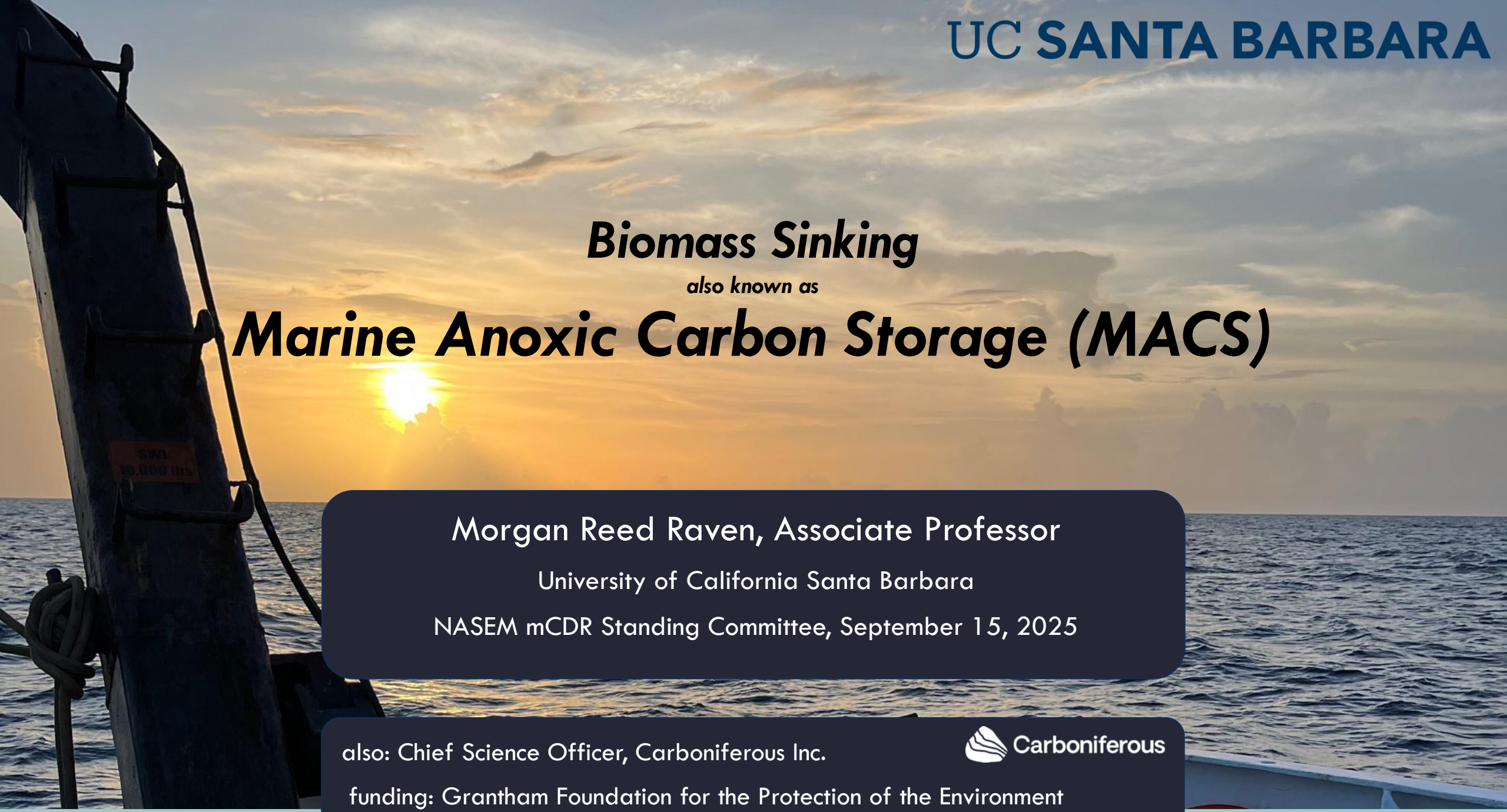


UC SANTA BARBARA

Biomass Sinking

also known as

Marine Anoxic Carbon Storage (MACS)

