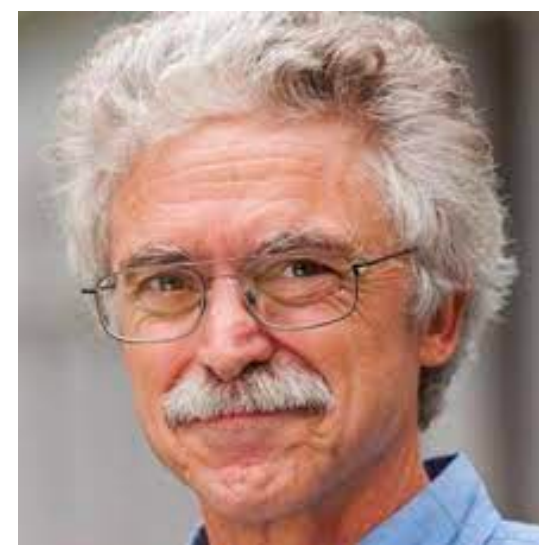


INTEGRATED MODELS + CARBON REMOVAL

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DICE: the world in 30 Equations

Appendix A: DICE MODEL EQUATIONS

Total factor of Productivity (TFP)

$$A_g(t) = A_{g0} \times e^{[-A_{gd} \times 10 \times (t-1)]}$$

$$A(t) = \frac{A(t-1)}{1 - A_g(t-1)}$$

Labor

$$L(t) = L_0 \times (1 - L_g(t)) + L_A \times L_g(t)$$

$$L_g(t) = \frac{e^{[L_{gd} \times (t-1)]} - 1}{e^{[L_{gd} \times (t-1)]}}$$

Capital

$$K(t) = I(t-1) + (1 - \delta_K)^{10} \times K(t-1)$$

$$I(t) = s(t) \times Q(t)$$

Production Function

$$Y(t) = Y_0 \times \left(\frac{A(t)}{A_0}\right) \times \left(\frac{K(t)}{K_0}\right)^\beta \times \left(\frac{L(t)}{L_0}\right)^{1-\beta}$$

$$Q(t) = (\Omega(t) - A(t)) \times Y(t)$$

$$Q(t) = C(t) + I(t)$$

Climate Change Damage

$$\Omega(t) = \frac{1}{1 + \Psi_1 \times T_{at}(t) + \Psi_2 \times T_{at}^{10}(t)}$$

$$T_{at}(t) = T_{at}(t-1) + \xi_1 \times [F(t) - \xi_2 \times T_{at}(t-1) - \xi_3 \times [T_{at}(t-1) - T_{lo}(t-1)]]$$

A1

A2

A3

A4

A5

A6

A7

A8

A9

A10

A11

$$T_{lo}(t) = T_{lo}(t-1) + \xi_4 \times [T_{at}(t-1) - T_{lo}(t-1)]$$

A12

$$F(t) = \Delta R_f \times \log_2 \left(\frac{M_{at}(t)}{M_{at}(1750)} \right) + F_{ex}(t)$$

A13

$$M_{at}(t) = E(t-1) + \phi_{11} \times M_{at}(t-1) + \phi_{21} \times M_{up}(t-1)$$

A14

$$M_{up}(t) = \phi_{12} \times M_{at}(t-1) + \phi_{22} \times M_{up}(t-1) + \phi_{32} \times M_{lo}(t-1)$$

A15

$$M_{lo}(t) = \phi_{23} \times M_{up}(t-1) + \phi_{33} \times M_{lo}(t-1)$$

A16

$$\xi_2 = \frac{\Delta R_f}{\Delta T}$$

A17

$$E(t) = E_{ind}(t) + E_{land}(t)$$

A18

$$E_{ind}(t) = \sigma(t) \times [1 - a(t)] \times Y(t)$$

A19

$$E_{land}(t) = E_0 \times 0.9^{t-1}$$

A20

$$\sigma(t) = \frac{\sigma(t-1)}{1 - \sigma_g(t)}$$

A21

$$\sigma_g(t) = \sigma_{g0} \times e^{[-10 \times \sigma_{gd} \times (t-1) - 10 \times \sigma_{ga} \times (t-1)^2]}$$

A22

$$F_{ex}(t) = F_{2000} + (F_{2100} - F_{2000}) \times (t-1)$$

A23

$$A(t) = \pi^{(1-\theta_2)}(t) \times \theta_1(t) \times a^{\theta_2}(t)$$

A24

Climate Change Abatement

$$\pi(t) = \varphi^{1-\theta_2}(t)$$

A25

$$\theta_1(t) = \left(\frac{P_g \times \sigma(t)}{\theta_2} \right) \times \left(\frac{P_r - 1 + e^{[-P_d \times (t-1)]}}{P_r} \right)$$

