Carbon Dioxide Removal Systems Analysis

Sally Homsy

Research Engineer, National Energy Technology Laboratory

Carbon Management Project Review Meeting 2024

August 6, 2024

Overview

1. Preliminary results from an update to NETL's 2022 "Direct Air Capture Case Studies: Sorbent System" report

2. Screening level techno-economic analyses (TEA) and life cycle assessments (LCA) of enhanced rock weathering (ERW) and marine CDR (mCDR) technologies

3. Other completed, ongoing, and upcoming TEA, LCA and markets analysis work will also be highlighted

DAC Case Studies: Sorbent System Update

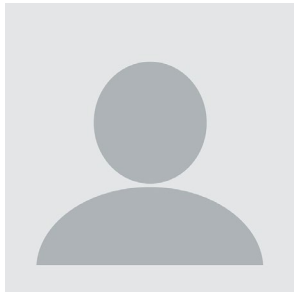
Background

- Presents a transparent and independent assessment of the performance and cost of generic sorbent-based DAC systems
- Utilizes NETL's standardized transparent TEA methodology allowing comparison across studies
- Provides guidance and sufficient details to allow this series to serve as a guideline for DAC TEA development

DAC Case Studies: Sorbent System Revision 1 doi.org/10.2172/1879535

DAC Case Studies: Solvent System doi.org/10.2172/1893369

Kshitij Patel
NETL support contractor



Troy Teel
NETL support contractor

Sam Henry
NETL support contractor

Sarah Leptinsky
NETL support contractor

Hari Mantripragada
NETL support contractor

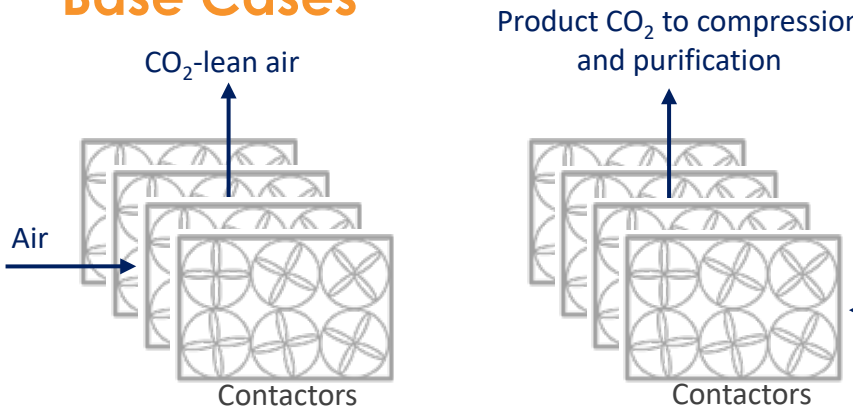
Alexander Zoelle
NETL support contractor

Timothy Fout
Department of Energy

Sally Homsy
NETL

DAC Case Studies: Sorbent System Update

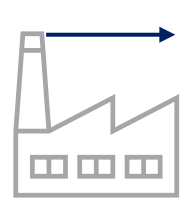
Base Cases



Generic Sorbent DAC

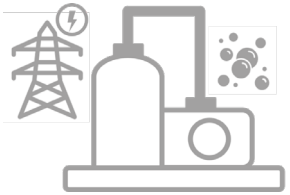
Steam

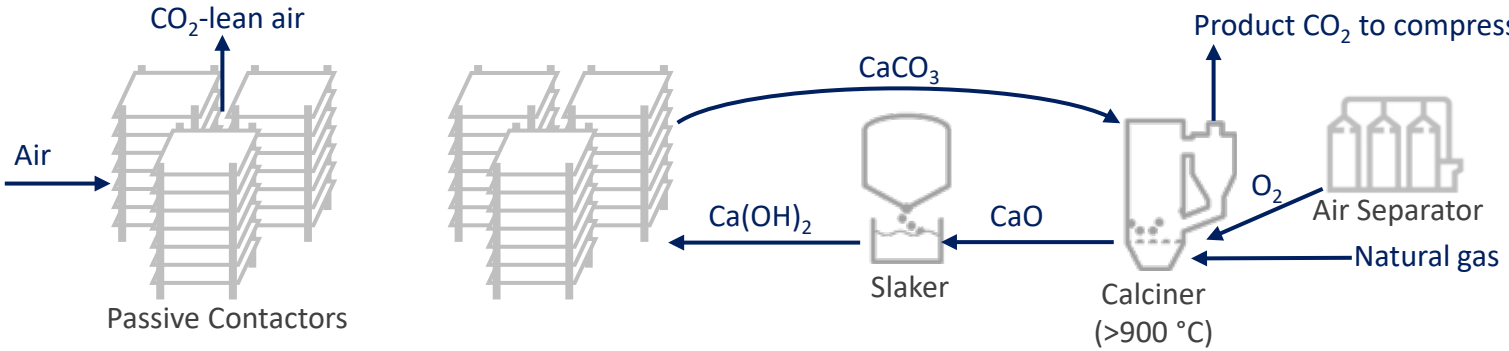
1. **Direct steam temperature and vacuum swing adsorption (TVSA)**
2. **Direct steam temperature swing adsorption (TSA)**
3. **Indirect steam TSA**



