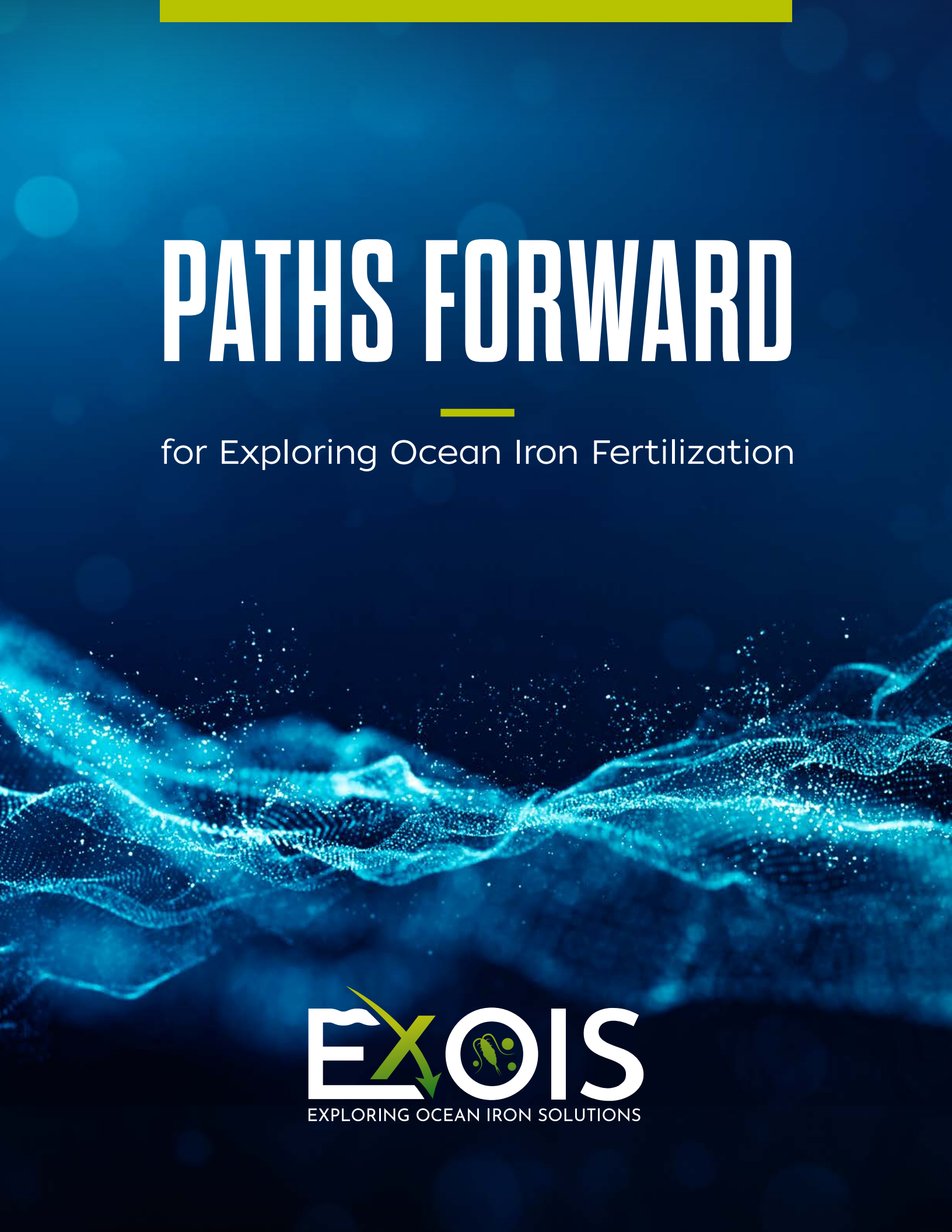
PATHS FORWARD

for Exploring Ocean Iron Fertilization



EXOIS

EXPLORING OCEAN IRON SOLUTIONS

EXECUTIVE SUMMARY

We need a new way of talking about global warming. UN Secretary General António Guterres underscored this when he said the "era of global boiling" has arrived. Although we have made remarkable progress on a very complex problem over the past thirty years, we have a long way to go before we can keep the global temperature increase to below 2°C relative to the pre-industrial times. Climate models suggest that this next decade is critical if we are to avert the worst consequences of climate change. The world must continue to reduce greenhouse gas emissions, and find ways to adapt and build resilience among vulnerable communities. At the same time, we need to find new ways to remove carbon dioxide from the atmosphere in order to chart a "net negative" emissions pathway. Given their large capacity for carbon storage, the oceans must be included in consideration of our multiple carbon dioxide removal (CDR) options (1).

