MTR CARBON CAPTURE

ENGINEERING DESIGN OF A POLARIS MEMBRANE CO_2 CAPTURE SYSTEM AT A CEMENT PLANT

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Carbon Management Project Review Meeting
Carbon Capture from Industrial Sources (FEED)
August 31, 2023

Project Overview

Award name: Engineering Design of a Polaris Membrane CO_2 Capture System at a Cement Plant
(DE-FE0031949; FOA-2178)

Project period: 10/1/20 to 3/31/23

Funding: $1.493 million DOE; $0.373 million cost share ($1.866 million total)

NETL FPM: Carl Laird

Participants: MTR, CEMEX, Sargent & Lundy

Project scope: Conduct an engineering design study of MTR's CO_2 capture process applied to the Cemex Balcones cement plant in New Braunfels, Texas

Project plan: The project is organized into 9 tasks. The end product is an engineering design report with detailed engineering drawings, a permit review, construction schedule, and capital/operating cost estimates - AACE Level 3 (+30/-20%)

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MTR Development Timeline

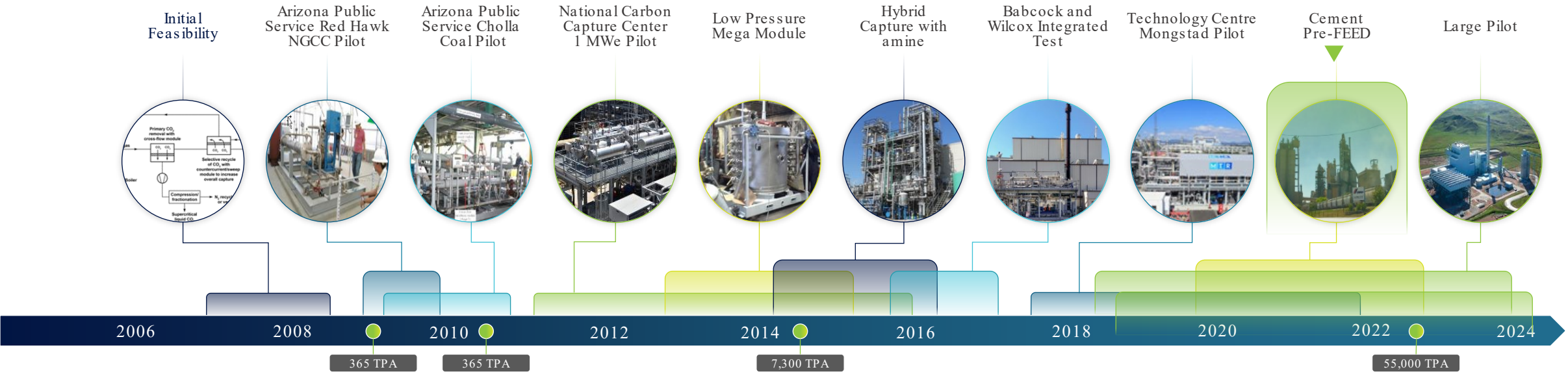
15 Year
Relationship with DOE

18+
DOE Awards Won

>$100mm
Total Funding Received from U.S. Government Agencies

- Support from the DOE has helped bring MTR's capture technology from early concept to the point of commercialization
- Together the DOE and MTR have collaborated to provide industrial and power facilities with a compelling carbon capture solution

Development Timeline



CEMEX Balcones Plant

- Produces ~1.1 million tonnes of cement/yr
- Flue gas from Kiln #2 contains 14.9% CO_2 (wet) at ~2700 tonnes/day

- Located in New Braunfels, Texas adjacent to the Balcones Quarry, which is the top crushed stone producer in the US
- Close proximity to residential areas highlights the importance of capture system environmental impact
- Eagle Ford shale with injection opportunities is nearby, but no current pipeline

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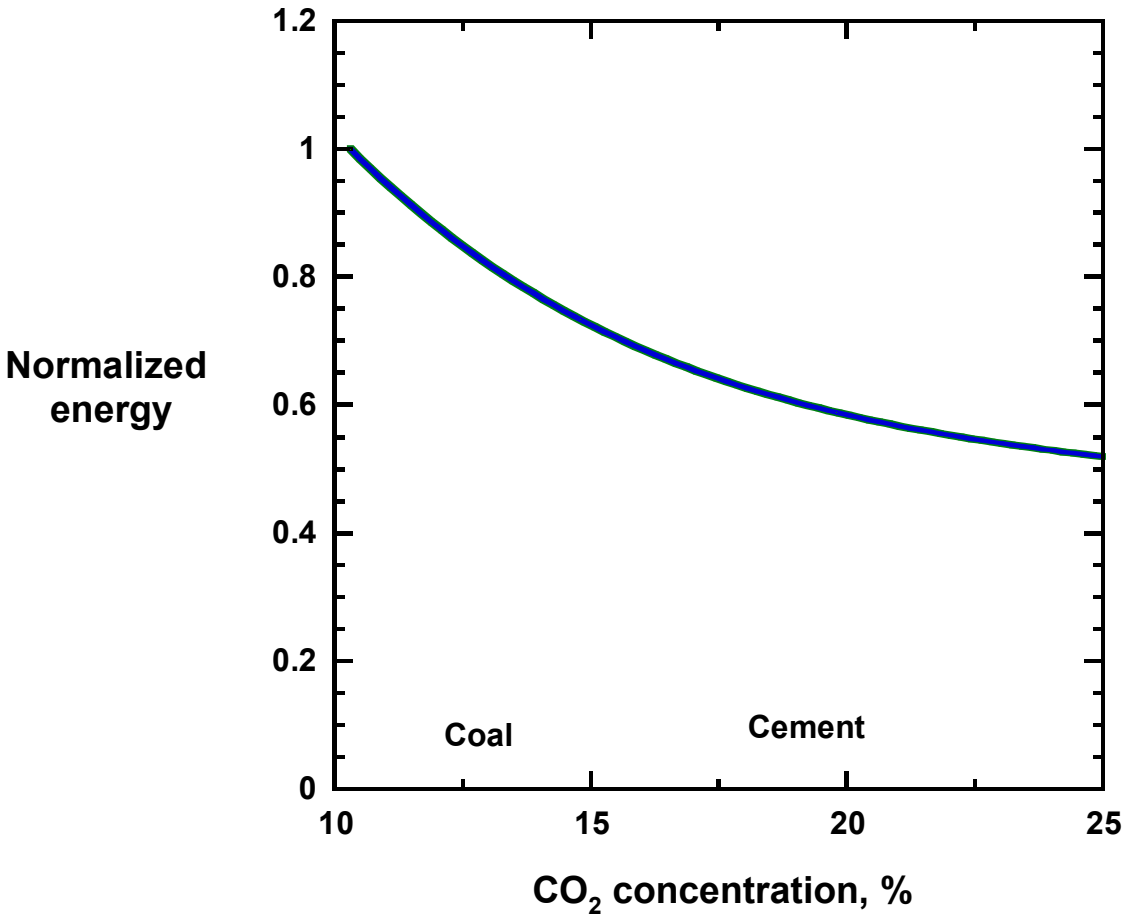
Why Membranes for Industrial Capture?



- A number of industrial capture cases, like cement, offer higher feed CO_2 content
- Cost and energy use for membrane systems depend strongly on CO_2 concentration (partial pressure)
- For example, energy use for 90% capture from flue gas with 20% CO_2 is ~30% less than at 12% CO_2
- Membranes are a clean capture approach → no secondary emissions, no steam, low water use

