



## **Fieldwork Planning Workshop Handbook**

**29-31 May 2024**

**Woods Hole Oceanographic Institution**

# Sponsors



# Program Office Welcome

## Dear Workshop Participants,

The ExOIS Steering Committee and Program Office warmly welcomes you to the ExOIS Fieldwork Planning Workshop, here at the Woods Hole Oceanographic Institution located on Cape Cod, Massachusetts. Firstly, we would like to thank you for giving your time and support to engage in this workshop, whether in person or remotely. For this, we are greatly indebted for the investment in time that you are giving ExOIS. By bringing your expertise and insight to this workshop, you will be contributing to the unique endeavour of applying state-of-the-art science to the decades old idea of using iron to durably store additional carbon in the deep sea for the purpose removing carbon dioxide from the atmosphere. As you will all know, the first generation of ocean iron fertilization (OIF) experiments successfully showed that iron can be used to make the ocean bloom in iron-limited regions, but these experiments were not designed to measure durably sequestered carbon. Today, in response to the most recent IPCC AR6 Synthesis Report, there is a new urgency to develop and test methods of carbon dioxide removal (CDR), including OIF. ExOIS aspires to answer the remaining unknowns surrounding OIF as a potential form of marine CDR, and to do this in a context of ExOIS' guiding principles. Over the next two and a half days, this workshop will discuss what the next generation of OIF field studies will look like, and formulate a roadmap of how these experiments will be implemented. No matter whether you are a returning or first-time visitor to WHOI, we hope that this workshop is a productive and worthwhile experience for you.

This workshop is only made possible through the generous support of our sponsors shown on the previous page. Furthermore, we would like to express thanks to the local network of support that the ExOIS Program Office has access to, both within WHOI, and through the local businesses that have provided services to support this event. As WHOI is a sponsor and host of ExOIS, we direct you to the WHOI Land Acknowledgement statement below.

With warm regards,

Ken Buesseler, Jessica Drysdale, Paul Morris – **ExOIS Program Office**

Kilaparti Ramakrishna, Joo-Eun Yoon, Mark Wells, Sarah Smith, Fei Chai – **ExOIS Steering Committee**



## WHOI Land Acknowledgement

We collectively acknowledge that Woods Hole Oceanographic Institution is located on the unceded ancestral and contemporary land of the Wôpanâak (Wampanoag people). We acknowledge the Mashpee, Aquinnah, Herring Pond, and Assonet Wampanoag Tribes as the original stewards and protectors of this land and surrounding waters. We recognize the perpetuated detrimental effects that systemic governmental oppressions have had on indigenous communities as a result of colonization. By offering this land acknowledgement we accept our responsibility to understand this history, invest in reconciliation, and build accountable partnerships with these communities.

# Workshop purpose and objectives

## ExOIS Overall Objective

To conduct research to evaluate if OIF is an efficient and responsible approach to reducing atmospheric CO<sub>2</sub>. And if so, provide research results that enable society to conduct OIF at scale.

## ExOIS Overall Outcome

To provide an open source description of the protocols to accelerate the implementation of at-scale OIF implementation, and to conduct experiments on how the State of Technology (SOT) can be improved by future entities

**Why new field studies:** Early OIF studies successfully demonstrated iron limitation for growth and uptake of CO<sub>2</sub> by phytoplankton in HNLC regions. They were not designed to target uncertainties in whether OIF is sufficiently effective, durable, scalable, and reproducible for mCDR, and with acceptable consequences for marine ecosystems. We need to reduce these uncertainties while optimizing efficiencies to inform decisions on the consequences and costs of deploying OIF for mCDR.

## Workshop objective

The workshop needs to arrive at a structure for what the first fieldwork deployment will look like, and to formulate a roadmap and work plan for launching a series of pilot studies, assuming different levels of funding.