A. NG combined heat and power plant

B. Grid power and electric boiler



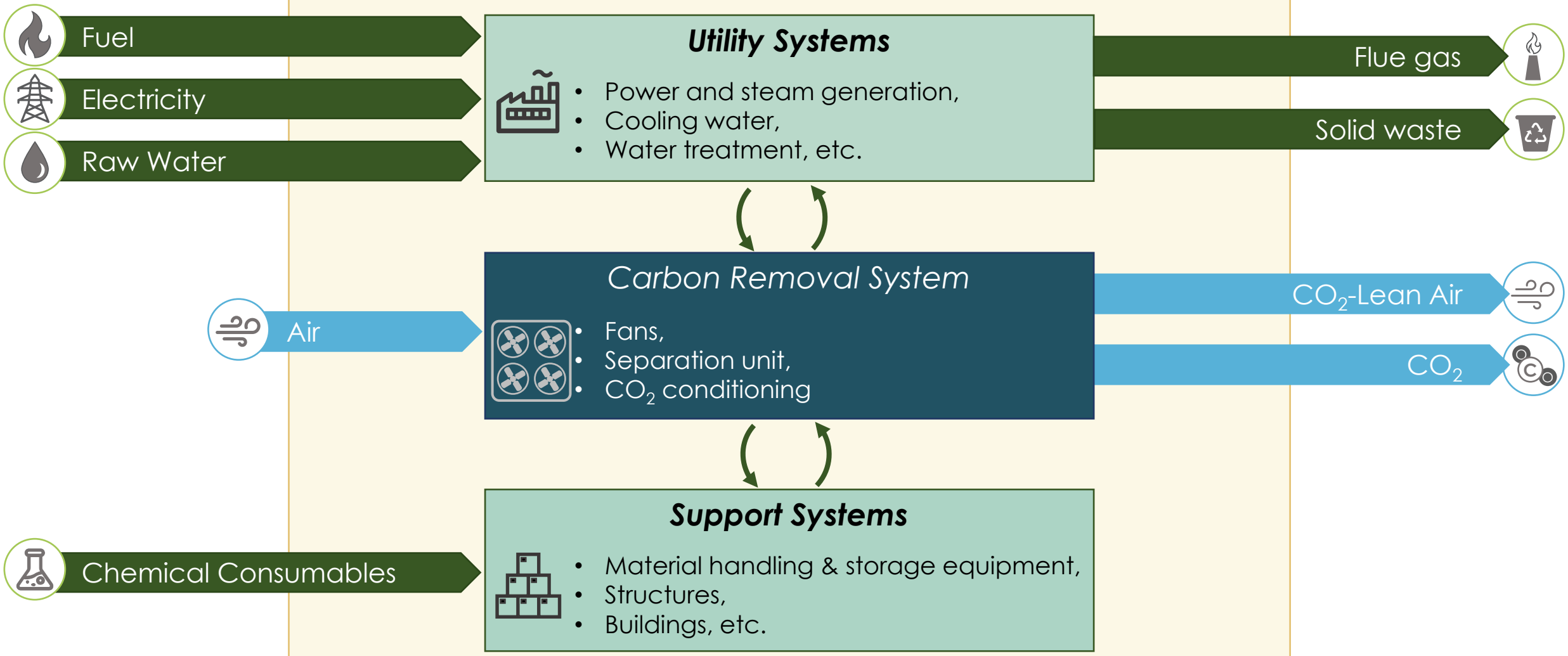


Looped $CaCO_3$/$Ca(OH)_2$ DAC

C. Grid power and natural gas oxy-combustion

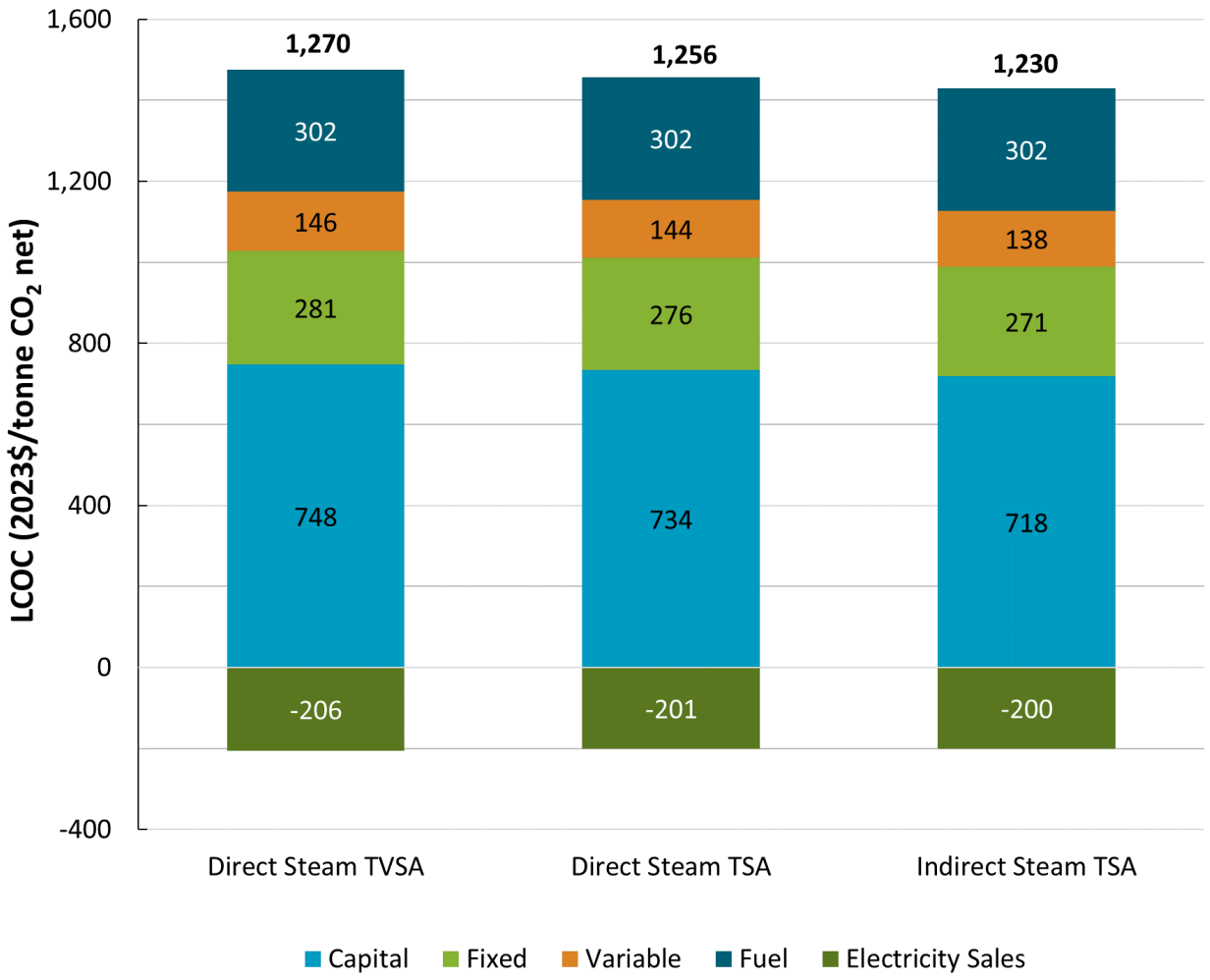
DAC Case Studies: Sorbent System Update

TEA Scope: full carbon removal plant [$/net tonnes CO_2 removed]



DAC Case Studies: Sorbent System Update

100,000 tonnes CO_2 net/yr DAC with NG CHP Results



Rev1 equivalent LOC = \$680/tonne CO_2 net