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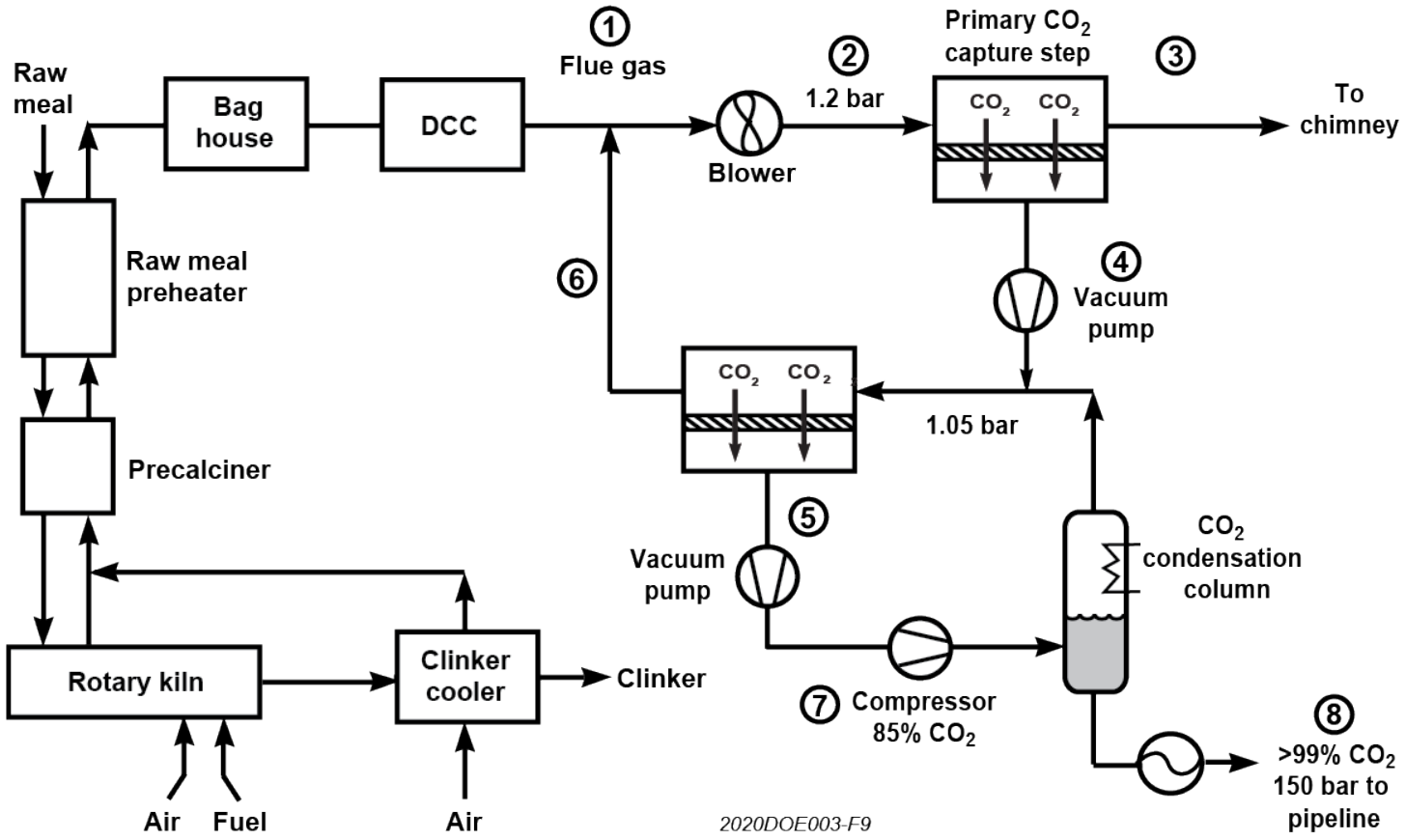
Baker et al., Ind. Eng. Chem. Res., v57, i47, pp 15963-15970 (2018)

Simplified Flow of Polaris Capture at Balcones



- Feed is 2700 tonnes CO_2/day at 14.9% CO_2 (wet) from Kiln #2 at Balcones
- Two stage Polaris membrane system with CO_2 liquefaction
- Base case examines 75% capture of plant CO_2 emissions (~2000 TPD or 0.71 million TPY captured)
- High purity CO_2 (>99.9%) meeting QGESS requirements available for offtake at 150 bar

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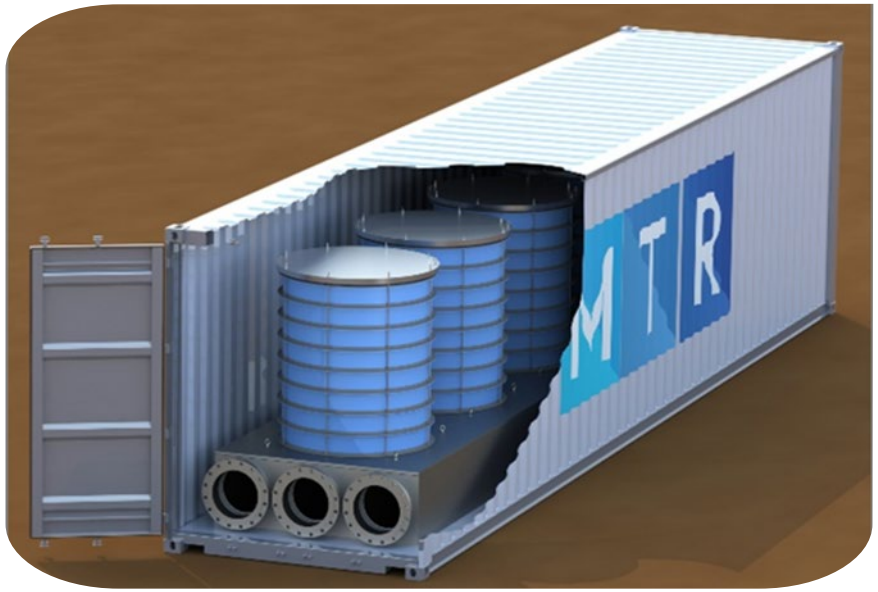
Polaris Membrane Containers



- Container with membrane stacks is the final modular unit for this capture technology
- Cemex study uses this configuration with today's Polaris membranes

- Test system recently operated at TCM in Norway using a single container of membrane stacks
- Cemex full scale system would use multiples of this unit building block

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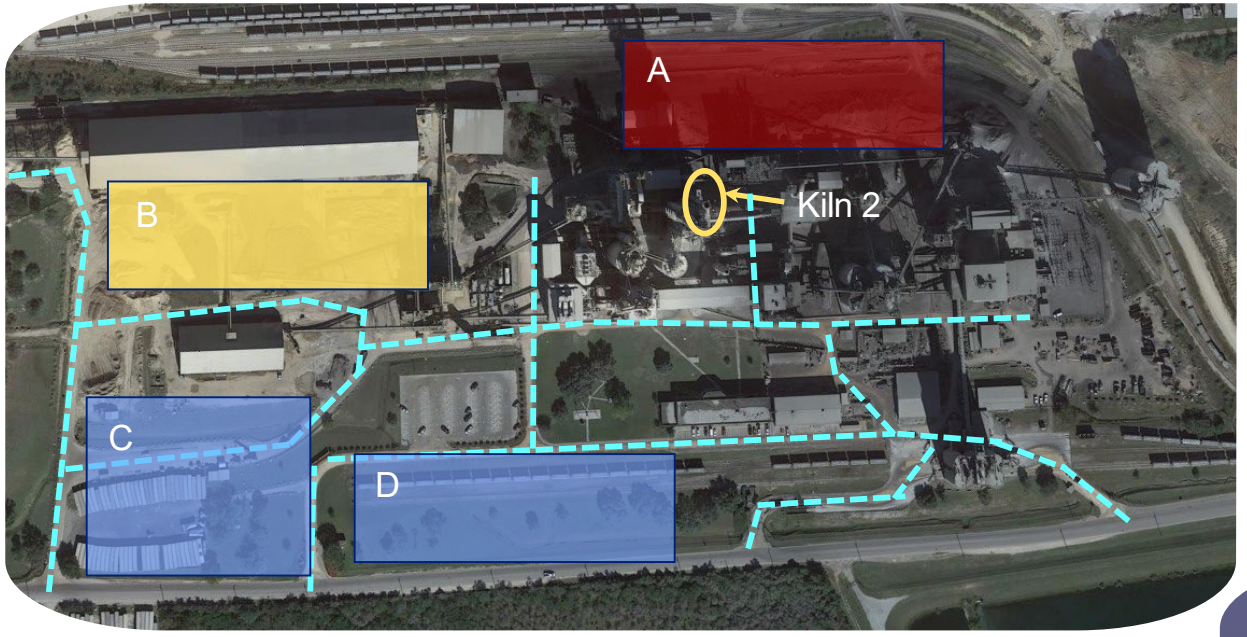
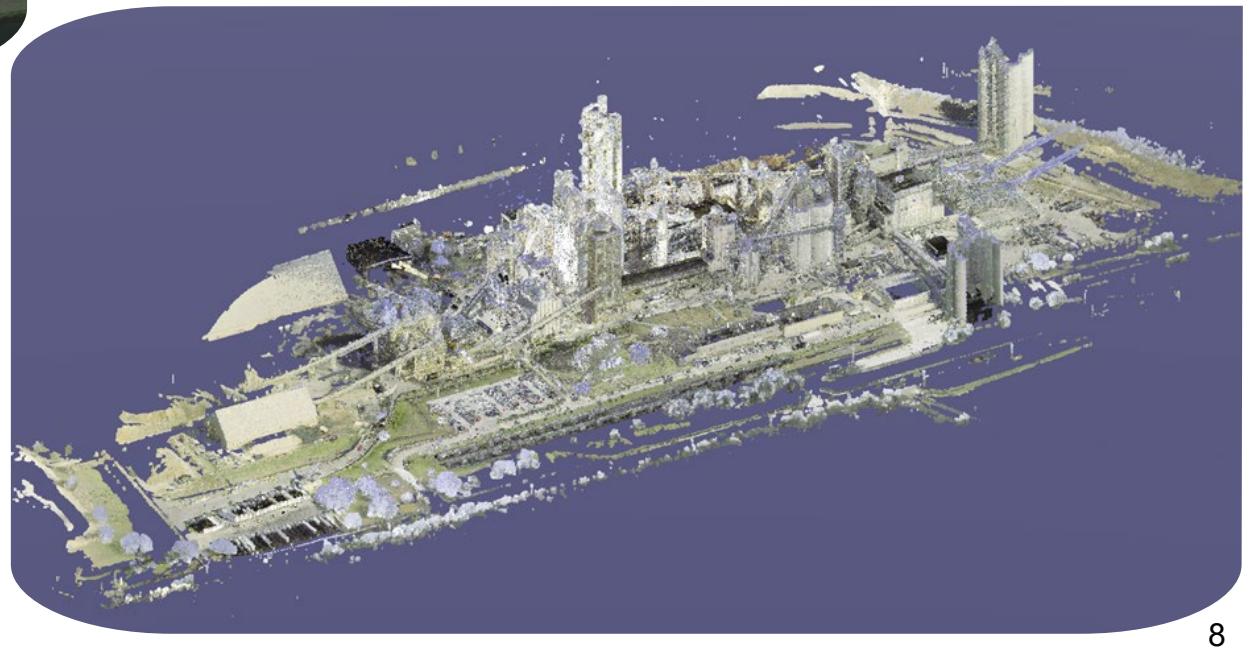
Capture System Site Selection