A26

Utility

$$U(t) = u(t) \times L(t)$$

A27

$$u(t) = \frac{c^{1-\alpha}(t)}{1-\alpha}$$

A28

$$c(t) = \frac{C(t)}{L(t)}$$

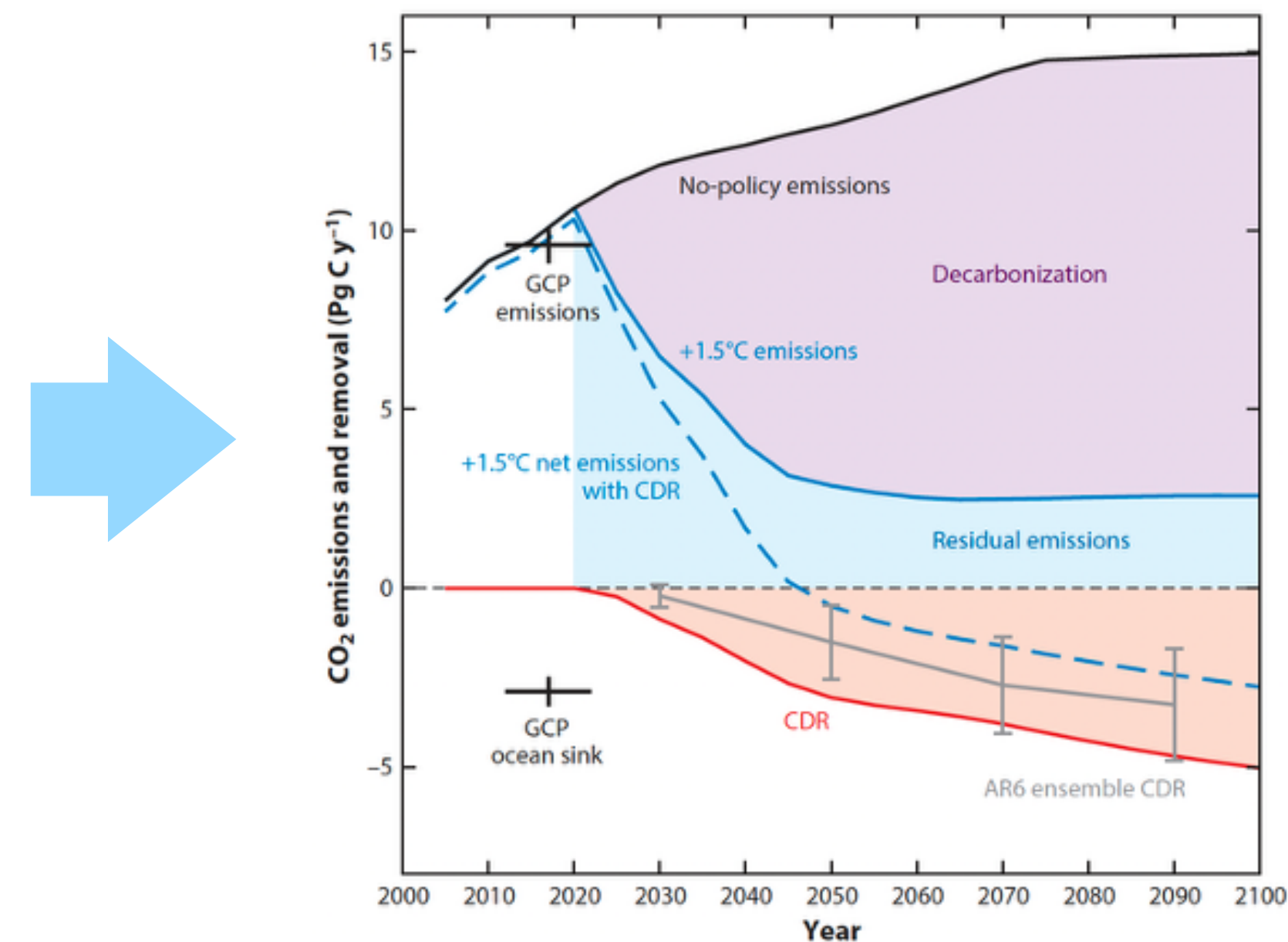
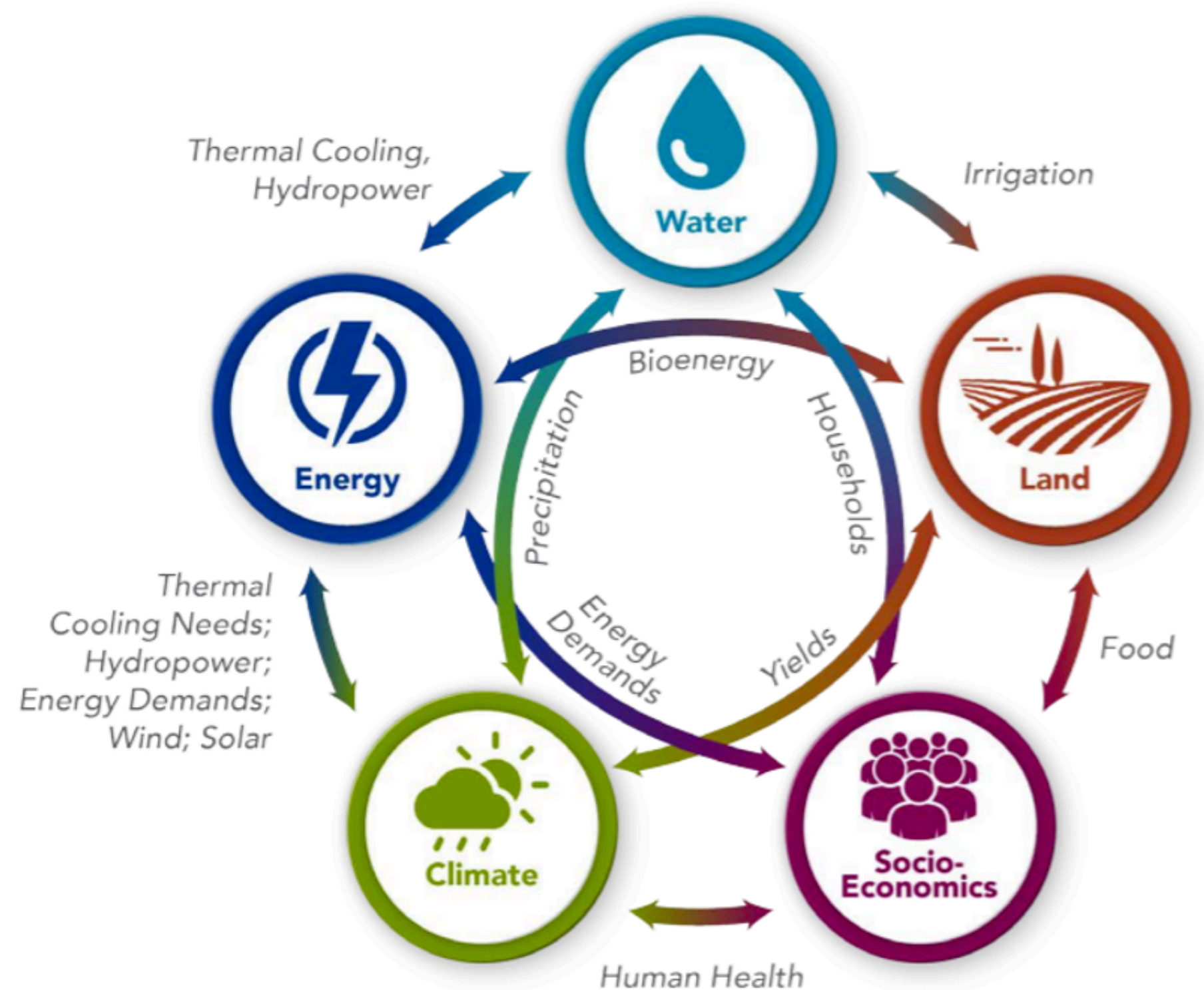
A29

