Pacific, subtropical LNLC, and Southern Ocean."*
- *"One aspect that could be highlighted, is the fact that the plankton communities in the SO differ from the North Pacific (quite a few endemic diatom and zooplankton species with different biogeochemical impacts on Si cycle/Krill-food webs…). In short, [ocean iron fertilization] experiments in the North Pacific would not necessarily mirror the response to and impacts (on Si cycling for example) of [ocean iron fertilization] in the SO at the relevant time scales of C sequestration."*
- *"The South Atlantic, particularly the Brazilian continental shelf, presents critical knowledge gaps that limit our ability to assess the additionality, scalability, and*

durability of processes related to the biological pump and CDR. Regions such as Cabo Frio (RJ), with historical series of primary productivity and phytoplankton community data dating back to the 1970s — often published only in internal bulletins and reports — as well as the influence of the Amazon plume (monitored in local projects, and its influence on the west tropical Atlantic in cooperation with the PIRATA project), represent strategic areas for field experiments and integrated analyses."

- *"As phytoplankton stimulation may have undesirable effects on HAB stimulation and/or water quality (DO, turbidity etc) it is important that locations are chosen with the least impact on coastal communities/local fisheries, and don't overly burden individual socio-economic/ethnic groups in those areas."*
- *"I foresee some trade-off between working within a country's jurisdiction inside EEZs, which provides an easier legal pathway to operate, with working farther offshore in open ocean areas, which may have fewer barriers due to co-use. ...speaking as a citizen of the world, I do worry about the environmental and geopolitical implications of countries setting a precedent of operating outside of EEZs without international cooperation and where a tragedy of the commons situation could be more likely compared to within EEZs."*

Response: Feedback showed we missed some locations, and so we keep the discussion of field trials more open-ended, recognizing local support for trials and theory of trial impact in the context of a comprehensive study design will be critical determinants.

Summary of Revisions:

- Recommended competitive (application-based) funding processes to support field trials, wherein proposals require a theory of impact, for field trials to be contextualized into a more comprehensive study design and purpose rooted in the recommended stage-gate approach.

Natural Analogs

Some commenters mentioned natural analogs, indicating that this research approach is a valuable tool for the PCS strategy.

- *"Natural analogs: ..... this represents a much greater opportunity than is often appreciated. In the last decade there have been at least 3 major natural [ocean iron fertilization] events, Australian wildfires, Kileaua eruption, Tonga eruption, all associated with potential substantial local draw down of CO2....in no case has there*

been a concerted response with ships, aircraft and better autonomous monitoring to more fully understand the scale of blooms, dynamics, and export of C as well as related environmental effects. These are essentially missed opportunities to more accurately measure bloom dynamics, export, remineralization, and environmental impacts. ***If rapid response funding were available more advantage could be gained from these opportunities****."*

- *"Spend more time looking at natural analogs: Putting a large amount of sedimentation and organisms to the benthos is risky."*

Response: Natural analog research remains in scope of a PCS program. The challenge is to balance PCS recommendations with the extensive field work already underway and seek the most effective ways to leverage that work.

Summary of Revisions:

- Expanded the discussion of natural analogs to emphasize that they can help address environmental impacts of PCS.
- Note that many natural analog studies are ongoing and expensive, so the Framework should focus on integrating that work into existing PCS study efforts and ensuring targeted and leveraged RD&D Program implementation where most impactful.
- Added a specific recommendation for 'rapid response funding' should an event-scale PCS natural analog occur naturally.

Environmental Impacts

Feedback covered a range of environmental impacts concerns:

- *"I would put CDR accounting at a lower priority than assessing ecology and social risks – especially the risk of non-action. CDR accounting is certainly important, but it is also largely a technology problem; MRV ultimately provides the means of monetizing carbon removal efforts and thus confers its own rewards for improvement. If ecological and socio-political risks are well-enough understood that we can responsibly open the way for large-scale deployment, then all of the key technologies (MRV accounting among them) will get to advance on their own learning curves. As long as the risks are poorly understood and communicated, the whole enterprise will be too scary to attract capital, and progress will remain slow."*
- *"Natural analogs show the risks: When you get nutrients coming down the Columbia River, and you get too much enhancement, that phytoplankton sinks to*

the bottom at once, and sucks the oxygen out of the water, and we get enormous fish kills from the resulting hypoxia…. they want to send a big wad of material down really fast, and if you do that in the wrong spot, you'll suck the oxygen out of the water and create dead zones."

