# Life Cycle Analysis and Techno Economic Analysis of Marine Carbon Dioxide Removal

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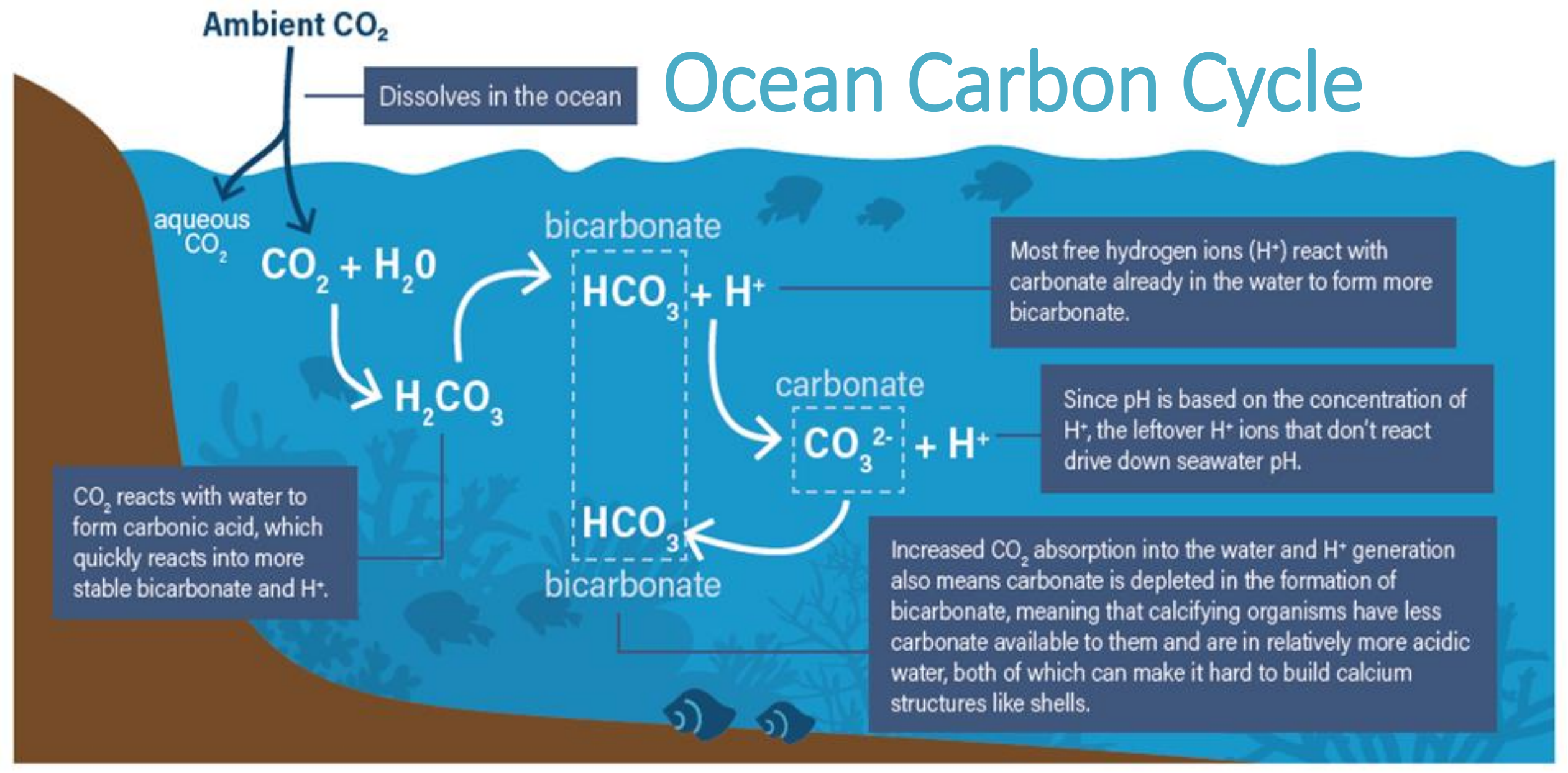
## Introduction

- Marine Carbon Dioxide Removal (mCDR) is defined as the indirect removal of $CO_2$ from the atmosphere "via an enhancement of the downward air-sea flux of $CO_2$ from the atmosphere to the surface ocean" [1].
- The surface of the ocean is in a constant exchange of $CO_2$ with the atmosphere and represents the largest exchange of $CO_2$ with the atmosphere compared to any other reservoir. The ocean carbon cycle can be seen below.



