Zero- and Negative-Emissions Fossil-Fired Power Plants Using Post-Combustion CO_2 Capture

Tianyu Gao* and Abhoyjit Bhown

Meeting on Net Zero Flexible Power: High Capture Rate
Philadelphia, PA
June 6-7, 2024

*tgao@epri.com

CO_2 Capture Rate – 90% or 99%?

- CO_2 capture processes have been generally designed to capture ~90% of the CO_2 from power plant flue gas
  - This ~90% capture rate standard is often considered to give the lowest unit CO_2 capture cost (\$/t CO_2 captured)
- Most integrated assessment models limit CO_2 capture to 90%, and assume the remaining ~10% (*~1 Gt/y for the current global power generation mix*) needs to be offset by negative-emissions technologies, such as direct air capture, in order to achieve net zero
  - For lowest cost for economy-wide net-zero emissions, the optimum CO_2 capture rate for flue gas can be higher than 90%

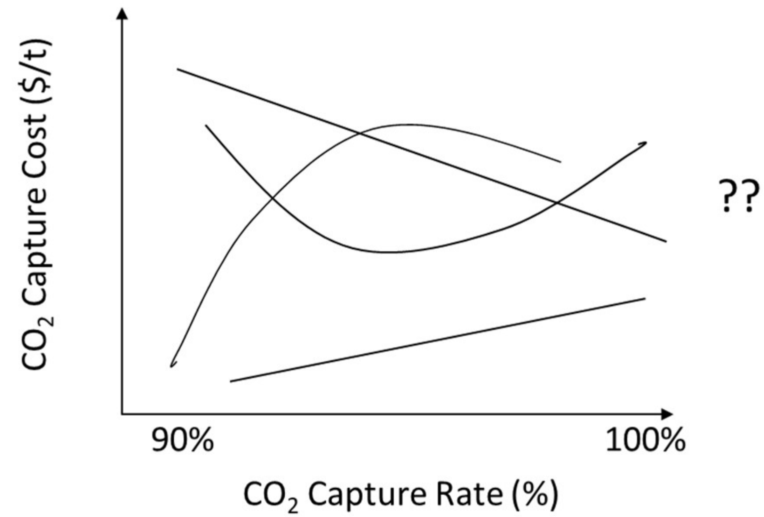
Pilot Demonstration of High CO_2 Capture Rate

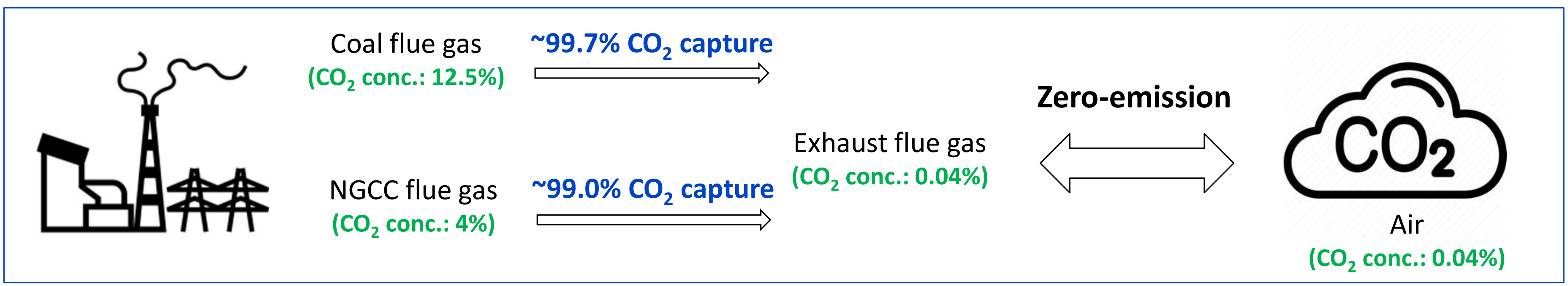
Pilot Plant	Flue Gas Condition	CO_2 Capture Rate	Solvent	Time
NCCC	Coal	99.9%	MEA	2018
	Coal	99.1%	PZ	2019
	NGCC	95.8%	PZ	2020
TCM	NGCC	~99%	MEA	2021
	NGCC	~98%	PZ/AMP	2021
	Coal	97.7%	NAS	2022
	NGCC	99.8%	NAS	2022

