Powering mCDR with Marine Renewable Energy

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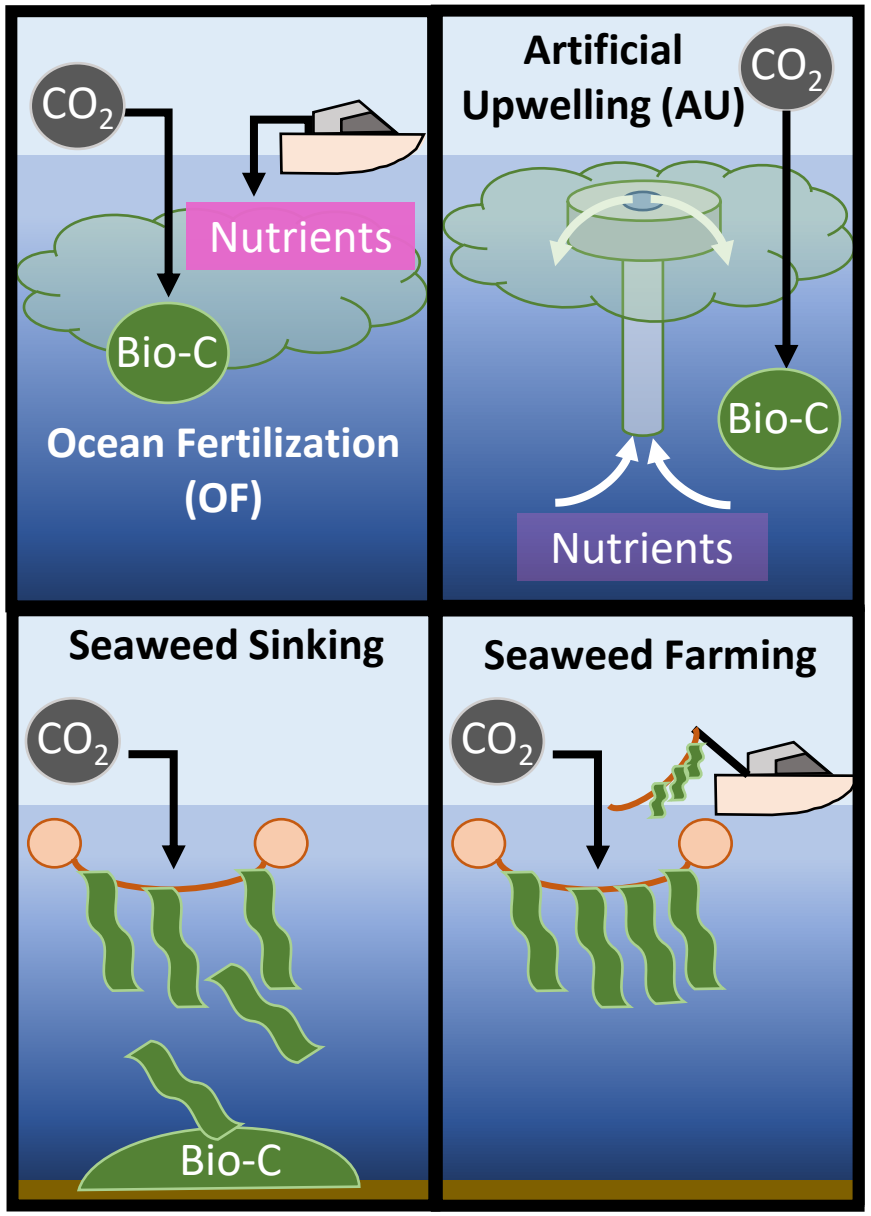
Why is mCDR of Interest for Marine Energy?

