Ocean alkalinity enhancement and mitigation of ocean deoxygenation
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Talk outline and take homes:

Ocean Alkalinity Enhancement (an “abiotic” approach to CDR)
• Ocean Alkalinity Enhancement approaches are developing rapidly
• Strong technology “push” from private sector is “pulling” research
• Example of accelerated, coordinated research into monitoring, reporting and verification and impacts
• Urgent need for coordinated, multi-sectoral, transparent, independent research

Mitigation of deoxygenation
• Loss of oceanic oxygen is, arguably, the most dangerous (and overlooked) threat to marine biodiversity and has positive climate feedback potential
• A possibility to mitigate oxygen loss through “ocean reoxygenation” may be about to appear, again from private sector “push”
• Very urgent need for consideration/ research effort/ assessment
RECENT INCREASED AWARENESS OF OCEAN-CDR (E.G. NASEM REPORT, 2021)

Several options under consideration. Two fundamental approaches which differ in the components of the marine ecosystem they manipulate.

“Framing” of options (e.g. use of the word “nature”) can impact social perception and policy.

Planetary Technologies is on a mission to remove 1 billion tonnes of carbon dioxide from the atmosphere by 2045.

Three field demonstration sites:
St. Ives, Cornwall, UK (underway);
Bedford Basin, Nova Scotia, Canada (2023);
West coast of Canada (TBA)

Addition of Mg(OH)$_2$ in slurry form via wastewater and thermal power plant outfalls initially

Coordinated but independent field experiments, measurement and modelling studies by 3rd parties aimed at MRV and Impacts research

MOVING VERY FAST!! A CHALLENGE TO THE RESEARCH SYSTEM.
How can science respond? What type of science is needed?

ALK-ALIGN. A multi-scale, multi-partner, international and multi-disciplinary research initiative to examine OAE effectiveness and impacts
Dalhousie University (Canada), GEOMAR and Uni-Hamburg (Germany), Univ. Tasmania and Southern Cross University (Australia)

“Living Labs” can form part of the research strategy

- A physical region or virtual reality, or interaction space,
- where companies, public agencies, universities, users, and other stakeholders form public-private-people partnerships (4Ps),
- to collaborate for creation, prototyping, validating, and testing of new technologies, services, products, and systems in real-life contexts

(Westerlund & Leminen, 2011).
Bedford Basin: a living lab for ocean biogeochemistry?

Manageable scale
Inputs/outputs measurable
MRV may be possible
Experiments can be repeated
Public participation likely

Weekly sampling since 1992

Well-characterized variability
of physical, chemical and microbial parameters
(including alkalinity, DIC, pCO₂, other greenhouse gases, etc.)

Phytoplankton biodiversity representative of open ocean
Bacteria and archaea biodiversity data also available

Robicheau et al., ISME Comms, 2022;

Kumiko Azetsu-Scott, DFO
A useful model framework

HRM3: Bedford Basin + Narrows
Horizontal resolution: 60 m
Forcing: HRM2 + ERA5
Bathymetry: NONNA

HRM2: Inner Scotian Shelf
Resolution: ~185 m
Forcing: HRM1 + ERA5
Bathymetry: NONNA

HRM1: Central Scotian Shelf
Resolution: ~900 m
Forcing: Tides + GLORYS + ERA5 + BGC climatology (ACM)
Bathymetry: GEBCO
Simulation: 1995 to present ongoing

Ability to test and validate models against LOTS OF data

Replacing atmospheric forcing with ERA5
Increasing the water turbidity
Ability to foster/support multisectoral research:
Nucleii for multi-sectoral, collaborative research and innovation
Including NGO’s, coastal communities

Cautions and some suggestions:
1) Pace of activity with OAE increasing but largely uncoordinated
   “mCDR is emerging ...... from innovation projects that pose co-benefits
   and conflicts between ocean protection, economy, and climate.”
   (Boettcher et al., 2021)
2) Independent funding agencies for research slow to react
3) Need for close combination of modelling and observation to address
   MRV challenge. This is rare and requires a data rich environment.
4) Public and NGO participation in the research should be encouraged

2) Governance issues:
mCDR’s “global commons” dimensions could serve as a springboard for
more coordinated international governance.
Dissolved Oxygen

• A soon-to-emerge issue

Ocean Deoxygenation:
2% decrease in O$_2$ inventory over 50 years;
~75% of O$_2$ decrease in deep ocean (>1200m);
Δwarming/solubility explains ~15%

Increased respiration/ removal?
Decreased ventilation/ supply?
BGC models have difficulty representing observed trends and patterns

Oschlies et al.,
Nature Geosci., 2018
Why does "deoxygenation" matter?