Morgan Reed Raven, Associate Professor

University of California Santa Barbara

NASEM mCDR Standing Committee, September 15, 2025

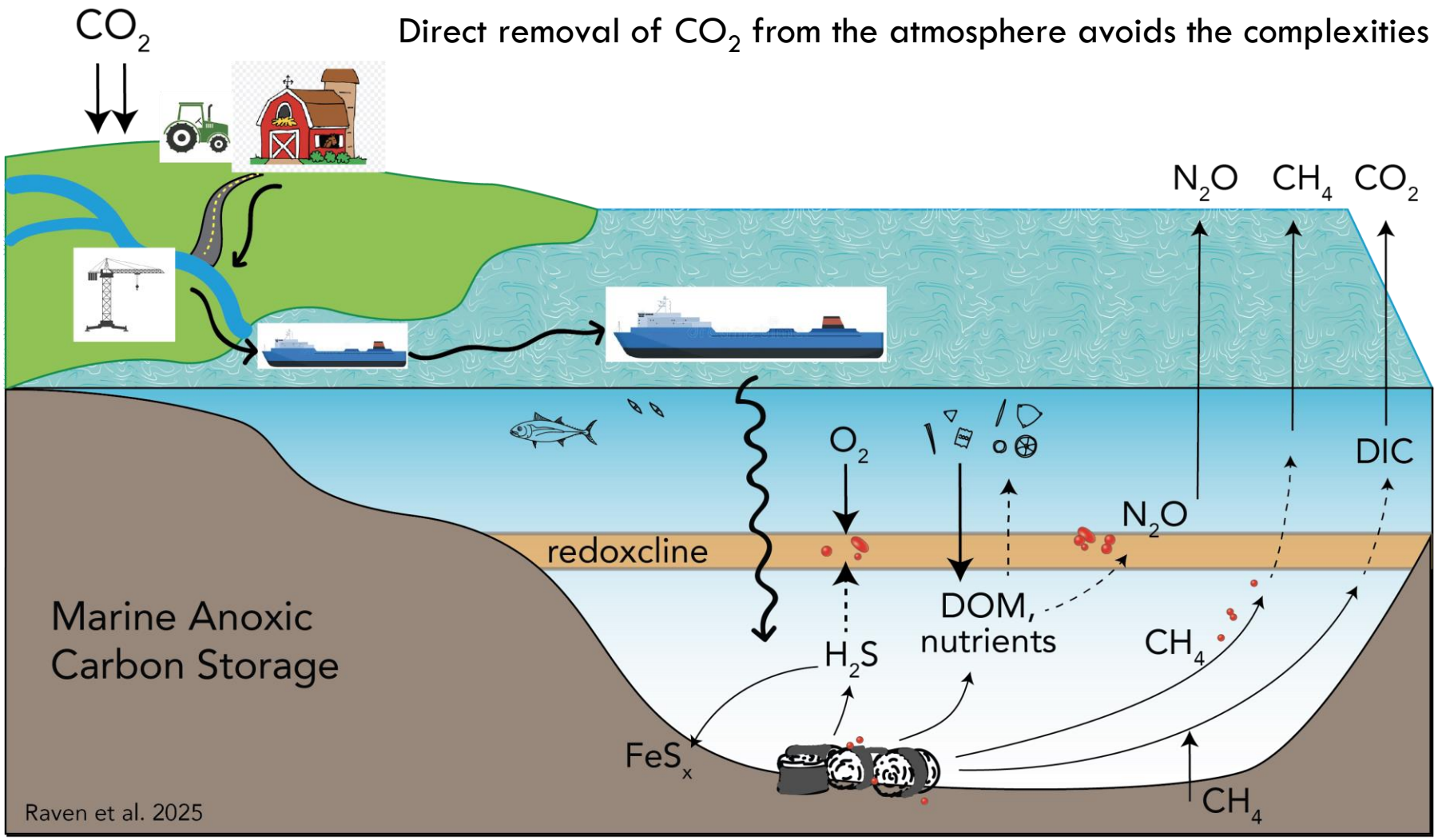
also: Chief Science Officer, Carboniferous Inc.

funding: Grantham Foundation for the Protection of the Environment

CDR approach: Store terrestrial biomass C in anoxic marine basins

Semantics note: MACS is a hybrid land–ocean CDR approach ("CDR with marine storage").