$CO_2$ reacts with water to form carbonic acid, which quickly reacts into more stable bicarbonate and $H^+$.

Most free hydrogen ions ($H^+$) react with carbonate already in the water to form more bicarbonate.

Since pH is based on the concentration of $H^+$, the leftover $H^+$ ions that don't react drive down seawater pH.

Increased $CO_2$ absorption into the water and $H^+$ generation also means carbonate is depleted in the formation of bicarbonate, meaning that calcifying organisms have less carbonate available to them and are in relatively more acidic water, both of which can make it hard to build calcium structures like shells.

*Used with permission from World Resources Institute [2]*

## TEA Methods

- Cost and performance estimates for three electrochemical mCDR technologies are presented. The reported costs are in May 2023 dollars.

| Case | Technology | mCDR Approach | Membrane Process | pH Shift | Capture Rate | $CO_2$ Product |
|---|---|---|---|---|---|---|
| MEB1[A] | mCDR | Electrochemical Engineering | Bipolar Membrane Electrodialysis (BPMED) | Acidic | 63% | $CO_2$ (g) |
| MEB2 | | | | Basic | 63% | |
| MEC1 | | | Electrolytic Cation Exchange Membrane (CEM) | Acidic | 62% | |

[A]M for mCDR, E for electrochemical engineering approach, B for bipolar membrane electrodialysis [BPMED] and C for electrolytic cation exchange membrane [CEM]), and pH shift (1 for acidic, 2 for basic), respectively.