- Marine carbon dioxide removal (mCDR) methods can capture, sequester, & convert CO_2 into products
  - At full scale, these technologies could process billions of tons of CO_2 per year (tCO_2/yr)
  - Groups can either earn revenue from carbon credits or co-products
- Deployments in the mCDR field are increasing
  - Scales are currently ~100 – 1,000 tCO_2/yr but there are plans to reach 100k to 1M tCO_2/yr scale facilities
  - Need near to offshore low carbon electricity for powering operations & for monitoring environmental impacts

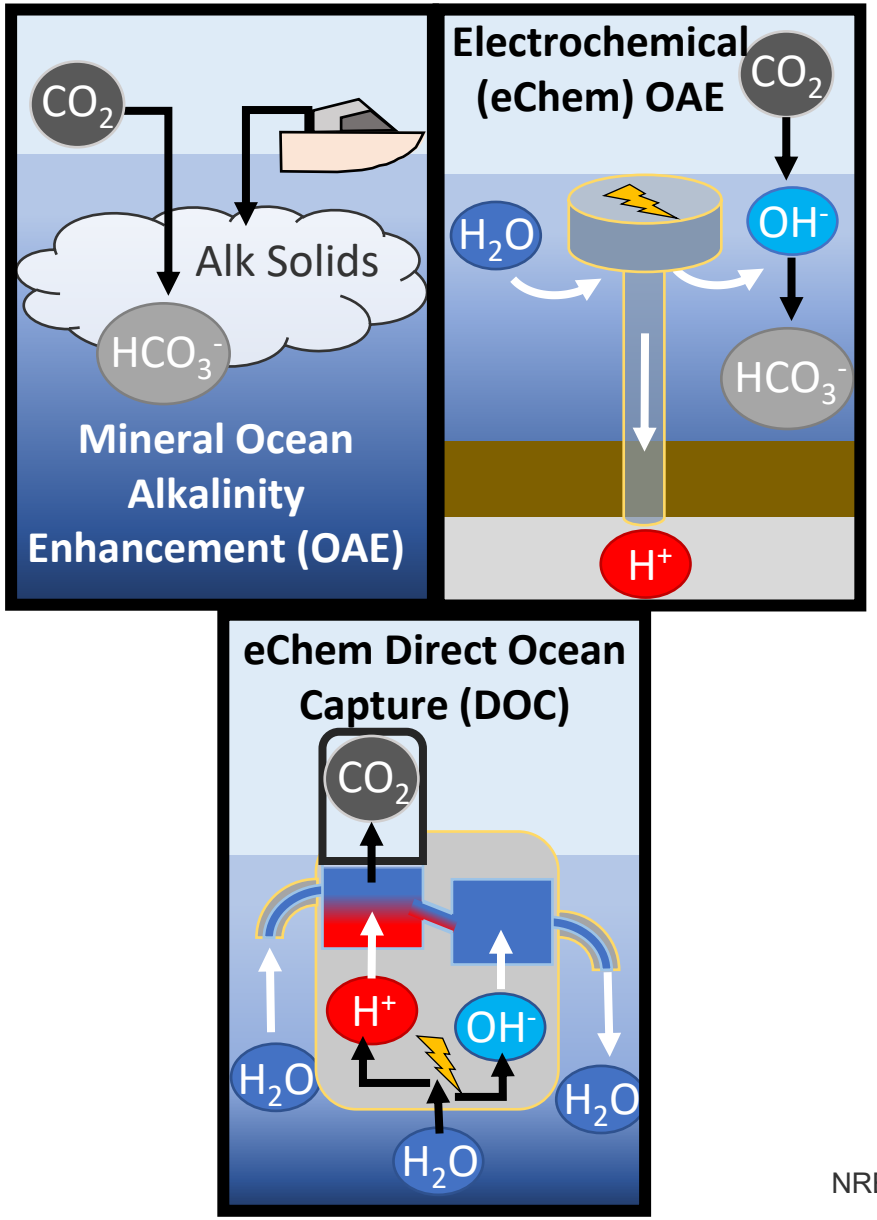
Biological mCDR



- OF, AU, & seaweed sinking struggle with measuring & verifying CO_2 removal
  - Likely will require more extensive ocean monitoring
  - Can cause low oxygen conditions & disrupt food chains
  - Deep sea can be especially sensitive
- AU & seaweed sinking require power for pumping (~10kW scale)
- Seaweed farming needs energy to convert seaweed into products & power nurseries