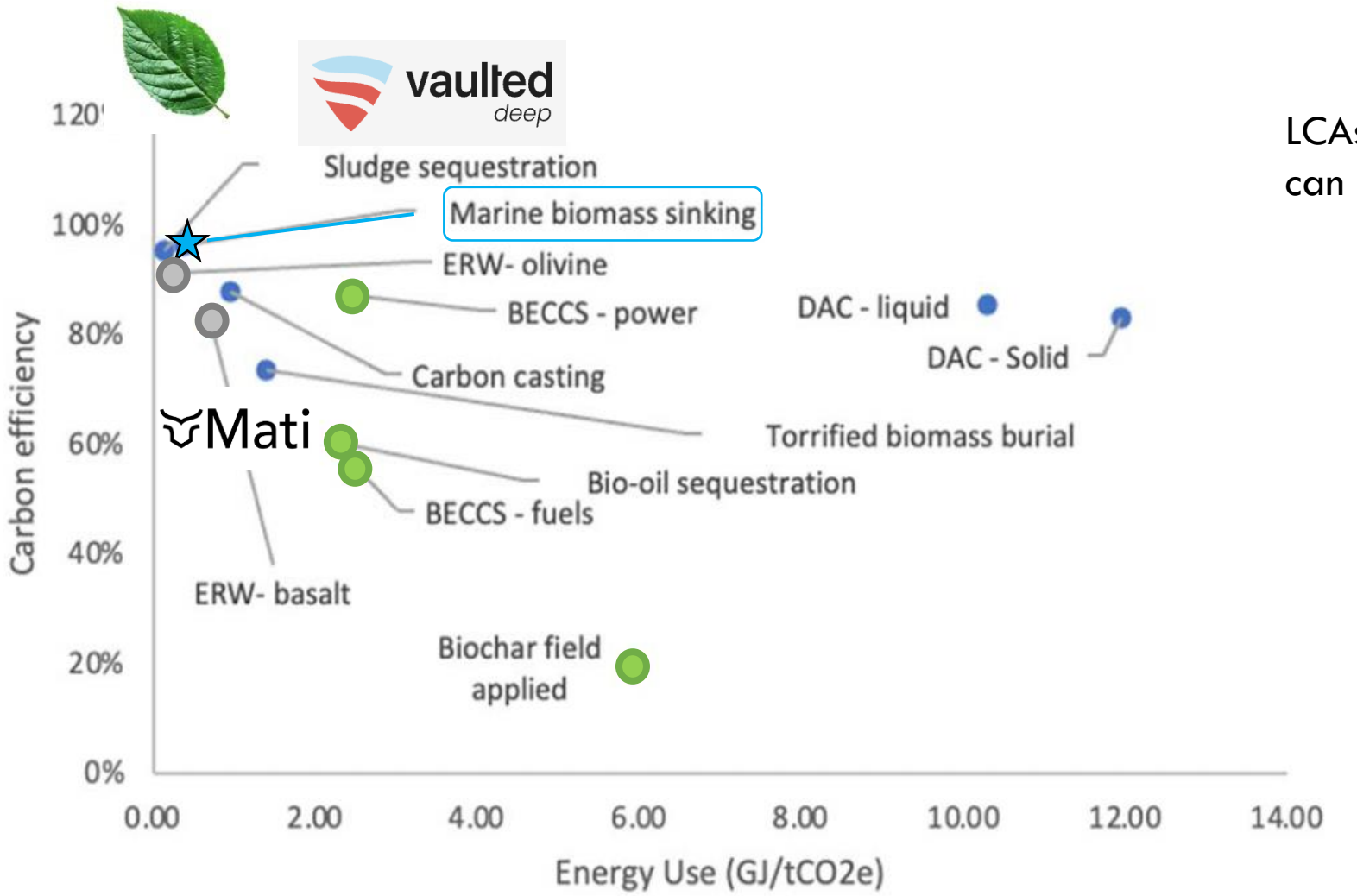
Direct removal of CO_2 from the atmosphere avoids the complexities of air-sea gas exchange.



- Density interface limits mixing
- Biomass is efficiently preserved under anoxic, hypersaline, deep conditions

Potential advantages of MACS for CDR:

- Photosynthesis is highly efficient; low energy requirements



LCAs vary by source and transport mode but can readily achieve >90% carbon efficiency.