- S&L conducted a laser scan of the Balcones site
- Used for detailed design and layout of capture system including interconnections to cement plant



- Four locations were considered for the capture system at Balcones
- Although not immediately adjacent to Kiln 2, Site B – currently used for bulk limestone and clay storage – was selected as least disruptive to operations

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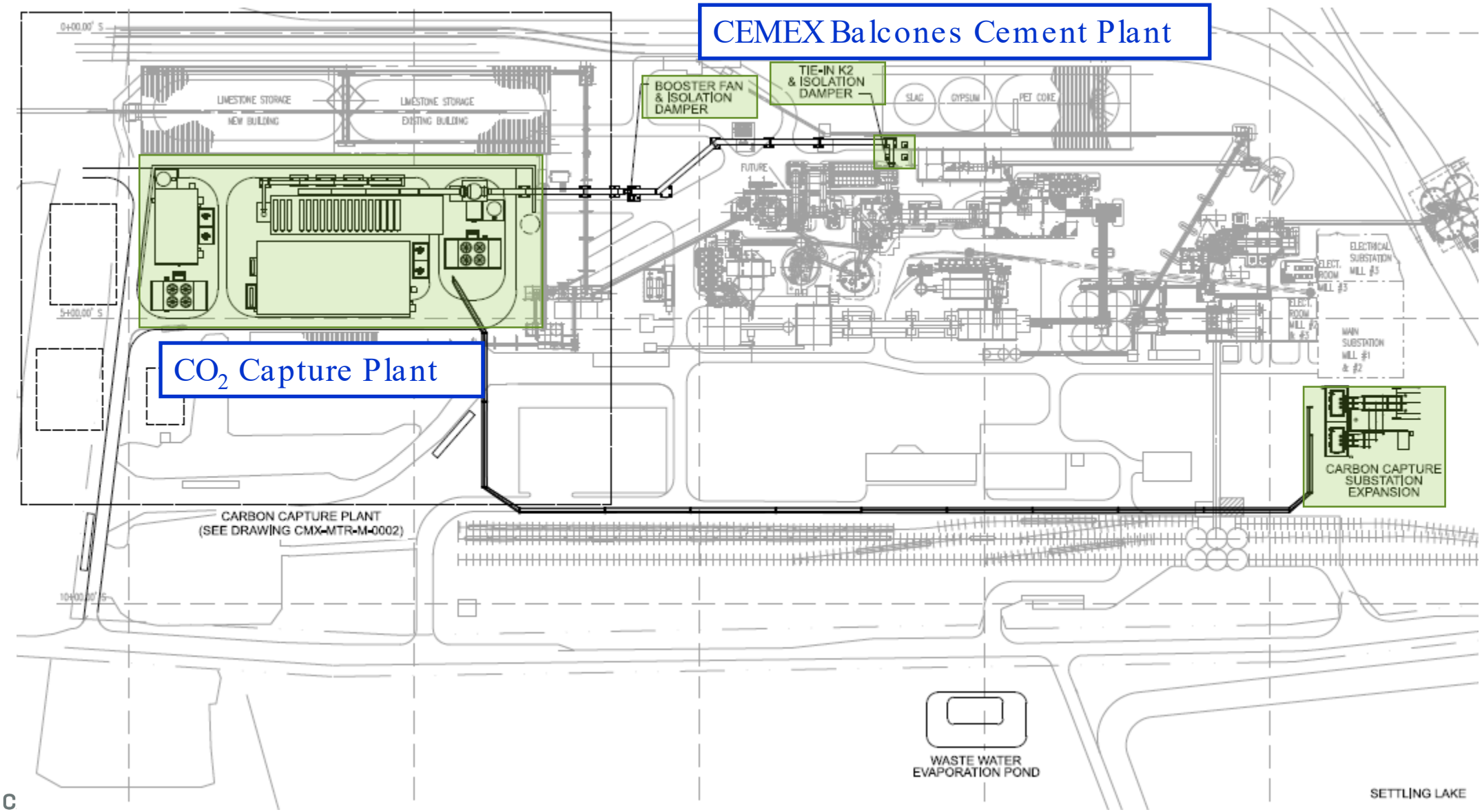
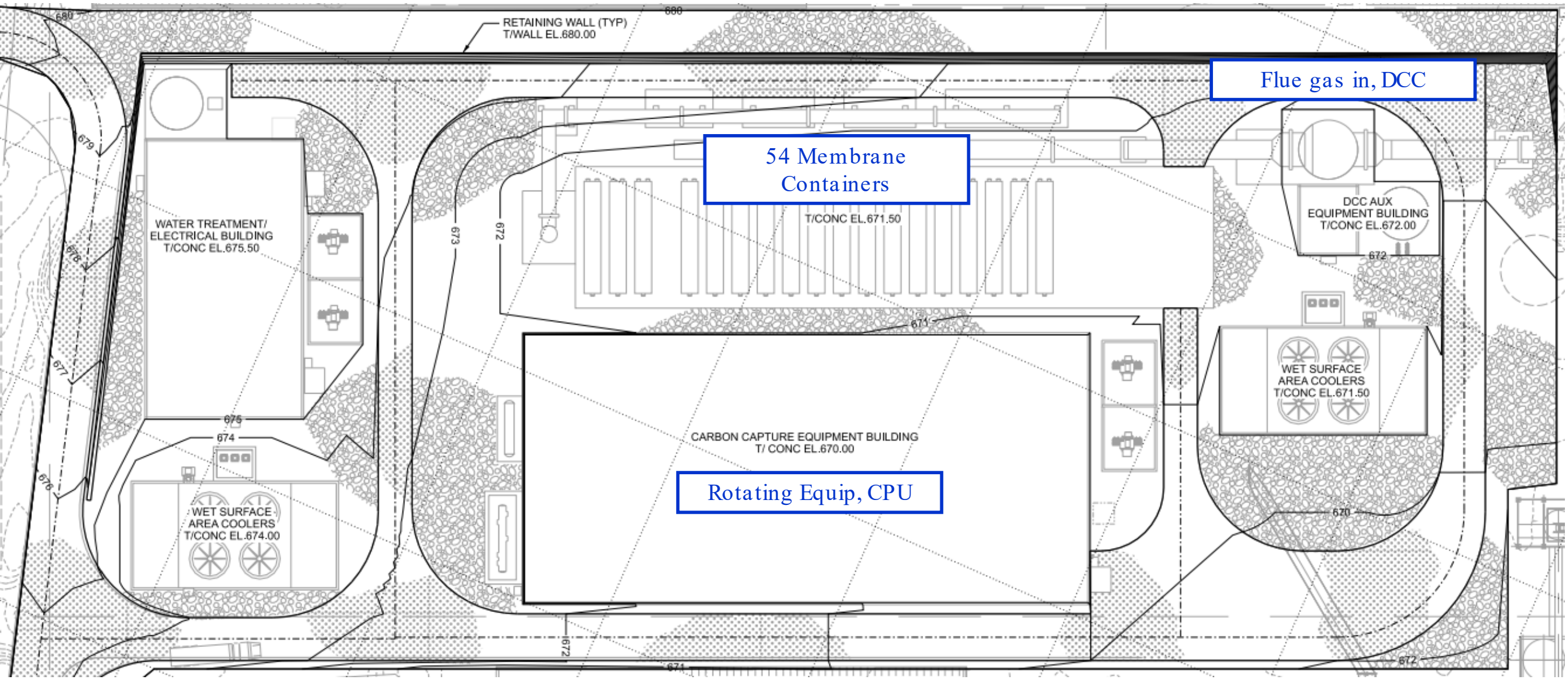
Polaris System Layout at Balcones