BA0

Objective of This Study

- Obtain a cost curve from 90% to nearly 100% CO_2 capture
- Potentially refine role of CCS in integrated assessment models and role of fossil fuels in future energy mix
- Details in Y. Du, T. Gao, G. T Rochelle, A.S. Bhown *Int J of GHG Control*, **111**, 105473 (2021)





"Zero Emission" means quantity of CO_2 in air intake equals quantity of CO_2 in exhaust flue gas discharged

Slide 4

BA0 We didn't define zero emission as ppm in = ppm out since the flowrates in and out can be different. Instead, we used the quantity of CO_2 in = quantity of CO_2 out (using a ratio of CO_2/N_2).

Bhown, Abhoyjit, 2024-06-03T21:36:07.659

Methodology

Solvent and model: MEA model:

- 30 wt% MEA, Developed by Carbon Capture Simulation for Industry Impact ($CCSI^2$) in Aspen Plus

Process optimization parameters:

- Solvent flow rate
- Absorber height
- Lean loading
- Temperature of solvent
- Solvent intercooling configurations

Reference cases:

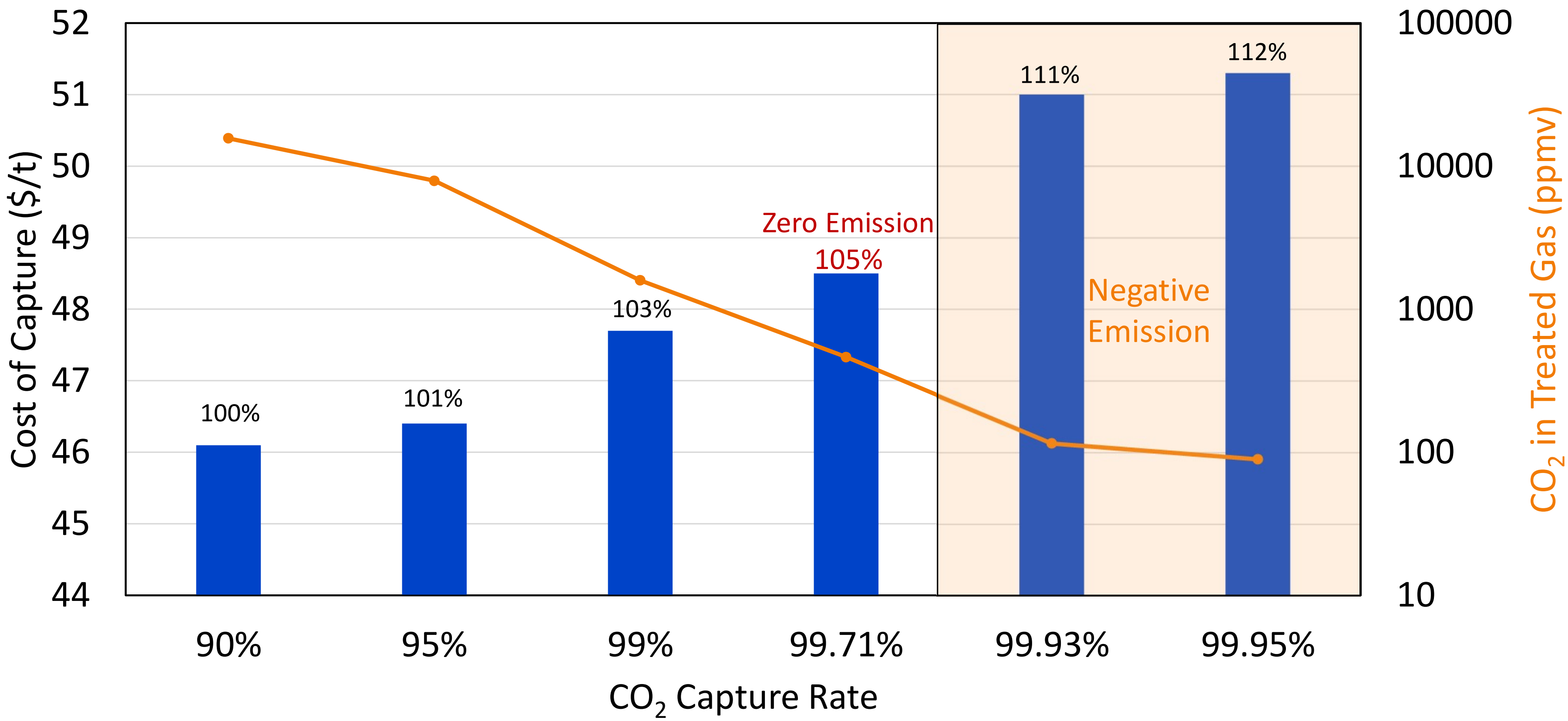
- 650 MW (net) supercritical coal-fired power plant — Case B12A in DOE/NETL 2019 baseline report
- 646 MW (net) NGCC power plant — Case B31A in DOE/NETL 2019 baseline report