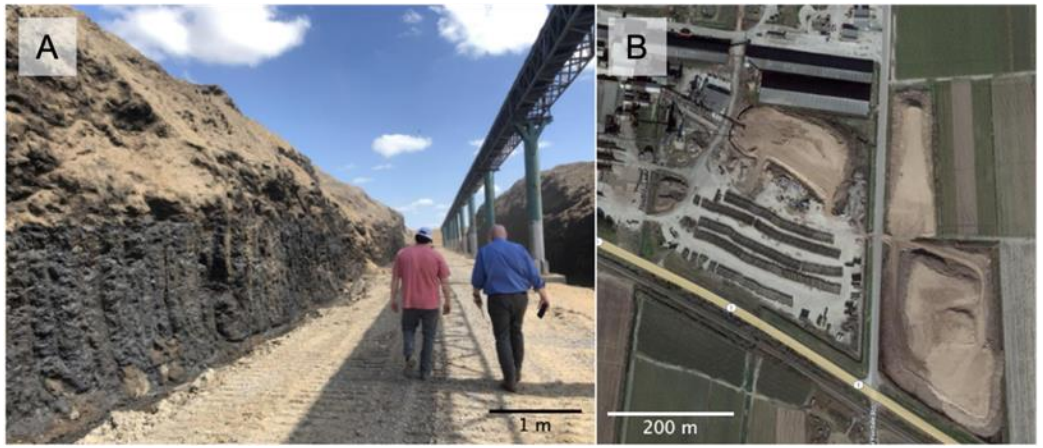
Sanchez et al., 2025

Potential advantages of MACS for CDR:

- Photosynthesis is highly efficient; low energy requirements
- Uses existing agricultural biomass and infrastructure with opportunities for co-benefits

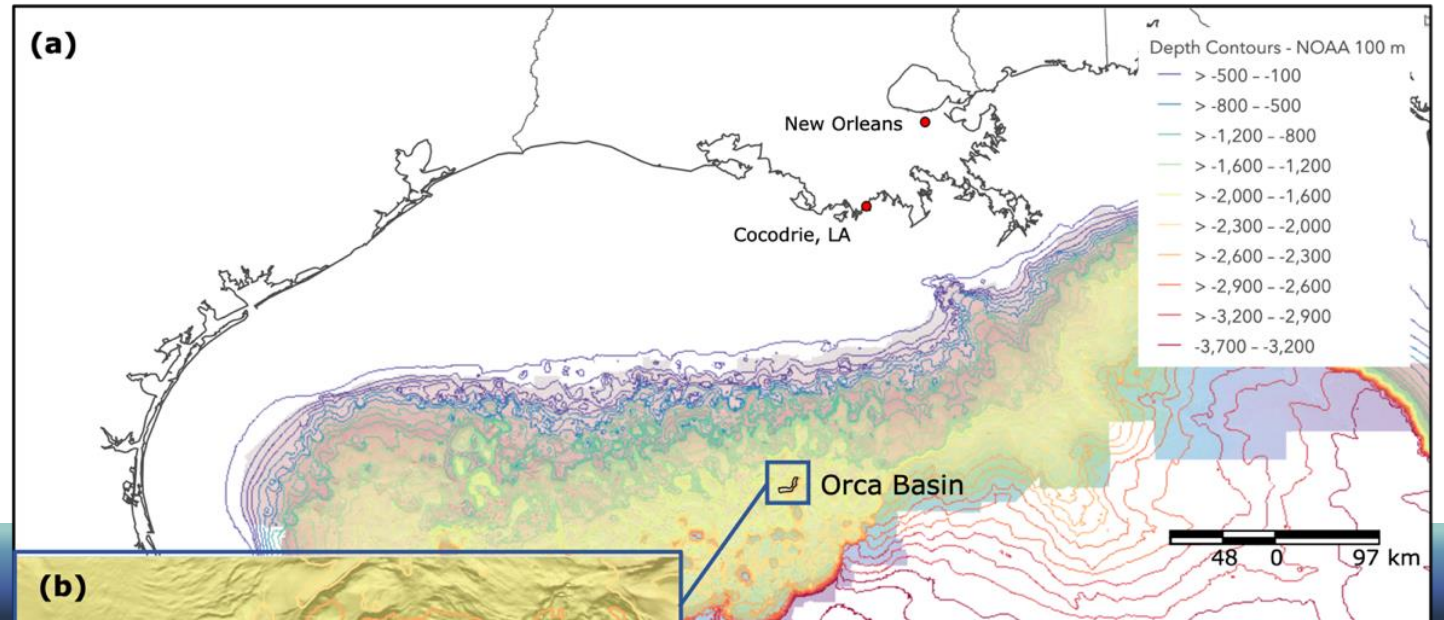
counterfactual
burned, stored in tended piles, methane emissions