$$R(t) = \frac{R(t-1)}{(1+\rho)^{10}}$$

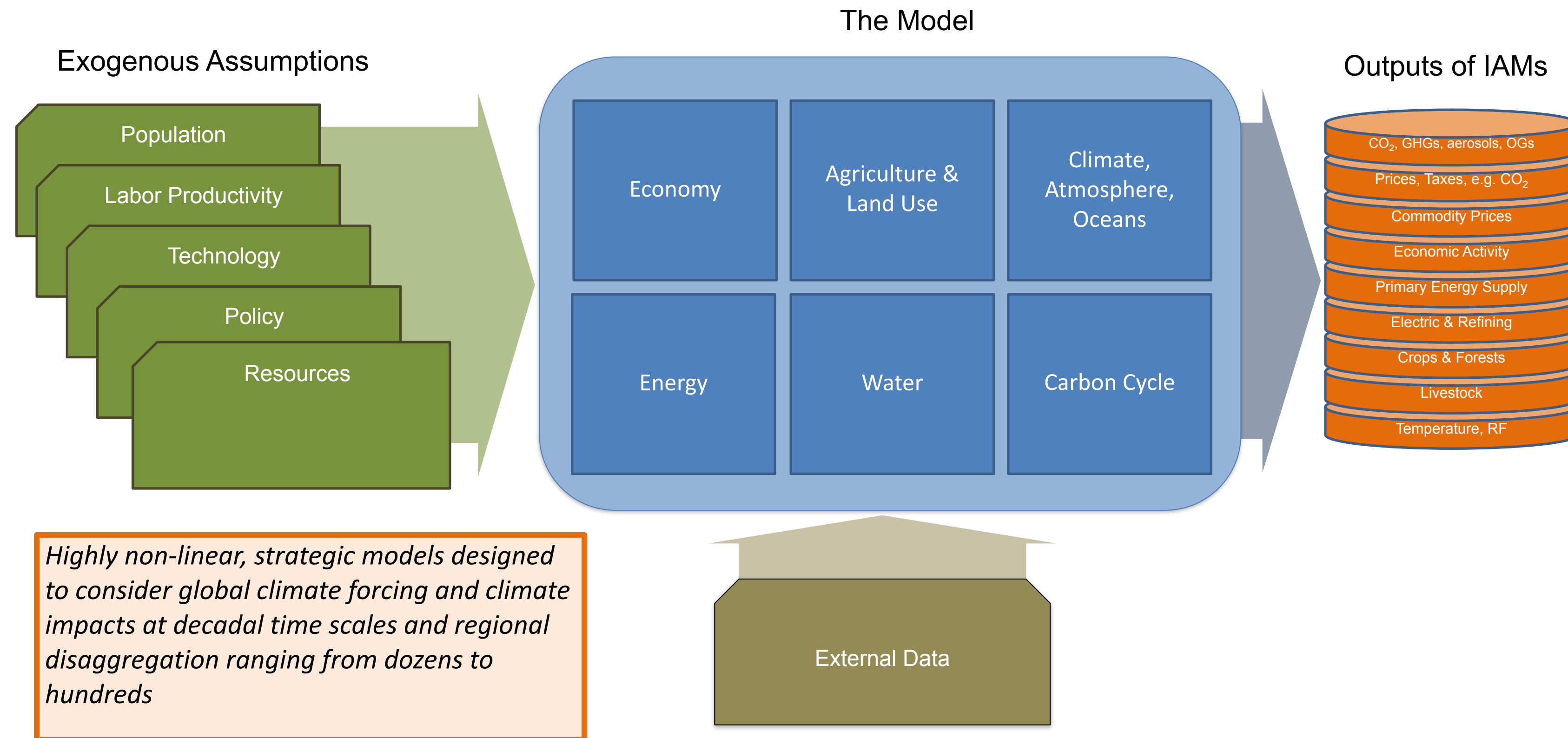
A30



How are IAMs used today?