This report focused on ocean iron fertilization (OIF) for marine CDR. This is by no means a new scientific endeavor. Several members of ExOIS (Exploring Ocean Iron Solutions) have been studying this issue for decades, but the emergence of runaway climate impacts has motivated this group to consider a responsible path forward for marine CDR. That path needs to ensure that future choices are based upon the best science and social considerations required to reduce human suffering and counter economic and ecological losses, while limiting and even reversing the negative impacts that climate change is already having on the ocean and the rest of the planet.

Prior studies have confirmed that the addition of small amounts of iron in some parts of the ocean is effective at stimulating phytoplankton growth. Through enhanced photosynthesis, carbon dioxide can not only be removed from the atmosphere but a fraction can also be transferred to durable storage in the deep sea. However, prior studies were not designed to quantify how effective this storage can be, or how wise OIF might be as a marine CDR approach.

ExOIS is a consortium that was created in 2022 to consider what OIF studies are needed to answer critical questions about the potential efficiency and ecological impacts of marine CDR (http://oceaniron.org). Owing to concerns surrounding the ethics of marine CDR, ExOIS is organized around a responsible code of conduct that prioritizes activities for the collective benefit of our planet with an emphasis on open and transparent studies that include public engagement (2; see inset pg. 3).

Our goal is to establish open-source conventions for implementing OIF for marine CDR that can be assessed with appropriate monitoring, reporting, and verification (MRV) protocols, going beyond just carbon accounting, to assess ecological and other non-carbon environmental effects (eMRV). As urgent as this is, it will still take 5 to 10 years of intensive work and considerable resources to accomplish this goal.

We present here a "Paths Forward" report that stems from a week-long workshop held at the Moss Landing Marine Laboratories in May 2023 that was attended by international experts spanning atmospheric, oceanographic, and social sciences as well as legal specialists (see inside back cover). At the workshop, we reviewed prior OIF studies, distilled the lessons learned, and proposed several paths forward over the next decade to lay the foundation for evaluating OIF for marine CDR. Our discussion very quickly resulted in a recommendation for the need to establish multiple "**Ocean Iron Observatories**" where, through observations and modeling, we would be able to assess with a high degree of certainty both the durable removal of atmospheric carbon dioxide—which we term the "**centennial tonne**"—and the ecological response of the ocean.

In a five-year phase I period, we prioritize five major research activities:

1. **Next generation field studies**
   Studies of long-term (durable) carbon storage will need to be longer (year or more) and larger (>10,000 km^2) than past experiments, organized around existing tools and models, but with greater reliance on autonomous platforms. While prior studies suggested that ocean systems return to ambient conditions once iron infusion is stopped, this needs to be verified. We suggest that these next field experiments take place in the NE Pacific to assess the processes controlling carbon removal efficiencies, as well as the intended and unintended ecological and geochemical consequences.
2. **Regional, global and field study modeling**
   Incorporation of new observations and model intercomparisons are essential to accurately represent how iron cycling processes regulate OIF effects on marine ecosystems and carbon sequestration, to support experimental planning for large-scale MRV, and to guide decision making on marine CDR choices.
3. **New forms of iron and delivery mechanisms**
   Rigorous testing and comparison of new forms of iron and their potential delivery mechanisms is needed to optimize phytoplankton growth while minimizing the financial and carbon costs of OIF. Efficiency gains are expected to generate responses closer to those of natural OIF events.
4. **Monitoring, reporting, and verification**
   Advances in observational technologies and platforms are needed to support the development, validation, and maintenance of models required for MRV of large-scale OIF deployment. In addition to tracking carbon storage and efficiency, prioritizing eMRV will be key to developing regulated carbon markets.
5. **Governance and stakeholder engagement**
   Attention to social dimensions, governance, and stakeholder perceptions will be essential from the start, with particular emphasis on expanding the diversity of groups engaged in marine CDR across the globe. This feedback will be a critical component underlying future decisions about whether to proceed, or not, with OIF for marine CDR.

Paramount in the plan is the need to move carefully. Our goal is to conduct these five activities in parallel to inform decisions steering the establishment of ocean iron observatories at multiple locations in phase II. When completed, this decadal plan will provide a rich knowledge base to guide decisions about if, when, where, and under what conditions OIF might be responsibly implemented for marine CDR.

The consensus of our workshop and this report is that now is the time for actionable studies to begin. Quite simply, we suggest that some form of marine CDR will be essential to slow down and reverse the most severe consequences of our disrupted climate. OIF has the potential to be one of these climate mitigation strategies. We have the opportunity and obligation to invest in the knowledge necessary to ensure that we can make scientifically and ethically sound decisions for the future of our planet.

GUIDING PRINCIPLES

For ocean carbon dioxide removal studies

1. Prioritize collective benefit for humans and the environment
2. Establish clear lines of responsibility to oversee studies
3. Commit to open and cooperative research, including risk assessments
4. Perform evaluation and assessment in an iterative and independent manner
5. Engage the public in consideration of climate intervention options

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