Cost methodology:

- DOE/NETL 2019 guideline (Revision 4)

BA0

CO_2 Capture Cost at Different Capture Rates – Coal-fired plants



Process configuration: Absorber with conventional solvent intercooler; Simple stripper

For coal plants to achieve zero-emission, the cost is ~5% higher than that at 90% capture
To achieve negative emission, the cost is ~12% higher

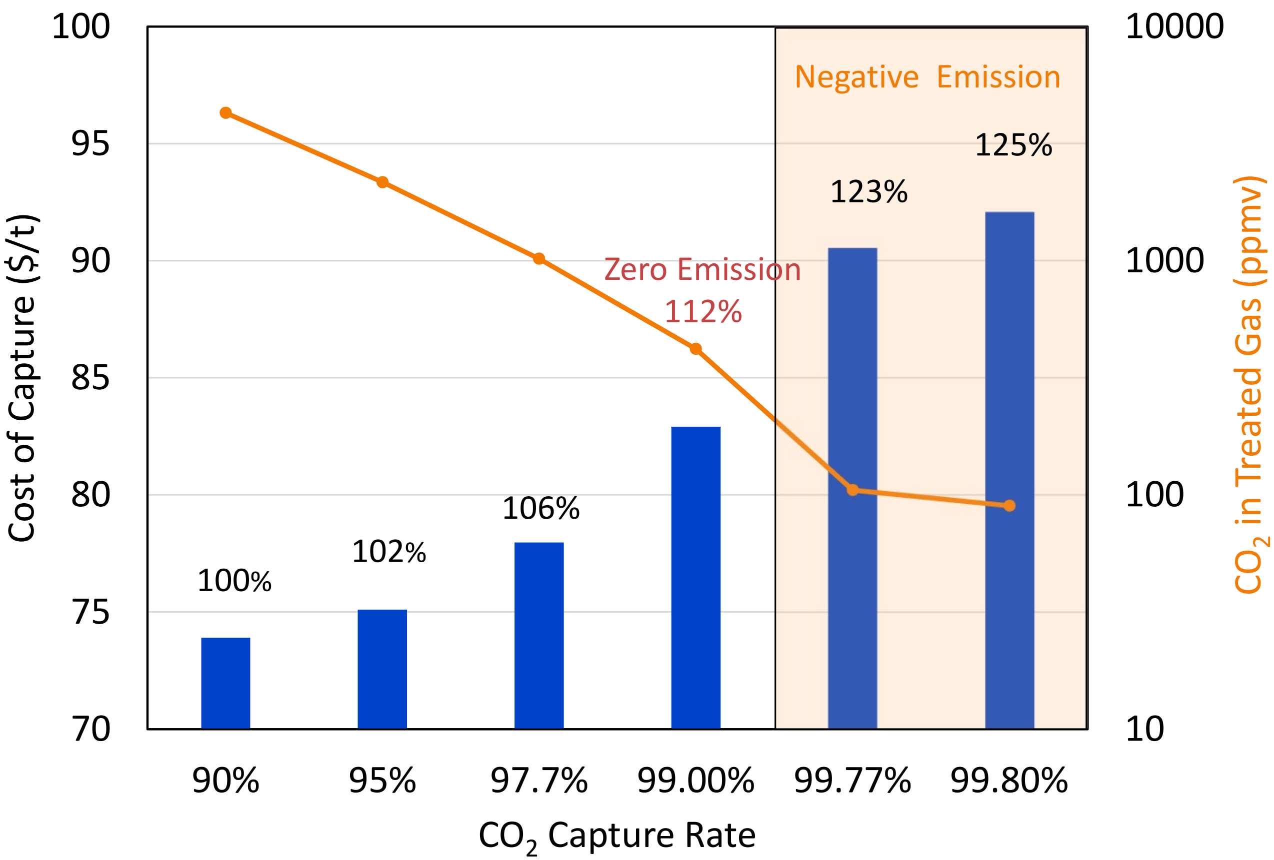
EPRI

Slide 6

BA0 Be sure to point out negative emissions too and what that means.