- *"I feel that environmental risk is given a lot of lip service but never unpacked or discussed in depth. No guidance is given on how to assess this, what metrics or indicators should be measured. I also saw no mention of feedbacks resulting from large scale implementation. Feedbacks resulting from changes to chemistry or biology may alter the carbon cycle, air sea exchange, greenhouse gas production etc. Environmental risk and safety needs attention - well beyond the brief mention given in multiple places. About 4 or 5 concerns are given. These should be discussed in detail. There is almost no mention of risk to deep-sea ecosystems. Environmental risk could include changes to ocean chemistry, oxygenation, microbial processes, animal behaviors, mortality from phytodetritus smothering. Feedbacks need attention."*
- *"Once introduced, it must be recognized that all PCS approaches have similar challenges, given they rely on BCP processes that enhance durable/additional C sequestration, here divided into those pathways that enhance productivity and/or those that enhance export. This means whether considering HNLC, LNLC, export enhancement- all will alter surface nutrients and transfer C to subsurface (or they don't work). This similarity needs to be stated upfront, and is rather unbalanced at present, and is discussed almost exclusively with regards to prior [ocean iron fertilization] HNLC studies (box 3 and elsewhere), and the same potential concerns are not considered for the other far less well studied paths. Specific statements about possible subsurface impacts to O2, or nutrient redistribution, apply to all PCS approaches. That is OK, as we can measure these impacts, and at least for [ocean iron fertilization] in HNLC regions, they have already been shown to have small consequences relative to CO2 sequestered (other GHG's), or didn't happen (HABS). These potential impacts are certainly not "unverifiable" s(box 3. Pg 8), and will form part of any future study – this has to be recognized. They are hard to model with current BCP parameterizations, which is why we need more observations."*

Response: We agree that there are many unknowns regarding environmental impacts and discuss the various research tools that are needed to address these (e.g., field trials, models, natural analog studies). As environmental impacts have been covered extensively in other mCDR reports, we do not present an in-depth discussion of environmental impacts but rather focus on the research tools necessary to address PCS knowledge gaps.

Summary of Revisions:

- Included an additional discussion in the Introduction that covers environmental impacts of PCS pathways, in general.
- Enhanced specificity on environmental impacts research being part of field trials and model recommendations.

Co-Benefits

Many comments called out the need for greater attention to co-benefits of PCS.

They included potential fisheries enhancement and mitigating current trends in reduced biological productivity in some ocean regions. For some commenters, these benefits could outweigh metrics of CDR scalability.

- *"I would like to see more emphasis placed on the use of PCS for restoration of ocean health, independent of its carbon drawdown potential… phytoplankton primary production has fallen steadily over the last several decades."*
- *"I think there should be room in the PCS research agenda for small-scale projects that provide a diversity of benefits beyond just carbon removal, and for community-led, community-scale, "distributed" carbon removal projects that may not achieve carbon removal impacts at large scales."*
- *"The concept of co-benefits is currently represented within the document but it is generally associated with community engagement and the phrase 'socio-economic and environmental risks and co-benefits' …. **This framing attaches the concept of co-benefits to the human dimensions part of PCS, rather than the scientific research and monitoring components.** I would like to see co-benefits centered throughout all aspects of the report, including within the stage-gate framework for justifying further investment in PCS pathways. I think it's worth speculating about, and building the science to assess, projects that might be justified by their co-benefits rather than (or in addition to) their carbon removal benefits."*
- *"I can imagine projects (possibly small-scale) that would be driven by societal interest in restoring ocean and coastal ecosystems that are experiencing declining productivity as a result of climate change, or that aim to enhance local fisheries. For example, fishermen in Narragansett Bay, Rhode Island, have been experiencing a decline in shellfish productivity over the last decade, apparently driven by declining nitrogen inputs that resulted from wastewater treatment upgrades. These declines are taking a major toll on the shellfishing economy and there is strong support among fishermen for targeted additions of nutrients to the bay to reverse the shellfish decline. If projects like this can be demonstrated to have a carbon benefit, and this carbon benefit could help pay for the projects, then the projects would be meeting a vital need, receiving strong support from coastal stakeholders, while also meeting carbon objectives."*