→ 30% increase due to sorbent price increase to ~ \$10/kg

→ 20% increase due to fixed turbine size

→ 18% increase due to year dollar

→ Additional cost increases due to water co-adsorption, sensible heating, and additional process components

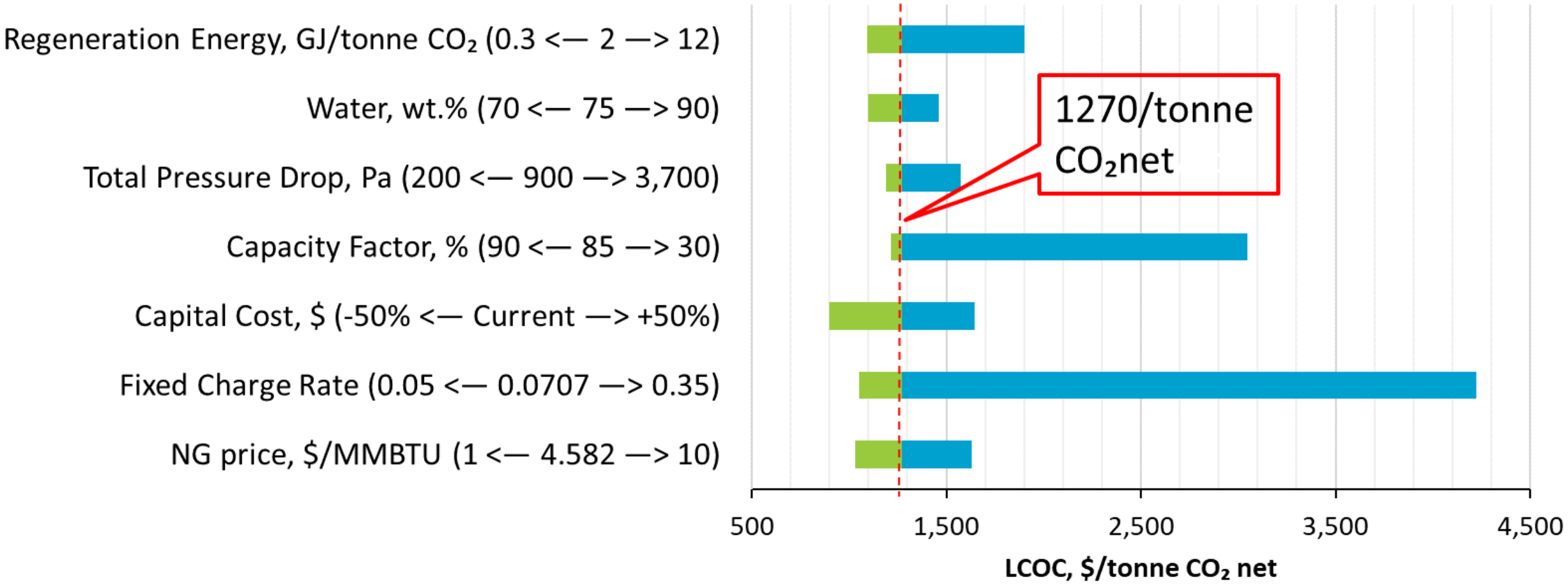
→ 12% reduction due to upgrade to a 97% capture system

→ Additional cost reductions due to shorter cycle time (1 hour)

→ Updated adsorber geometry, sorbent performance parameters and configuration based on 2024 literature review are also impactful