Sugarcane bagasse

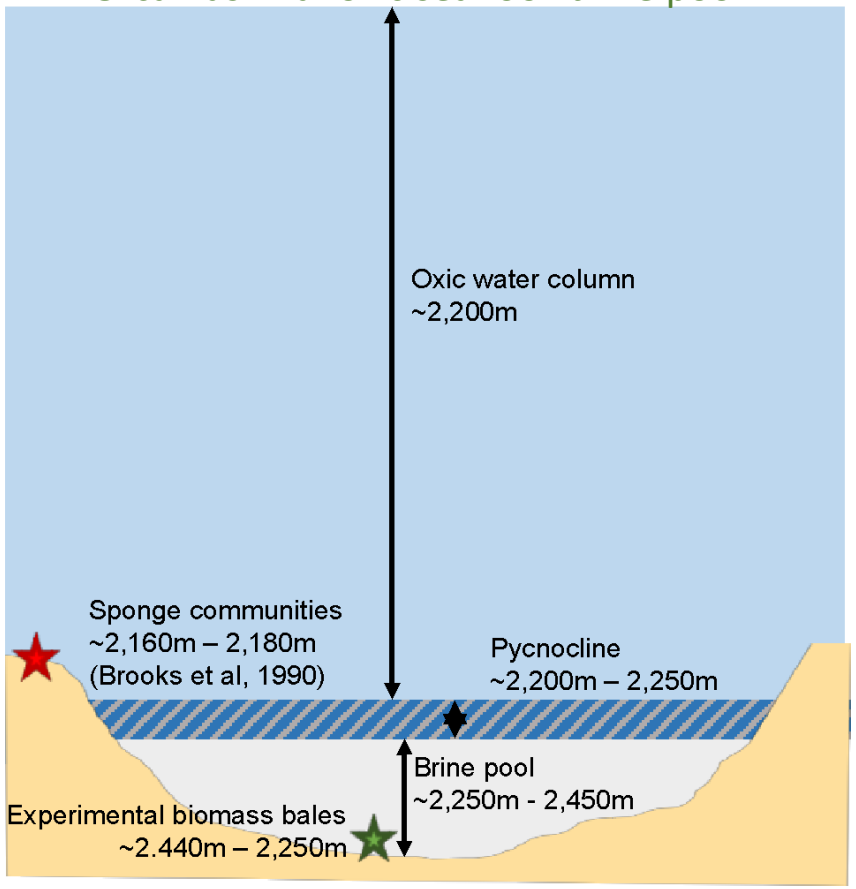


Potential advantages of MACS for CDR:

- Photosynthesis is highly efficient; low energy requirements
- Uses existing agricultural biomass and infrastructure with opportunities for co-benefits
- Isolated anoxic basins have edges
  - Facilitates monitoring + permitting in a defined jurisdiction
  - Reduces potential impacts on surrounding environments
- Anoxia limits biological processes
  - No seafloor macrofauna / animals
  - Enhanced organic matter preservation