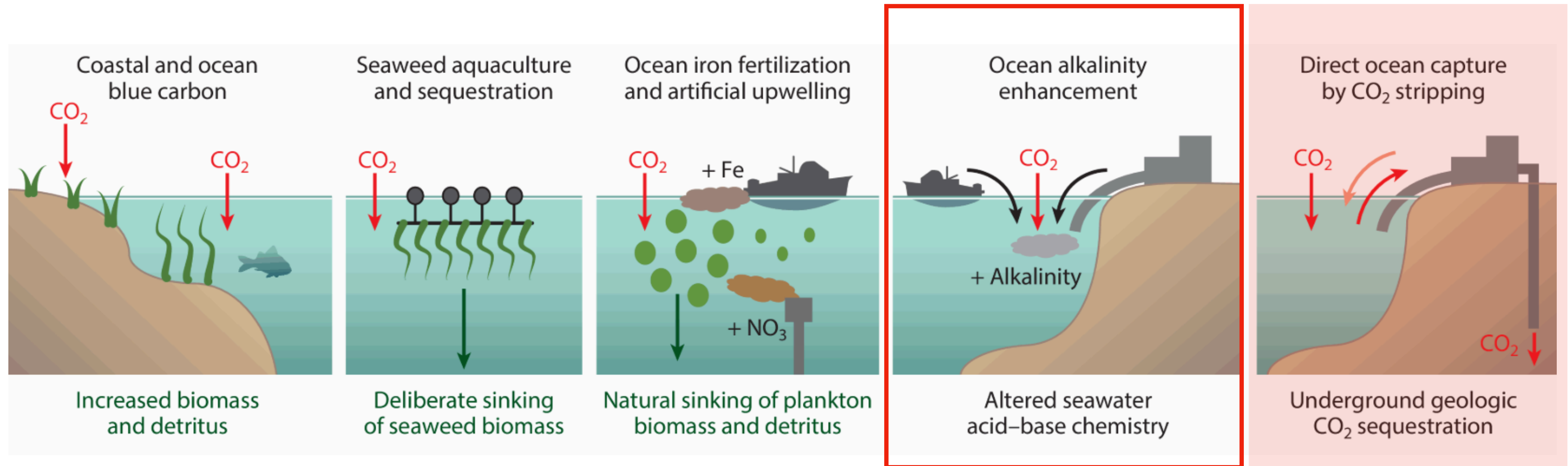
Global Change Analysis Model



Adapted from Jae Edmonds



mCDR approaches

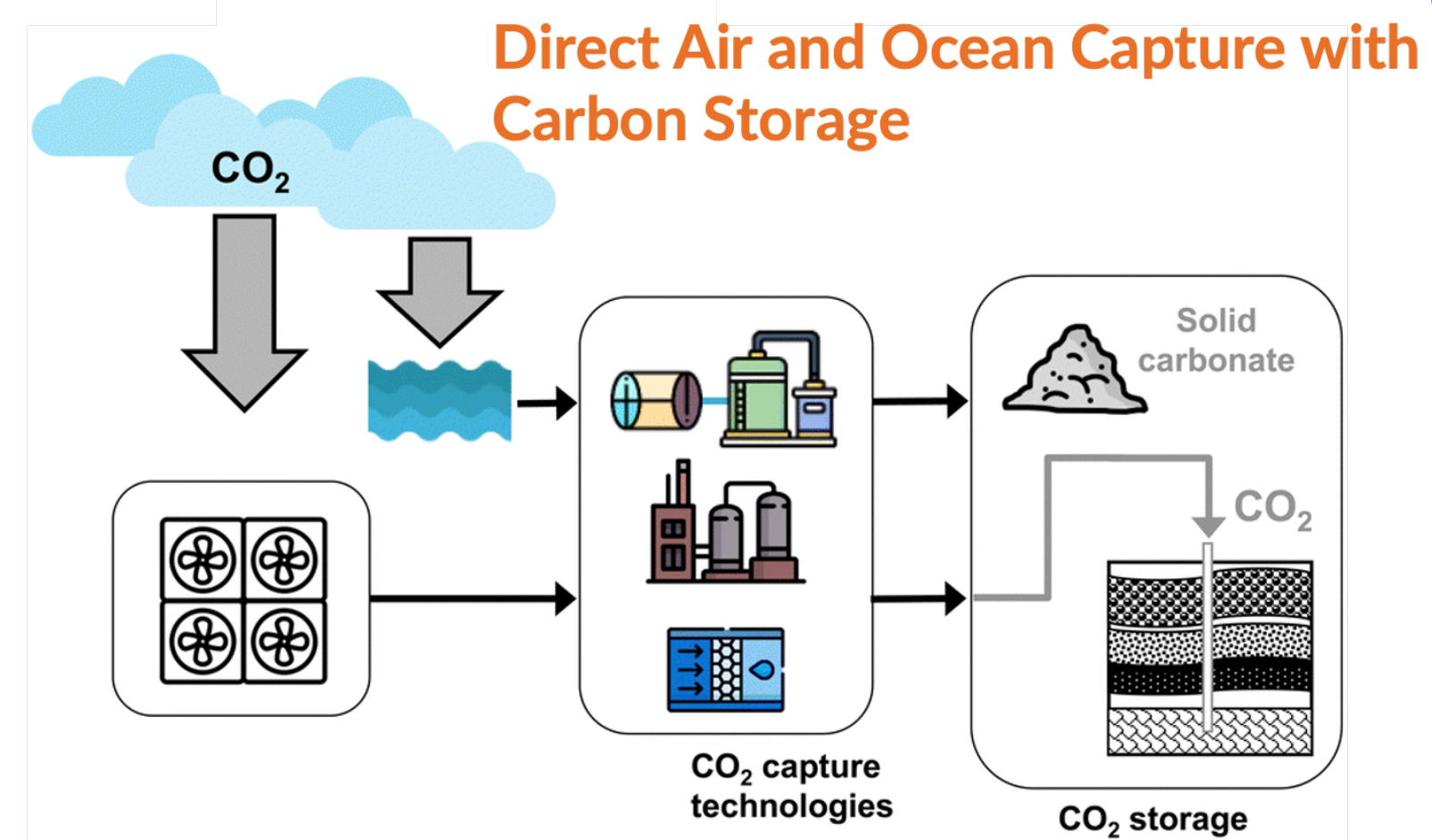
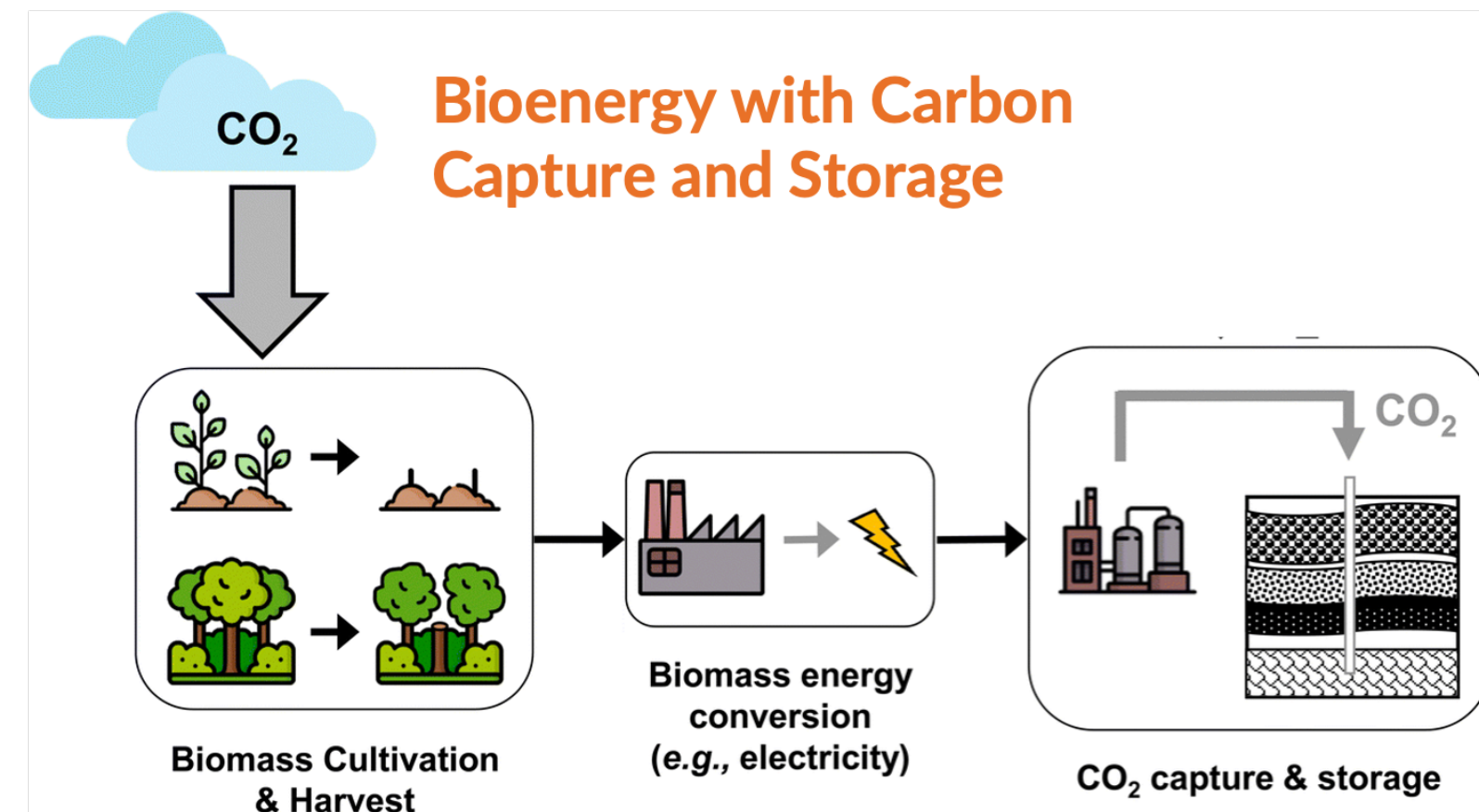


