Preliminary Techno-Economic Assessment of High-Efficiency Post Combustion Carbon Capture from NGCC

Preliminary results based on pilot testing at TCM using ION ICE-31 solvent

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2024 FECM/NETL Carbon Management Research Project Review Meeting
Aug 7th 2024

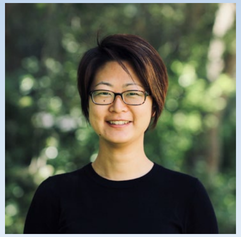
Project overview

- Funding: $2,895 k
  - LLNL: Project Management + TEA
  - ION: Experiment Testing in TCM
  - LBNL: Emission Impact Analysis

- Overall Objective & Timeline:
  - Conduct comprehensive assessment of the performance and impacts of applying high efficiency capture on NGCC plants using ICE-31, including technical feasibility, economics and environmental impacts.
  - Project Date: 2023/10 - 2024/10

❑ LLNL Team

Wenqin Li (PI)



Mengyao Yuan

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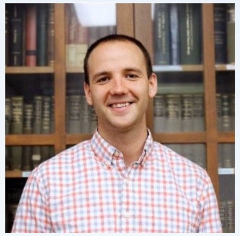

Nathan Fine

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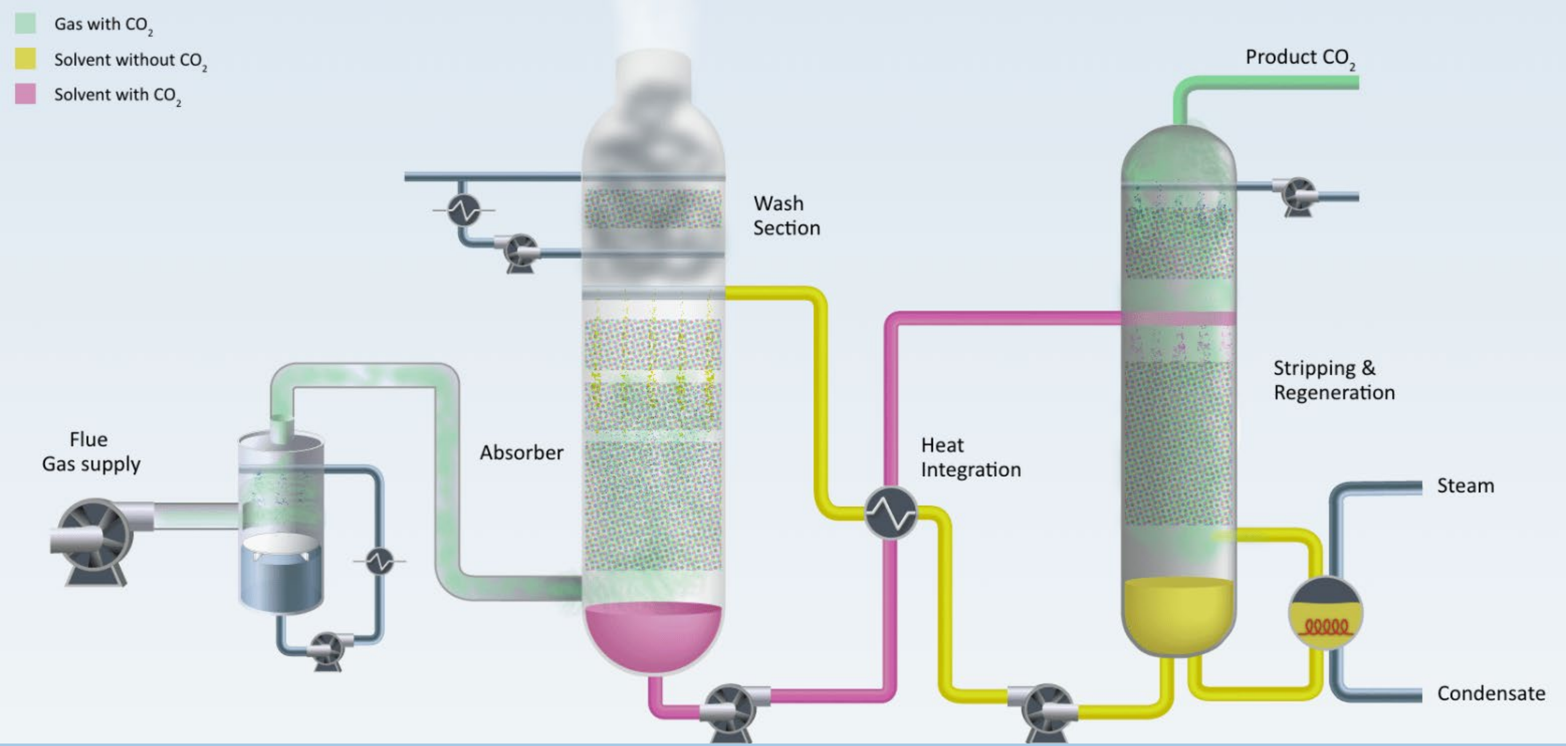
What we learned

- Achieving high-efficiency NGCC post-combustion capture with ION ICE-31 solvent has been experimentally demonstrated to be feasible, with a capture cost increase of less than 10%.
- The cost of capturing CO_2 from NGCC flue gas could increase significantly if the power plant faces early retirement (short plant lifetime) or is used as backup power for renewables (low capacity factor). Additionally, the cost is sensitive to fluctuations in energy prices to provide heat.
- The incremental cost for 99%-99.5% capture (<420 ppm CO_2 in flue gas) using ION ICE-31 solvent is comparable to the state-of-the-art direct air capture costs reported in the literature.
- To achieve true net zero emission electricity from NGCC, extremely low upstream leakage emissions are required. Currently, the methane leakage rate in the US is hundreds of times higher than the permissible rate.

TCM campaign

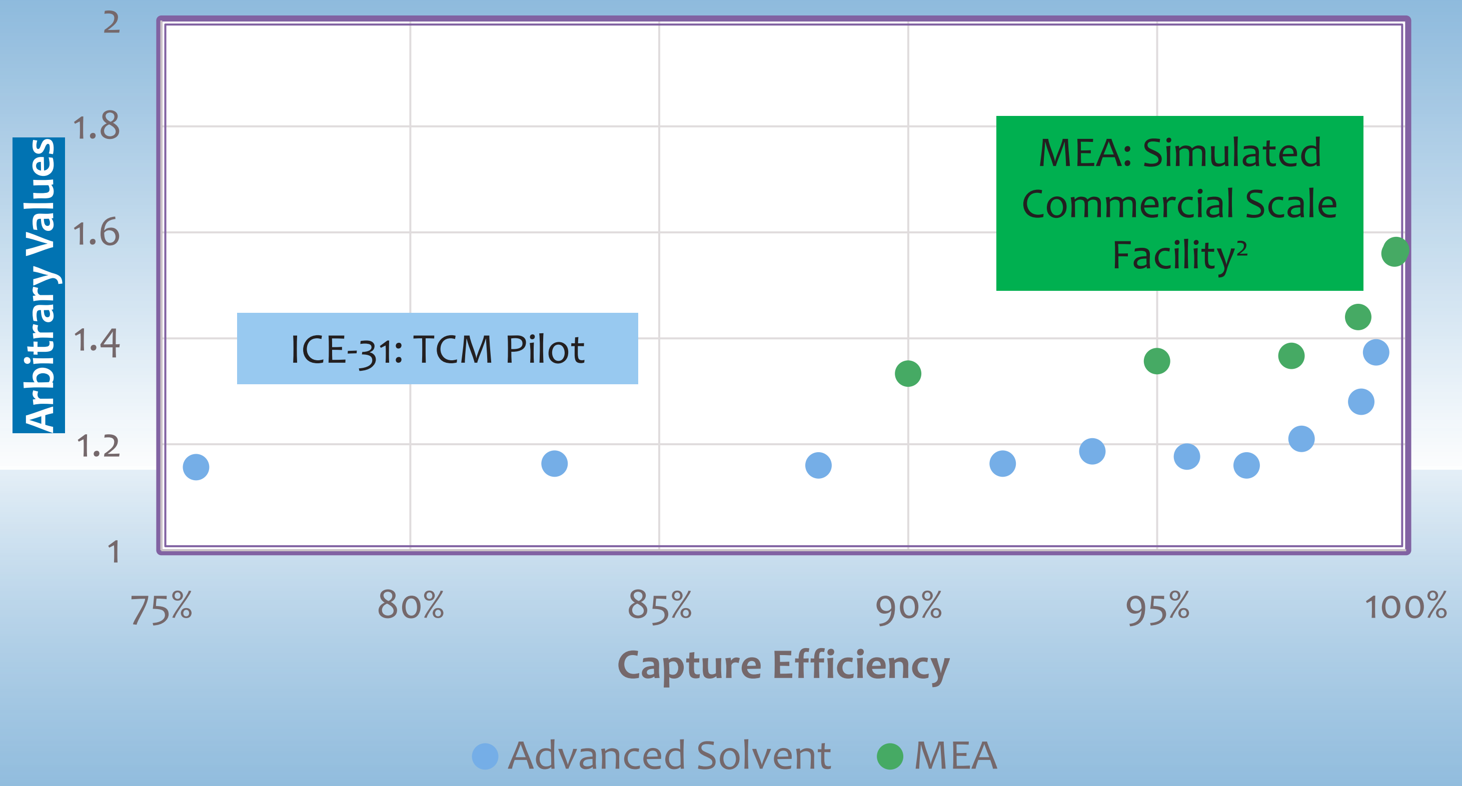
- Validate technology at major demonstration scale with > 10 MW_e
- Validation of process simulation results
- Gather empirical results to feed TEA analysis