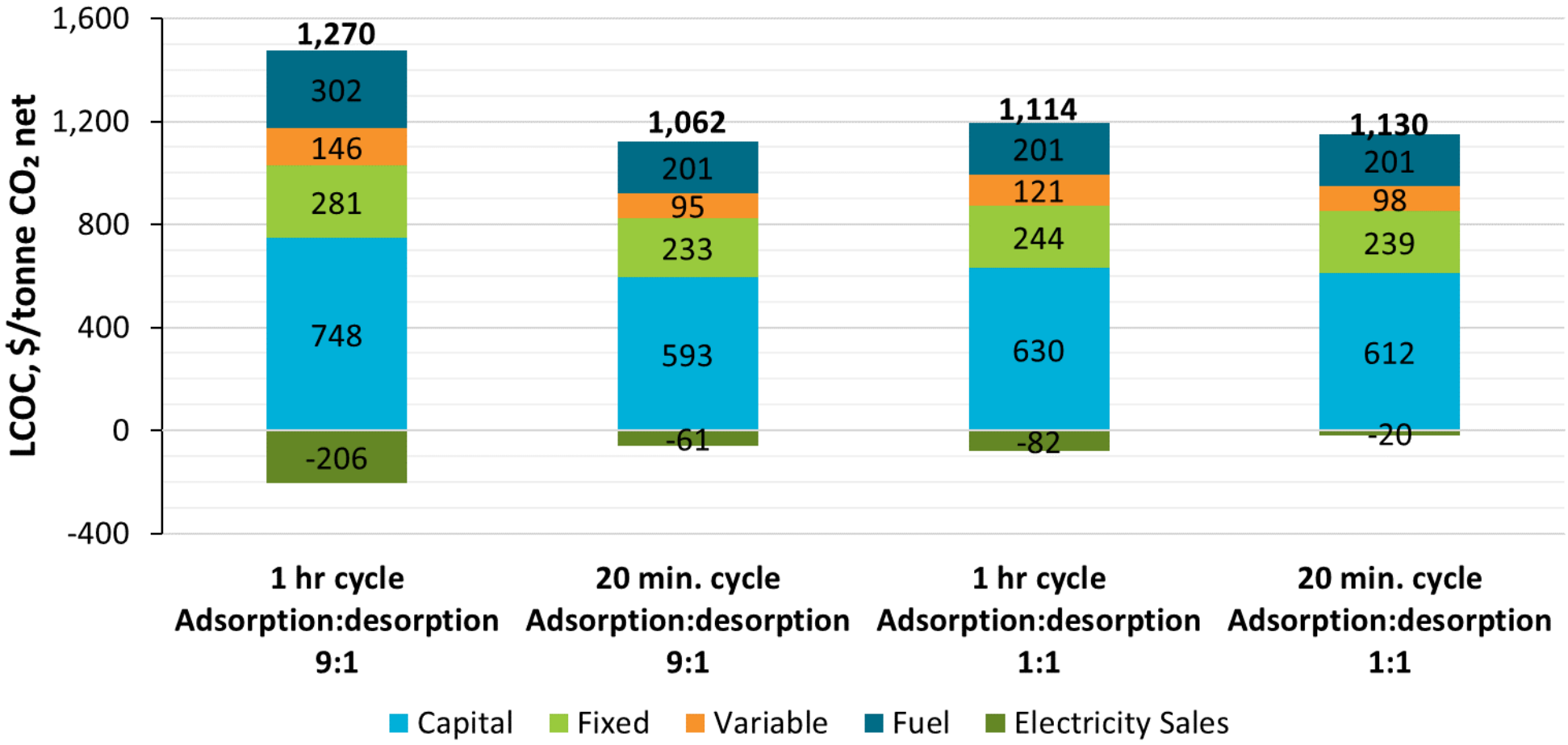
DAC Case Studies: Sorbent System Update

100,000 tonnes CO_2 net/yr DAC with NG CHP: Direct Steam TVSA Case



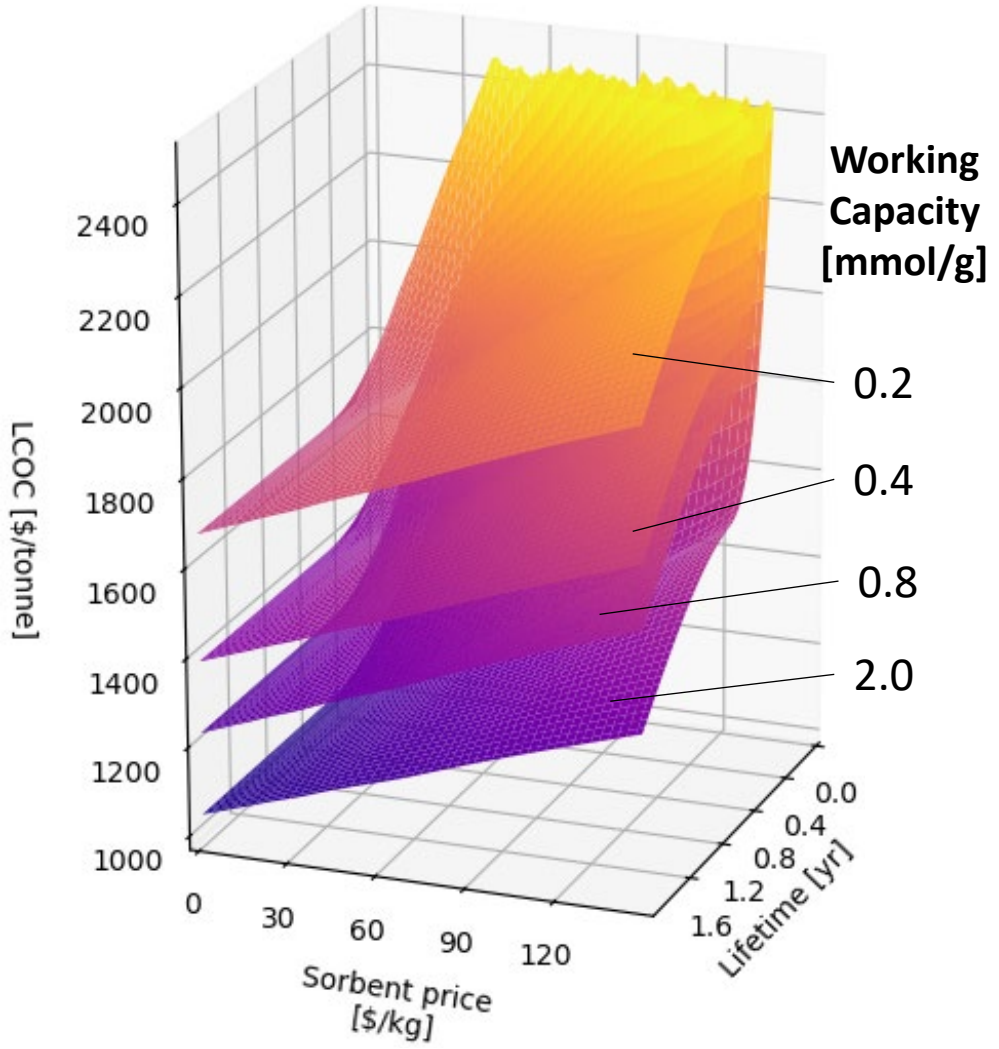
DAC Case Studies: Sorbent System Update