- Co-benefits mentioned include:
  - *"enhanced atmospheric methane removal via iron salt aerosols and/or enhanced chlorine that can promote more of nature's methane oxidation"*
  - *"ocean restoration based on the idea that reduced primary production and increased stratification already cause some kind of nutrient robbing"*

Response: We agree that the assessment of co-benefits need to be clearly represented in scientific priorities and knowledge of co-benefits can contribute to building societal support for PCS research. We disagree that PCS co-benefits could be prioritized over CDR benefits as the priority scope of PCS is to evaluate CDR solutions. However, there may be strategic social license building opportunities associated with PCS projects that more squarely center co-benefits. We do not implement requests to present PCS as a focus for ocean ecosystem restoration or fisheries enhancements due to the potential for green-washing of this approach and the priority focus of this work on CDR.

Summary of Revisions:

- Enhanced emphasis on co-benefits as a scientific priority throughout the report and in the Stage Gate approach.
- Expanded the assumption for the need of a 1 GtCO2 threshold to include that evidence for co-benefits might warrant lower CDR threshold.
- Added emphasis on benefits measurement against conditions that would result under business-as-usual treatment.

Biological Carbon Pump Baseline

Several commentors advocated for placing PCS in the context of natural baseline dynamics shifts but others recommended deprioritizing investment in BCP baseline.

BCP baseline and BAU trends comments overlapped in some cases with co-benefit considerations.

- *"I think there's a missed opportunity here to draw attention to the ragged state of ocean health, and the fact that even if nobody cared about carbon drawdown, working to understand and stimulate the ocean's primary productive engine would very likely be of benefit to all."*

- *"I would like to see more emphasis placed on the use of PCS for restoration of ocean health, independent of its carbon drawdown potential. Whether or not we, as a society, like the idea of modifying ocean processes to help us recover from our collective mistakes, the fact remains that we've been modifying these processes for decades. The ocean is not pristine and untouched, because we've already done a lot to damage it. Acidification is a significant part of this, but we also see that phytoplankton primary production has fallen steadily over the last several decades, stratification has increased, and long-established circulation patterns are now in question."*
- *"Yes, modeling is critical, and essential for extrapolating the space/time scales that are limited in observations, and for planning field studies and incorporating data. In this regard, the emphasis on natural analog and BCP studies fits to our mind wholly within the modeling priority, as we agree such natural BCP studies "provide valuable insights, they cannot substitute for controlled trials needed to validate interventions of scale PCS". As a subset of modeling, better use of existing BCP data should be encouraged, but shouldn't be a priority of new BCP studies. This could be clarified by moving natural BCP results as a sub-activity, within the modeling priority.*
- *"Interrogation of datasets from natural analogues and the ocean's natural BCP would be better framed within the discussion of modelling, because that's where prior studies can really help inform models. It is currently a distraction from the need to move forward on artificial iron additions. As is, it is unclear (for example Table 1) what is meant by building "a better foundation"- is that an ARGO network investment? Or a testing a model against existing natural BCP and natural Fe source studies? Moving natural BCP into the modeling priorities seems advised."*
- "*The emphasis on natural analog and BCP studies fits to our mind wholly within the modeling priority"*

Response: Understanding the BCP remains a priority. We agree that we can improve the emphasis that this priority is to catalyze BCP understanding in the context of PCS risk-benefits.

Revision:

- Revised statements that could be misinterpreted that the BCP baseline priority merits a large-scale investment of PCS funding.
- Clarified that this topic is a priority for catalytic investments (e.g., synthesis activities, communication strategies).