1) TCM Website We impart knowledge - TCM (tcmda.com)

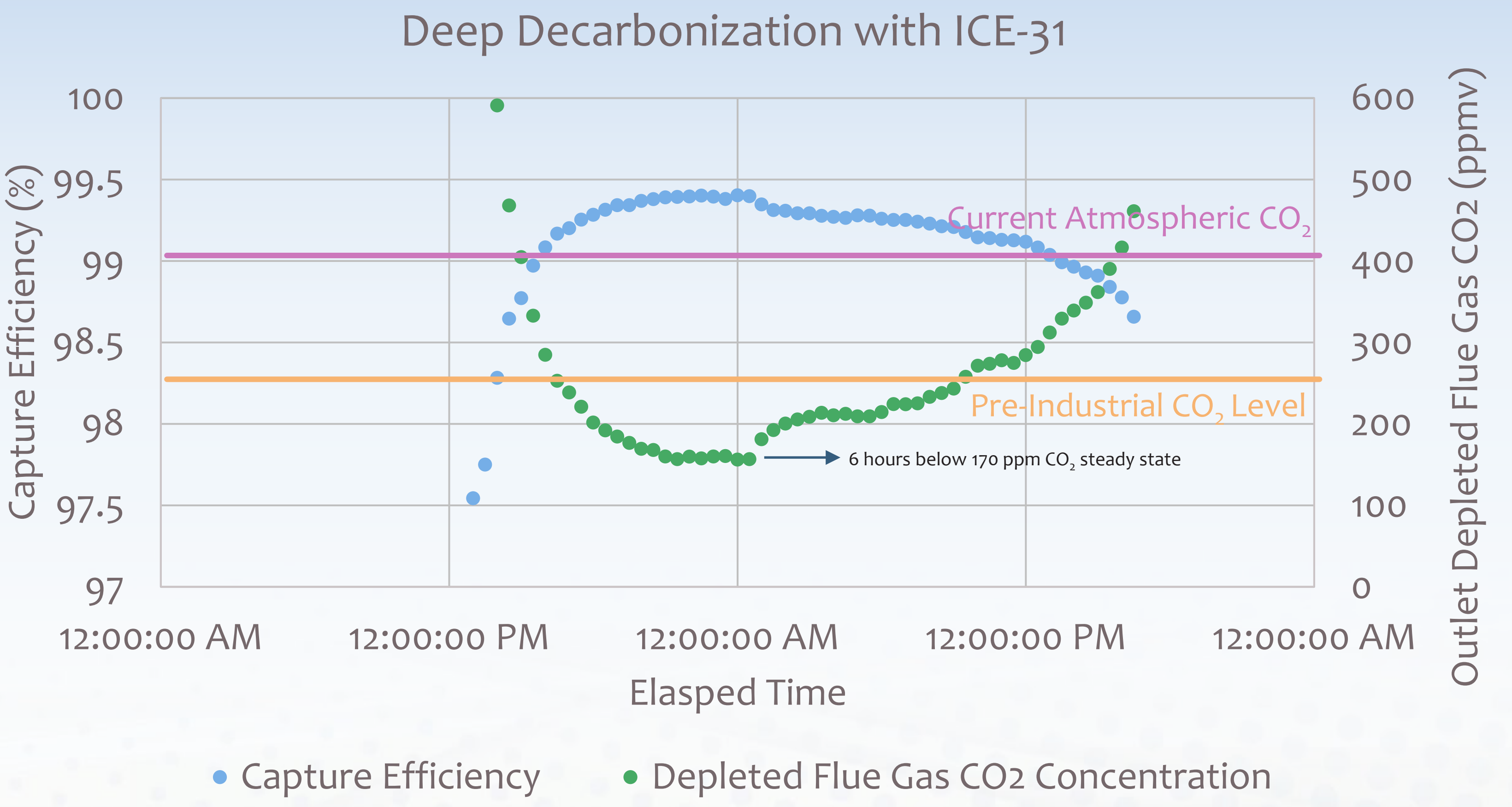
Energy requirements for deep decarbonization

- ION ICE-31 solvent 76 - 99.4% capture efficiency skew, fixed packing height
- MEA simulated capture efficiency from 90 - 100%[2], packing height optimized for high capture efficiencies (TEA optimized)
- Heat loss at TCM of 10% not applied to ICE-31 solvent data for comparison to un-corrected, simulated MEA results



2) Yang Du, Tianyu Gao, Gary T. Rochelle, Abhoyjit S. Bhown, Zero- and negative-emissions fossil-fired power plants using CO2 capture by conventional aqueous amines, International Journal of Greenhouse Gas Control, Volume 111, 2021, 103473, ISSN 1750-5836, https://doi.org/10.1016/j.ijggc.2021.103473.

Above 99% capture efficiency – empirical results at TCM



- 99% capture equivalent to 420 ppm depleted flue gas CO_2 concentration – current atmospheric levels
- 99.4% capture equivalent to 170 ppm depleted flue gas CO_2 concentration – pre- industrial atmospheric levels

ProTreat model, developed by ION

- ProTreat model is a rigorous rate based, first principles model developed for the ICE-31 solvent based on previous pilots and lab analysis. ProTreat model is fully validated by TCM pilot testing data for capture efficiency from 90-99.5%

- Two Modeling strategies:
  - *Fixed absorber height for all capture efficiencies:*
    - starting with baseline case of 98% capture efficiency and maintaining fixed absorber packing height while varying capture efficiency via steam load
  - *Variable absorber height for all capture efficiencies:*
    - optimizing packing height based on absorber performance targeting the same capture efficiencies with intention of minimizing reboiler duty

Techno-economic analysis methodology

- Bottom-up approach
  - Cost represented on unit operation level (e.g., absorber, stripper, compressor, etc.)
  - Equipment sizing, energy requirements, and cost correlations for process equipment such as heat exchangers and pumps are based on and validated by peer-reviewed publications, engineering textbooks, and Aspen Plus simulations
- **Target NGCC plant size: 727 MW-net**
  - Case B31A in DOE/NETL's "Cost and Performance Baseline for Fossil Energy Plants, Vol.1, Rev. 4"
  - Flue gas: 3,927,398 kg/hr (138,406 kmol/hr)
  - Absorber and stripper cross sectional area is scaled from TCM pilot size to target NGCC size based on fluxes

Economic assumptions (NETL methodology)