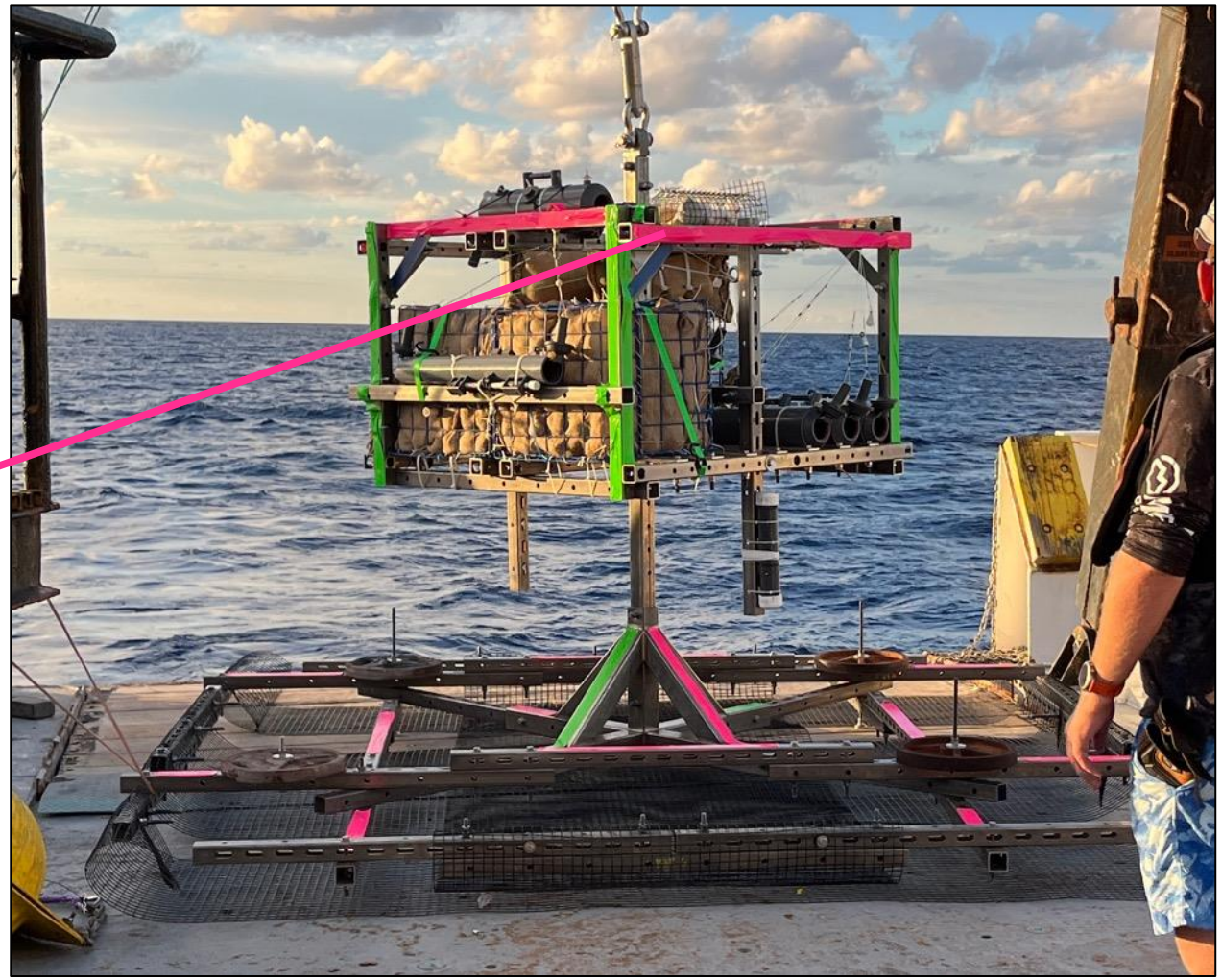
Orca Basin: anoxic seafloor brine pool



Ocean Carbon Retention under Anoxia (OCRA 1–4) project

Benthic lander incubations of various biomass materials; parallel lab incubations @ UCSB

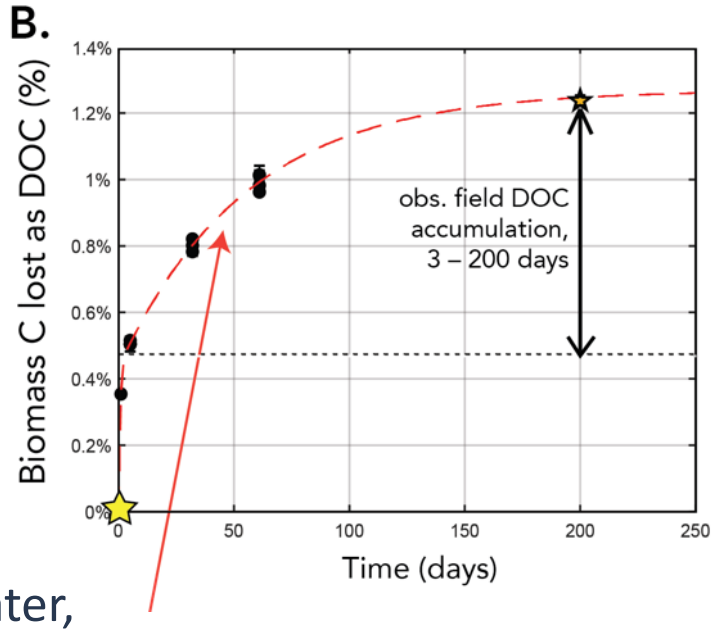
Biomass (softwood, algae) recovered after 200 days in Orca Basin shows exceptional preservation.