Abiotic mCDR

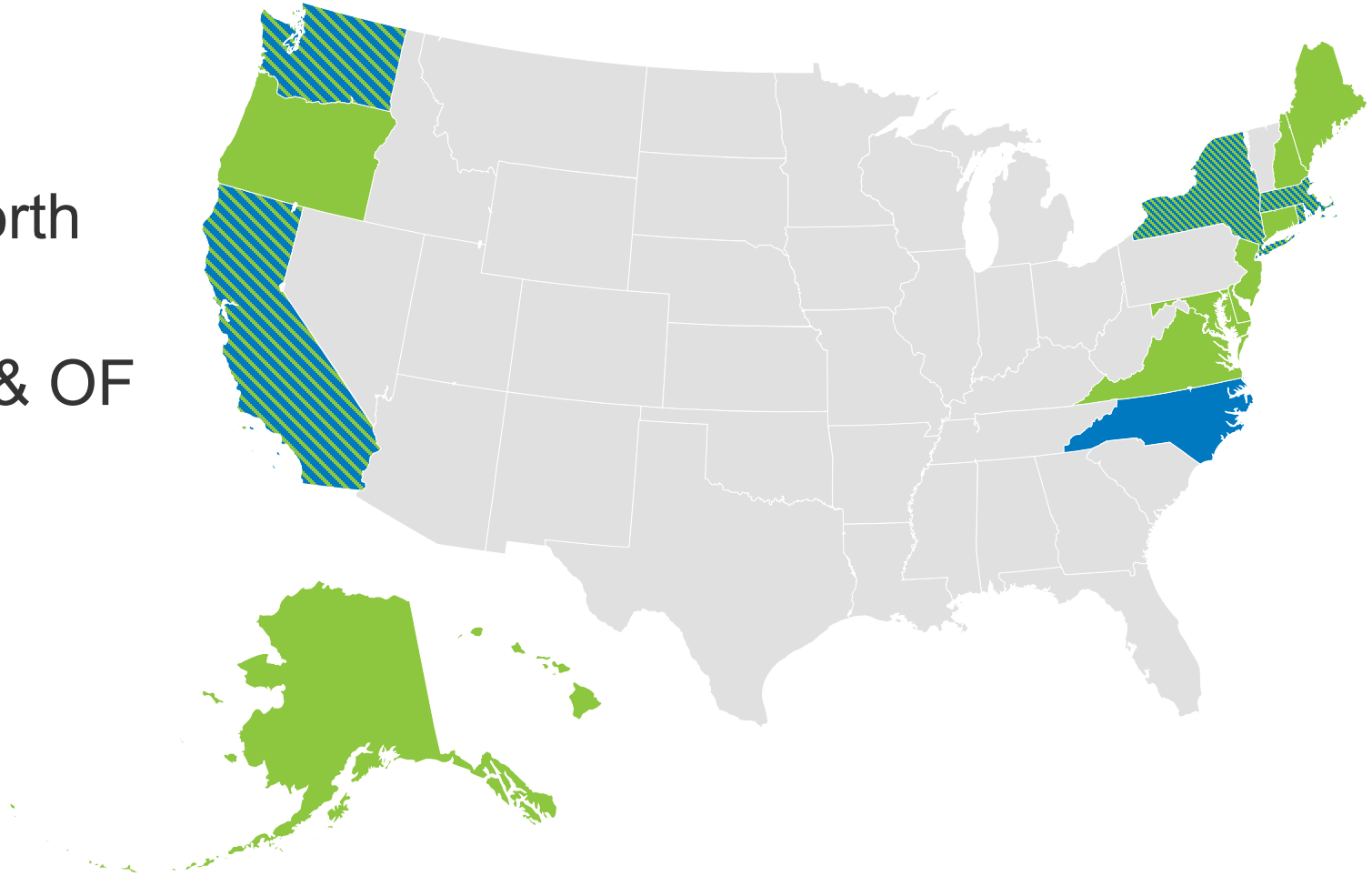
- Mineral OAE largely needs offshore power for monitoring
  - Track alkalinity & ecological changes
  - May unintentionally cause OF
- Electrochemical OAE & DOC
  - Generate NaOH & HCl from seawater using electrolysis or electrodialysis (~MW scale)
  - Electrolysis can also make H_2 but needs steady power
  - Electrodialysis can operate with variable direct power inputs