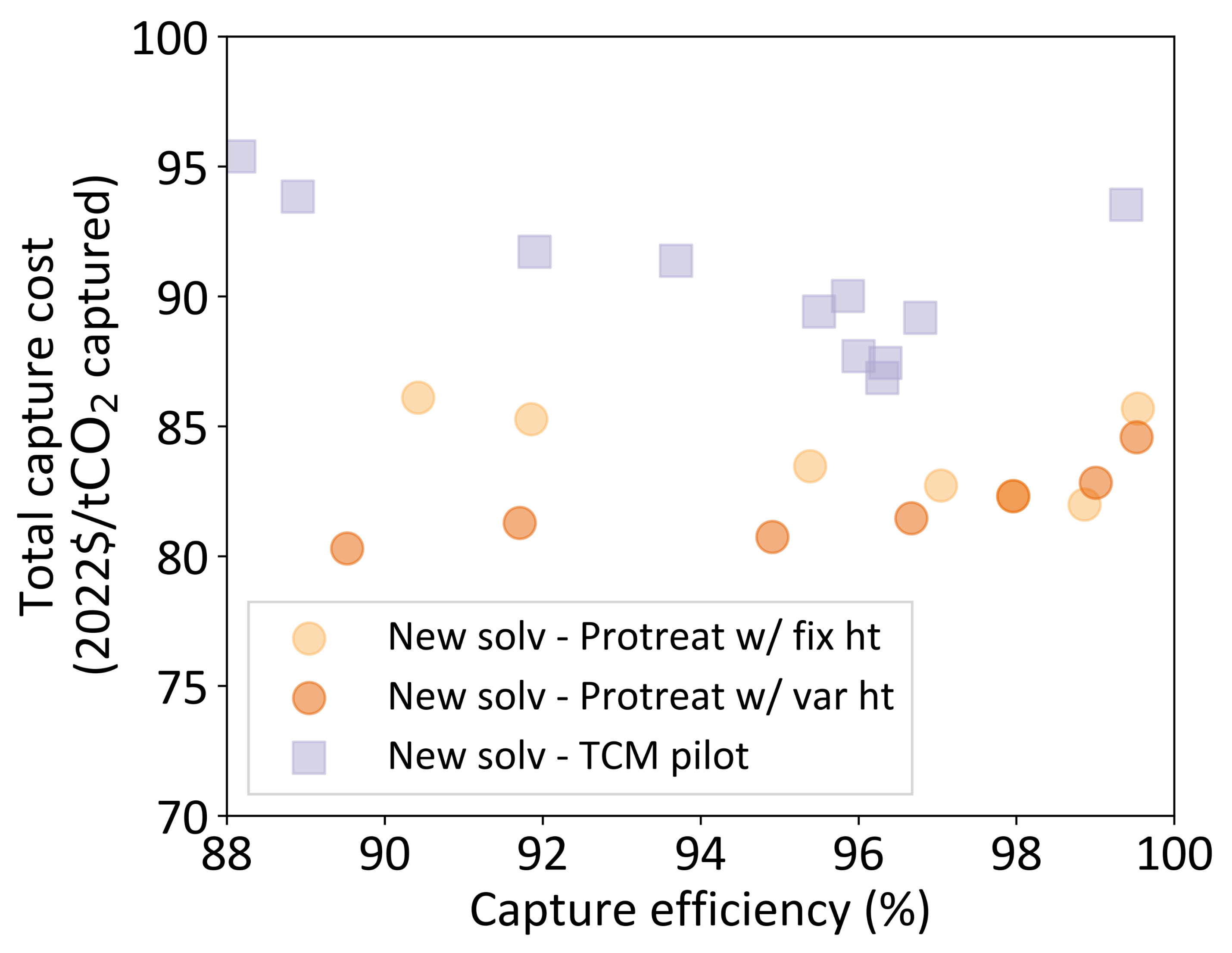
Parameter	Unit	Baseline value
Overall economic assumptions		
Plant operating period	years	30
Capacity factor	-	85%
After-tax discount rate (real)	-	4.72%
Escalation rate (real)	-	0%
Fixed cost assumptions		
EPC contractor service cost	% BEC	20%
Process contingency	% (BEC + EPC)	15%
Project contingency	% (BEC + EPC)	23%
Owner's cost	% TPC	21.07%
TASC/TOC factor	-	1.093
Effective capital charge factor	1/yr	0.0773
Total annual fixed O&M cost	% TPC	3.1%

Note: Cost year **2022 USD**

Capture cost curve

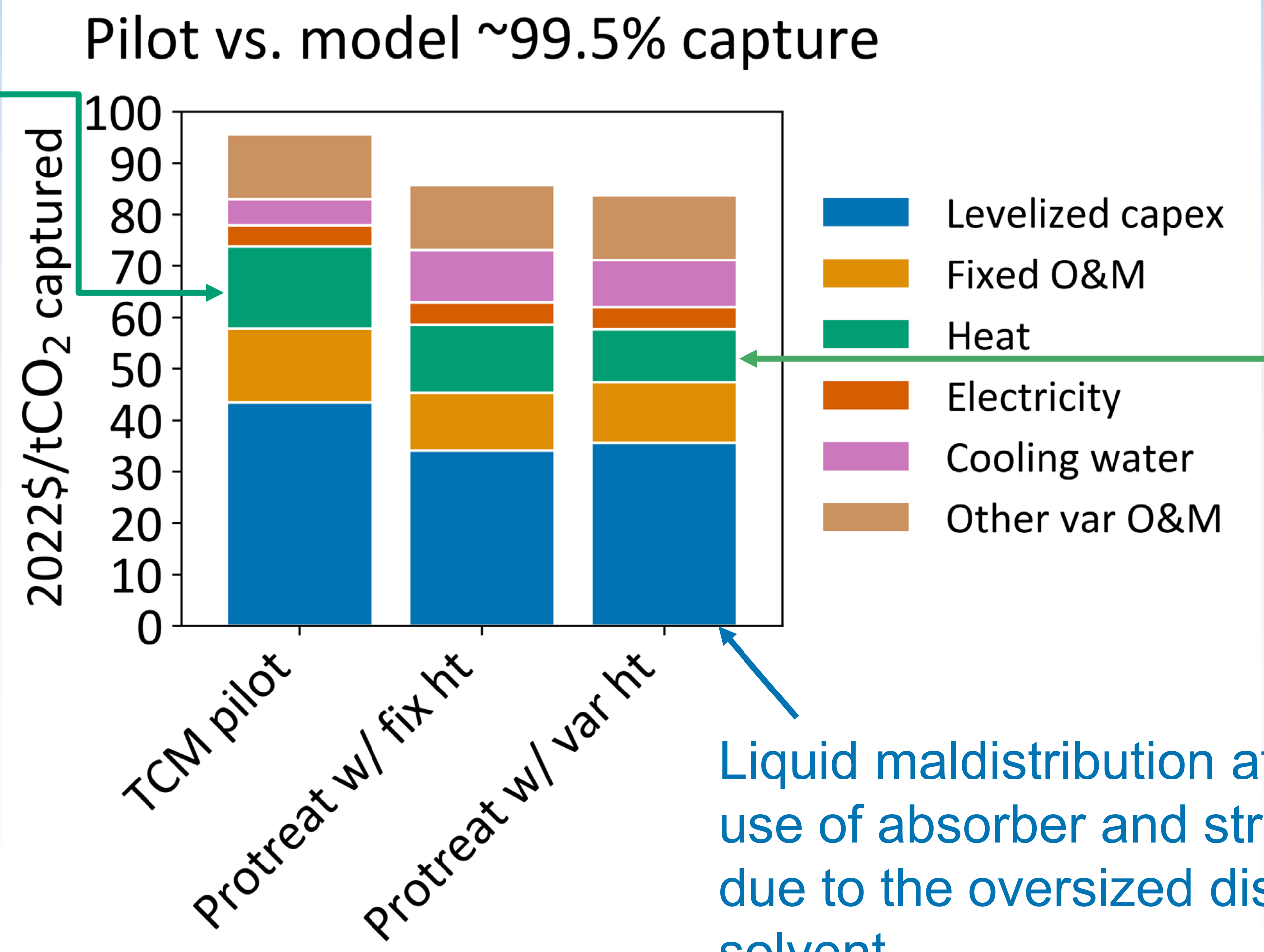
- **High performance case with two sets of ProTreat modeling data provided by ION:**
  - Reflects “more ideal” solvent performance in commercial scale design

- **Low performance case:**
  - “New solv – pilot” = Scaled TCM results to typical NGCC scale
  - Reflects solvent performance *“less ideal”* due to TCM plant design (oversized due to improved new solvent kinetics) and feed gas condition



ProTreat modeling results is more capital- and energy-efficient than TCM pilot tests

ProTreat model has better heat integration.