100,000 tonnes CO_2 net/yr DAC with NG CHP: Direct Steam TVSA Case



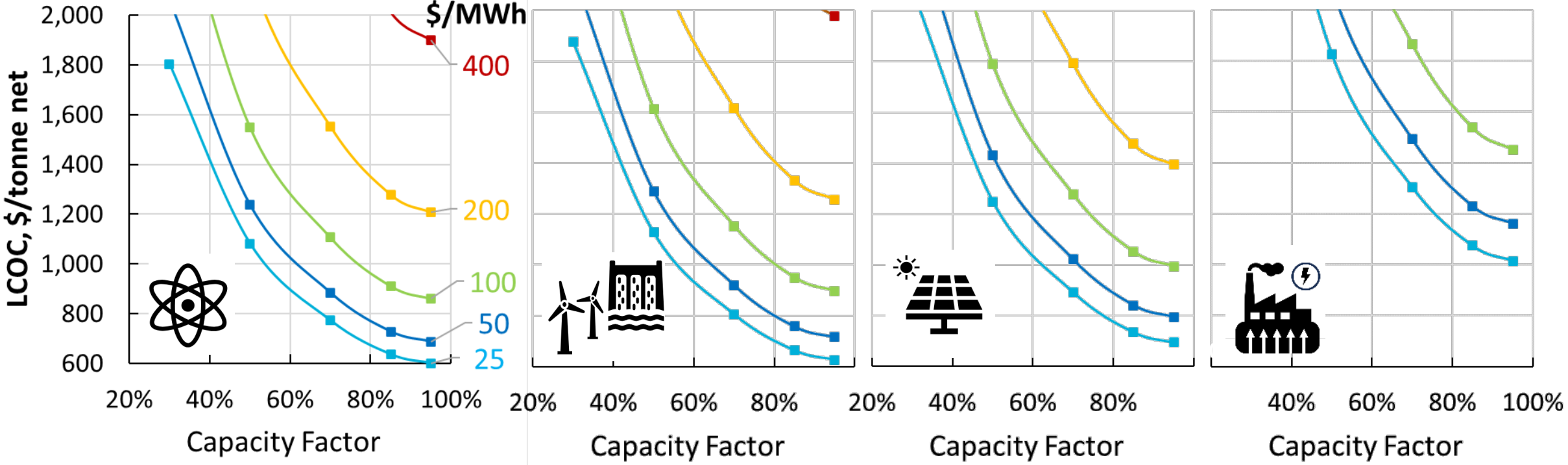
DAC Case Studies: Sorbent System Update

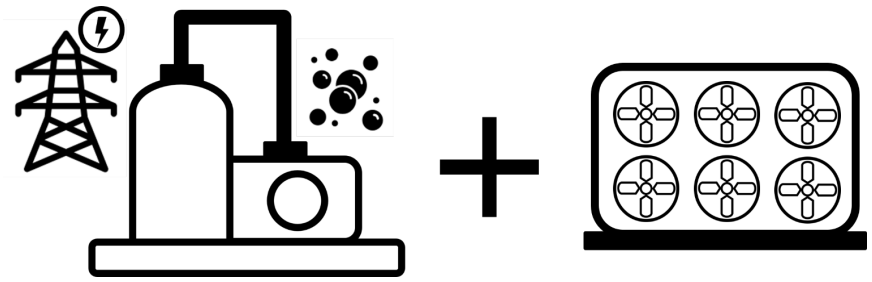
100,000 tonnes CO_2 net/yr DAC with NG CHP: Direct Steam TVSA Case