Key Opportunities for Marine Energy

High Latitude Deployments

- Biotic (green):
  - Ideal to grow seaweed along West Coast & North Atlantic Coast
  - Longer storage for AU & OF on West Coast & HI
- Abiotic (blue)
  - eChem OAE & DOC deployed in WA, CA, Quebec, & Norway
  - Mineral OAE in North Atlantic Coast



At high latitudes marine energy could be advantageous over solar

Monitoring mCDR

- Small scale marine energy can power offshore monitoring
  - ~1 – 100W range
- Applies to all forms of mCDR & needs to cover large areas (~km^2)
  - Critical to assess CDR & environmental impacts
  - Biotic also often requires monitoring at depth in the water column (~km)

Biotic Parameters

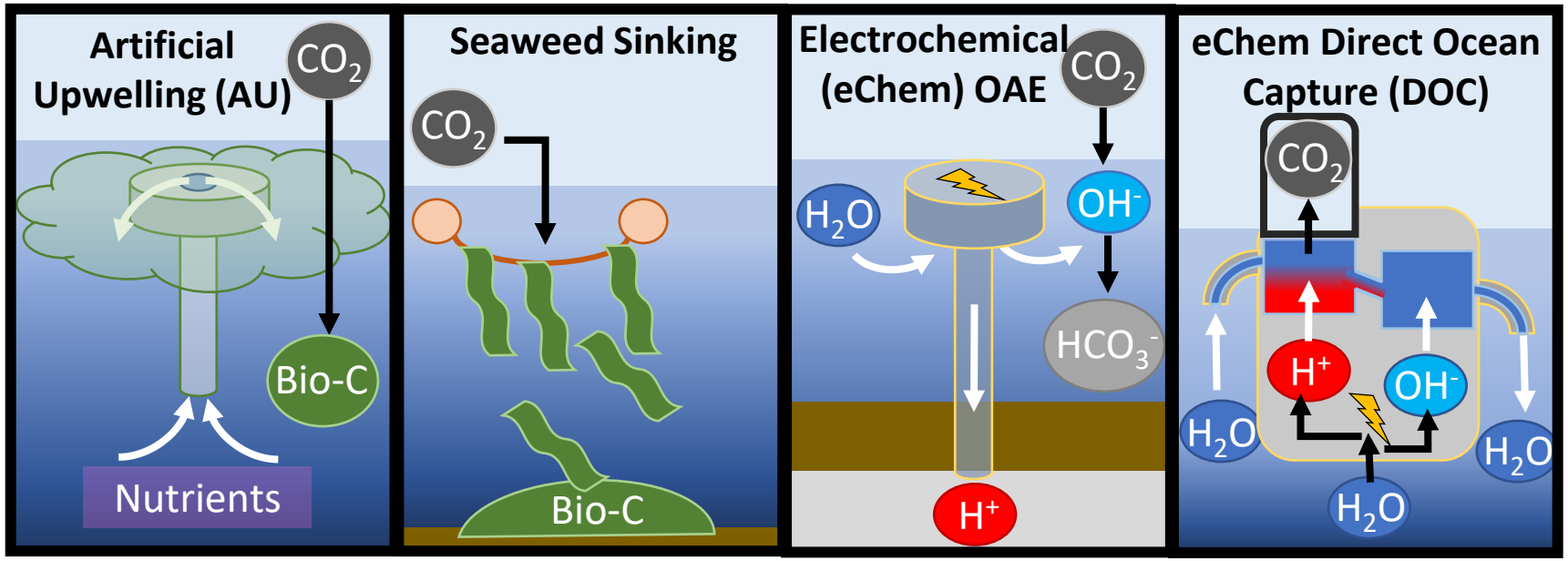
- Assess CDR via:
  - Chlorophyl a, plankton species & size, growth rate, & eDNA
- Environmental impacts:
  - Released gases (N_2O, CH_4, CO_2), DIC, O_2, pH, temperature, DOC, POC, nutrients, salinity, currents, & turbidity