Doney, S. C., Wolfe, W. H., McKee, D. C., & Fuhrman, J. G. (2025). The science, engineering, and validation of marine carbon dioxide removal and storage. *Annual Review of Marine Science*, 17(1), 55-81.

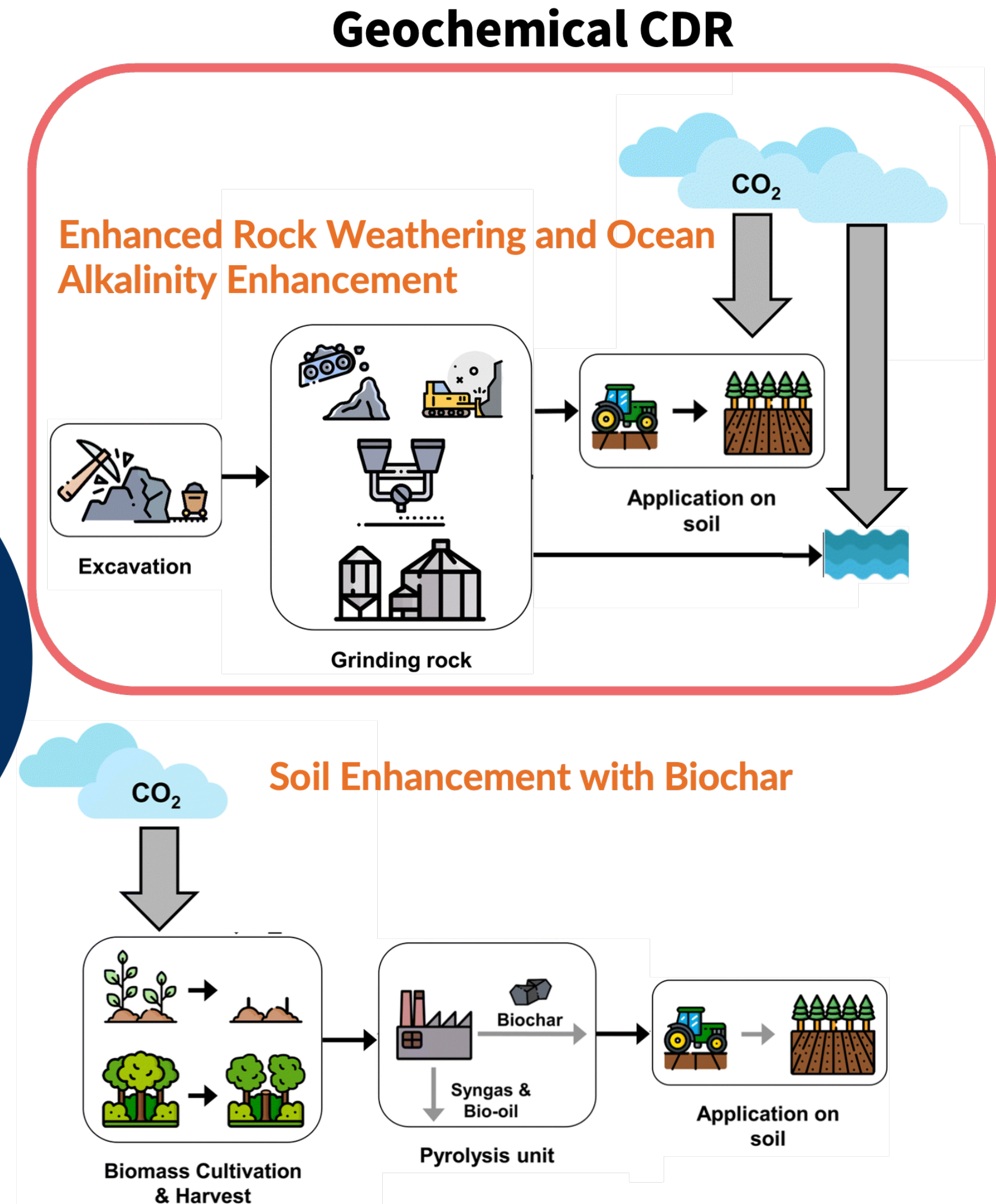
Fuhrman, Jay, Candelaria Bergero, Maridee Weber, Seth Monteith, Frances M. Wang, Andres F. Clarens, Scott C. Doney, William Shobe, and Haewon McJeon. "Diverse carbon dioxide removal approaches could reduce impacts on the energy-water-land system." *Nature Climate Change* 13, no. 4 (2023): 341-350.