Bhown, Abhoyjit, 2024-06-03T21:36:35.297

CO_2 Capture Cost at Different Capture Rates – NGCC



- For NGCC to achieve zero-emissions, the cost is 12% higher than that at 90% capture. For negative emissions, the cost is ~25% higher.
- The larger cost penalty is due to the low L/G in the NGCC case which makes the simple intercooling not as efficient for temperature control

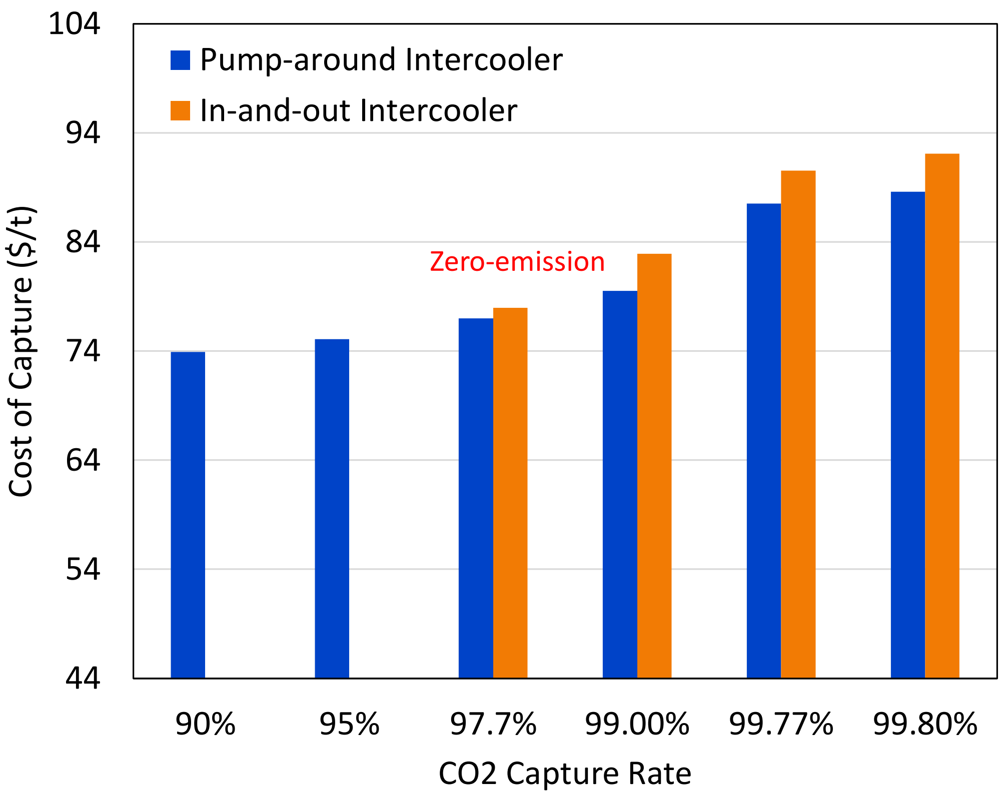
Process configuration: Absorber with simple solvent intercooler