Abiotic Parameters

- Assessing CDR requires 2 of 4:
  - pH, DIC, TA, & pCO_2
- To evaluate environmental impacts can investigate:
  - Nutrient concentrations, temperature, salinity, & dissolved O_2

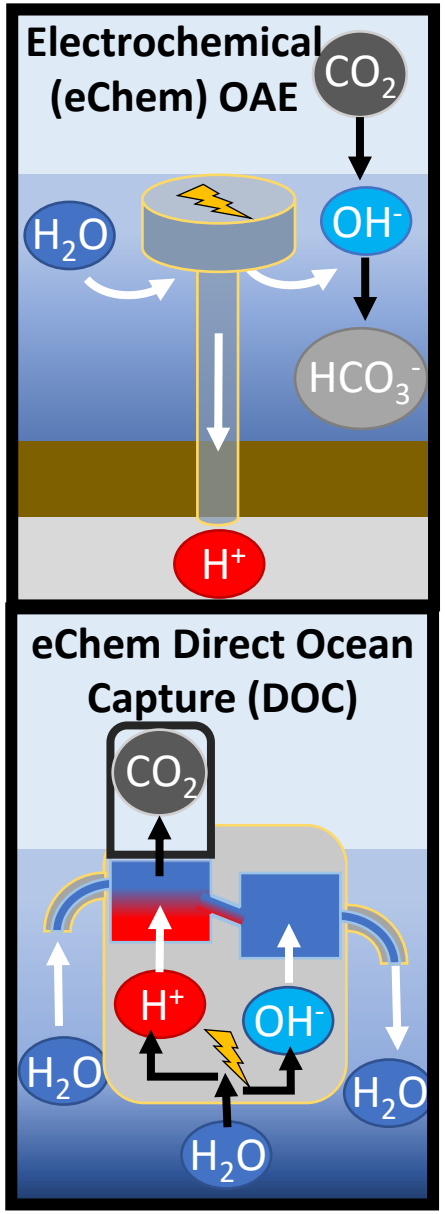
Pumping

- Many types of mCDR require pumping
  - ~10 – 100kW range (at full scale potentially MW)
  - Could directly use mechanical power
- mCDR industry has shown interest in “passive pumping”
  - eChem mCDR process large water volumes (~10k L/min for ~ktCO_2/yr)
  - AU has explored wave powered pumping