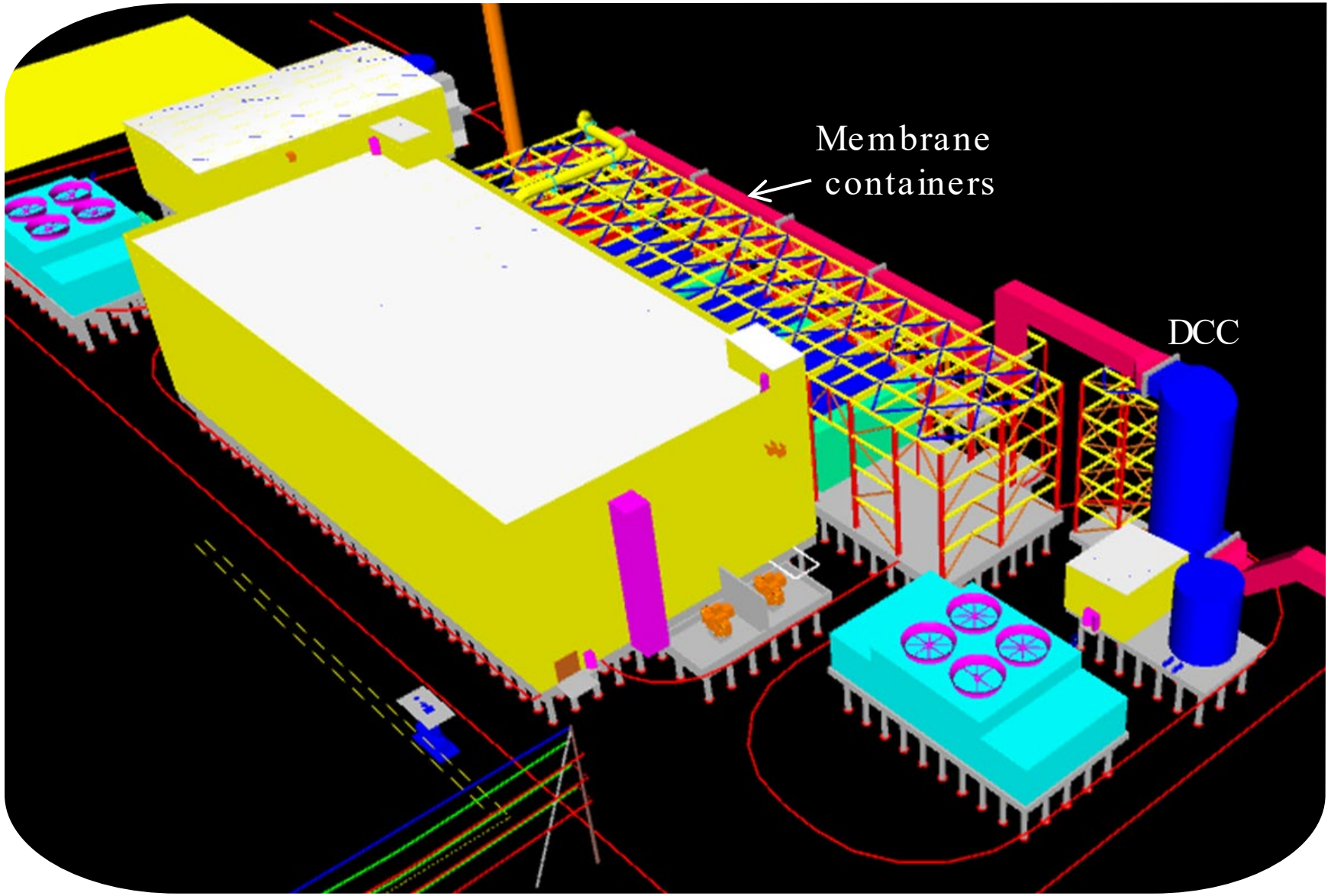


Polaris System Layout



Capture island plot is approximately 250 ft x 500 ft

GA Drawing of Polaris Capture Plant



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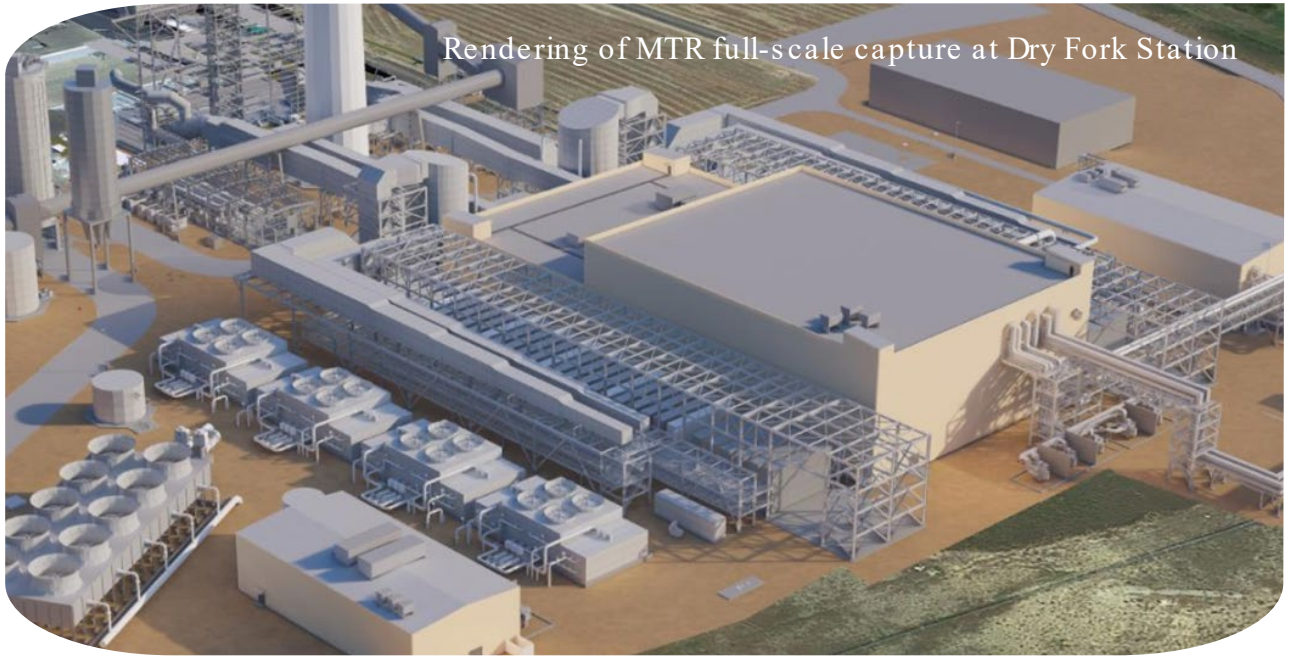
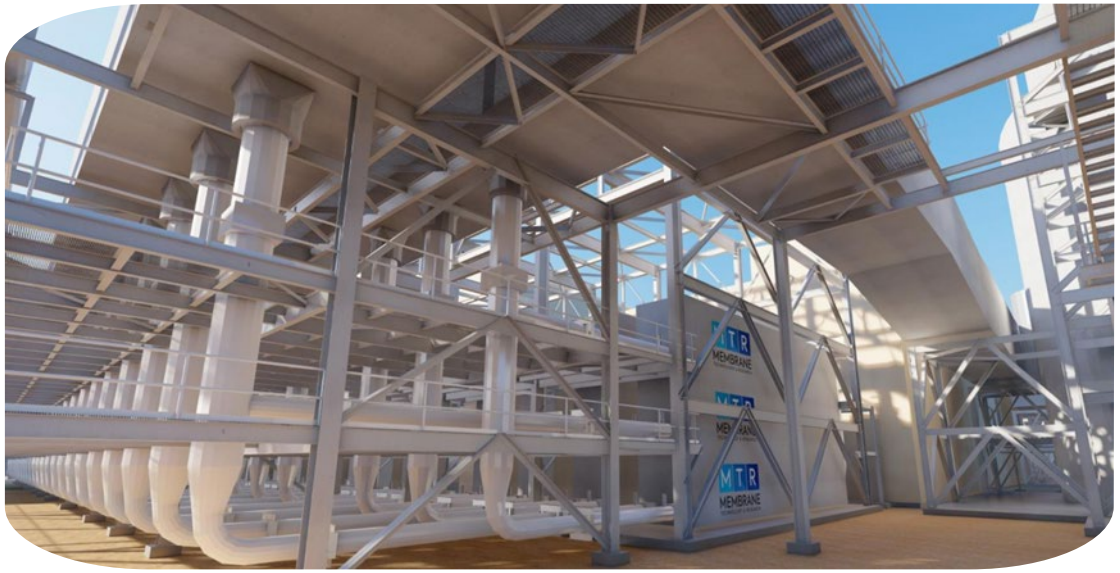
Equipment Sizing and Costing