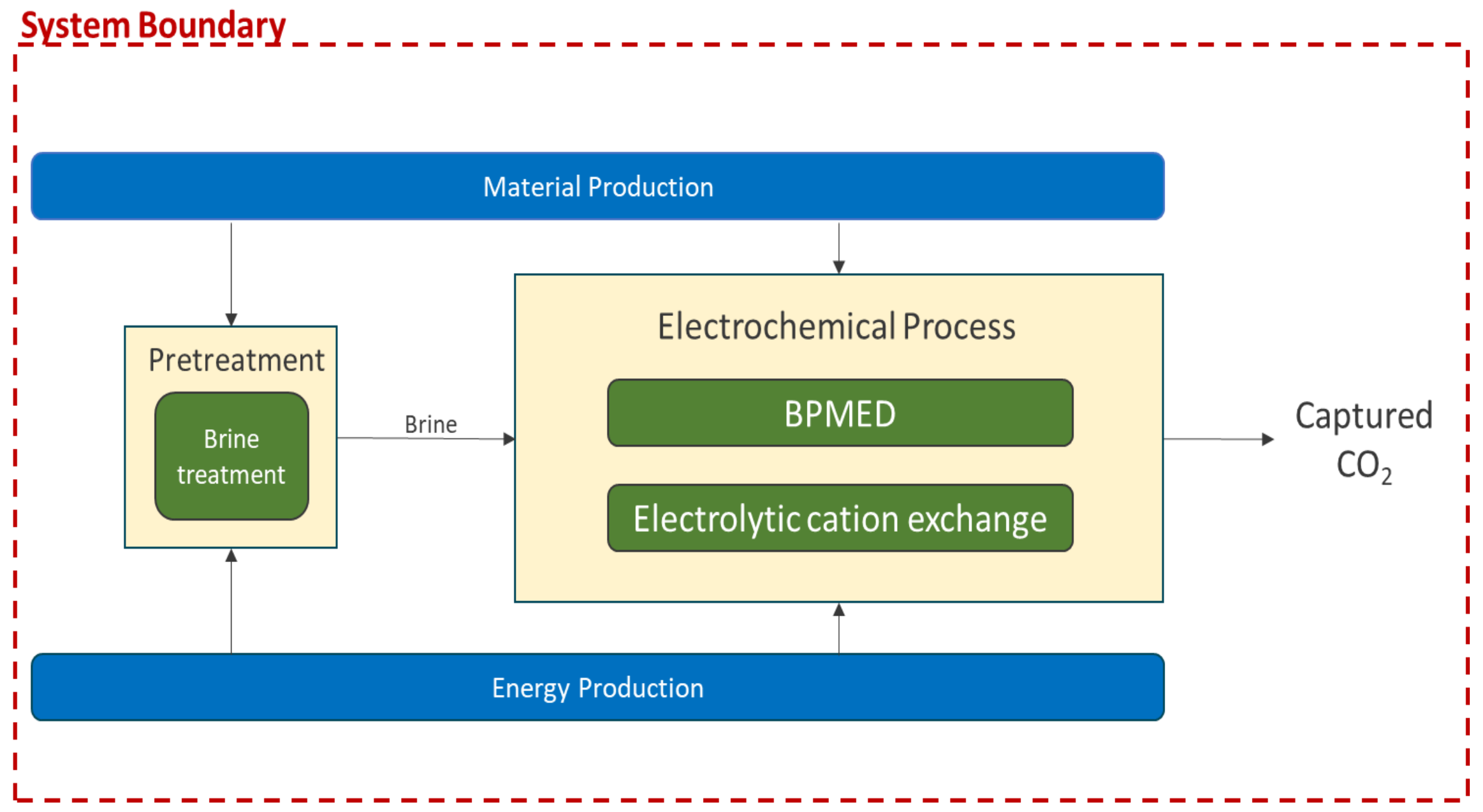
- The scale is based on an expected $CO_2$ capture rate of an mCDR facility co-located with an average sized desalination plant in the U.S.
- The estimating models are based on a U.S. Florida Atlantic Coast location, and the labor cost was scaled from a Midwest Gulf Coast location.

| Performance Summary | MEB1 | MEB2 | MEC1 |
|---|---|---|---|
| Inlet DIC ($CO_2$e), umol/kg (ppmw) | 2,074<br>(126) | 2,074<br>(126) | 2,074<br>(126) |
| **$CO_2$ capture rate, %** | **63** | **63** | **62** |
| $CO_2$ product flow rate (pipeline quality), tonne/yr | 13,000 | 13,000 | 13,000 |
| $H_2$ product flow rate, tonne/yr | - | - | 1,481 |
| **Total auxiliary load, kWe** | **11,994** | **16,455** | **71,754** |