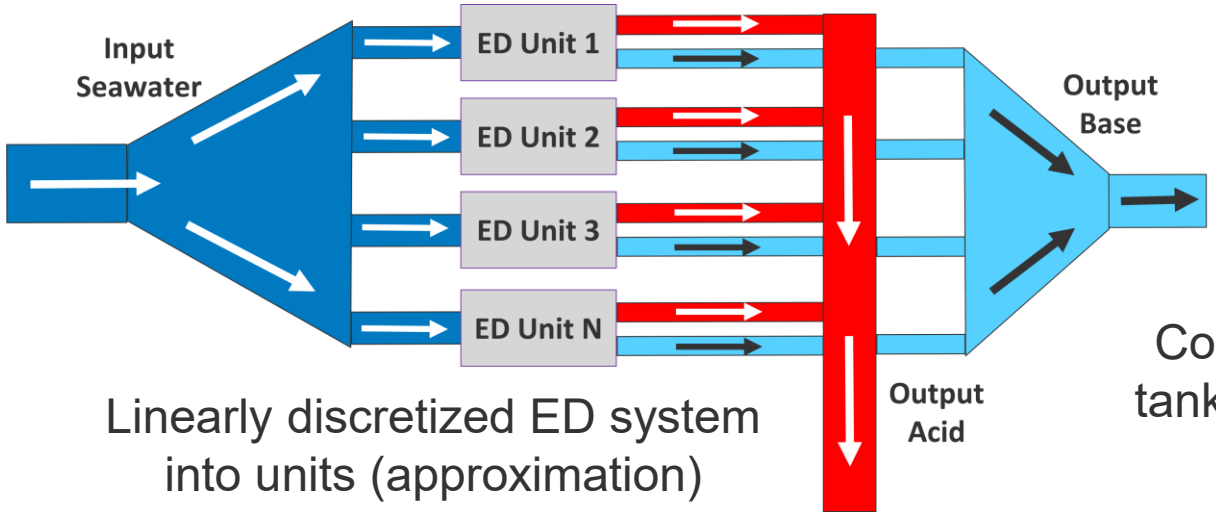


Electrodialysis (ED) Based mCDR

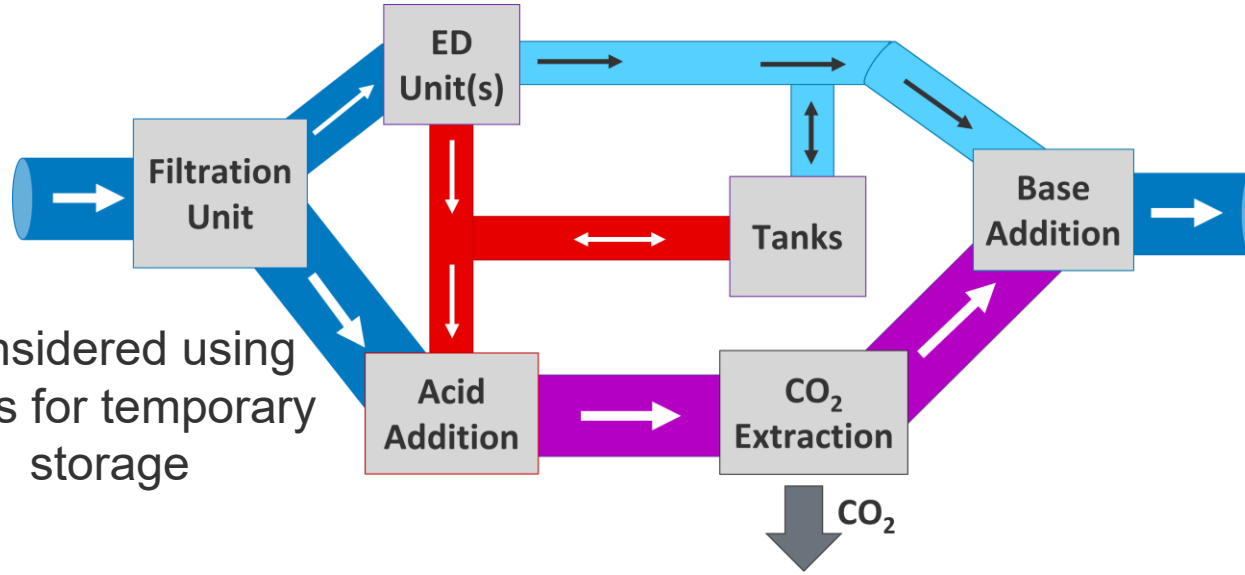
- The electrochemical systems used in eChem OAE & DOC require ~100kW to MW (~100MW at full scale)
- ED based systems:
  - Can handle hourly or more frequent power variability
    - Reduce need for smoothening power output
    - Advantageous for wave energy
  - Research is currently evaluating the impacts of the variability on long term performance
    - Results are promising so far