- Equipment selection and costing information from this prior study was available for use in the current work
- Balcones capture plant is about 1/3 as large as DFS; in many cases, a smaller number of the same modular equipment was needed



- MTR and S&L recently completed a FEED study of full-scale capture at the DFS coal power plant including an AACE class 2 cost estimate

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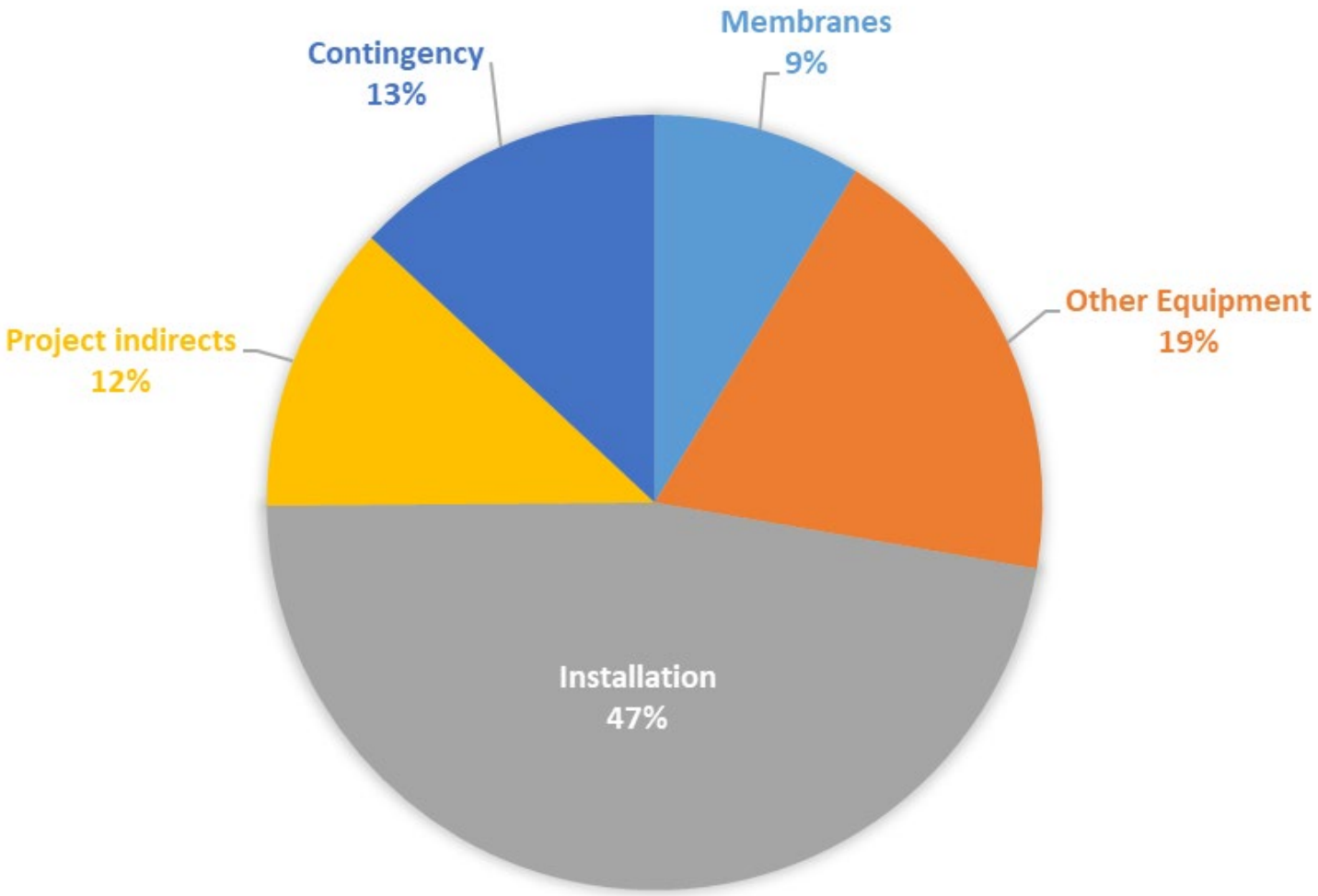
Capital Cost Breakdown



- Total system Capex in Q1 2022 dollars is $432 million
- Membrane skids are a relatively small portion of the total Capex (although size of membranes impacts BOP and installation costs)
- Overall, equipment is about a quarter of the Capex, indirects and contingencies are about a quarter, and installation is half the cost

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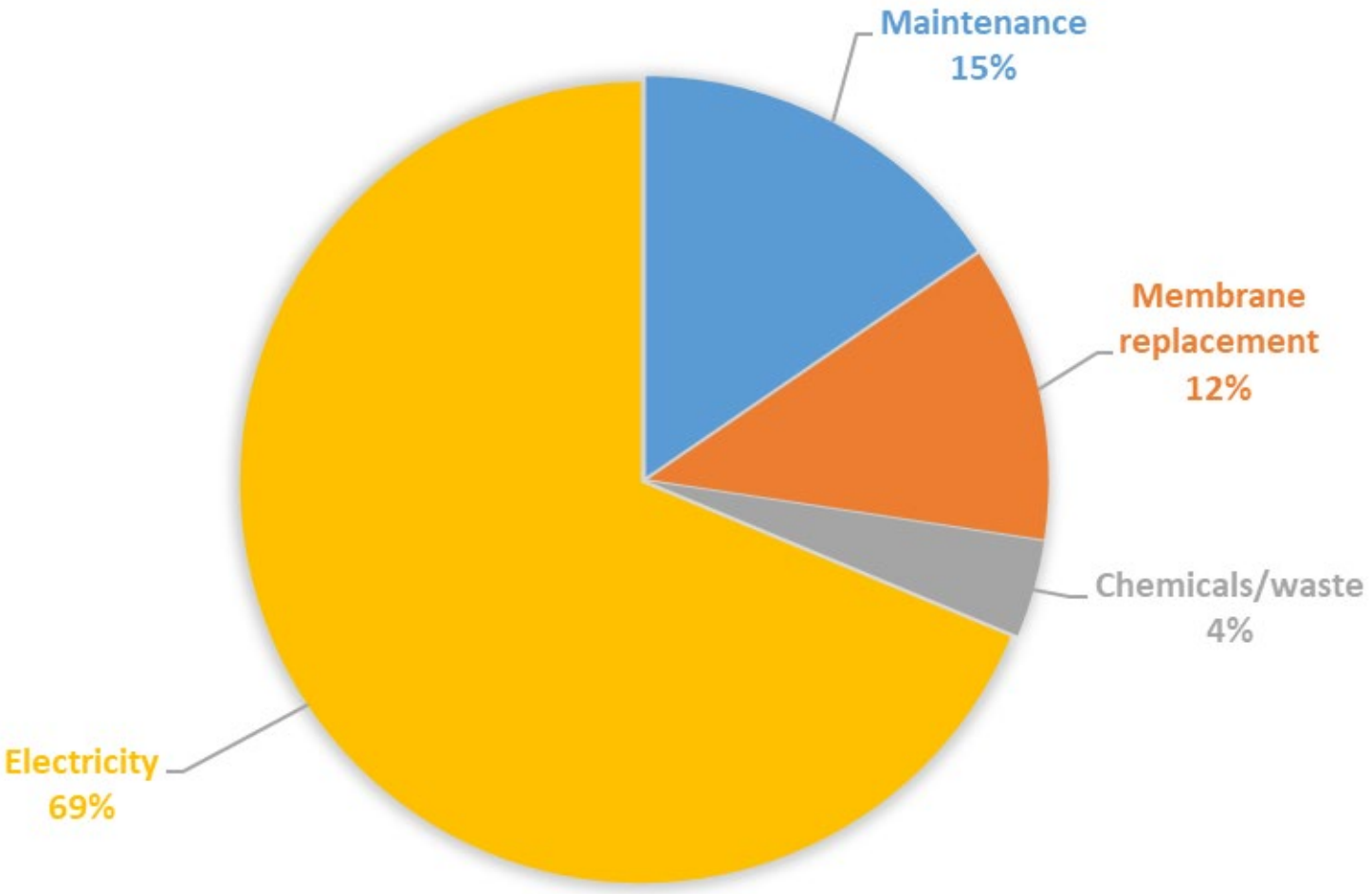
Operating Cost Breakdown