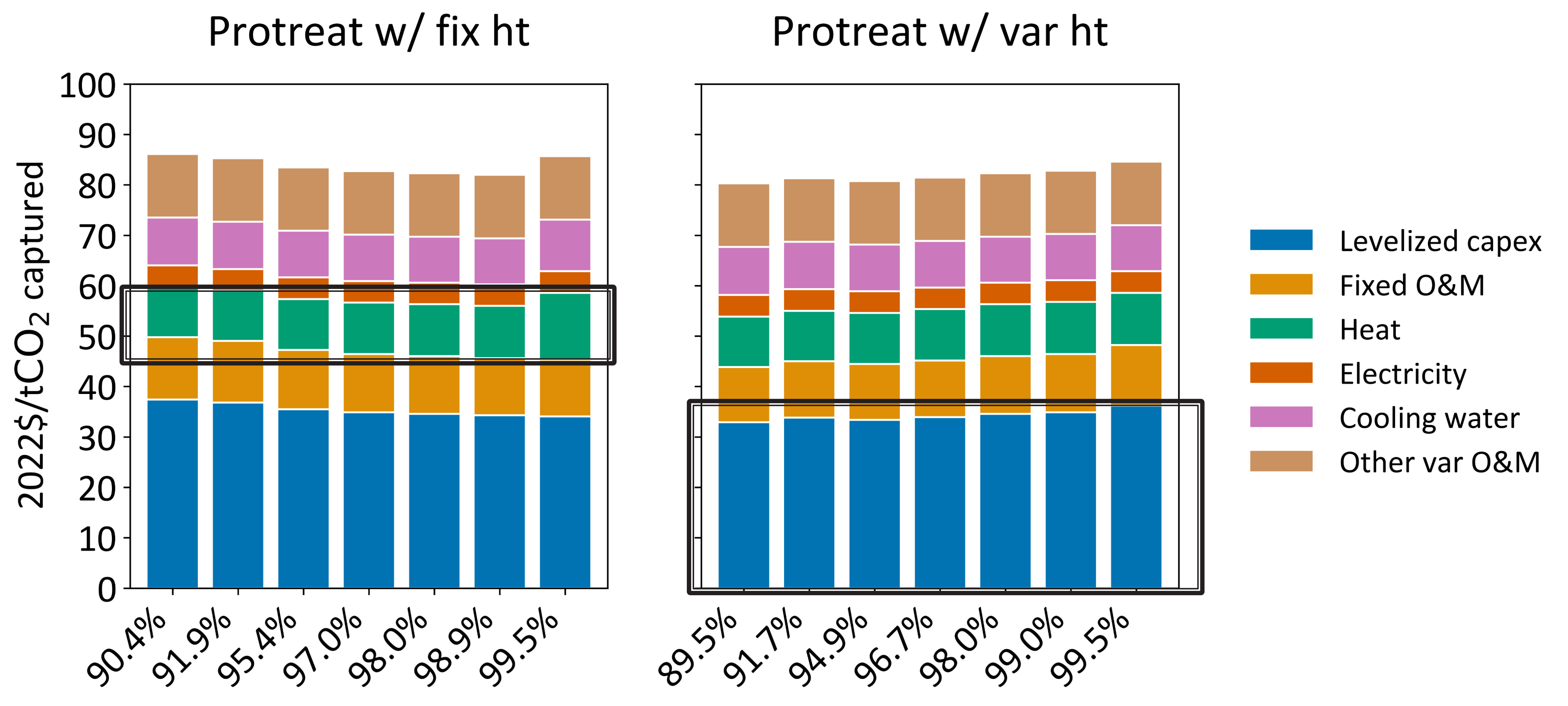


Heat loss associated with the relatively older equipment settings in TCM.

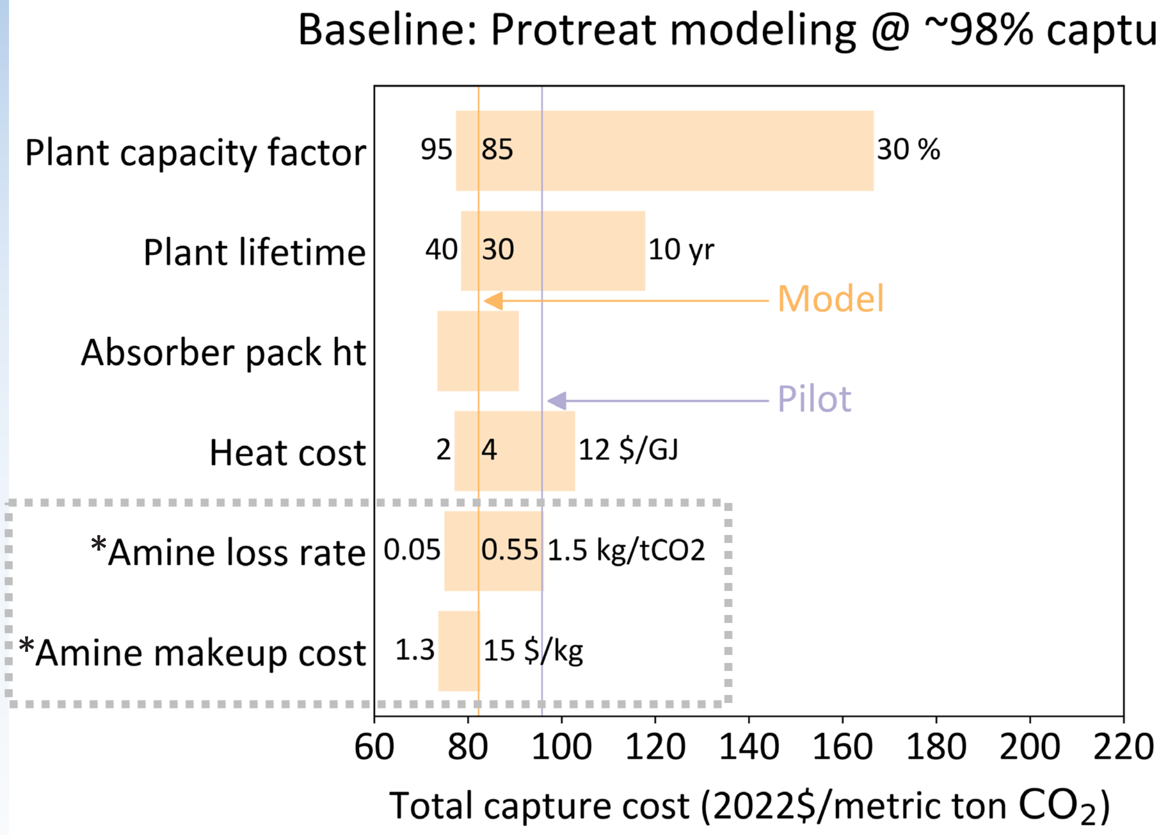
Liquid maldistribution at TCM → inefficient use of absorber and stripper contact area due to the oversized distributors for ICE-31 solvent.

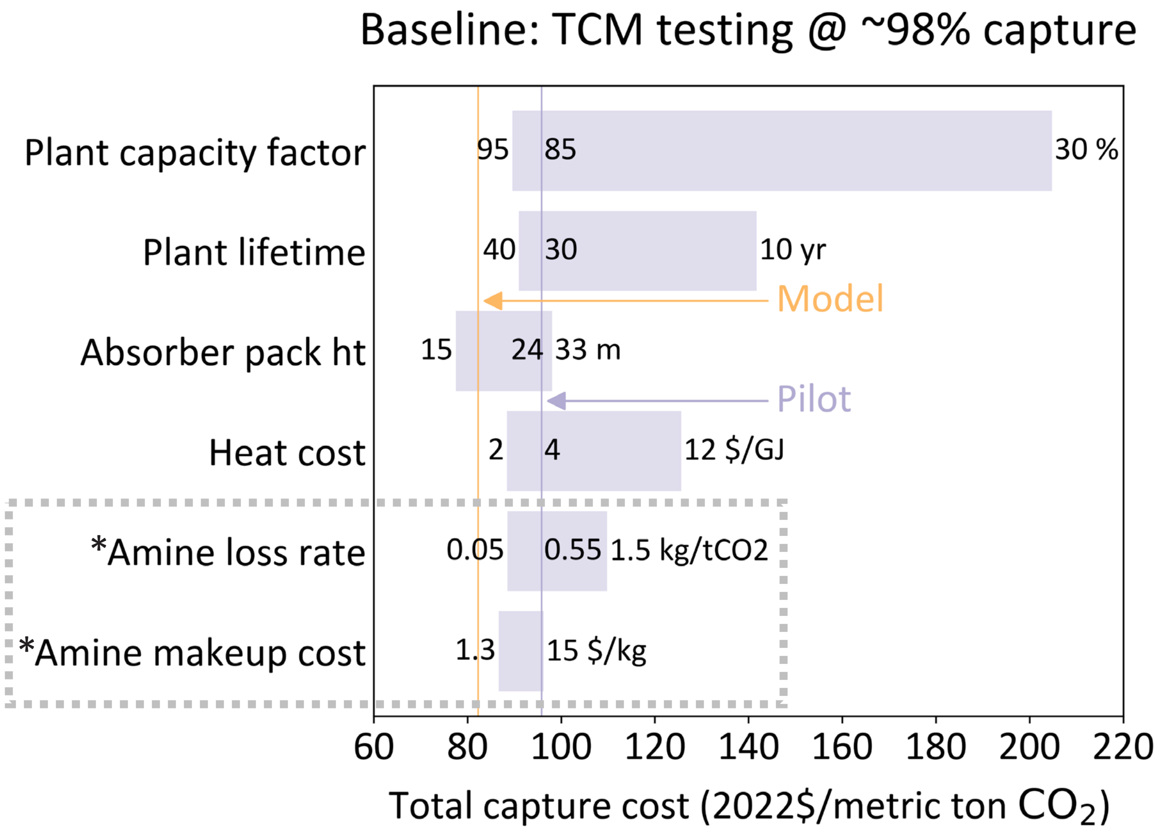
Note: Model results are based on process modeling using optimal absorber performance for commercial-scale system (727 MW-net NGCC).