Quick Results: Fate of sugarcane bagasse in anoxic seawater

Some dissolves:

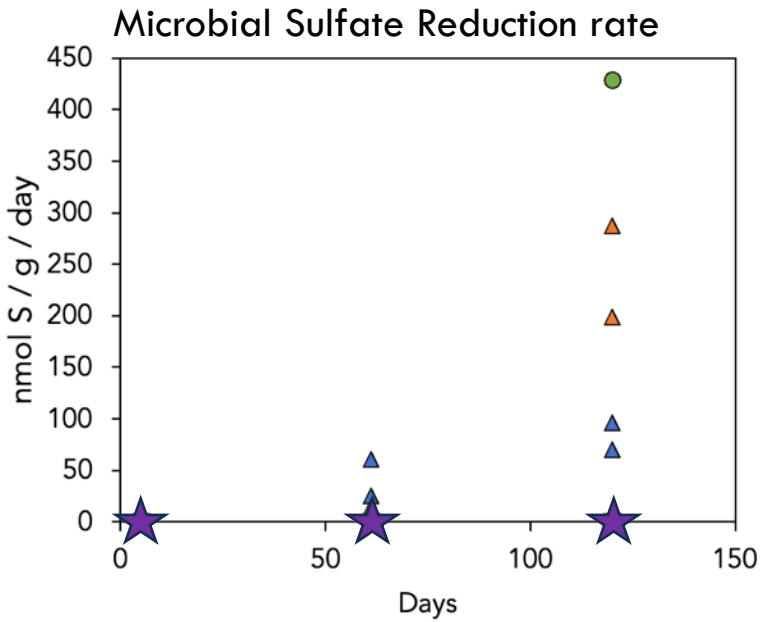
- About 1.3 mol% of initial C in bagasse dissolves after 200 days.



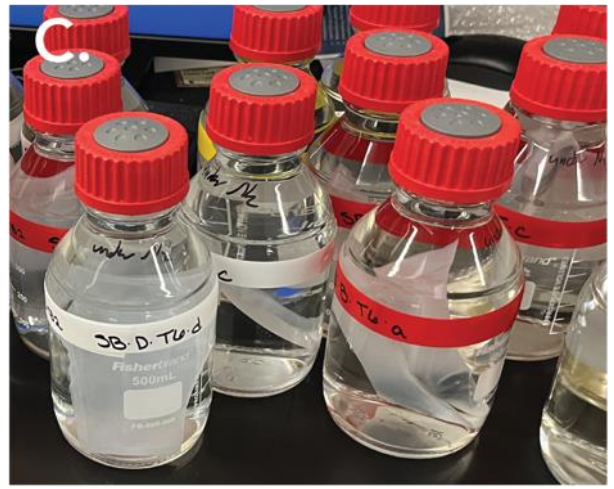
Slow microbial breakdown in seawater, but not in brine:

Anoxic seawater supports slow bagasse respiration via nitrate, iron, sulfate reduction, and traces of methanogenesis.

None of these were detectable for Orca brine.



Long-term breakdown experiment, 180 days in bottles



★ Brine (<2 nmol S/g/day)