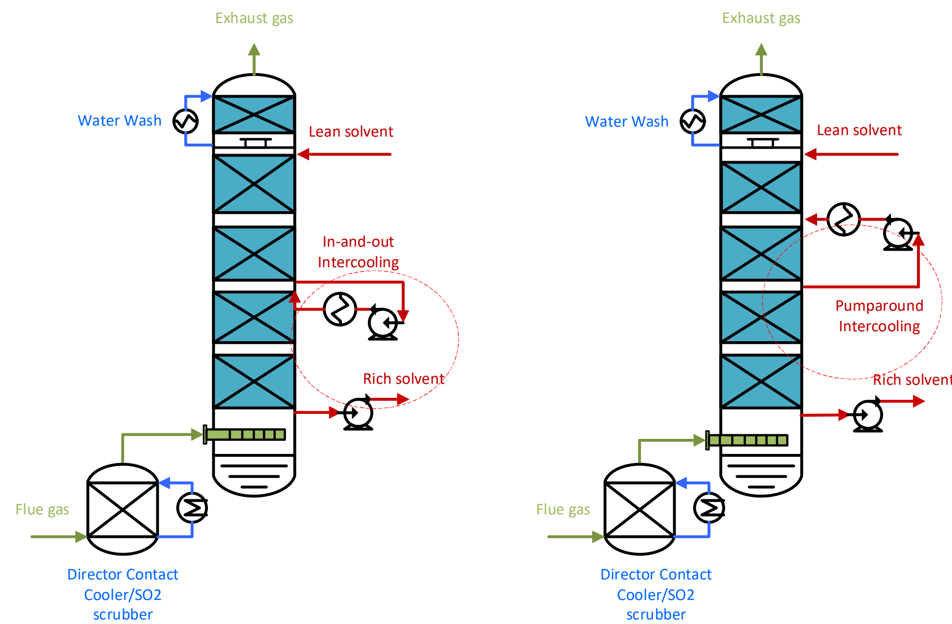
Slide 7

BA0 Provide numbers for highlighted text

Bhown, Abhoyjit, 2024-06-03T21:38:10.225

Intercooling configurations for Capture from NGCC



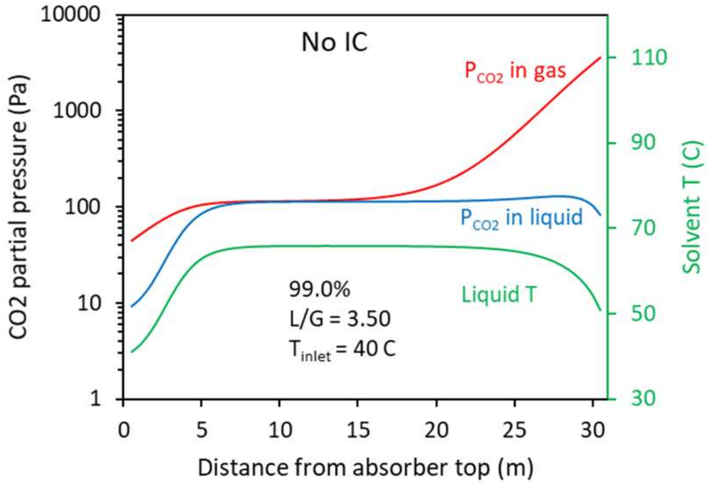


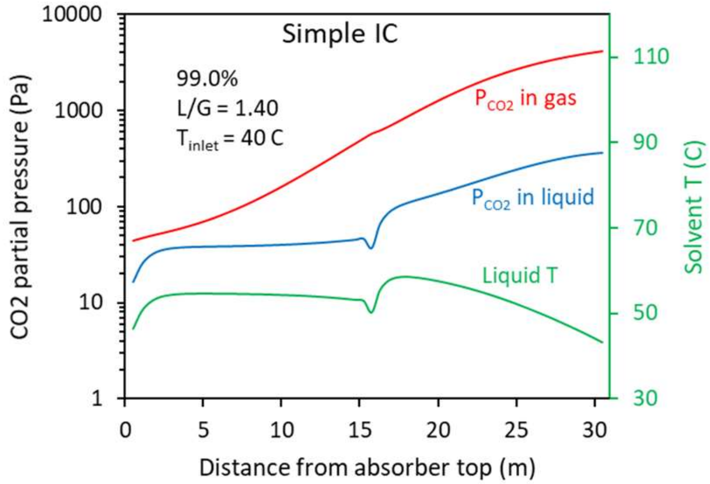
With simple in-and-out intercooling, the cooling capacity is limited by the flowrate of the solvent. (Low L/G)