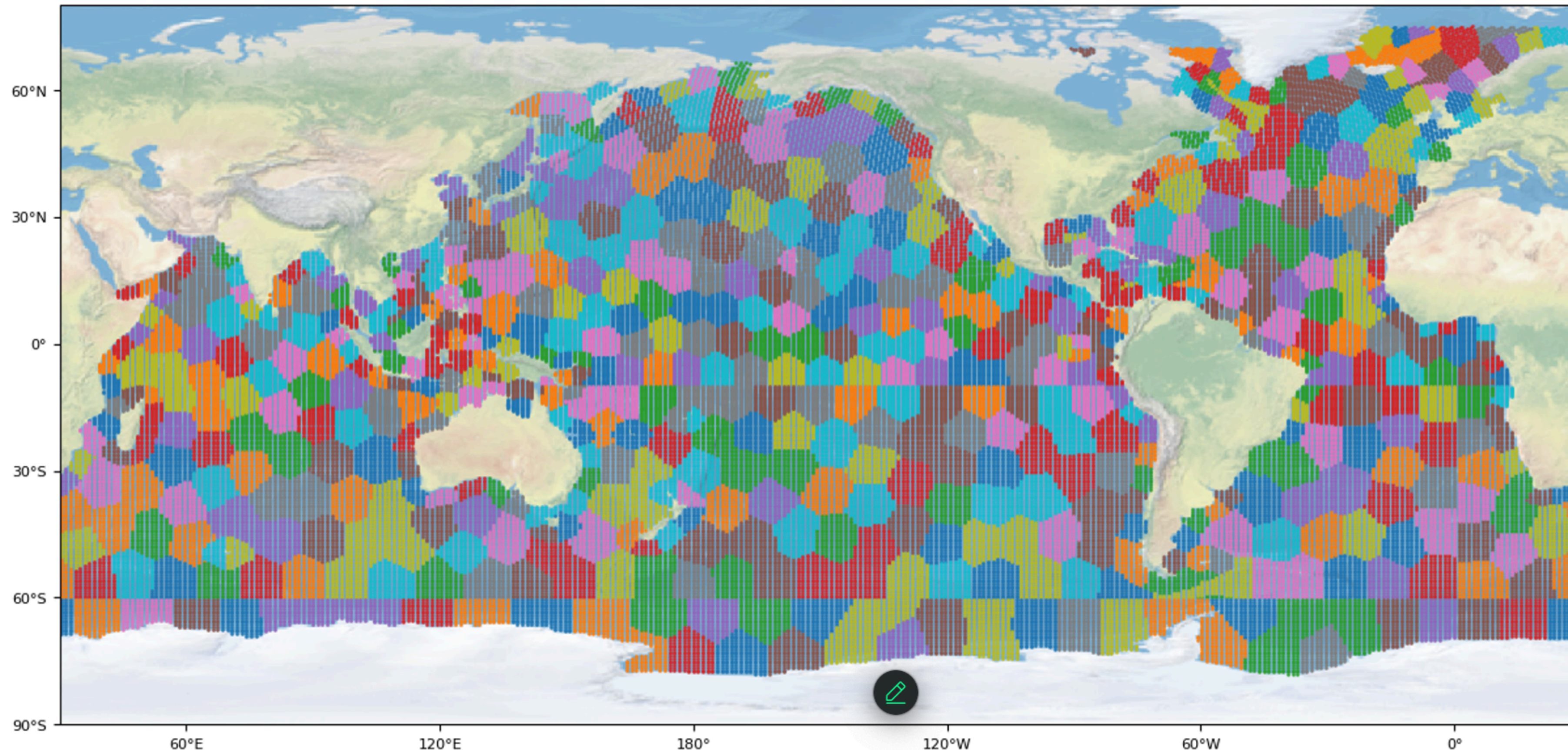
Research Gap



Portfolio of
Carbon Dioxide
Removal in
MESSAGE_ix



690 Open Ocean Regions and Exclusive Economic Zones