### **Priorities for the first field experiment in the NE Pacific are:**

0. Create and track a coherent and large bloom.
1. Track export and fate of the additional particulate C to at least 100 yr (500 m) scales and over months/season.
2. Assess surface DIC and pCO<sub>2</sub> drawdown with observations and track with models air/sea exchange.
3. Document ecosystem and environmental impacts.
4. Use the observations made during the field experiment to assess MRV technologies and to develop and validate MRV model.
5. Use the field data (obs and models) to assess scalability, costs, and with models, regional and climate impacts.
6. Learn from the field study to design future studies to maximize mCDR potential, evaluate variability and reduce costs at this site and others.

**Characteristics of new pilot studies:** deploy iron over larger/longer scales than in past experiments to create a bloom at a site where a patch will remain coherent. Site needs to be logistically accessible with known baseline conditions and iron limitation. Studies to include MRV activities need to assess the additionality, durability, and leakage of carbon uptake, including eMRV activities assess the ecological and environmental impacts.

**Priorities need to be set to optimize study design and improve OIF C efficiencies.** These priorities will lead to decisions on iron and patch deployment and identify “core” parameters for monitoring. Identify spatial and temporal needs for observations and modeling requirements for planning, data assimilation, and extrapolations. The list of priorities is needed decide how minimum funding level needed and how to spend and distribute resources.

**Other characteristics of field plan to include:** open data sharing; international collaboration; broad public and stakeholder engagement; adhering to the permitting process as defined under LP/LC; support from a blend of funding sources and in-kind contributions (federal, international, philanthropic, individual, commercial) to fund core science team and ancillary groups without the sale of C credits or shares in IP or other products; encourage participation by other groups (e.g. MRV testing; additional field observations; modeling; public/govt. engagement, etc); more....

**Workshop deliverables:** field costs for different funding scenarios; sufficient specificity to apply for 18 month (2-3 experiments) permit under US EPA; internal implementation plan to share/post, to include milestone and go/no go tables and lists of MRV/eMRV variables (general, or with specific method/accuracy?); other? (**See new outcomes and deliverables sections below**)

# ExOIS field planning workshop – Outcomes and deliverables (**draft**)

## 1. Science clarity – “setting the bar”

Describe a field program that meets ExOIS priorities (top 6 list) – with enough detail to convince peers, mCDR community, potential funders, social science and governance groups, markets, why OIF studies are needed, what they would accomplish, and what they would entail including phase 1 replicate plans (up to 4 experiments).

### **Deliverables**

- ✓ Group leads- Turn BO and discussion topics into web-based materials/report (There is lots of information already in the PF report and manuscript)
- ✓ Use field plan to lock in international collaborators and in-kind contributions (ships; science; AVs etc.) & reach out to those whose expertise is missing/essential to success
- ✓ ID short term initial science/tech/model needs and hero’s (OSSE’s; Fe delivery), and the funds needed to get going
- ✓ Establish WG to assist w/proposals (VICC; DOE CDR pilots)- time commitments need consideration.

## **2. Costs/budgets**

Gather sufficient info for costing Low (minimum viable project MVP), Med (top 3 priorities), and High (all 6 priorities) level field experiments and replicates in sufficient detail to secure funding, and plan for contingencies.

### **Deliverables**

- ✓ Leave workshop with costs models (MVP and full costs)
- ✓ Use costs to seek funding from private & philanthropic sources
- ✓ Use costs to identify the best components for seeking government funding
- ✓ Use budgets to seek out in-kind contributions
- ✓ See above as costs needed to write competitive agency and mCDR proposals

## **3. Permits – EPA under LC/LP**

Workshop to provide enough detail on experimental design to convince under LC/LP that scientific merit exceeds potential harm. Need to be able to write an impact assessment for a specific location, time, plan, MRV/eMRV, risks, go/no go points, etc.