DAC Case Studies: Sorbent System Update

100,000 tonnes CO_2 net/yr DAC with Electric Boiler: Direct Steam TVSA Case

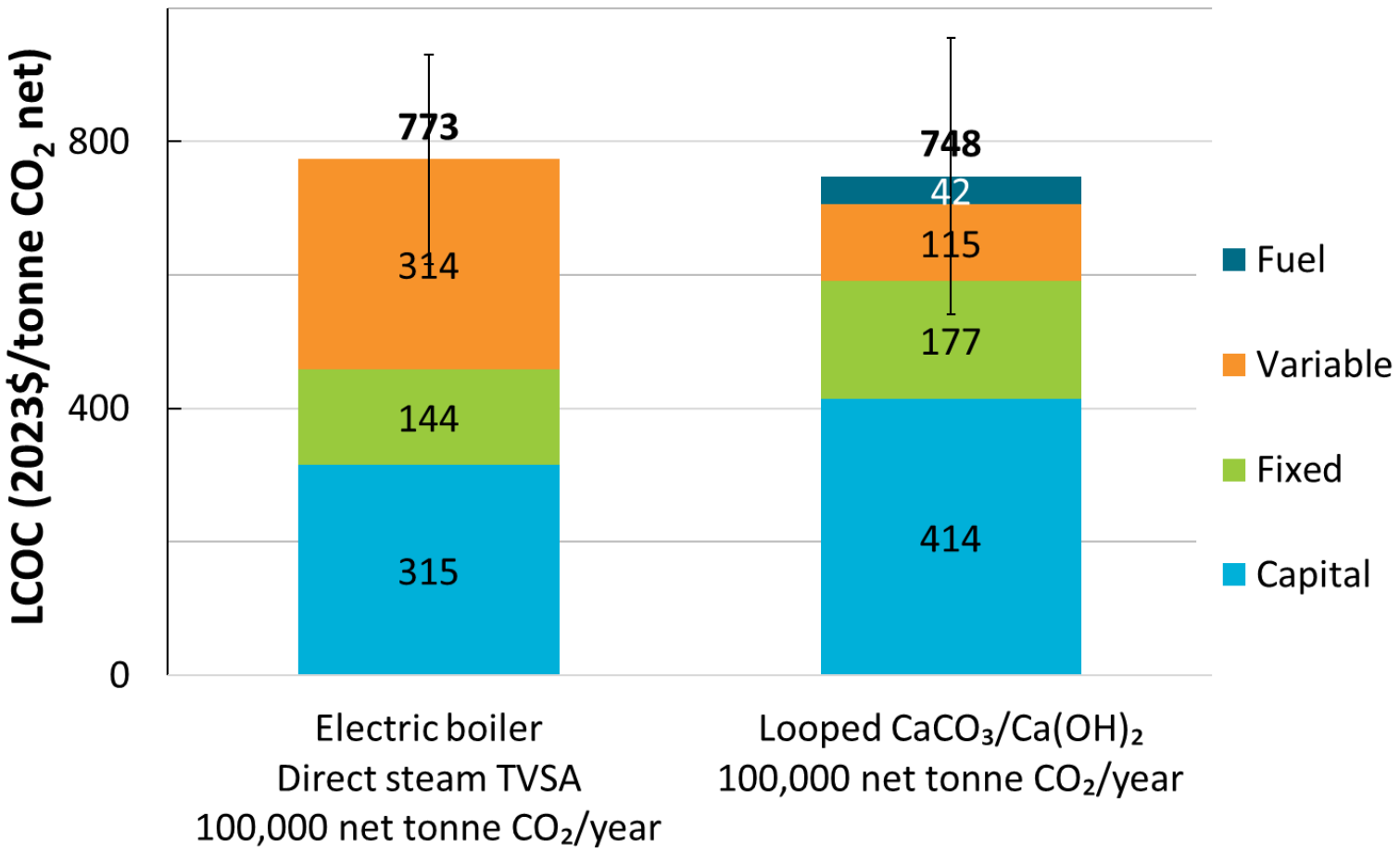




As the carbon intensity of electricity increases, net capture decreases and the LCOC increases

DAC Case Studies: Sorbent System Update

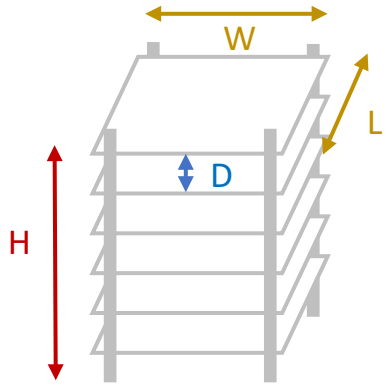
100,000 tonnes CO_2 net/yr DAC Looped $CaCO_3/Ca(OH)_2$ DAC



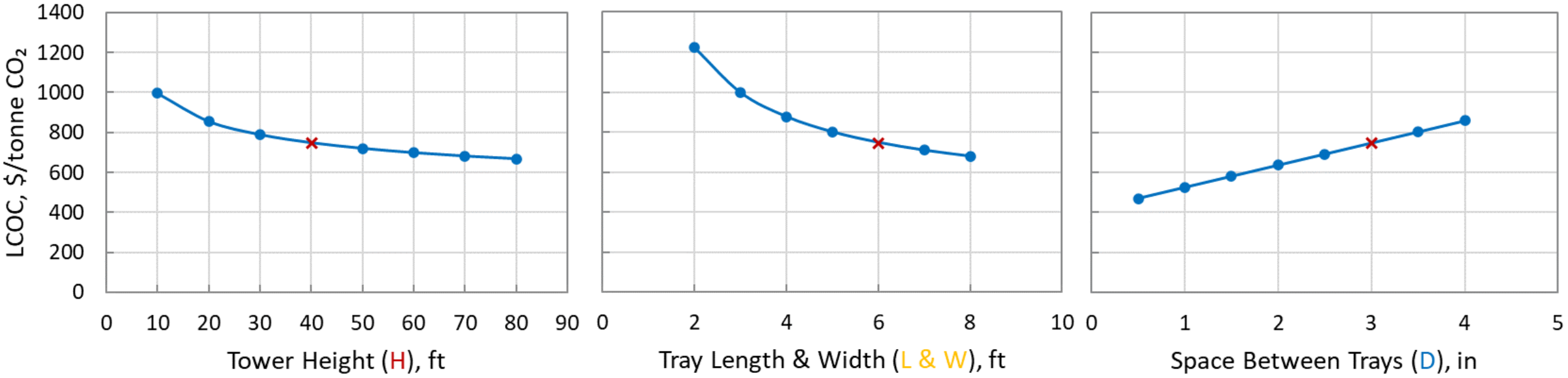
Looped $CaCO_3/Ca(OH)_2$ can be competitive with other DAC technologies