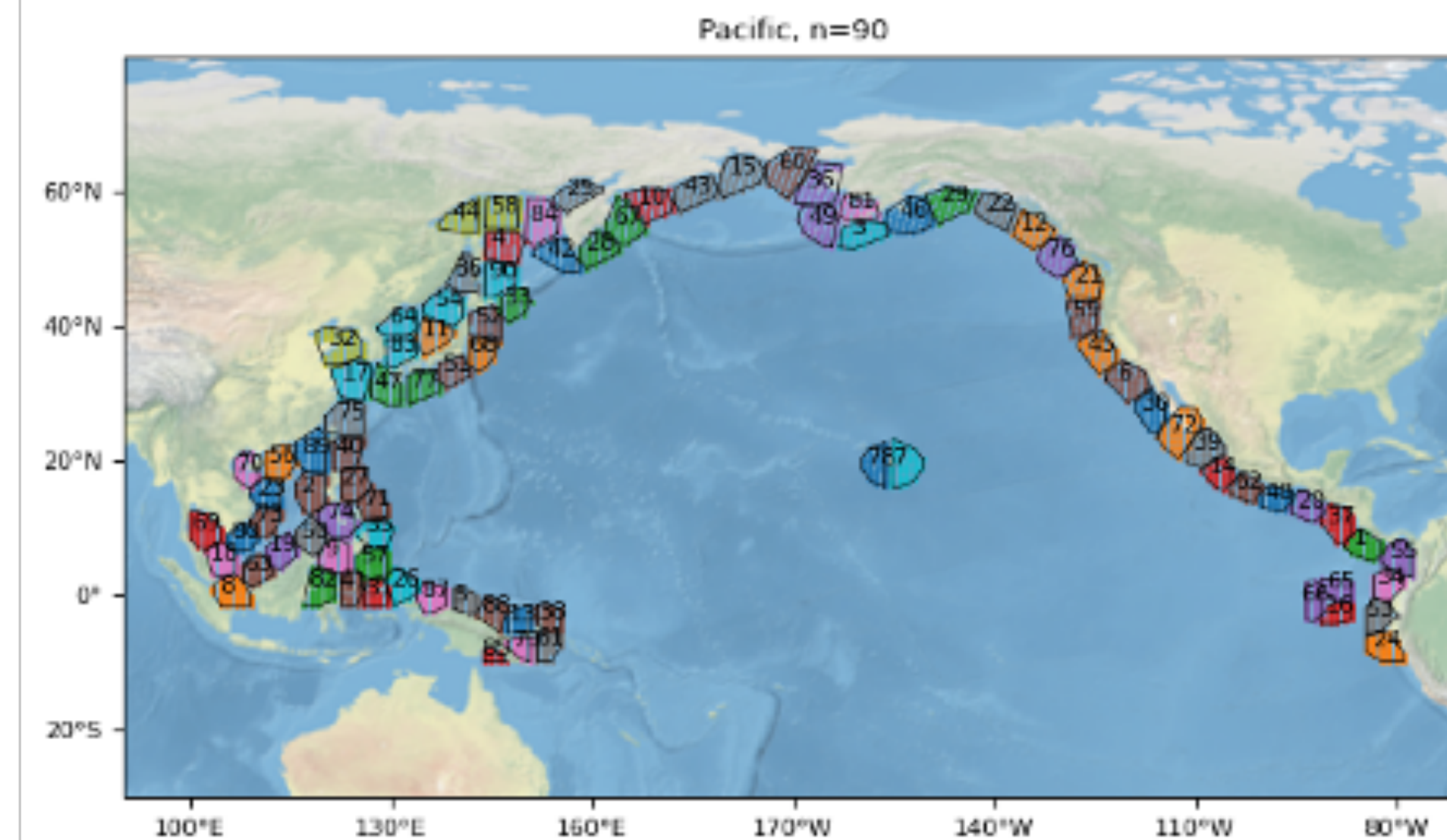
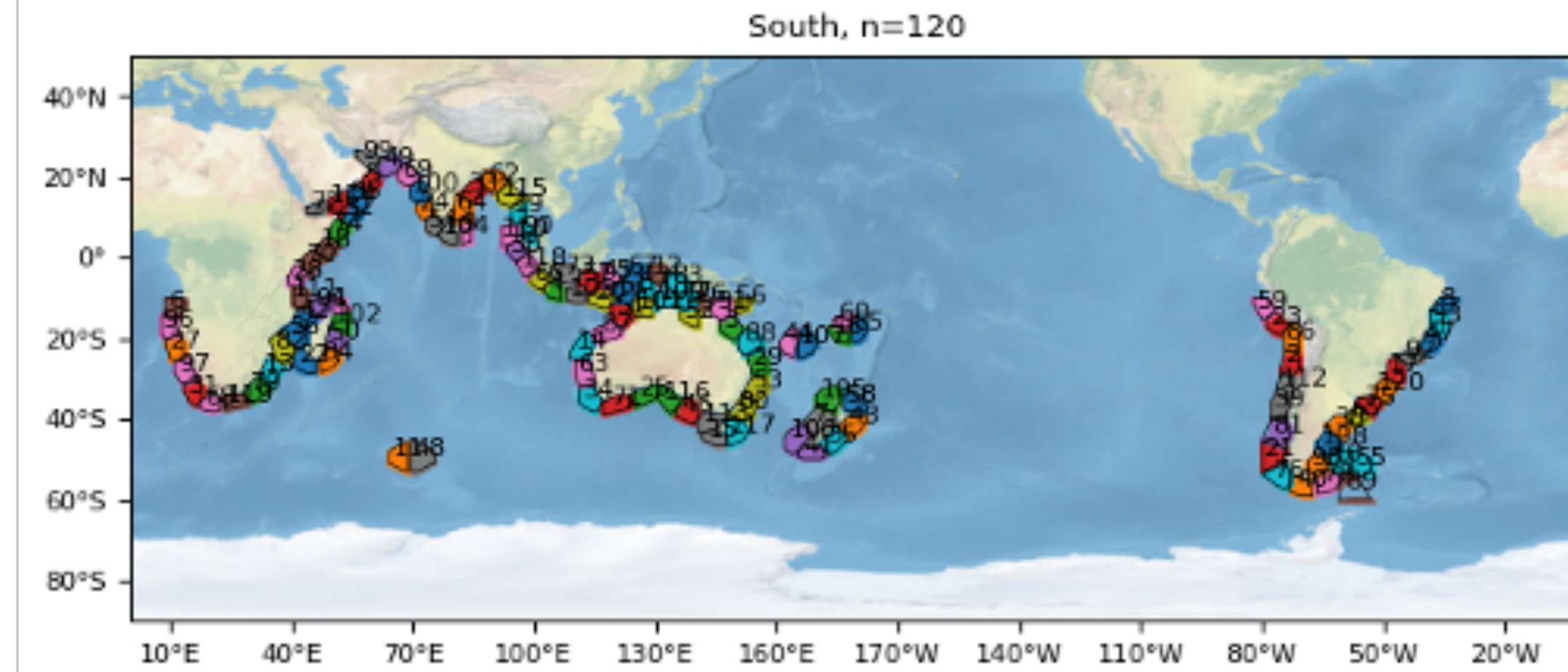
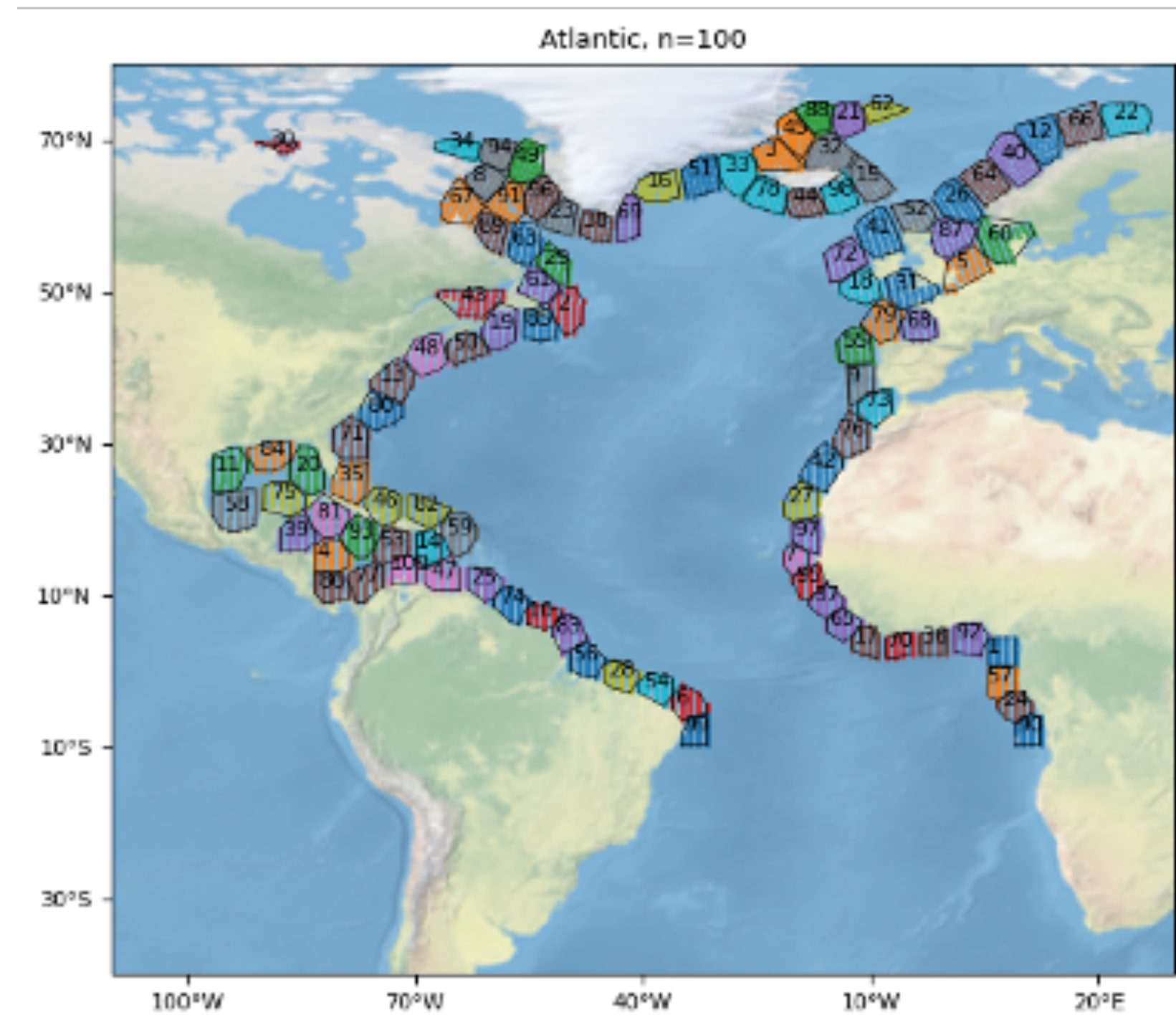