### **Deliverables (*comes after social/governance workshop*)**

- ✓ Establish WG to initiate EPA permit- step 1 pre-permit application; step 2 full permit (several steps of negotiation); permit is valid for 18 months from the day the ship leaves the dock, which could cover 2-3 experiments
- ✓ Establish WG to identify and engage stake holders (regional; mCDR community; public)

## **4. 4. Structural considerations**

What will it take to pull this off? management, structure, oversight of field project over multiple years w/different sources of funding; agendas; reporting; motivations

### **Deliverables**

- ✓ Leave workshop with advice to PO and ExOIS SC how to organize field studies, including, structure to move ahead- flexible core team versus RFP model,
- ✓ Leave workshop with steps/timelines for support activities (e.g. PO tasks, outreach, data management, other activities?)
- ✓ Identify short term funding needed to launch- salary for organization, including WG members; permit process; scale up outreach (work with WHOI Development & others)

# Participants

## In-person

Ken Buesseler	Woods Hole Oceanographic Institution	USA
Fei Chai	Xiamen University	China
Jay Cullen	University of Victoria	Canada
Jessica Drysdale	Woods Hole Oceanographic Institution	USA
Meg Estapa	University of Maine	USA
Makio Honda	Japan Agency for Marine-Earth Science and Technology	Japan
Dennis McGillicuddy	Woods Hole Oceanographic Institution	USA
Paul Morris	Woods Hole Oceanographic Institution	USA
Melissa Omand	University of Rhode Island	USA
David Siegel	UC Santa Barbara	USA
Sarah Smith	Moss Landing Marine Laboratories	USA
Yui Takeshita	Monterey Bay Aquarium Research Institute	USA
Ben Twining	Bigelow Laboratory for Ocean Sciences	USA
Mark Wells	University of Maine	USA
Angelicque White	University of Hawaii at Manoa	USA

## Virtual

Phil Boyd	University of Tasmania	Australia
Seth John	University of Southern California	USA
Jun Nishioka	Hokkaido University	Japan

# Agenda

Time (EDT)	Activity/Session	Lead/Co-leads, team, (virtual)
<b>Tuesday 28 May</b>		
18:30	<b>Ice breaker</b>	
<b>Wednesday 29 May - Day 1</b>		
08:00 - 08:30	<b>Breakfast</b>	
08:30 - 08:45	Open, welcome, housekeeping	<b>Ken &amp; Paul</b>
08:45 - 09:15	Introductions	<b>All</b>
09:15 - 09:45	Setting the stage for ExOIS	<b>Ken</b>
09:45 - 10:15	1) Study location and size	<b>Fei, Dennis, Jay, (Phil)</b>
10:15 - 10:45	2) Delivery of FeSO <sub>4</sub> & inert tracers	<b>Mark, Ben, Dennis, (Seth)</b>
10:45 - 11:00	<b>Break - 15 min</b>	
11:00 - 11:20	2b) Operational - mapping patch size & coherence	<b>Phil</b>
11:20 - 11:30	Breakout group logistics and reporting	<b>Paul &amp; Ken</b>
11:30 - 12:30	<b>Breakout groups</b>	
	BO A) General parameters	<b>Dennis, Angel, Fei, Dave</b>
	BO B) Particle fate	<b>Meg, Ken, Makio, Malissa, Ben, (Seth)</b>
	BO C) Observations for eMRV	<b>Sarah, Mark, Yui, Jay, Paul</b>
12:30 - 13:15	<b>Lunch - 45 min</b>	
13:15 - 14:00	<b>Breakout groups continued</b>	
	BO A) General parameters	<b>Dennis, Angel, Fei, Dave</b>
	BO B) Particle fate	<b>Meg, Ken, Makio, Malissa, Ben, (Seth)</b>
	BO C) Observations for eMRV	<b>Sarah, Mark, Yui, Jay, Paul</b>
	<b>All reconvene</b>	
14:00 - 15:00	Reports from breakout groups - 20 mins each (A/B/C)	<b>All</b>
15:00 - 15:30	<b>Break - 30 min</b>	
15:30 - 16:30	3) Core parameter discussion/Review day 1	<b>Discussion lead TBD</b>
16:30 - 18:30	<b>Free time</b>	
18:30	<b>Dinner</b>	



