A Model of Large Scale Electrochemical Direct Ocean Capture Under Variable Power

James Salvador Niffenegger[1*], Todd Deutsch[1], Michael Lawson[1], Robert Thresher[1], and Kaitlin Brunik[1]

[1]*National Renewable Energy Laboratory, Golden, CO*

[*]*Corresponding Author Contact: james.niffenegger@nrel.gov*

Abstract

Since limiting warming to 1.5ºC by 2100 will not only require an energy transition but also billions of tons of CO_2 removal (CDR) per year, it is essential to expand these efforts. This can be done offshore via electrochemical direct ocean capture (eChem DOC) which extracts CO_2 from seawater that can later be stored underground or converted into products (see Figure 1). Deployments of eChem DOC will likely be powered by renewable energy and therefore need to function with variable power inputs. This project aims to support future large-scale deployments by developing a model of eChem DOC plant operation, informed by industry and literature, and assessing performance under variable power and varying designs.
Initial analysis suggests that discretizing the eChem system has a higher impact on increasing overall capture than storing the chemical solutions to continue capture during periods of lower power availability, but this is likely situation dependent. Future work will use more realistic power profiles.

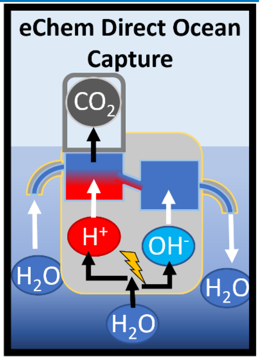

Figure 1: *Graphic describing eChem DOC*

Results for Discretizing ED Units & Using Tanks

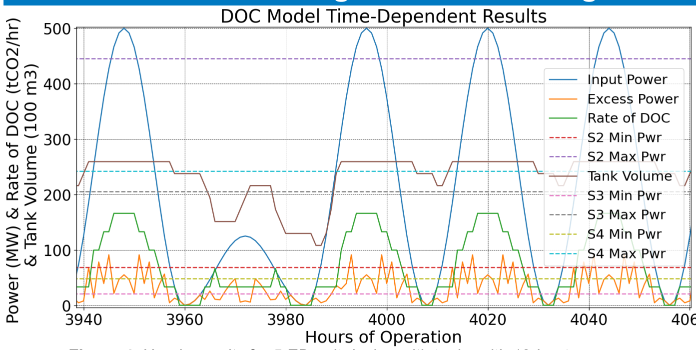

Figure 4: *Hourly results for 5 ED unit design with tanks with 12-hr storage*

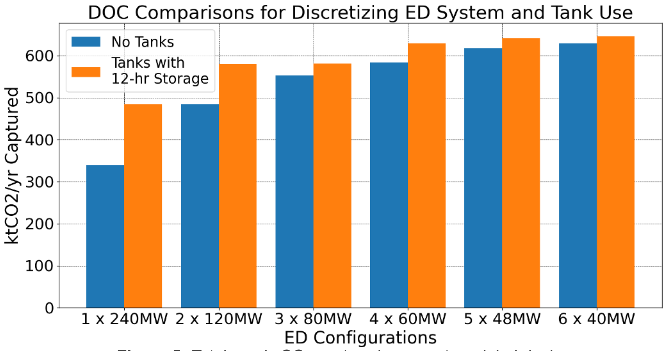

Figure 5: *Total yearly CO_2 captured amongst modeled designs*

Model Description

This model focuses specifically on electrodialysis (ED) based eChem DOC systems and was developed using information from literature about eChem DOC and advisement from a company in the industry. Note that the model is not specific to just this company but is generic and the generated results shown in this poster use generic data.

ED Model:

- Uses ED efficiency to determine concentrations of acid & base generated
- Overall DOC plant hourly power & volume need varies depending on number of ED units used

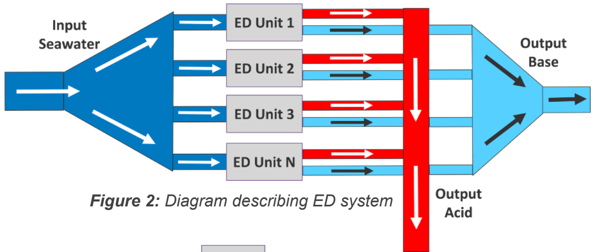

Figure 2: *Diagram describing ED system*

Ocean Chem Models:

- Use carbonate buffer chemistry equations to determine how seawater pH & dissolved CO_2 concentration changes in the process
- Amount of CO_2 extracted determined by extraction efficiency ~90%

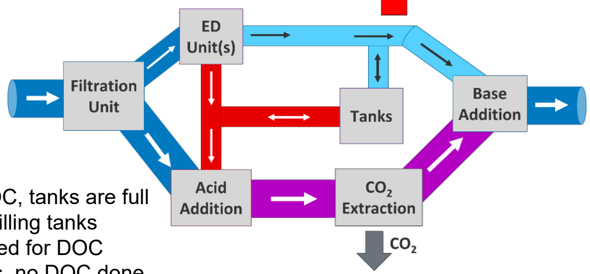

Figure 3: *Diagram describing full eChem DOC system modeled*

Operation Scenarios:

- S1: ED units used for DOC, tanks are full
- S2: ED used for DOC & filling tanks
- S3: Solutions in tanks used for DOC
- S4: ED units just fill tanks, no DOC done

Power Needs and Input:

- Hourly power needs vary depending on power availability, stored volume, number of ED units, & operation scenario
- Typical power needs are: S3 < S4 < S2 < S1
- Power profile for this study is a regular sine wave with a 24-hour period & wave height about the system's max power
  - Every 5th day the amplitude is reduced to 25%

Discussion

- Simulations used the model to assess different DOC plants designs (using 1-6 ED units & tanks with 12 hours of storage for minimum DOC vs no tanks) under the same yearlong power profile & total ED capacity
- Appears that as the number of ED units increased the difference in overall capture between models with & without tanks decreased
- Could be due to the lower difference between the minimum power needs of using the ED units (S1 & S2) vs the tanks (S3) for DOC at higher numbers of ED units
  - Implying that **further ED discretization could be more cost effective than using tanks** (which can be expensive to construct)
- However, this **heavily depends on the power profile provided** & capture with tanks could improve by forecasting/ estimating future power availability
- Future work will incorporate this model into NREL's Hybrid Optimization Performance Platform to assess its performance with realistic power profiles from wave, wind, & solar energy

Citations

Niffenegger, J.; Greene, D.; Thresher, R.; Lawson, M. Mission Analysis for Marine Renewable Energy To Provide Power for Marine Carbon Dioxide Removal. Technical report, National Renewable Energy Laboratory, 2023.

Digdaya, I.; Sulliva, I.; Lin, M.; Han, L.; Cheng, W.; Atwater, H.; Xiang, C. A direct coupled electrochemical system for capture and conversion of CO2 from oceanwater. Nature Communications 2020, 11, 1–10.

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