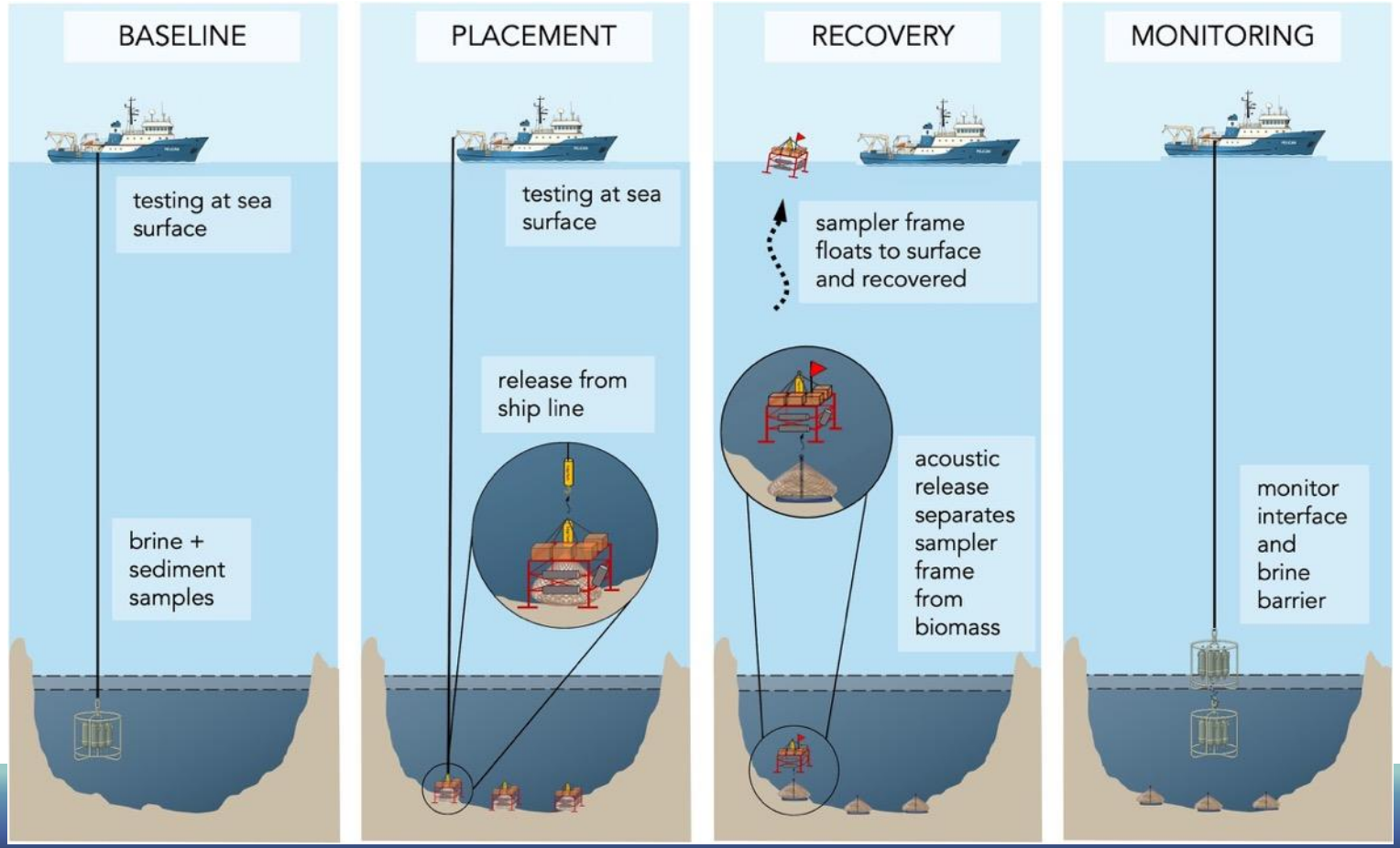
Evans, Martinez, and Raven, in prep

Ahead: U.S. EPA MPRSA Research Permit status (to Carboniferous)

Public comment period was open June 12 – July 14, 2025.

Would allow the placement of up to 20, one-tonne bales of compressed sugarcane bagasse into Orca Basin over 18 months.

- In-situ incubations to compare with lab mesocosms
- Development and validation of MRV tools



MACS Workshop: Bucharest, Romania, February 4–5, 2025

- Brought together >30 researchers and community leaders from 15 countries
  - Identified key open questions and potential risks
  - Evaluated potential sites
  - Developed five priority criteria that could limit the potential global scale of MACS

In prep manuscript for submittal to Biogeosciences:

Ideas and Perspectives: Max MACS – constraining the potential global scale of Marine Anoxic Carbon Storage for CO_2 removal

Raven M.R.,*[1,2] Amiel N.,[3] Angel D.L.,[3,4] Barry J.P.,[5] Biocenco L.,[6] Blattman T.M.,[7] Crémière A.,[8] Evans N.,[1,9] Gallarotti N.,[7] Hehemann J.H.,[10] Lal P.,[12] Lordkipanidze D.,[13,14] Luostarinen T.,[15] Martinez A.M.,[1] Matzelle A.J.,[16] Menabit S.,[17] Muresan M.,[17] Neumann A.,[18] Paris J.-D.,[19,20] Pearce C.,[21] Reynard N.,[22] Sanchez D.L.,[23] Schubotz F.,[10] Slabakova V.,[24] Stanica A.,[17] Sweetman A.,[25] Treude T.,[26] Voynova Y.,[18] Zarokanellos N.[28]

* = corresponding author; raven@ucsb.edu

Marine Anoxic Carbon Storage: Where are we now?

MACS (aka terrestrial biomass sinking) has the potential to contribute to near-term CO_2 removal needs in the U.S. and globally.

Key unknowns can be addressed with a focused research program.

Field trials are needed to validate initial results and better understand outcomes at scale.

Although MACS is a hybrid terrestrial/marine approach, it nevertheless deserves consideration as part of the updated NASEM marine CDR strategy.

Thank you!

Rodrigo Pacheco-Ruiz, Hürriyet DN