The pump-around intercooling can enhance the flowrate locally (Large L/G)

With pump-around intercooling, the cost for NGCC to achieve zero-emissions is 7.6% higher than 90% capture

Importance of Solvent Intercooling for High Capture Rate (NGCC)





	No intercooler	Simple intercooler
CO_2 capture rate (NGCC)	99.0%	
Height(ft)	100	
L/G (kg/kg)	3.5	1.4
Diameter (ft)	80.5	69.2
Reboiler duty (GJ/t CO2)	8.49	4.41

Marginal CO_2 Capture Cost

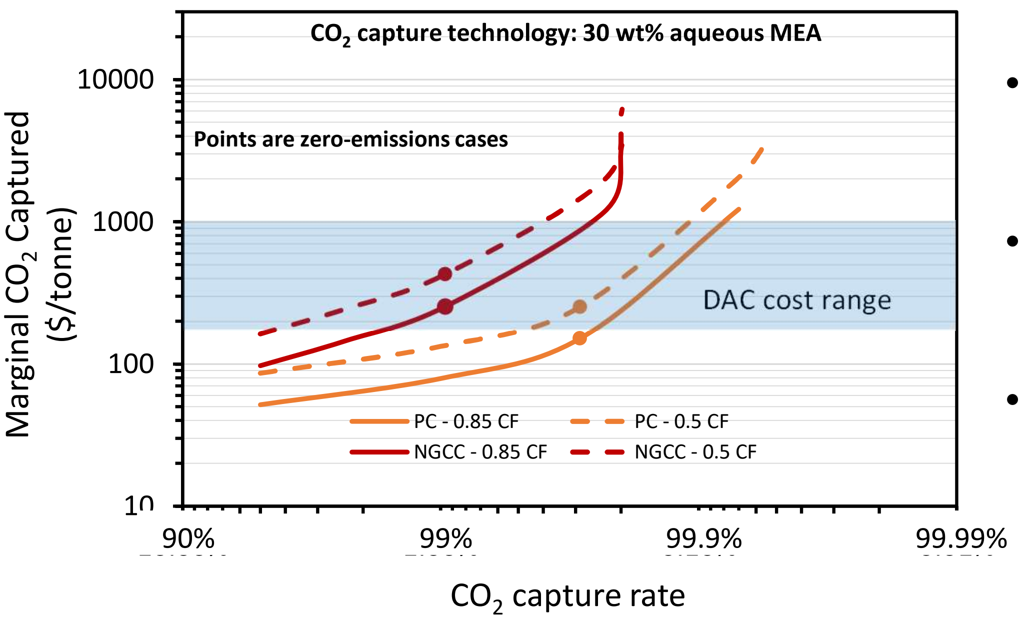
- Although increasing the level of CO_2 capture from 90% to that at zero-emissions has a small effect on the average unit cost, the **marginal cost may increase rapidly past a certain level of CO_2 capture**.
- It is important to determine this **limiting level of CO_2 capture** for CCS at which **the marginal cost becomes higher than** the cost of using **DAC** to remove CO_2 from the atmosphere. (i.e., how much do we need to rely on DAC to achieve zero-emissions for power plants?)

$$Marginal\ cost|_{x2} = \left.\frac{\partial C}{\partial x}\right|_{x2} \approx \frac{C_{x2} * x_2 - C_{x1} * x_1}{x_2 - x_1}$$

x = CO_2 capture (%); x_2 is a higher level of CO_2 capture than x_1

C = CO_2 capture cost

Marginal CO_2 Capture Cost vs. DAC Cost



- As a novel technology which has not been demonstrated at scale, the cost estimate for DAC has a high degree of uncertainty
- At high capacity factor (CF), the marginal cost of CCS at the rate for zero-emission is comparable to the average claimed cost for DAC
- When CF is low, it may be beneficial to couple CCS with DAC to fully decarbonize PC and NGCC plants

	95% capture		Zero-emission (400 ppm CO_2 in exhaust gas)		Negative-emission (100 ppm CO_2 in exhaust gas)	
Flue Gas	PC	NGCC	PC	NGCC	PC	NGCC
Marginal cost at this capture rate ($/t CO_2)*	$75	$124	$278	$354	>$1000	