<b>Time (EDT)</b>	<b>Activity/Session</b>	<b>Lead/Co-leads, team, (virtual)</b>
<b>Thursday 30 May - Day 2</b>		
08:00 - 08:30	<b>Breakfast</b>	
08:30 - 09:00	Recap and plan for day 2	<b>Ken &amp; Paul</b>
09:00 - 09:30	4) Patch tracking	<b>Melissa, Dave, Dennis, (Phil)</b>
09:30 - 10:00	5) Shore support and PO needs	<b>Dave, Melissa, Mark, Dennis, Yui, Angel</b>
10:00 - 10:30	6) Measurements related to Fe	<b>Ben, Mark, Jay, (Seth)</b>
10:30 - 11:00	<b>Break - 30 min</b>	
11:00 - 12:30	<b>Breakout groups</b>	
	BO D) Replicate experiments	<b>Jay, Makio, Ben, Yui, (Jun, Phil, Seth)</b>
	BO E) Formalize go/no-go criteria	<b>Angel, Meg, Sarah, Makio, Fei</b>
	BO F) Costs high/med/low	<b>Ken, Dave, Paul, Melissa, Mark</b>
12:45 - 13:30	<b>Lunch - 45 min</b>	
	<b>All reconvene</b>	
13:30 - 14:30	Reports from breakout groups - 20 mins each	<b>All</b>
14:30 - 15:00	<b>Break - 30 min</b>	
15:00 - 16:30	Review of the whole	<b>Discussion lead TBD</b>
16:30 - 18:30	<b>Free time</b>	
18:30	<b>Dinner</b>	
<b>Friday 31 May - Day 3</b>		
08:00 - 08:30	<b>Breakfast</b>	
08:30 - 09:00	Recap and plan for day 3	<b>Ken &amp; Paul</b>
09:00 - 09:30	8) Scientific team structure & international collaboration	<b>Jay, Makio, Ken, Fei, (Jun)</b>
09:30 - 10:00	9) Data management	<b>Paul, Angel, Yui</b>
10:00 - 10:30	10) Funding models	<b>Ken, Paul</b>
10:30 - 11:00	<b>Break - 30 min</b>	
11:00 - 11:30	11) Social and Governance	<b>Paul, Ken</b>
11:30 - 12:30	12) Next steps to action	<b>Ken</b>
12:30	<b>Meeting close</b>	
12:30 - 13:30	<b>Lunch</b>	

# Working Groups

## Plenary Sessions

	<b>Session groups</b>	<b>Lead/Co-leads, team, (virtual)</b>
<b>1</b>	Study location and size	<b>Fei, Dennis</b> , Jay, (Phil)
<b>2</b>	Delivery of FeSO <sub>4</sub> & inert tracers	<b>Mark</b> , Ben, Dennis, (Seth)
<b>2b</b>	Operational	<b>Phil</b>
<b>3</b>	Core parameters	<b>Ken, All</b>
<b>4</b>	Patch tracking	<b>Melissa</b> , Dave, Dennis, (Phil)
<b>5</b>	Shore support and PO	<b>Dave</b> , Melissa, Mark, Dennis, Yui, Angel
<b>6</b>	Measurements related to Fe	<b>Ben</b> , Mark, Jay, (Seth)
<b>7</b>	Review of the whole	<b>Ken</b>
<b>8</b>	Scientific team structure & international collaboration	<b>Jay</b> , Makio, Ken, Fei, (Jun)
<b>9</b>	Data management	<b>Paul</b> , Angel, Yui
<b>10</b>	Funding models	<b>Ken</b> , Paul
<b>11</b>	Social and Governance	<b>Paul</b> , Ken
<b>12</b>	Next steps to action	<b>Ken</b>

## Breakout Groups

	<b>Breakout groups</b>	<b>Lead/Co-leads, team, (virtual)</b>
<b>A</b>	General parameters	<b>Dennis</b> , Angel, Fei, Dave
<b>B</b>	Particle fate	<b>Meg</b> , Ken, Makio, Melissa, Ben, (Seth)
<b>C</b>	Observations for eMRV	<b>Sarah</b> , Mark, Yui, Jay, Paul
<b>D</b>	Replicate experiments	<b>Jay</b> , Makio, Ben, Yui, (Phil, Jun, Seth)
<b>E</b>	Go/No-go criteria	<b>Angel</b> , Meg, Sarah, Makio, Fei
<b>F</b>	Costs	<b>Ken</b> , Dave, Paul, Melissa, Mark