DAC Case Studies: Sorbent System Update

100,000 tonnes CO_2 net/yr DAC Looped $CaCO_3/Ca(OH)_2$ DAC

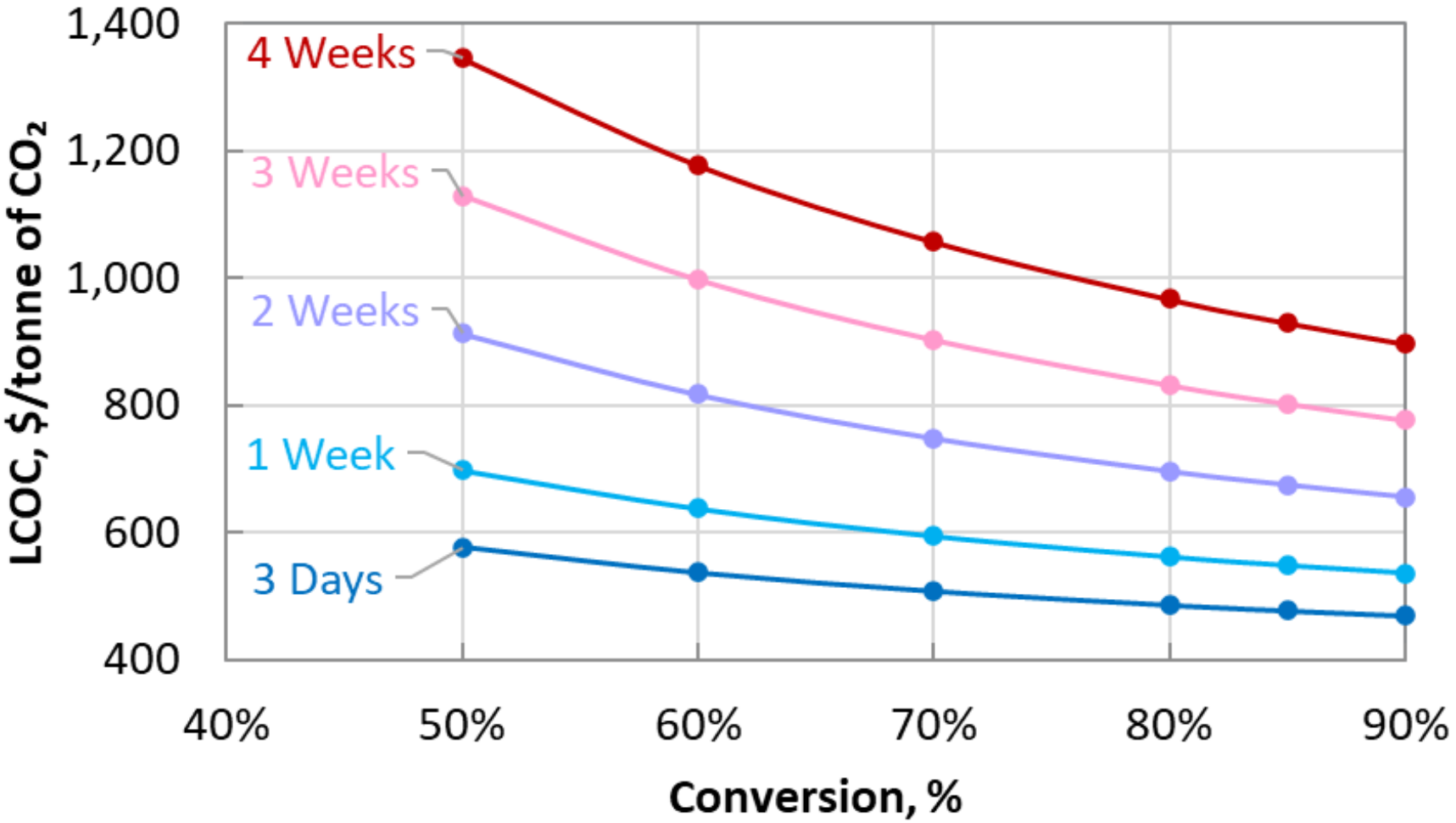


- The base case is highlighted with a red x
- Utilizing larger towers with more densely packed trays can reduce the LCOC by reducing the number of towers required, and land requirement, assuming this arrangement does not negatively impact the capture rate



DAC Case Studies: Sorbent System Update

100,000 tonnes CO_2 net/yr DAC Looped $CaCO_3/Ca(OH)_2$ DAC



- 50–80% $Ca(OH)_2$ conversion over 2–4 weeks of exposure is typically cited
- At higher conversion rates, less material is processed reducing equipment size and cost
- Adding fans to increase the conversion rate may be a tradeoff worth exploring

DAC Case Studies: Sorbent System Update

Conclusions

- Revision 2 of the "DAC Case Studies: Sorbent System" is expected to be published this fall
- The updated cases are also being incorporated into an updated Nuclear powered DAC report, a joint NETL/INL/ANL effort published in 2023: Assessment of Nuclear Energy to Support Negative Emission Technologies
  Nicolas E. Stauff[1], W. Neal Mann[1], Anton Moisseytsev[1], Venkat Durvasulu[2], Hari Mantripragada[3], Timothy Fout[4]
- Further refinement towards NETL Baseline studies is ongoing for all DAC approaches. Input from DAC technology developers on this effort is greatly appreciated

"Assessment of Nuclear Energy to Support Negative Emission Technologies"