- Operating costs are dominated by electricity needed to run the capture equipment (membrane uses only electricity to power the capture process)
- This was particularly true for spring 2022 when electricity prices in TX were much higher than historical average

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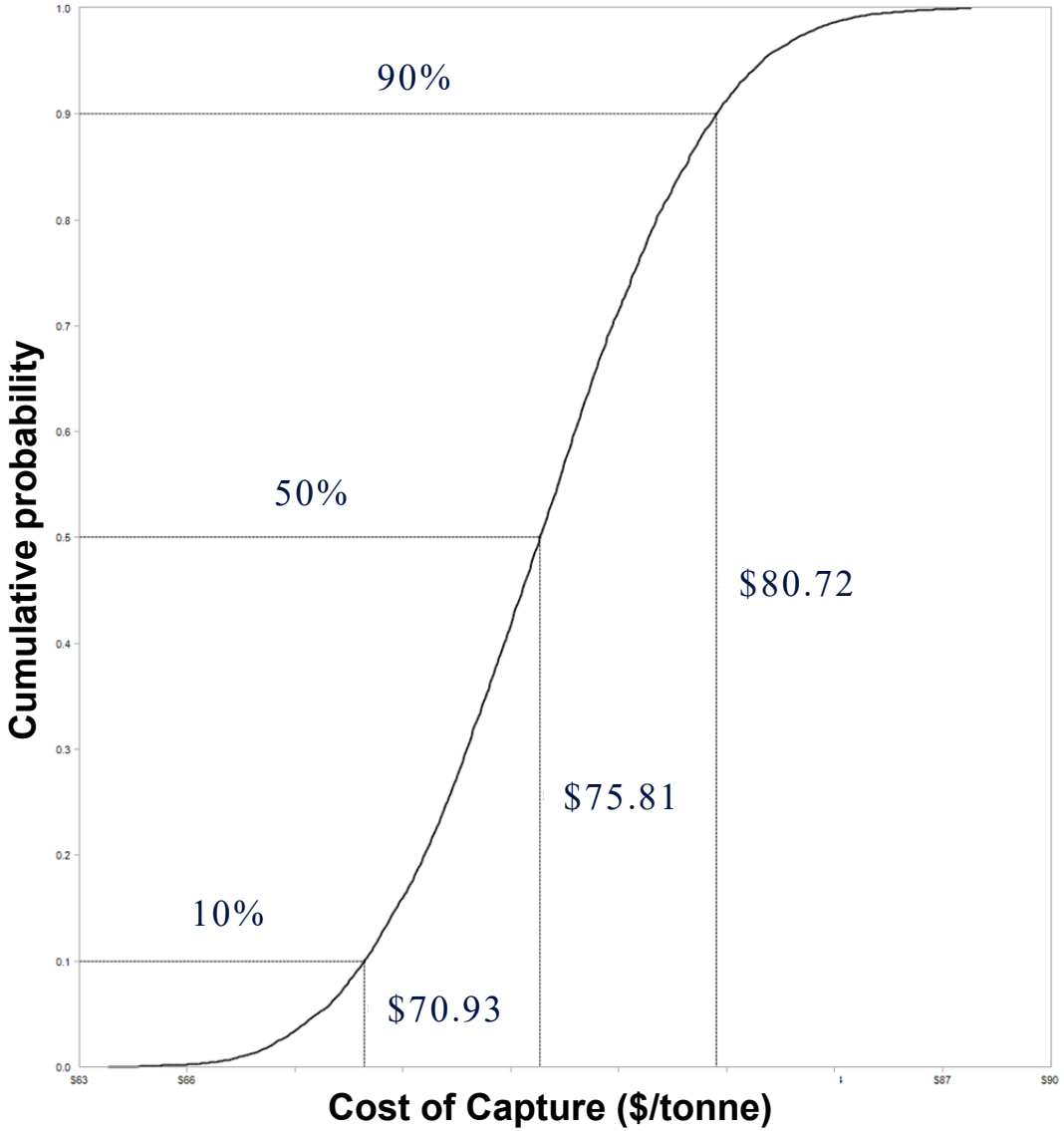
Balcones Cost of Capture



- Based on S&L estimated costs (adjusted to 2019 Q4), a capture cost was calculated using a Monte Carlo analysis (ModelRisk™) to account for parameter uncertainties
- Process variables including membrane cost, membrane life, installation costs, BOP costs, cost of electricity, capacity factor and contingencies were allowed to change
- The expected cost of capture is $75.81/tonne (Dec 2019 USD) with 90th and 10th percentile confidence interval values of $80.72 and $70.93, respectively

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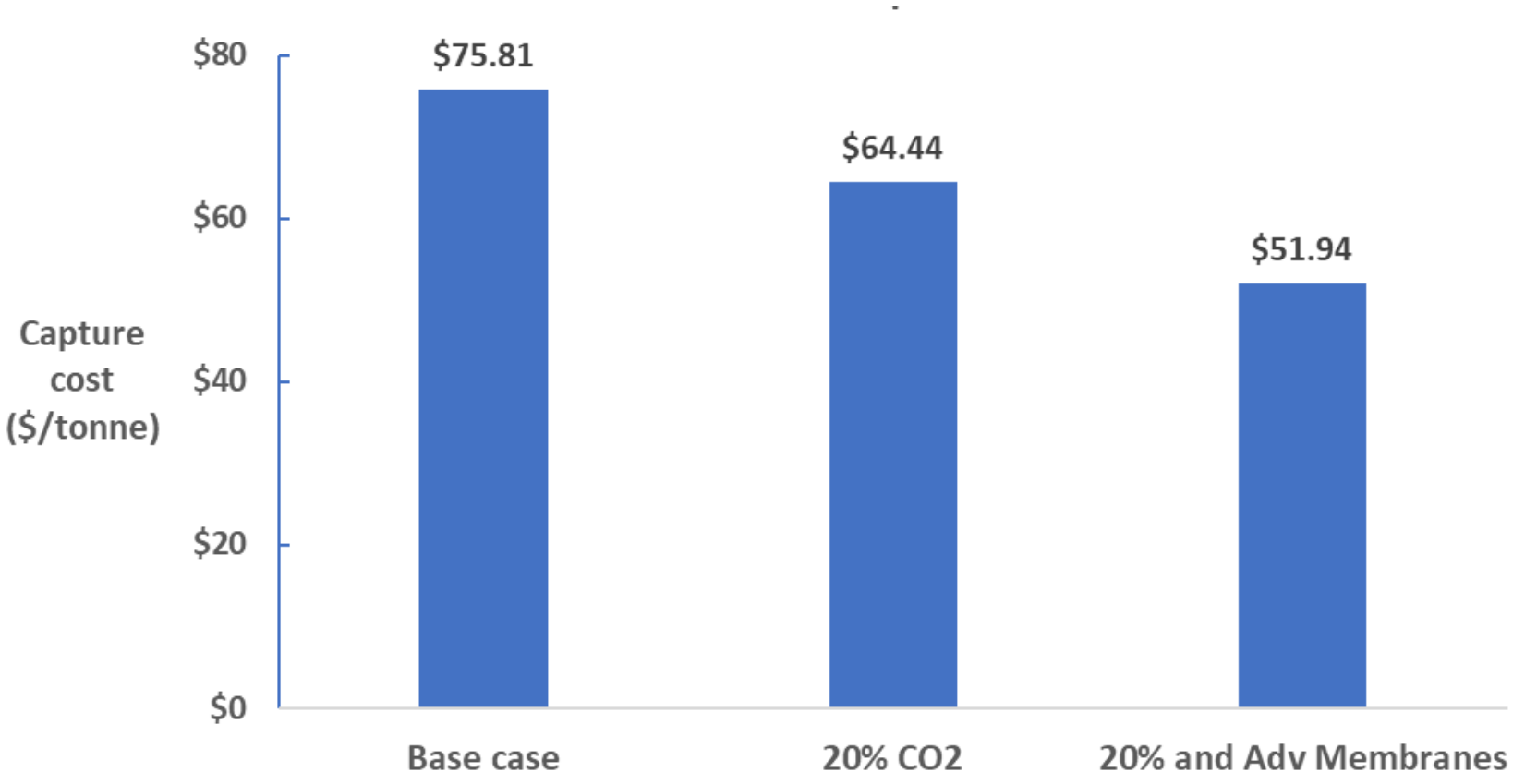
Expected cost in $2022 Q1 = $91.30