Broader Engagement

Community engagement priorities received widespread support, e.g., *"The report's call for early stakeholder engagement and co-designed outreach is critical for maintaining public trust"*. Comments also included recommendations for implementation:

- *"Fund the capacity of coastal communities to first learn about PCS pathways and subsequently engage with research project leads, permitting authorities, and others to advance knowledge about PCS in a way that is informed by these communities' priorities."*
- *"We recommend encouraging dedicated staff in project budgets to conduct work on engagement and decision-making."*

Commercial sector engagement was recommended in the context of scaling an industry.

- *"No real commercial angle has been really discussed which is what will really be required in order to encourage investment. Carbon credit can only get you that far and will not suffice."*
- *"If any form of CDR is going to really scale appropriately it will only be done if there are market incentives."*
- *"Work closely with project developers….This will also ensure that the research objectives align with actual industry needs.*

International governance bodies engagement:

- *"Closer liaison with the regulator (IMO) and industry is encouraged, this will assist in decision making, socio economic and environmental assessments as well as industry partnerships for operational management considerations."*

Response: We maintained a focus on inclusive scientific research, including prioritizing community and fisheries engagement and leveraging commercial activities when relevant for addressing PCS priorities via transparent and independent scientific research.

Summary of Revisions:

- Enhanced treatment of the importance and potential pathways for community engagement
- Clarified the opportunities available to better monitor and incorporate learnings from commercial scientific efforts

Other Revisions

Numerous revisions were made in response to detailed feedback and at the discretion of the project leads. In addition, the following revisions were made:

- Reduced repetitive content.
- Addition of "Outcomes" for recommendations on Implementation Priorities.
- Scientific accuracy corrections.
- Corrected landscape omissions.
- Acknowledgement of individuals who engaged in this work, including non-anonymous public feedback participants.

Google Form Questions

Below are the prompts used in the Google Form for soliciting feedback on the draft PCS report:

- **Full Name.** Your name will not be made public unless you provide permission. Your demographic information will be used to assess our success in obtaining a diversity of perspectives.
- **Affiliation.**
- **Select your geographic affiliation.** This information will be used to assess our success in obtaining a diversity of perspectives.
- **Select the group that best represents you.** This information will be used to assess our success in obtaining a diversity of perspectives.
- **Describe your area(s) of expertise.**
- **Acknowledgement.** Ocean Visions is committed to inclusive and transparent review processes and would like to acknowledge your contribution to this process. Your specific feedback will not be attributed to your name.
- **Select the sections of the report you reviewed.** Check all that apply. You do not need to have read the entire report in order to provide feedback.
- **Do you agree with the proposed research priorities outlined in the 'PCS Strategy Foundation' and 'Recommended RD&D Action Plan'?**
- **Justification.** Please explain your score above.
- **Should any of the proposed priorities receive more attention?**
- **Should any receive less attention, or otherwise be modified?**
- **Do you have any other suggested revisions to the priorities?** Please justify.
- **Stage Gate Framework (Figure 2).** What are your views on the proposed stage-gates and evaluation metrics for deciding whether specific PCS pathways merit continued support, and how would you refine or improve those metrics? Are the stage gates clear? Is the sequence correct? Are the proposed standards verifiable?
- **Field Trials.** Field trials are a critical step in increasing direct evidence of effectiveness of different mCDR approaches and are important opportunities for public engagement. Field trials can also be expensive, and findings may not always be transferable to other times of year or locations. We invite comments on the role, timing, and/or location priorities of small or large-scale PCS field trials and conditions under which you would support such field trials.
- **Implementation.** Please provide feedback on the recommendations for future implementation of the proposed activities, covering socio-economic considerations, decision-making, and operational management.

- **Scientific Errors.** Please identify any specific scientific errors as defined by peer reviewed documents (references encouraged).
- **Landscape Omissions.** Please list programs, projects, or organizations that should be included in or potentially involved in the PCS RD&D program.
- **Final Comments.** Do you have any additional comments or questions you would like to see addressed in the final report?