**Based on CF of 0.85. At CF of 0.5, the costs would be 60-70% higher*

High Capture Rate of Non-aqueous Solvent (NAS)

Engineering Scale Testing of Transformational NAS-Based Carbon Dioxide Capture Process at Technology Centre Mongstad (DE-FE0031590)

Key Metrics

- Solvent performance including capture rate, energy requirements, solvent losses
- Solvent degradation, corrosion, emissions
- **Technoeconomic** and EHS evaluation
- Achieved 90%-99% and 90%-97.5% removal on NGCC and PC plant conditions using TCM equipment

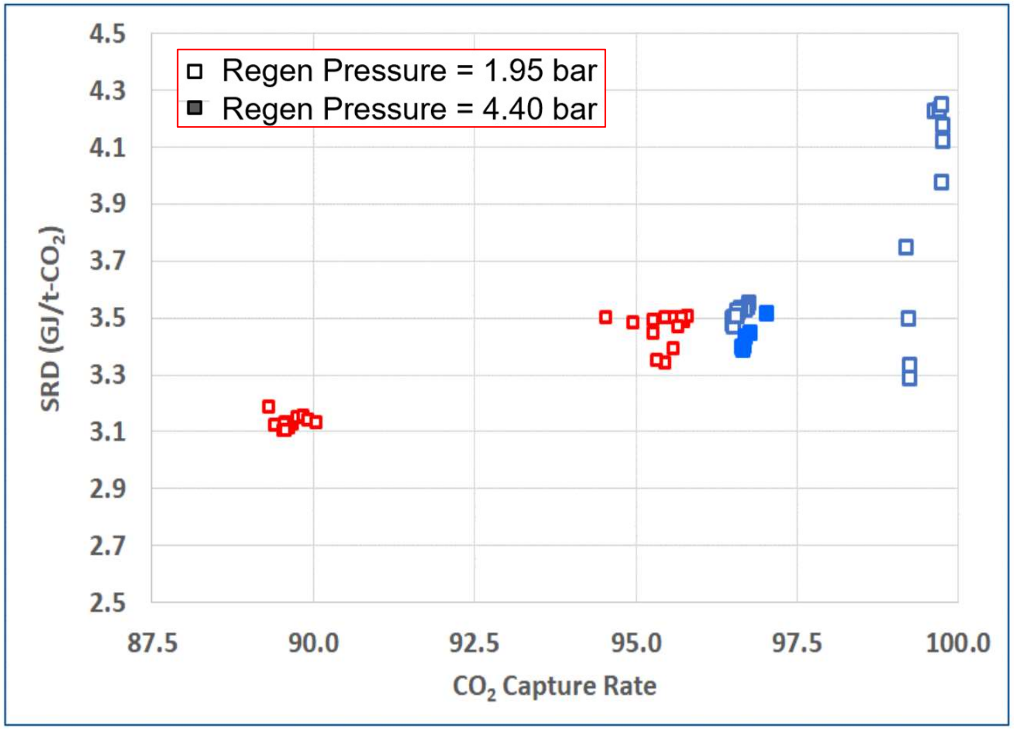
RTI INTERNATIONAL

EPRI ELECTRIC POWER RESEARCH INSTITUTE

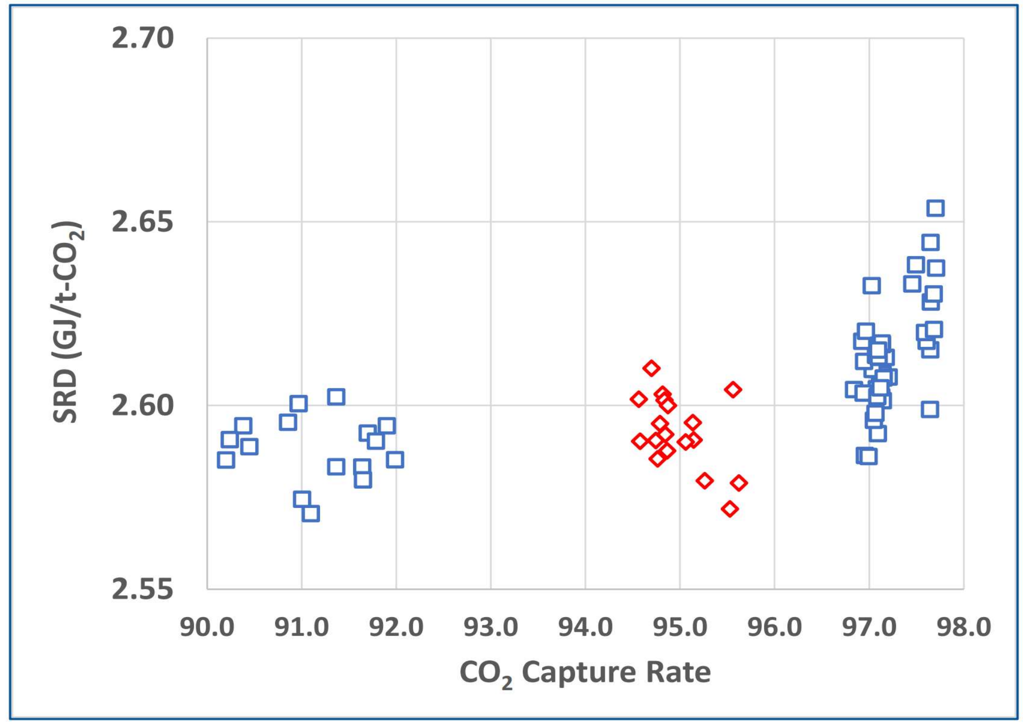
NexantECA

NAS- High Capture Tests

NGCC conditions



PC conditions



Regenerator Pressure = 1.95 – 4.4 bar
Reboiler Temperatures = 88.4 – 113.5 C

Regenerator Pressure = 4.2 bar
Reboiler Temperatures = 106 – 114 C

Techno-economic Analysis and High Capture Rate

- RTI-NAS technology achieved 90% capture at a cost of 30.5 and 47.7 $/t for SC PC and F-class NGCC
- For PC, cost of capture is 2% less at 97% and about the same at 99% capture
- For NGCC, cost of capture is 9% higher around 95-97% and 20% higher at 99% capture

Power Plant	PC				NGCC, F-Class			
Capture Rate, %	90	95	97	99	90	95	97	99
Total Gross Power, MWe	762	756	763	774	692	689	687	687
Net Power, MWe	657	648	653	650	647	641	635	631
BEC for Capture System, $MM	226	230	232	236	221	260	256	295