Impact of CO_2 Content and Advanced Membranes



Note: graph data in $2019 Q4; Base case in $2022 Q1 = $91.30

- Increasing the flue gas CO_2 content from 14.9 to 20 mol% reduces membrane area and power requirements significantly
- Cement plants with less false air ingress will be most attractive for capture
- Advanced membranes (Gen 3) currently being scaled up would also drop cost substantially mostly through plant size reductions

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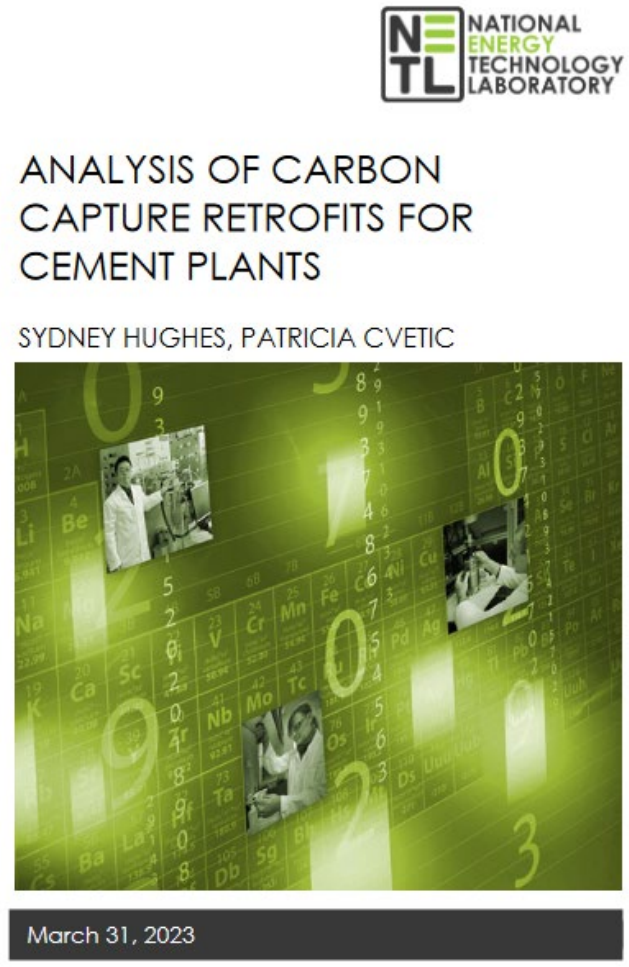
Comparison with Recent DOE Cement Study



- Recently, DOE published study on costs of capture from cement plants using amine absorption (Cansolv)
- MTR Balcones costs were adjusted to DOE study conditions (95% capture, Nov 2022 dollars, $67.28/MWh, etc) for better comparison
- DOE examined 3 feed CO_2 contents: 14.5%, 25%, and 31%; lowest content is close to Balcones
- Advanced Gen 3 MTR membranes used in calculations

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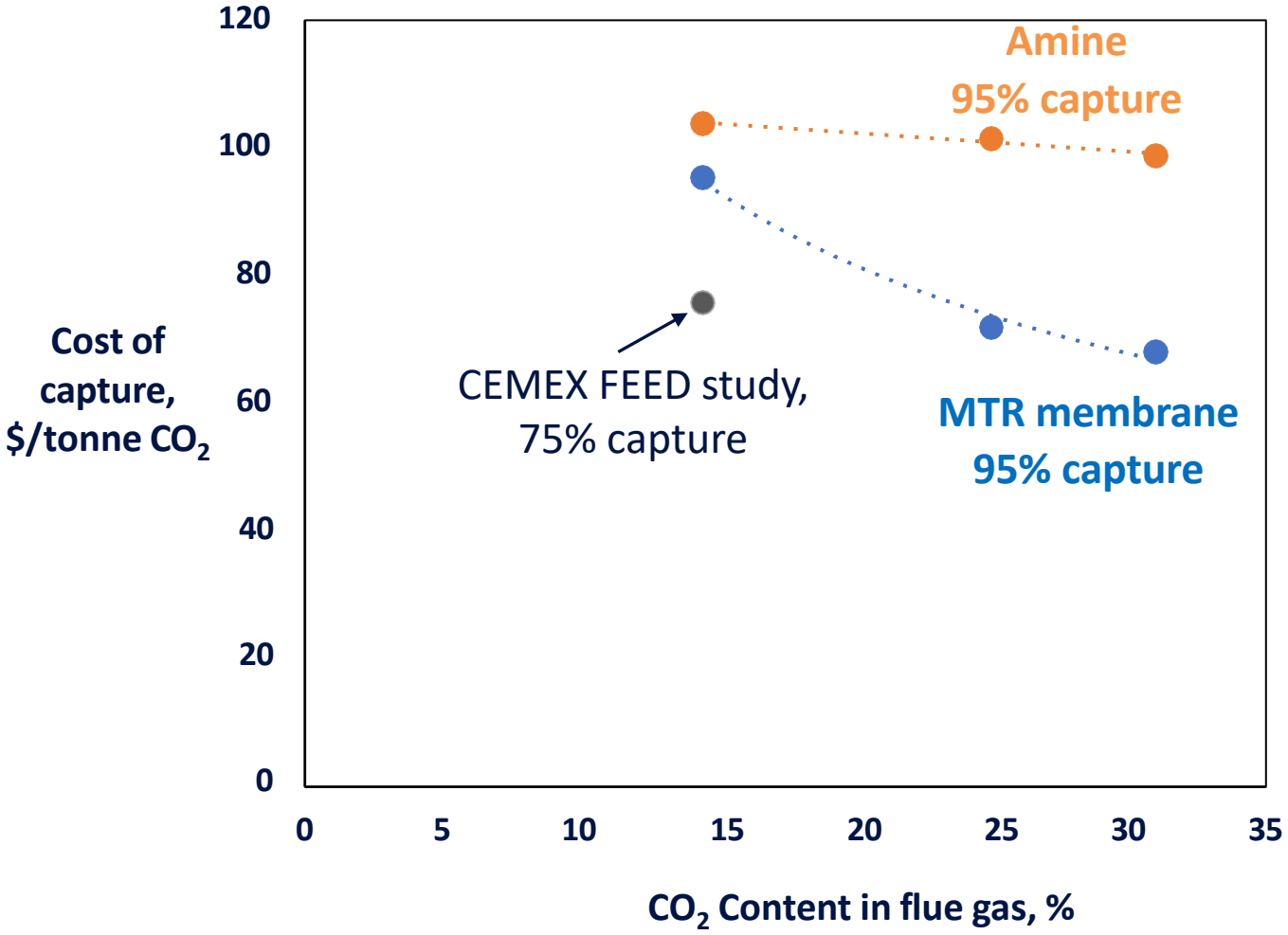
Cost Comparison with DOE Baseline



- Both technologies show a decreasing capture cost as feed CO_2 content increases
- However, membrane costs decrease faster resulting in significant savings (~30%) at CO_2 content >20%
- Membrane environmental advantages: DOE study shows amine uses ~400 gal water/ tonne CO_2 captured; membrane < 50 gal/tonne

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Summary

- Engineering study examined MTR membrane capture of CO_2 emissions from Kiln 2 at CEMEX Balcones cement plant
- Membrane capture costs compare favorably with DOE cement baseline study particularly for sources with higher CO_2 content
- Compared to Balcones study base case, improved membrane, higher CO_2 feed content, and lower power costs would all substantially lower capture costs, while higher capture rate increases cost
- The next steps are a pilot demonstration test at a suitable cement facility to quantify membrane performance/lifetime

Acknowledgements

This material is based upon work supported by the Department of Energy under Award Number DE-FE0031949.