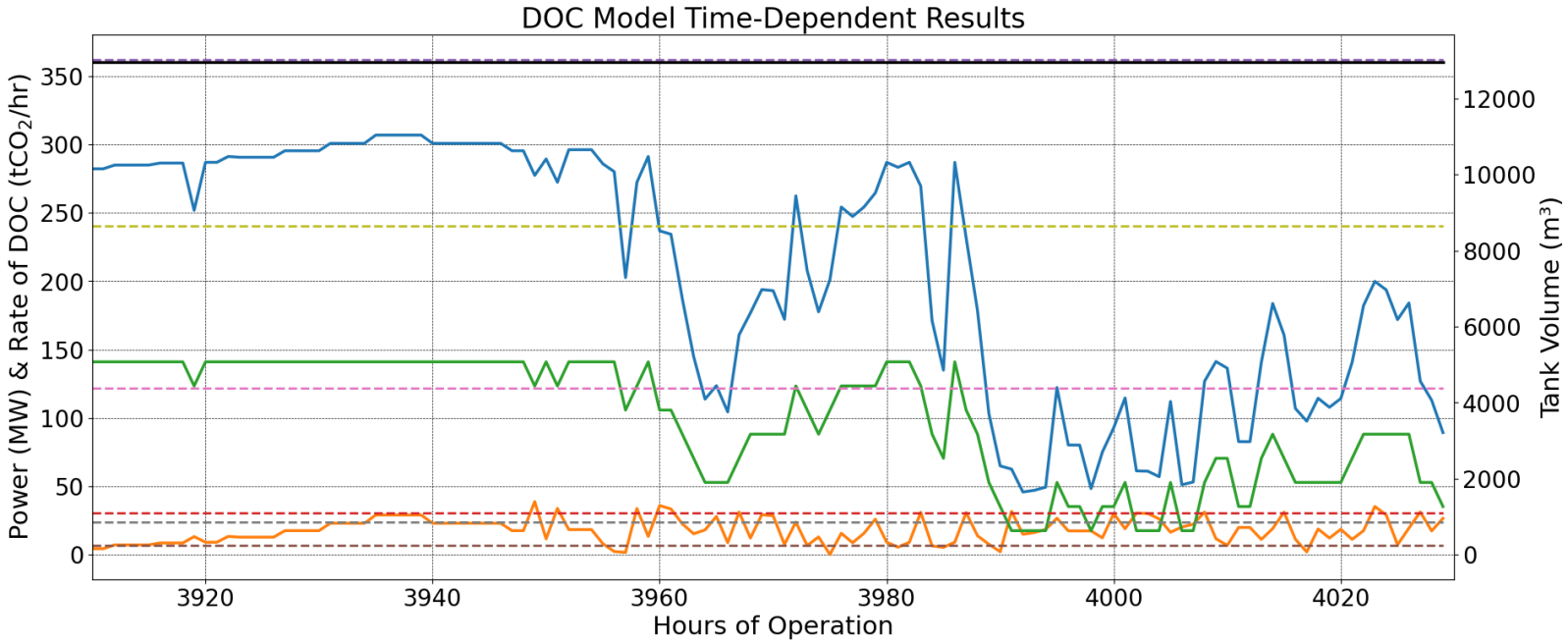
ED-DOC Performance Modeled With Variable Power



Linearly discretized ED system into units (approximation)



Considered using tanks for temporary storage



Time dependent results for example $MtCO_2$/yr DOC plant powered with 330MW offshore wind, 31MW wave (RM3), & 200MWh batteries off OR coast

Energy & DOC capacity factors of ~45%

Key Takeaways

- mCDR is a growing new coastal to offshore industry that requires low carbon energy sources
- Multiple deployments & ideal locations for mCDR are at higher latitudes where marine energy could have an advantage over solar power
- All types of mCDR require power (~1 – 100W) for monitoring large areas (~km^2) (& depths (~km) for biotic methods)
- Many types of mCDR require pumping (~10 – 100kW) & there's interest in passive mechanical pumps
- ED based eChem mCDR (~1 – 100MW) can utilize variable power inputs with less processing
  - Potentially including sub-hourly power fluctuations from wave energy

Thank You!

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