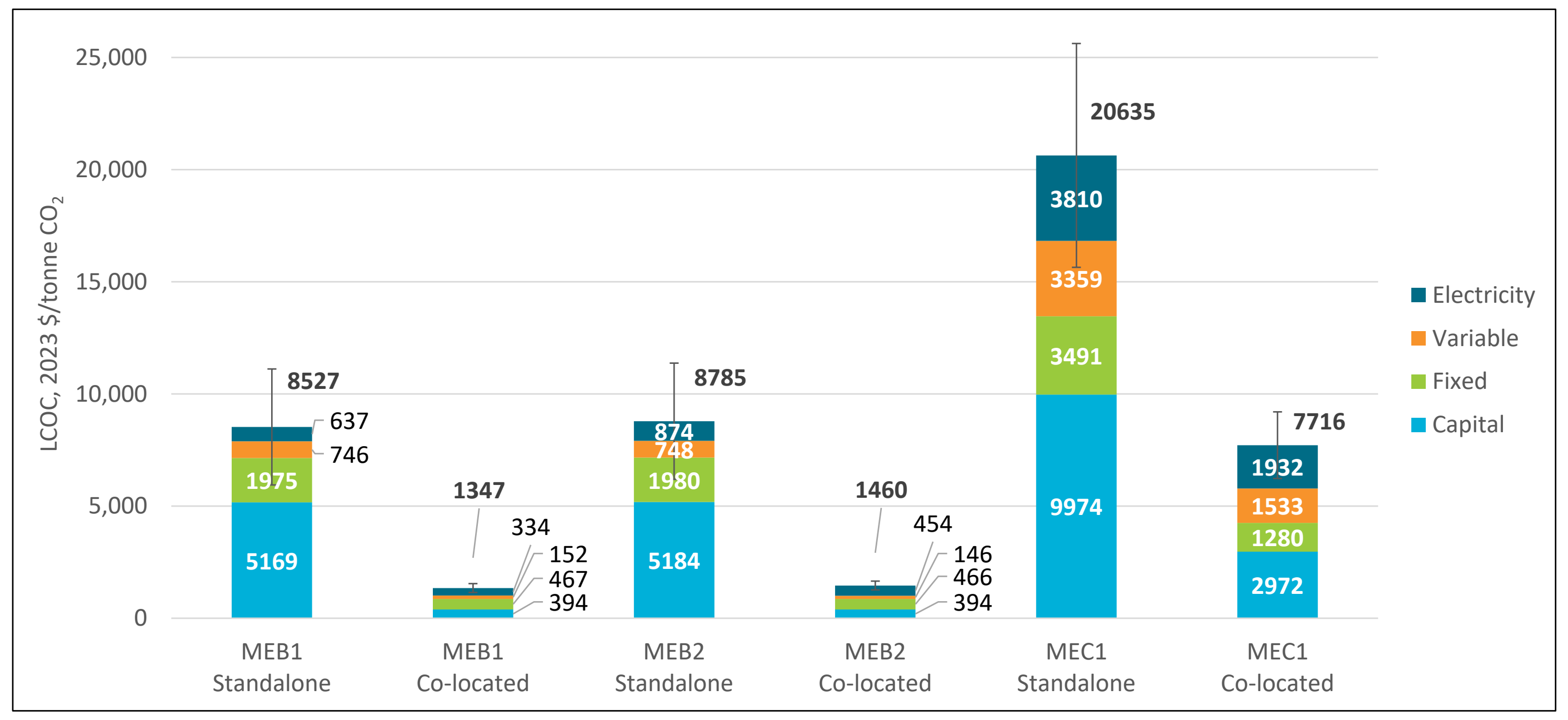
[1] National Academies of Sciences, Engineering, and Medicine. 2021. *A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration*, Washington, D.C.: The National Academies Press.
[2] Lebling, K., E. Northrop, C. McCormick, and E. Bridgwater. 2022. *Towards Responsible and Informed Ocean-Based Carbon Dioxide Removal: Research and Governance Priorities,* Washington, D.C.: World Resources Institute.