1. Oxygen concentration can be a “tipping point” for life in the ocean.
Deoxygenation is a global threat to marine life.

With accelerating greenhouse gas emissions, species losses from warming and oxygen depletion alone become comparable to current direct human impacts within a century and culminate in a mass extinction rivaling those in Earth’s past. Reversing greenhouse gas emissions trends would diminish extinction risks by more than 70%, preserving marine biodiversity accumulated over the past ~50 million years of evolutionary history.

Climate feedbacks are also a risk.

Bedford Basin: seasonally, hypoxic fjord in an urban setting

Manageable scale
Inputs/outputs measurable

Weekly sampling since 1992
Figure 2: The boxplots represent the climatology of Bedford Basin (2000-2021) and the colored curves show the values for the indicated years derived from weekly CTD deployment at Compass Buoy site. Subhadeep Rakshit, Andrew W. Dale, Douglas Wallace, Christopher Algar. “Sources and sinks of bottom water oxygen in a seasonally hypoxic fjord”, Submitted to JGR Oceans, 2023
Amount of N\textsubscript{2}O Produced due to hypoxia in Winter 2021-2022

• Peak concentration 600 nM (6 x 10\textsuperscript{-4} mol m\textsuperscript{-3})
• 40m thick low-oxygen layer
• Area of Basin >40m depth: ca. 10 km\textsuperscript{2} or 10\textsuperscript{7} m\textsuperscript{2}
• Peak Inventory  2.5 x 10\textsuperscript{5} moles N\textsubscript{2}O or 11 tonnes of N\textsubscript{2}O

With GWP of 267 this is equivalent to emission of 3000 tonnes of CO\textsubscript{2}

Is enhanced N\textsubscript{2}O production a sign of things to come?
Warmer winters → growing hypoxia in coastal regions?
Is mitigation of N\textsubscript{2}O emissions possible by regulation of oxygen?

Can the threat of deoxygenation be mitigated?
An analysis from a small Swedish fjord

Approaches considered:
A. Relocate sewage outfalls; decrease nutrient input
B. Pump oxygen into basin water (“reoxygenation”)
C. Increase turbulent mixing (“stirring”)
D. Pump buoyant water to depth (“artificial downwelling”)
E. Alter topography of fjord to reduce residence time
It’s not just the deep, open ocean
Oxygen time-series near Rimouski
Quebec, Canada
(Head of the Laurentian Channel)

Subsurface spreading of a tracer
following injection in October 2021
Observed June 2022

CIOPS-E Model prediction for
June 2022

Injection of ca. 250 g of SF₆CF₃ (non-toxic;
highly inert tracer) at depth of 250 m on
σ = 27.26 density surface
Can we (and should we) mitigate deoxygenation?

Stephenville, Newfoundland, Canada

Hydrogen Generation Plant proposed for Stephenville, SW Newfoundland

Figure 1-2 Project Location

Figure 1-3 Simplified site offgas flow diagram

Figure 1-4 Simplified interface for offgas to hydrogen production
Table 2.7  Oxygen Production Rates

<table>
<thead>
<tr>
<th>Site A Plant Name-Plate Capacity, MW</th>
<th>Utilization Factor, %</th>
<th>Max O2 Production, tons per day</th>
<th>Max O2 Production, tons per annum</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>100</td>
<td>1,300</td>
<td>480,000</td>
</tr>
<tr>
<td>500</td>
<td>50</td>
<td>650</td>
<td>240,000</td>
</tr>
</tbody>
</table>

2.6.4.2 Oxygen Emissions

The plant will emit oxygen to the atmosphere as a byproduct of the electrolysis process; this byproduct will be discharged safely to the atmosphere or captured as a value stream. In the event that a market is identified for the oxygen generated during the process, a capture, storage, and re-use facility will be incorporated into the hydrogen facility.
Average depth: 400 m
LCW/NACW thickness 250 m
Channel length: 850 km
Channel width: 100 km
Volume: $2 \times 10^{13}$ m$^3$

Rate of O$_2$ decline ($z>150$ m):
1-2 mmol m$^{-3}$ yr$^{-1}$
2-4 x $10^{10}$ mol yr$^{-1}$
6-12 x $10^5$ tons O$_2$ yr$^{-1}$

Production of H$_2$ plant:
$4.8 \times 10^9$ tons O$_2$ yr$^{-1}$

Location, location, location

Average vectors from long-term current meters (Bugden)

Tracer spread from TReX
Should “artificial respiration” (reoxygenation) be considered for vulnerable ocean regions/ ecosystems?

Rapid appearance of large quantities of cheap oxygen from the green hydrogen industry, coupled with the threat of deoxygenation to marine biodiversity may motivate schemes to reoxygenate parts of the ocean.

Many questions!!

• Will reoxygenation qualify for biodiversity credits and offsets?
• What approaches are effective/ responsible at ocean scale?
• Will reoxygenation be effective in mitigating biodiversity loss?
• Are there risks?

Very little is known at present. It’s a new topic.