# Session Details & Assignments

**Open, welcome, housekeeping** (15 min) - **Ken, Paul**

## Plenary Sessions

**Introductions** (30 min) – Individual introductions, to include background, motivation, COIs – **All**

**Setting the stage for ExOIS** (60 min) – Overall view of the field plan, priorities, core measurements and outputs of the workshop – **Ken**

**1) Study location and size** (30 min) – Season; In and Out sampling; pre-cruise OSSEs – **Fei, Dennis, Jay, (Phil)**

**2) Delivery of FeSO<sub>4</sub>** (30 min) – How to do/pattern/logistics (& Fe isotopes?); SF<sub>6</sub>/inert tracers; delivery vessels – **Mark, Ben, Dennis, (Seth)**

**2b) Operational** (20 min) – Mapping patch size & coherence – **Phil**

**3) Core parameters** and priorities discussion, and review of day 1 (60 min) – Discussion lead **TBD**

**4) Patch tracking** (30 min) – 60-90 days, chemical, floats, sail drone, remote sensing – **Melissa, Dave, Dennis, (Phil)**

**5) Shore support and PO needs** (30 min) – **Dave, Melissa, Mark, Dennis, Yui, Angel**

**6) Measurements related to Fe** (30 min) – concentration, forms, isotopes – **Ben, Mark, Jay, (Seth)**

**7) Review of the whole** (90 min) – Field experiment; High/Med/Low cost tradeoffs, timeline; core parameters, including patch tracking, Fe addition, replicates, etc – **Discussion lead TBD**

**8) Scientific team structure** (30 min) including formalizing international collaborators (science & ships) – **Jay, Makio, Ken, Fei, (Jun)**

**9) Data management** (30 min) – **Paul, Angel, Yui**

**10) Funding models** (30min) & how could RFP's work (or not) – **Ken, Paul**

**11) Social and Governance** (30 min) Overview of topics at June kick-off meeting, including EPA permit application & stakeholder and public engagement – **Paul, Ken**

**12) Next steps to action** (60 min) Products for ExOIS forums, web, etc – **Ken**

## Breakout Groups

**BO A) General parameters** (60+45 min) – Hydrographic team: T, S, O<sub>2</sub>, chlorophyll, nutrients, pigments, DIC/pCO<sub>2</sub>; ship based; AVs; pre/during/post bloom – **Dennis, Angel, Fei, Dave,**

**BO B) Particle fate** (60+45 min) – Traps; optical; geochemical (234Th; C budgets; O<sub>2</sub> budgets); specific to 100 yr depth/upper 500-1000m; remineralization length scales of C and Fe, N, P, Si – **Meg, Ken, Makio, Melissa, Ben, (Seth)**

**BO C) Observations for eMRV** (60+45 min) – HABS, community structure (rates?); zooplankton and secondary community responses; other gasses(O<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, DMS) – **Sarah, Mark, Yui, Jay, Paul (others?)**

**BO D) Replicate experiments** (90 min) merits and goals (and feasibility) at the same location; role of replicate incubations; consider next locations – **Jay, Makio, Ben, Yui, (Phil, Jun, Setph)**

**BO E) Formalize go/no-go criteria** (90 min) – for experiment & phase II, for C, and negative impacts – **Angel, Meg, Sarah, Makio, Fei**

**BO F) Costs high/med/low** (90 min) – for single experiments with timeline, include number of AVs, teams, ships – **Ken, Dave, Paul, Melissa, Mark**

**Reports from breakout groups** – 20 min each

# ExOIS Members

## Steering Committee



**Ken Buesseler**  
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Oceanographic  
Institution



**Kilaparti  
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