## LCA Methods

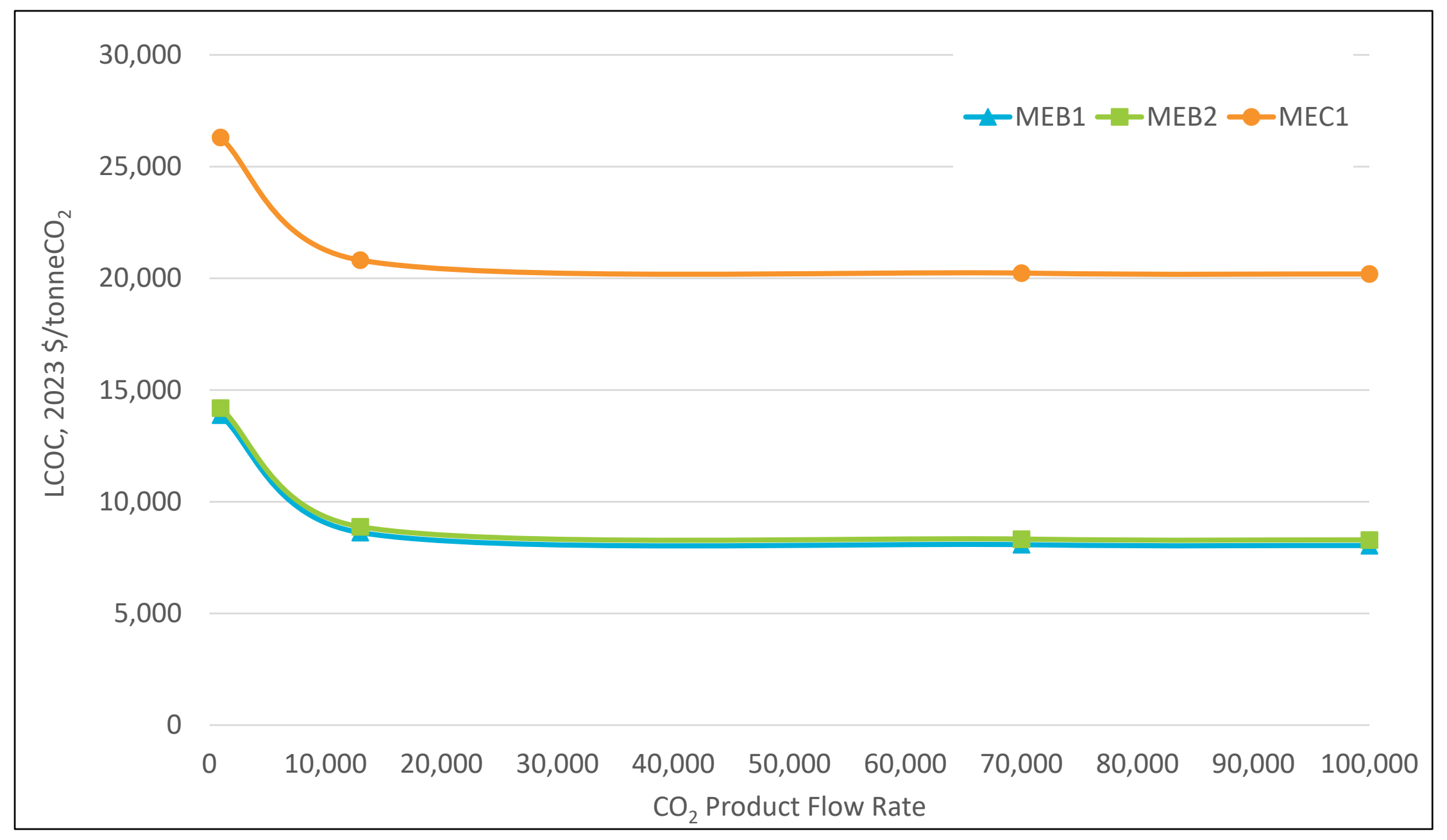
- Boundary: Cradle-to-Gate
- Functional unit: 1 kg of CO2 captured
- Modeling platform: openLCA v2.1.1
- Impact assessment: Traci 2.1 (AR6 100-year time horizon)
- Life cycle inventory: TEA material and energy flows