Cost breakdown – ProTreat modeling with fixed vs. variable height



Sensitivity analysis

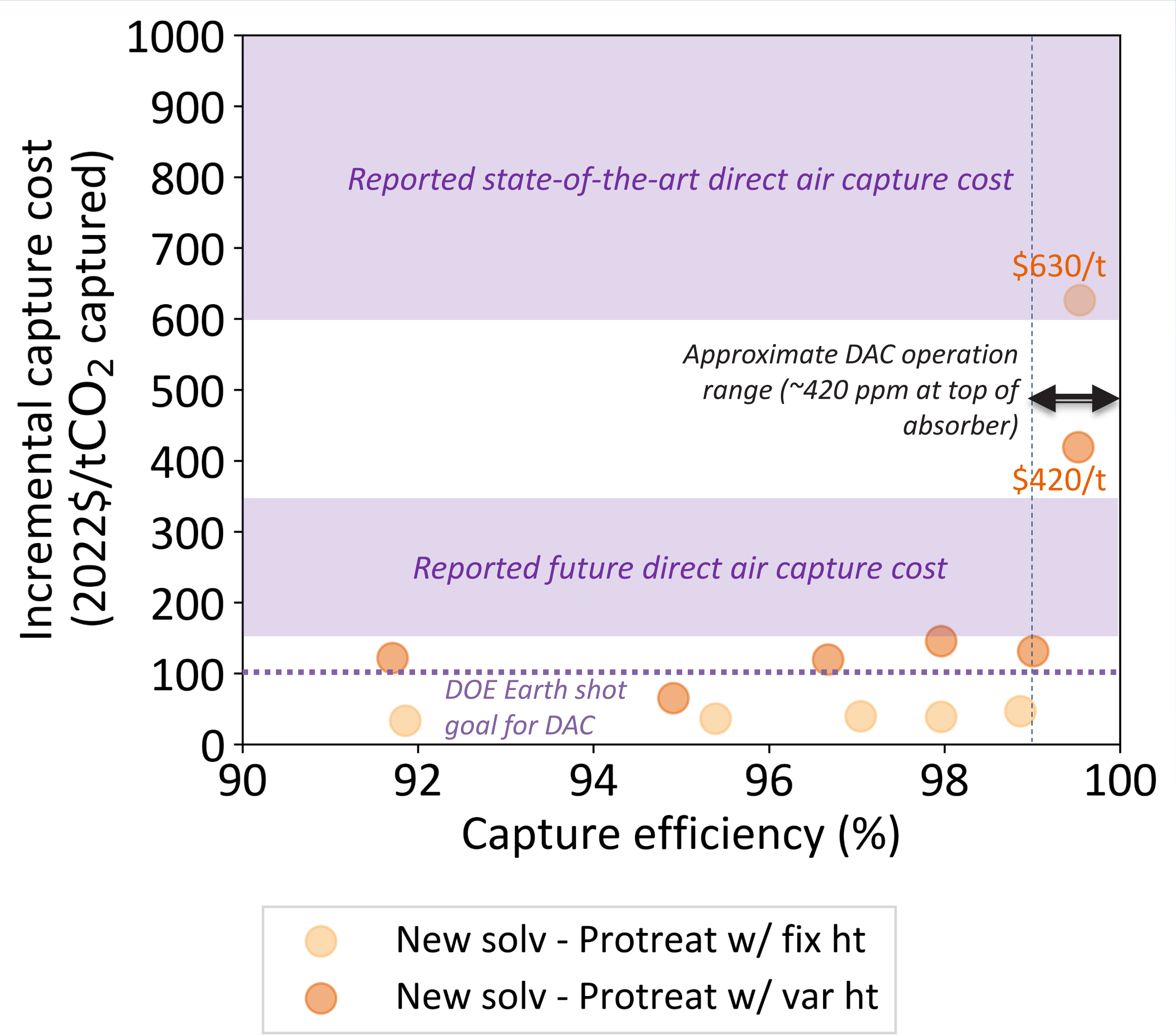




**Note: Amine loss rates and costs are based on public solvent data (see Back Slide).*

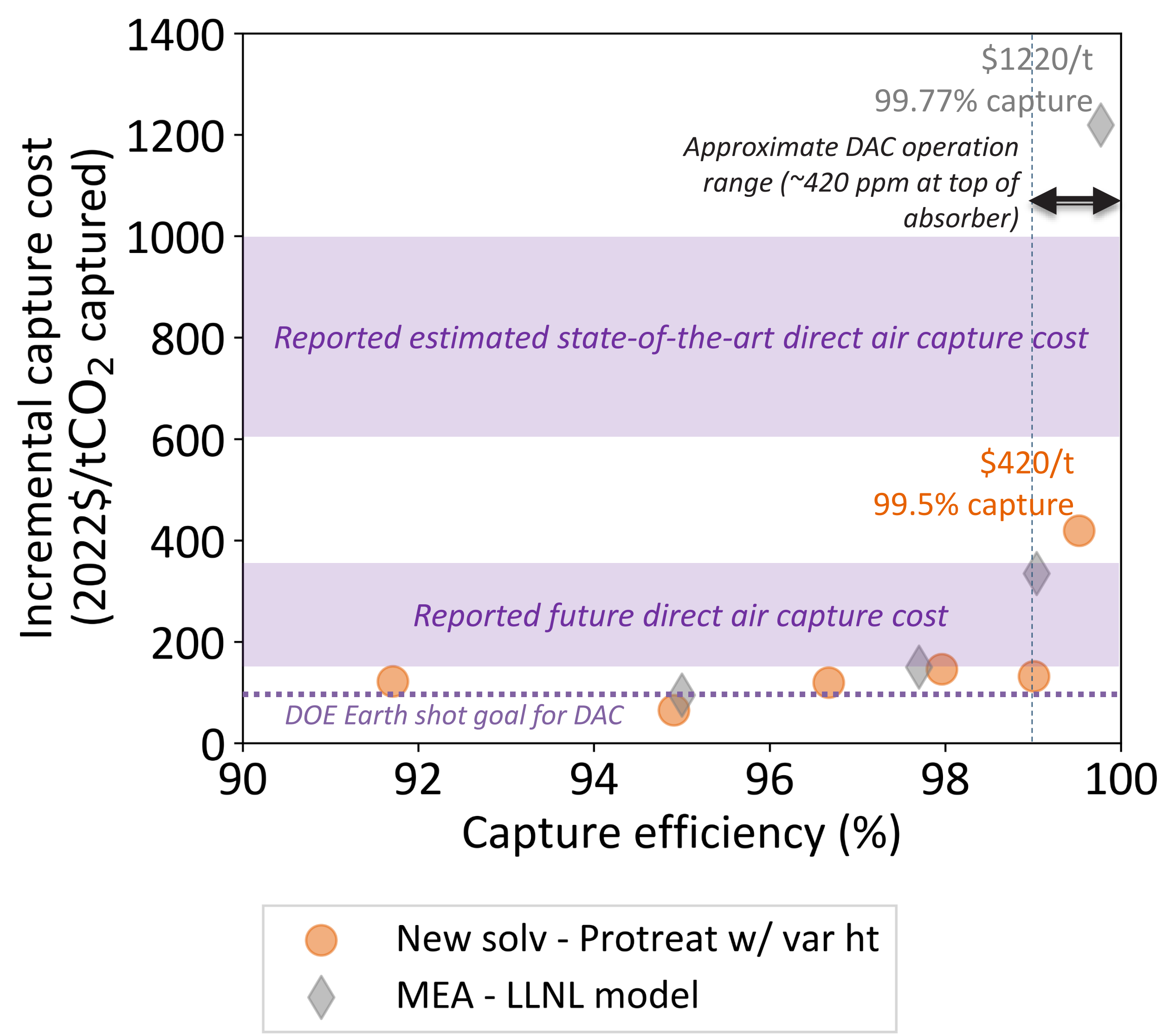
- Total capture cost is most sensitive to plant capacity factor
- Note: 85% chosen as baseline to align with NETL Fossil Baseline
  - *This is optimistic compared to average capacity factors for US power plant* in past 10 years (EIA): nuclear 90–93%; NGCC 48–57%)

Incremental capture cost from 99% to 99.5% of the ICE-31 solvent is comparable to current literature state of art direct air capture cost