[1]ANL; [2]INL; [3]NETL support contractor; [4]NETL

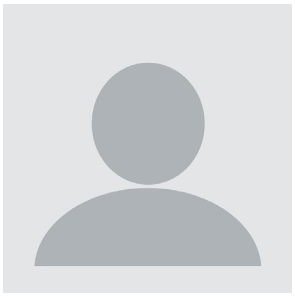
Screening TEA & LCA of ERW

Overview

- Reports on the cost and capacity for global warming potential reduction associated with a ERW project deployed in the Midwest utilizing igneous rocks (basalt & dunite) or industrial waste (biomass ash & cement kiln dust)
- A detailed sensitivity analysis is provided revealing avenues for maximizing capture potential and reducing cost
- Anticipated publication in the fall


Sarah Leptinsky
NETL support contractor


Jorge Izar Tenorio
NETL support contractor


Priyadarshini
NETL support contractor


Hari Mantripragada
NETL support contractor


Alexander Zoelle
NETL support contractor

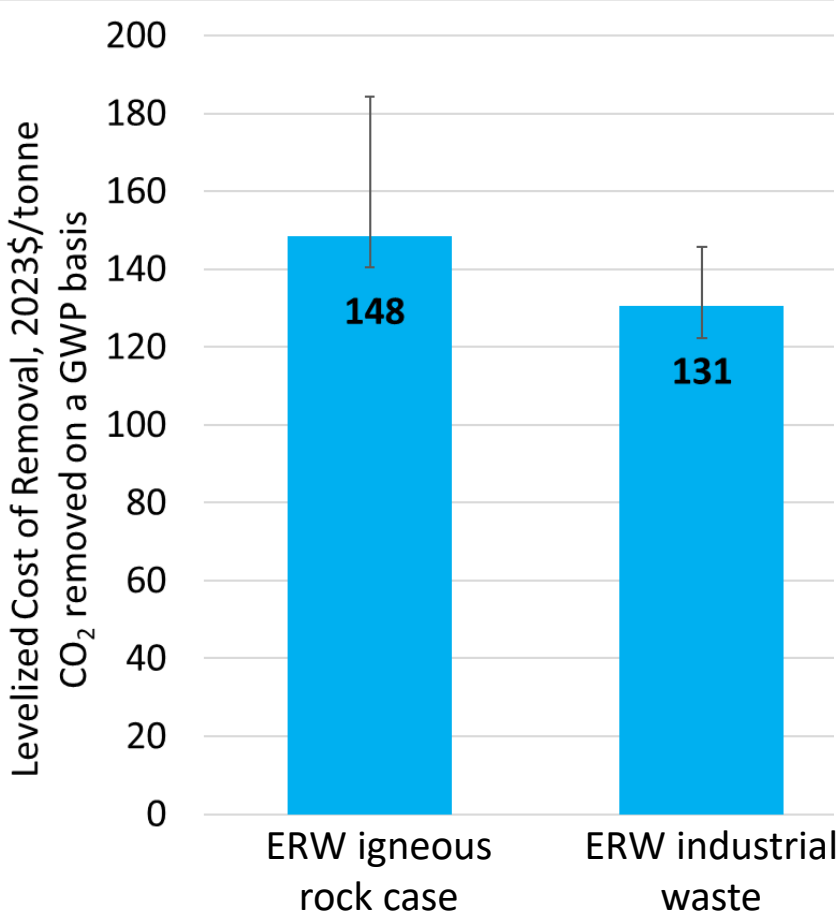

Matt Jamieson
NETL


Timothy Fout
Department of Energy


Sally Homsy
NETL

Screening TEA & LCA of ERW

Results



Weathering rate [mol·m^{-2}s^{-1}]

Weathering potential [kg CO_2/tonne]	1.E-07	1.E-08	1.E-09	1.E-10	1.E-11	
200	358	358	358	534	3,503	Biomass ash
300	239	239	239	356	2,335	
400	179	179	179	267	1,751	
500	143	143	143	214	1,401	
600	119	119	119	178	1,168	
700	102	102	102	153	1,001	
800	90	90	90	133	876	
900	80	80	80	119	778	Cement kiln dust
1000	72	72	72	107	701	
1100	65	65	65	97	637	
1,200	60	60	60	89	584	
1,300	--	--	--	--	--	

Utilizing materials with high weathering potential in suitable locations can lead to relatively low levelized cost of removal (~$100-200/tonne CO_2 removed)

Screening TEA & LCA of mCDR

- Transparent preliminary TEA and LCA case studies examining the cost and performance of three electrochemical mCDR technologies

- Interest in input from mCDR tech developers to refine these cases

Thomas Schmitt
NETL support contractor

Roksana Mahmud
NETL support contractor

Hari Mantripragada
NETL support contractor

Alexander Zoelle
NETL support contractor

Matt Jamieson
NETL

Timothy Fout
Department of Energy

Sally Homsy
NETL

Other Efforts

Recent Publications

- Nadejda Victor, Christopher Nichols, Impact of carbon dioxide removal technologies on deep decarbonization: EMF37 MARKAL–NETL modeling results. *Energy and Climate Change 5, 100143, https://doi.org/10.1016/j.egycc.2024.100143*
- Jason Boerst, Ivonne Pena Cabra, Smriti Sharma, Connie Zaremsky, Arun Iyengar, Strategic Siting of Direct Air Capture Facilities in the United States. Energies 2024 https://doi.org/10.3390/en17153755

Ongoing Work

- Examining the potential of alternative regeneration for DAC, including microwaves
- Refinement of DAC studies moving towards NETL Baseline studies is ongoing. Input from DAC technology developers on this effort is greatly appreciated

Disclaimer

Questions/ Comments

VISIT US AT: **www.NETL.DOE.gov**

@NETL_DOE

@NETL_DOE

@NationalEnergyTechnologyLaboratory

CONTACT:
Sally Homsy
Sally.Homsy@netl.doe.gov