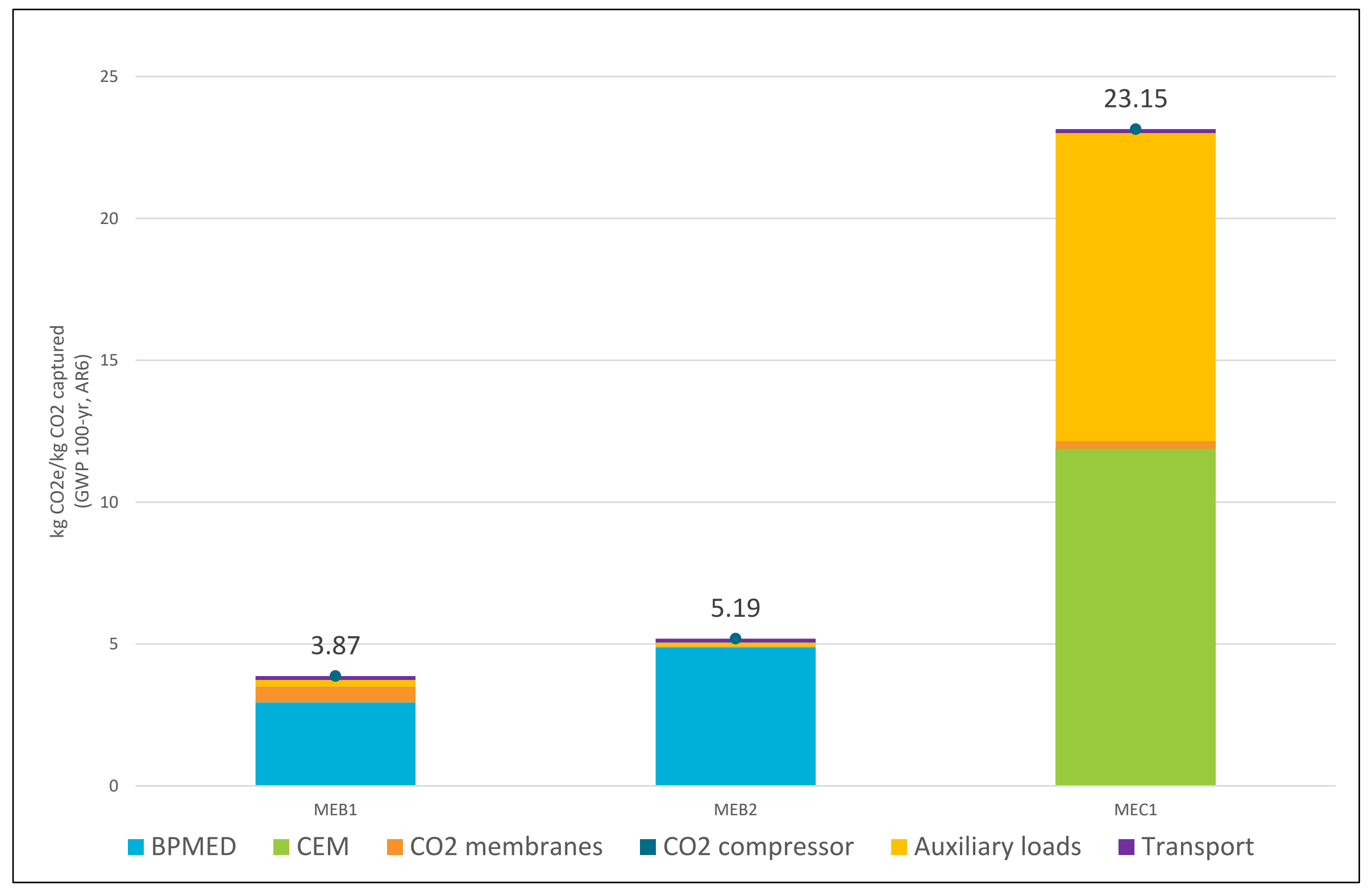
## Results



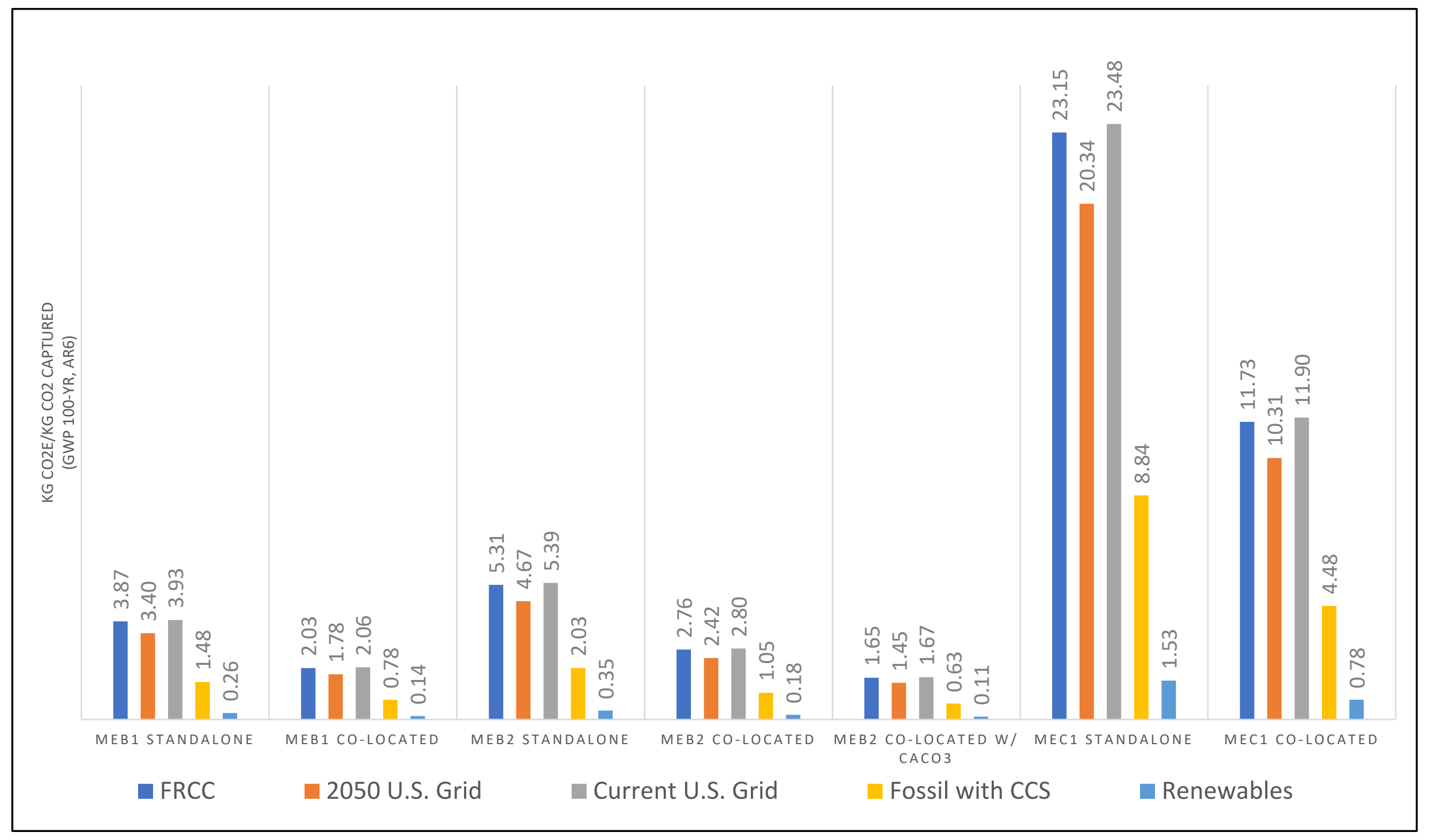
Levelized cost of capture (LCOC) comparison.



Sensitivity of mCDR technologies to plant size.



GWP impacts of standalone and co-located marine CDR facilities.



Sensitivity analysis for different electricity sources scenarios.

## Conclusion

- The preliminary TEA indicates that an LCOC > \$1,000/tonne $CO_2$ can be expected for electrochemical mCDR technologies.
- The analysis of environmental impacts highlighted that under certain conditions (renewable electricity source) electrochemical mCDR technologies can be net negative.
- These results are preliminary, based on limited availability of transparent data.

**Preliminary Results, Do Not Cite**