Each of these patches have different ocean chemistry that impacts OAE performance

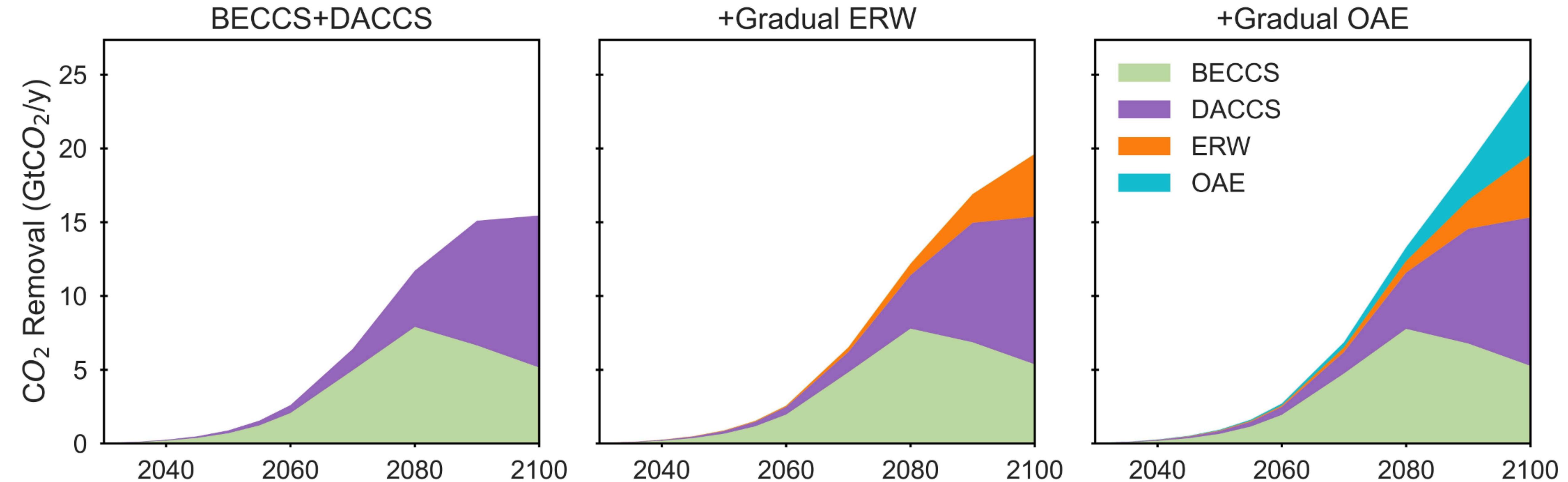
Zhou et al., Mapping the global variation in the efficiency of ocean alkalinity enhancement for carbon dioxide removal. Nature Climate Change. 2025.



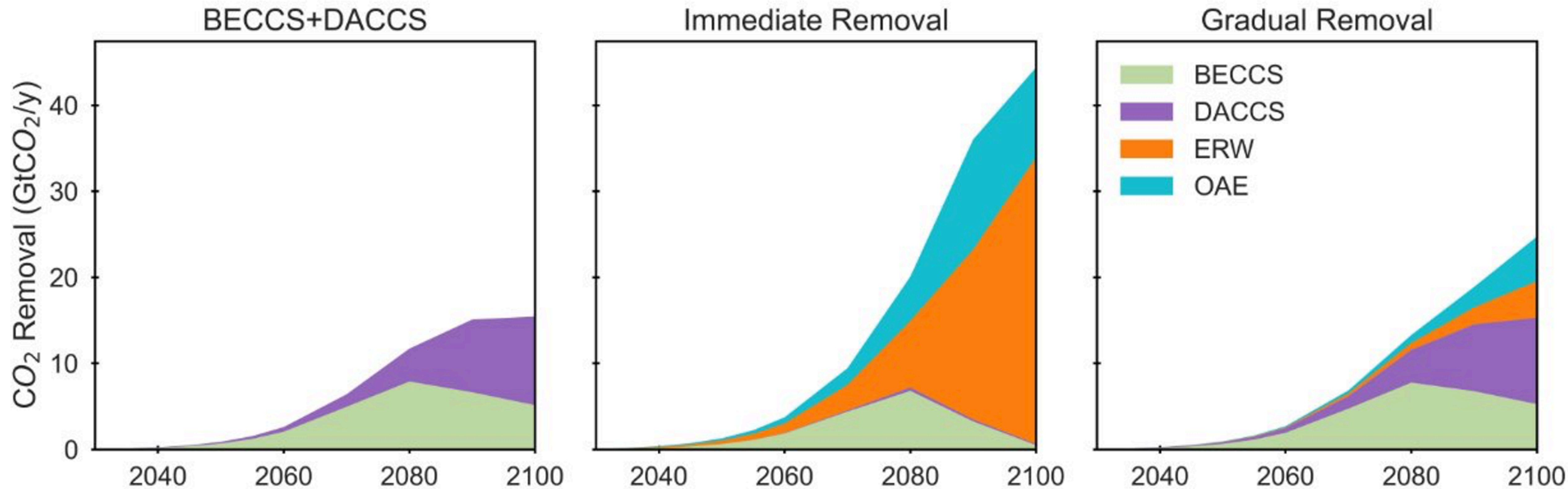
Focusing on only Exclusive Economic Zones



ERW and OAE Uptake Under Gradual Efficiencies



ERW and OAE Uptake - Immediate vs Gradual Removal



Potential of OAE in 2100