- "Above 99% capture" = Capture from air
- Different operation strategy to achieve high capture efficiency (*<u>with fix absorber height</u> versus <u>with variable absorber height</u>*) can lead to quite different incremental cost for "capturing CO_2 from air"
- "Last 1% capture" of typical NGCC plant, equals ~22,000 tonne CO_2/year

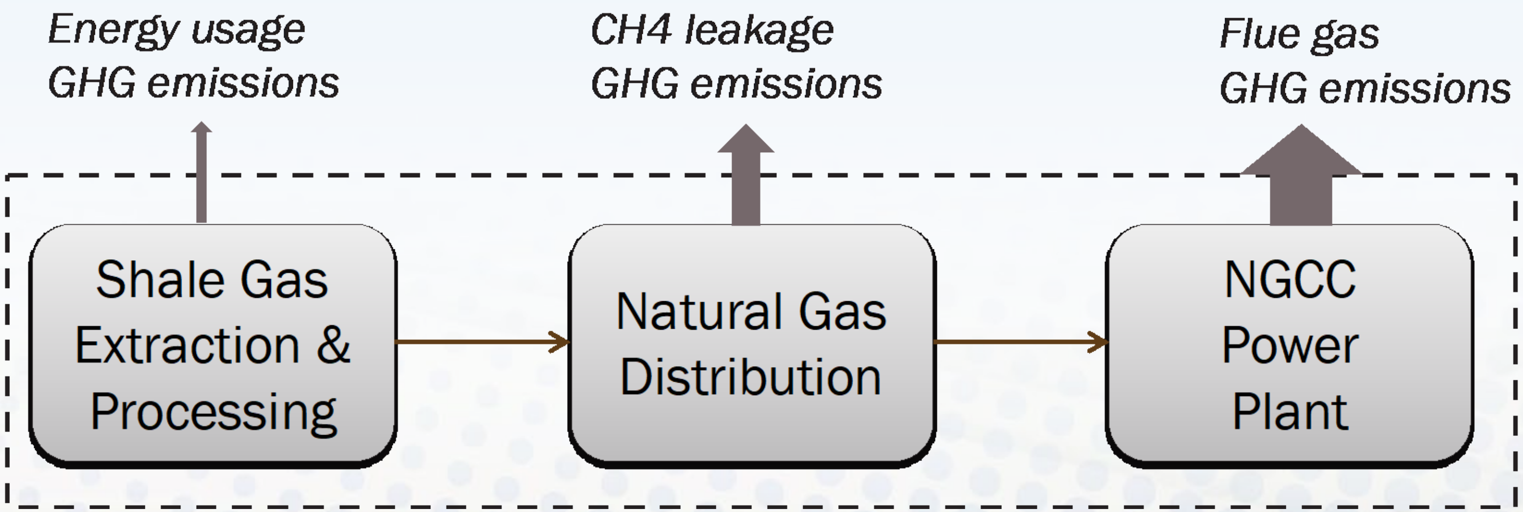
The incremental capture cost compares ION ICE-31 solvent with the MEA case



- The MEA data is based on LLNL process modeling. The model has been validated for low capture efficiency ranges (<95%) but lacks experimental validation at higher capture ranges.
- Solvent makeup costs ($/tonne CO_2) are assumed to be fixed across all capture efficiencies for each solvent, due to a lack of publicly available experimental data at high capture efficiencies.

What is the permissible CH_4 leakage for achieving net-zero electricity from NGCC

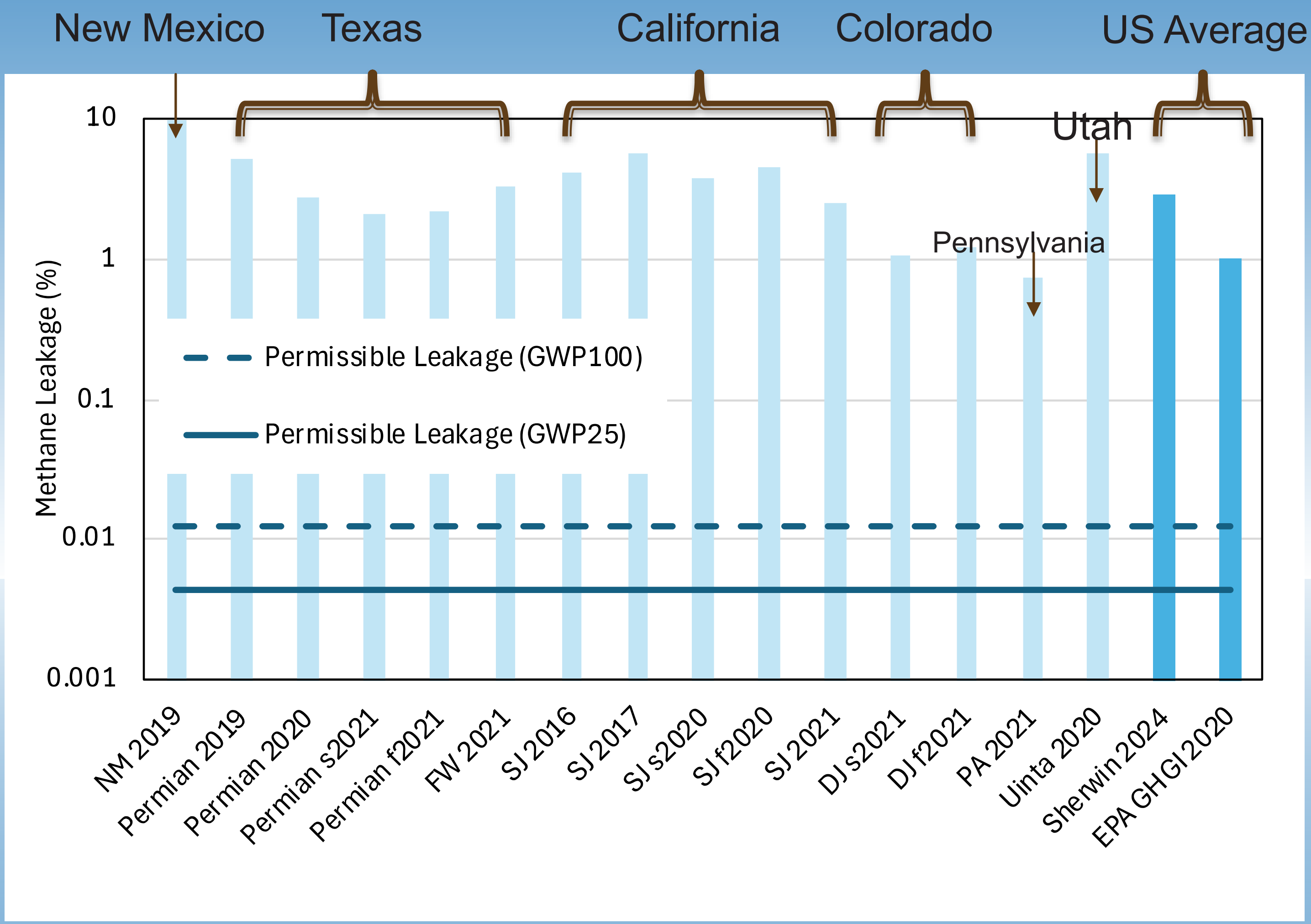
- Last 1% NGCC flue gas capture = DAC
- Last 1% NGCC flue gas capture emissions = Total allowable emissions from upstream CH_4 leakage
  - Assume all energy related emissions can be mitigated by renewables; so upstream emissions only came from CH_4 leakage



Current CH_4 leakage are hundreds of times higher than “permissible” for net zero electricity

- Maximum percent upstream methane “permissible” for true net zero emission electricity is:
  - 0.004% for GWP 25
  - 0.01% for GWP 100

- Recent estimates for US average CH_4 leakage is 1-3%



Values from Sherwin et al., *Nature*, 2024

Thank you!

Questions?