Total Plant Cost, $MM	2,085	2,092	2,102	2,130	935	1,001	1,001	1,075
Total Overnight Cost, $MM	2,558	2,567	2,579	2,613	1,166	1,246	1,247	1,336
Levelized Cost of Electricity ($/kW)	92.6	94.6	94.3	96	59.8	62.5	63	65.7
Cost of CO_2 Captured, $/t CO_2	30.5	30.5	29.8	30.6	47.7	52.0	52.0	57.3

Slide 14

BP0 Please check Net Power for 97 and 99% Capture for PC. It is higher then 95% Capture case.
Babul Patel, 2024-05-24T16:04:05.512

BP1 Suggest to spell out TPC, TOC, T&S in footnote for clarity.
Babul Patel, 2024-05-24T16:41:15.919

BA2 Possible to calculate marginal cost and marginal avoided cost? Also, what's the % capture that corresponds to zero emission in these tables?
Bhown, Abhoyjit, 2024-06-03T21:57:48.677

Summary

- It is technically feasible for both PC and NGCC power plants to achieve zero emissions and negative emissions using CCS (~400 ppm CO_2 in exhaust gas).
- Solvent intercooling is important at high CO_2 capture rate, especially for NGCC
- At high plant capacity factor (CF), PC and NGCC plants can achieve zero-emissions with CCS alone at competitive costs
- When CF is low, it may be beneficial to couple CCS with DAC to fully decarbonize PC and NGCC plants (as long as DAC developers can demonstrate the cost they claim)
- EPRI has extended the high capture rate analysis for other solvents as well as hydrogen production (SMR & ATR)

TOGETHER...SHAPING THE FUTURE OF ENERGY®

www.epri.com