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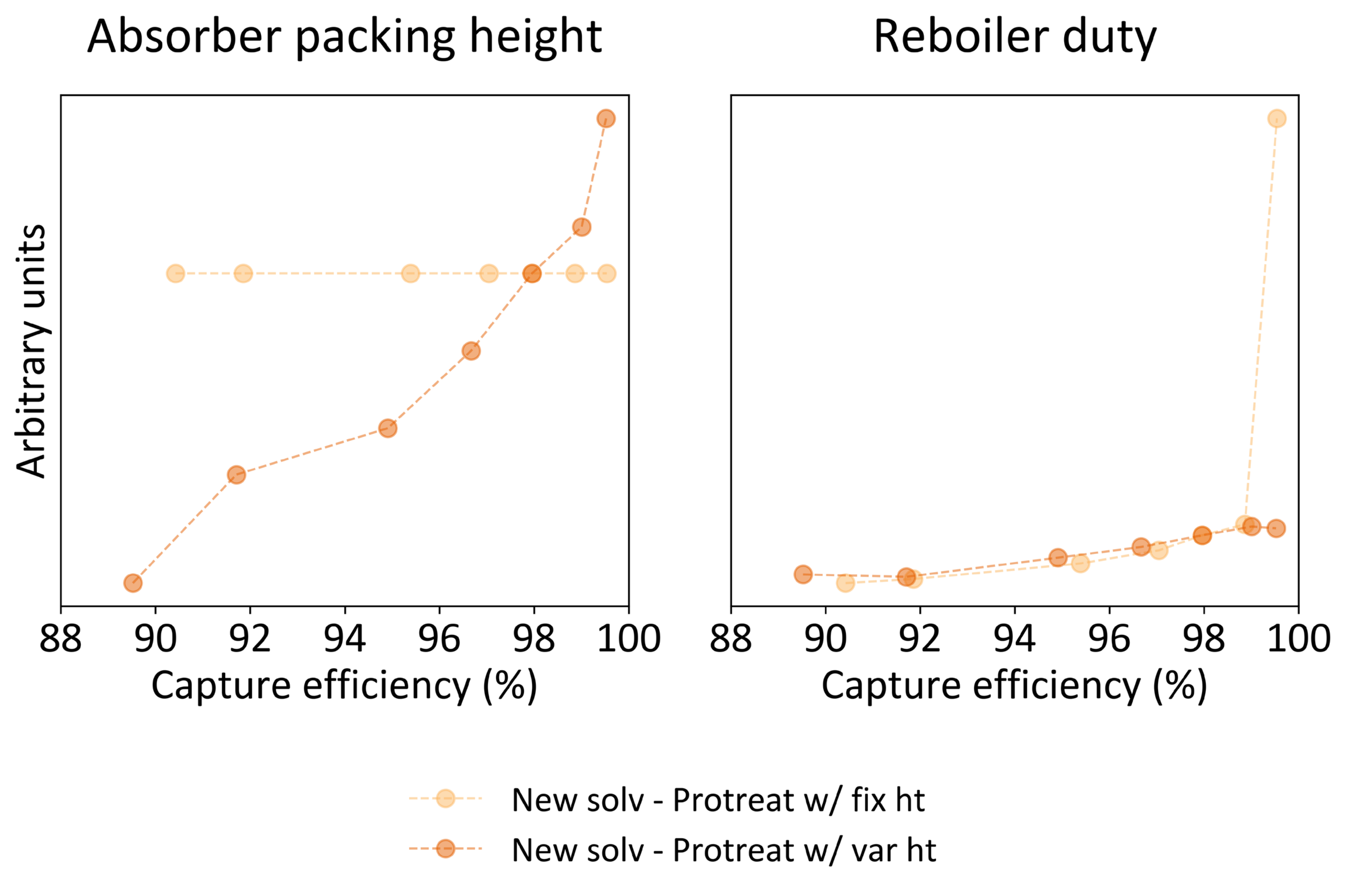
Sensitivity assumptions for amine loss rates and costs

- **Amine loss rate**
  - Base = CESAR-1 = 0.55 kg/tCO_2 (Manzolini et al., 2015)
  - Low = PZ = 0.05 kg/tCO_2 (Manzolini et al., 2015)
  - High = MEA = 1.5 kg/tCO_2 (Manzolini et al., 2015; Brandl et al., 2021)
- **Amine makeup cost**
  - Base = CESAR-1 = $14.7/kg (Manzolini et al., 2015; average cost weighted by PZ and AMP loss rate)
  - Low = MEA = $1.3/kg (Du et al., 2021)
  - High = AMP = $15.1/kg (Manzolini et al., 2015)
- **Heat cost is calculated based on recent 5 years industrial sector natural gas prices**
  - Base: US average; Low: TX; High: CA (EIA)

Compare two ProTreat modeling approach to achieve high capture efficiency



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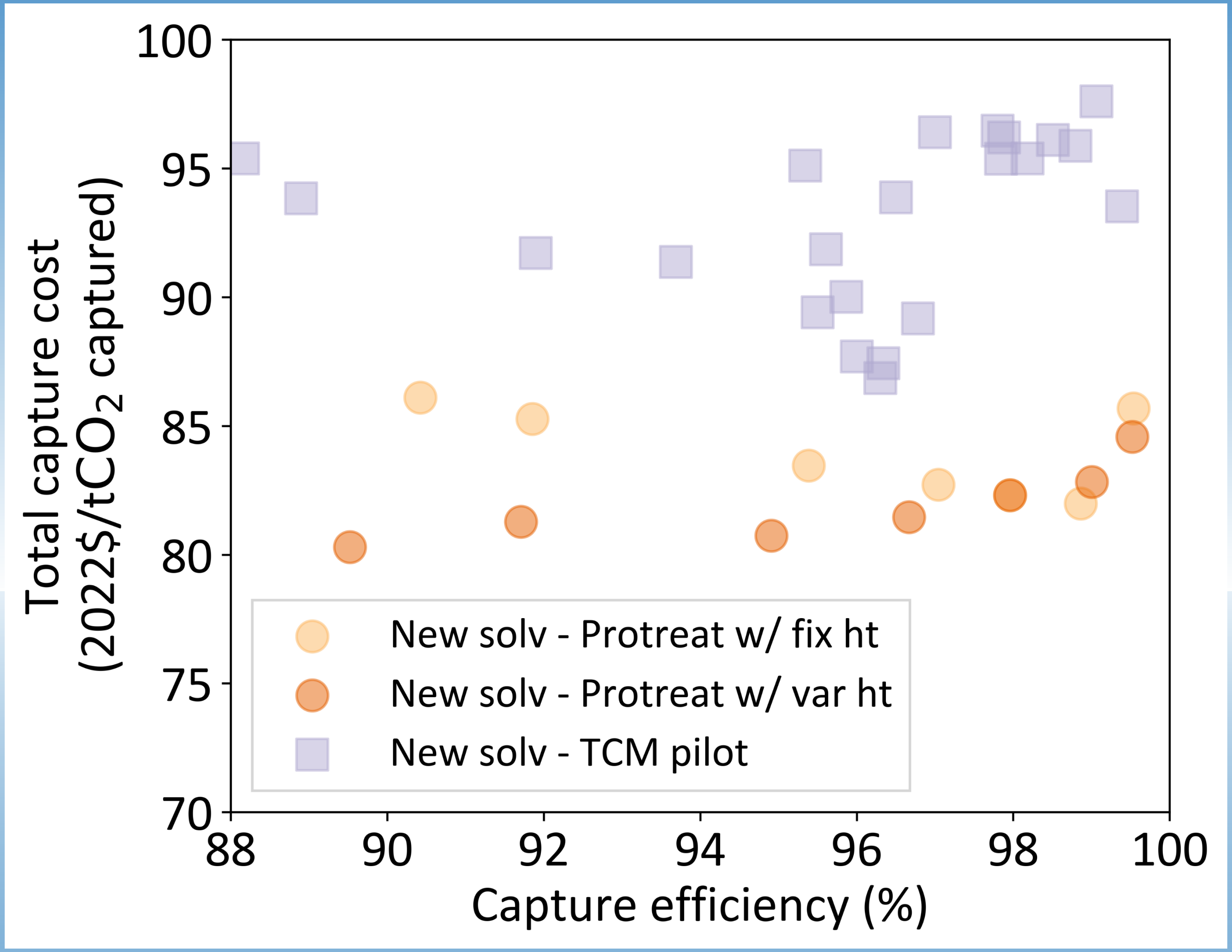
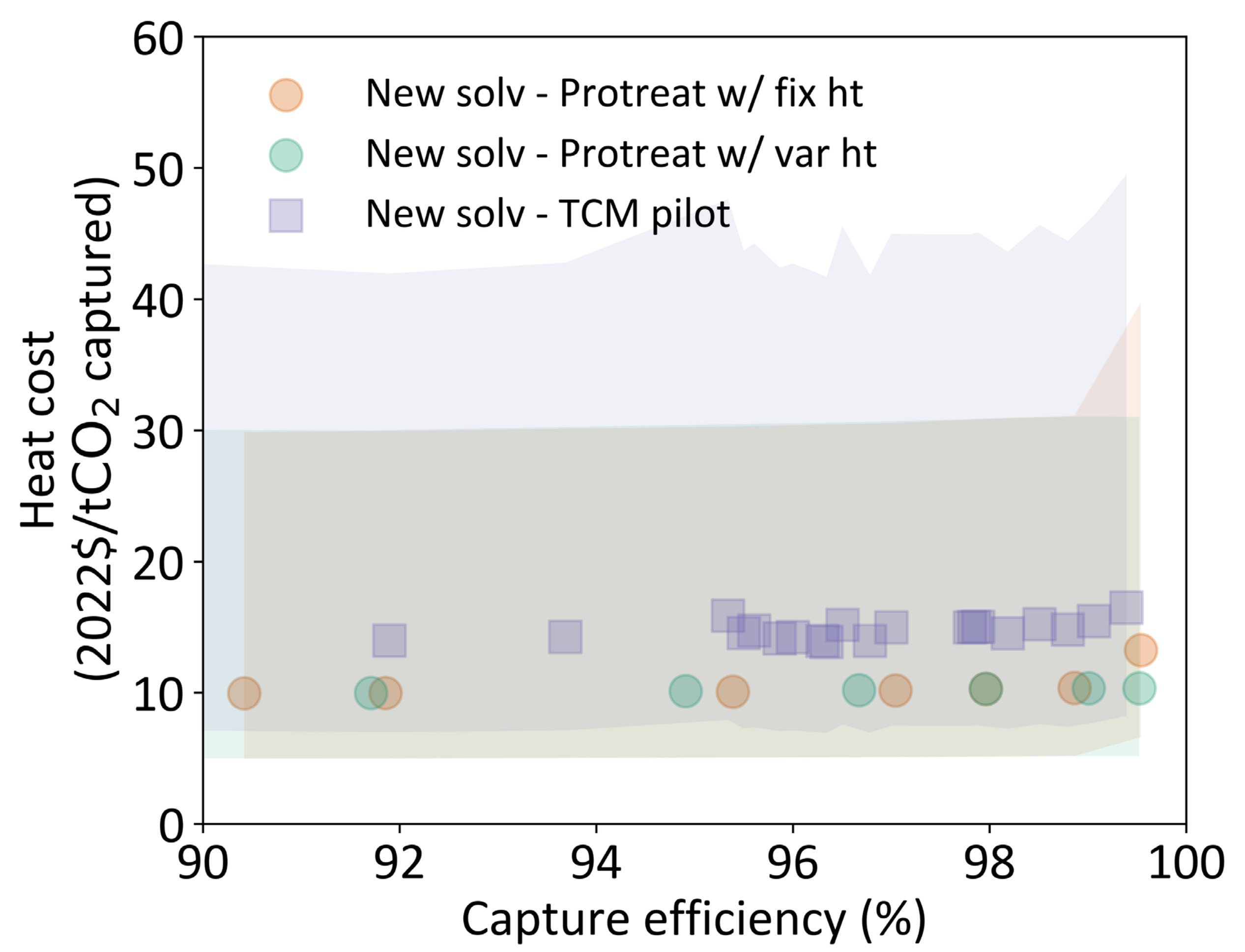
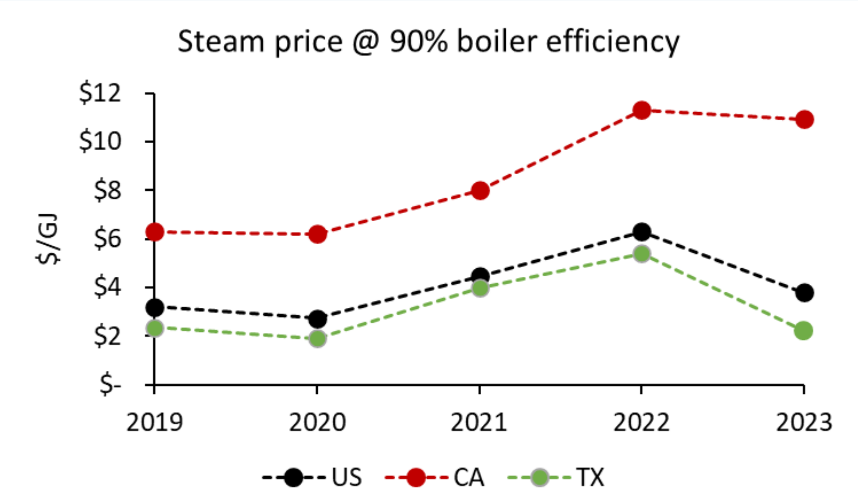
ProTreat results not filtered



Capture cost can be sensitive to volatility in steam price



- TCM pilot represents TCM reboiler duty without heat correction
- Heat cost based on recent industrial sector natural gas prices
  - 2019–2023; US average, CA, TX (EIA)
  - Low-High steam price: $2-$12/GJ

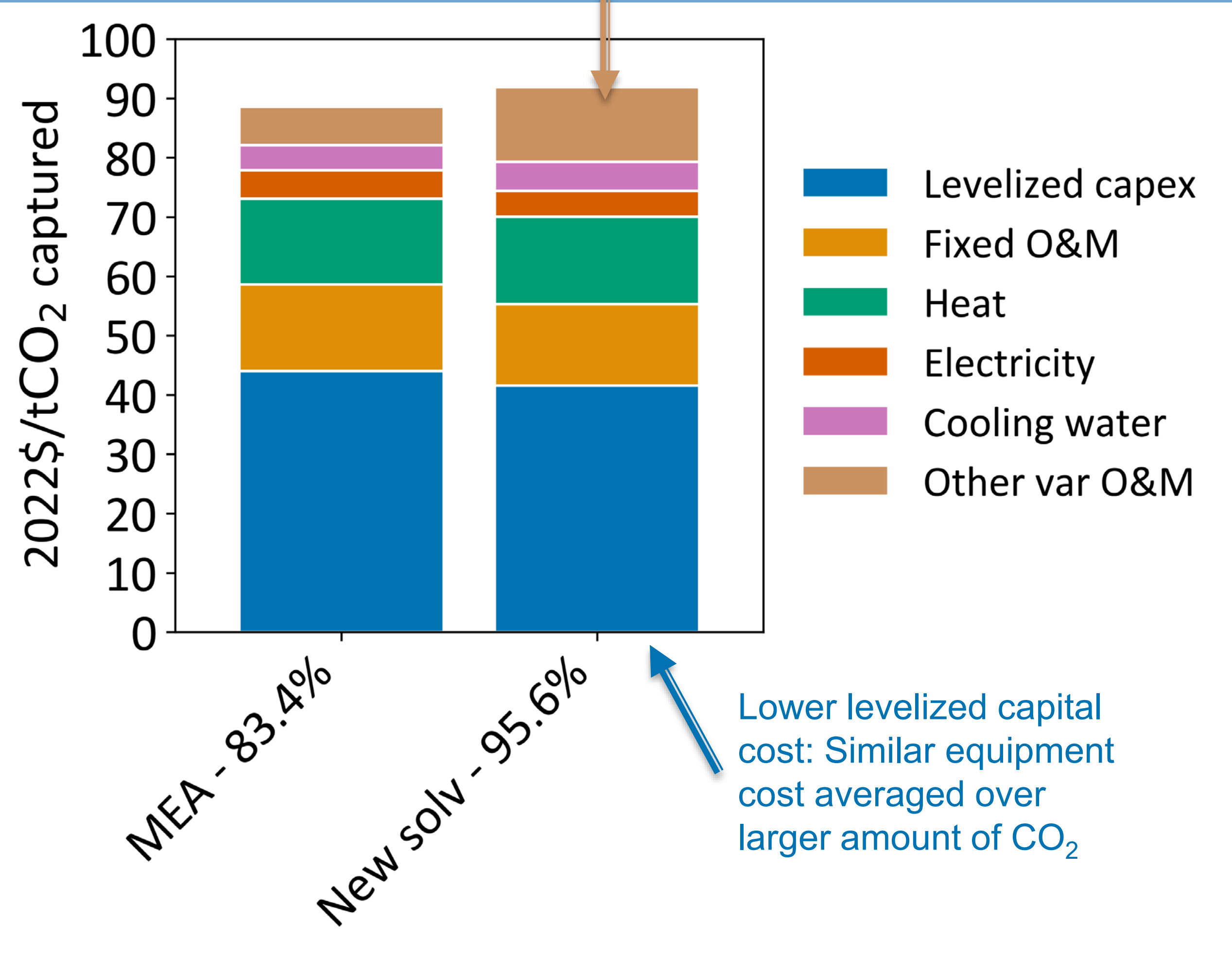


Breakdown cost comparison using MEA in TCM under the same operational conditions

- MEA Baseline = 2015 MEA campaign at TCM
  - Data from Faramarzi et al., 2017

- ICE-31 solvent can achieve higher capture efficiency (~95%) than MEA (~83%) using similar equipment and at similar operating conditions at TCM

Inflated amine makeup cost
(if assuming CESAR-1 cost and loss rate)



Lower levelized capital cost: Similar equipment cost averaged over larger amount of CO_2