Disclaimer

Capture Cost Summary

Case	Case No. in DOE report	CO2 content in flue gas (vol%)	Capture rate (%)	Amine capture cost ($/tonne)	MTR membrane capture cost ($/tonne)	CO2 captured (MTA)
MTR CEMEX base case	-	14.9	75		76.10	0.75
DOE Case 1: 14.5% CO_2	CM95-B with 400,000 ACFM air ingress	14.5	95	103.80	95.38	1.1
DOE Case 2: 25% CO2	CM95-B1	25	95	101.40	71.88	1.1
DOE Case 3: 31% CO2	CM95-B	31	93.7	98.80	68.02	1.1

- 2022 Nov. Dollars
- Same electricity price: $67.28 / Me

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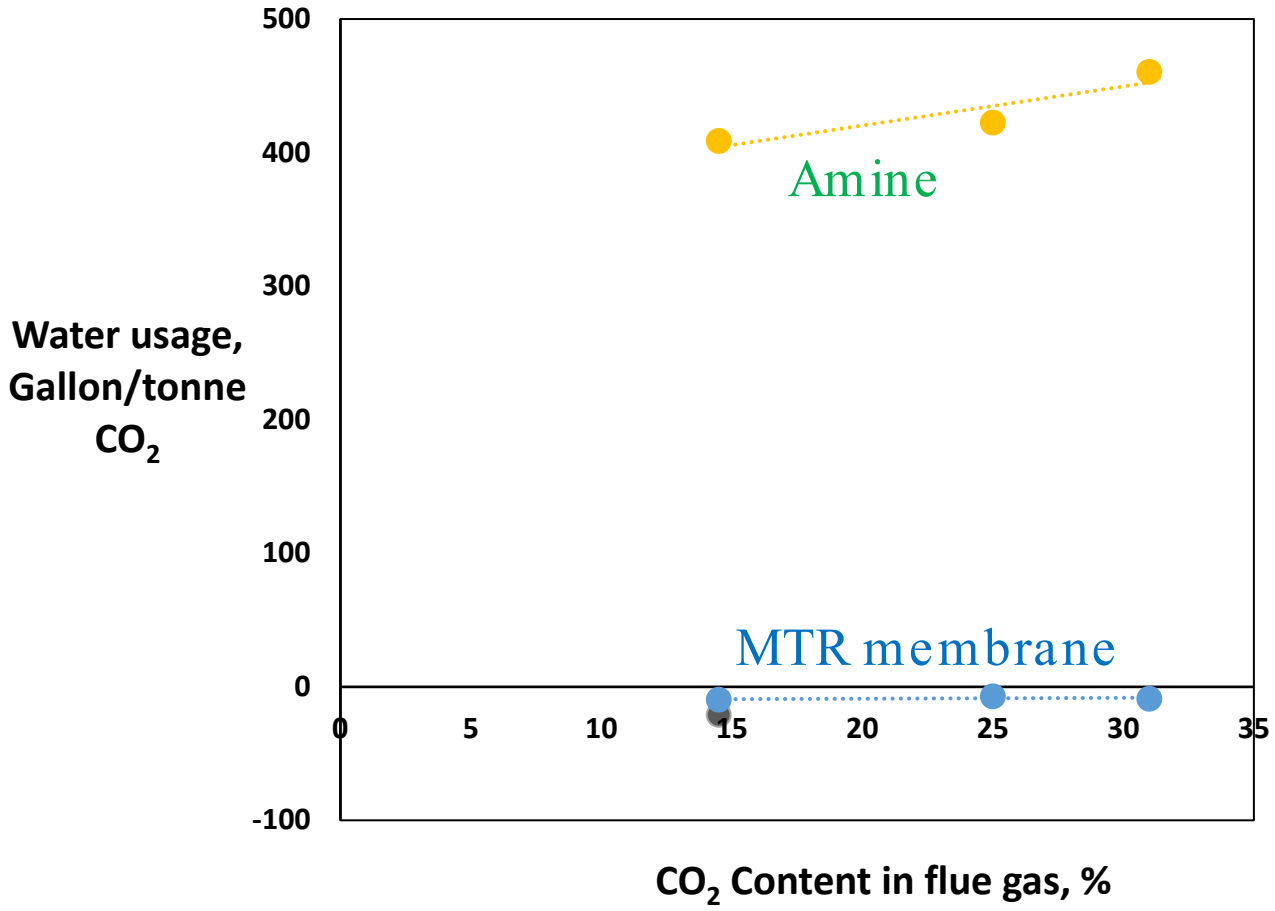
Water Use Comparison



- Recently, DOE published study on costs of capture from cement plants using amine absorption
- MTR

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S&L Engineering and Design Package

- S&L performed an initial engineering & design to retrofit the MTR CO_2 Capture Facility at the CEMEX Balcones Cement Plant
  - Performed all Balance of Plant (BOP) engineering & design
  - Provided input/oversight on Process project deliverables
  - Developed technical specifications/datasheets used to solicit budgetary quotes
  - Prepared a detailed engineering deliverables package
  - All of which culminated into a Class 3 Capital Cost Estimate

General	Mechanical	Environmental	Electrical	Instrumentation & Controls	Architectural, Civil & Structural
•Design Criteria •Site Plan/GA •Equipment List •Equipment Datasheet/Specifications •Solicit Budgetary Quotes •PHA Facilitation	•Process & Instrumentation Diagrams (P&ID) •Piping & Valve Design Tables •Pipeline List	•Overall Process Flow Diagram •Water Balance & Studies •Project Emissions •Waste Disposal Estimates •Permit Matrix •Environmental, Health & Safety Assessment	•Load List •Single Line Diagram •Control & Electrical Room Layouts •Cable Tray, Cable Bus & Non-seg Bus Layouts •Switchyard Expansion & New CC Substation •Lighting & Grounding	•Network Architecture Diagram •Controls Description •Typical Loop Diagrams & I/O Tables •Preliminary I/O List •Instrument List •Building Security Infrastructure	•Flue Gas Ducting: Tie-In, Supply & Retentate Vent •Structural/Support Steel •Foundation Drawings •Civil Sitework/Grading •Spill Containment

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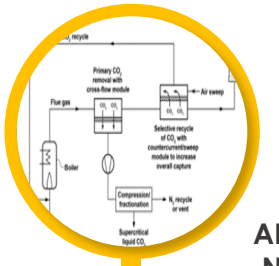
MTR Development Timeline

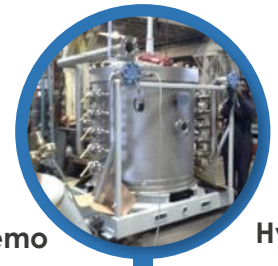
Feasibility Study
(NT43085)
- Sweep concept proposed
- Polaris membrane conceived



APS Cholla Demo
(NT0005312)
- First Polaris coal flue gas test
- 1TPD CO_2 captured (50 kWe)

APS Red Hawk NGCC Demo
- First Polaris flue gas test
- 250 lb/d CO_2 for algae farm

Low Pressure Mega Module
(FE0007553)
- Design/build low Δp module



NCCC 1 MWe Demo
(FE0005795)
- 11,000 hrs of 1 TPD system operation
- 1 MWe (20 TPD) system operation

Hybrid Capture
(FE0013118)
- Membrane solvent hybrids with UT, Austin

B&W Integrated
(FE0026414)
- Integrated operation of 1 MWe system with B&W's 0.6 MWe coal-fired boiler

Large Pilot & Full Scale FEED
(FE0031587 & FE0031846)
- Design, build, operate 150 TPD Large Pilot capture at WITC
- Full scale study of retrofit to Dry Fork Station

Cement FEED
(FE0031949)
- Retrofit study of capture from Cemex Balcones cement plant

0.1 TPD
1 TPD
20 TPD
150 TPD

2006 2008 2010 2012 2014 2016 2018 2020 2022

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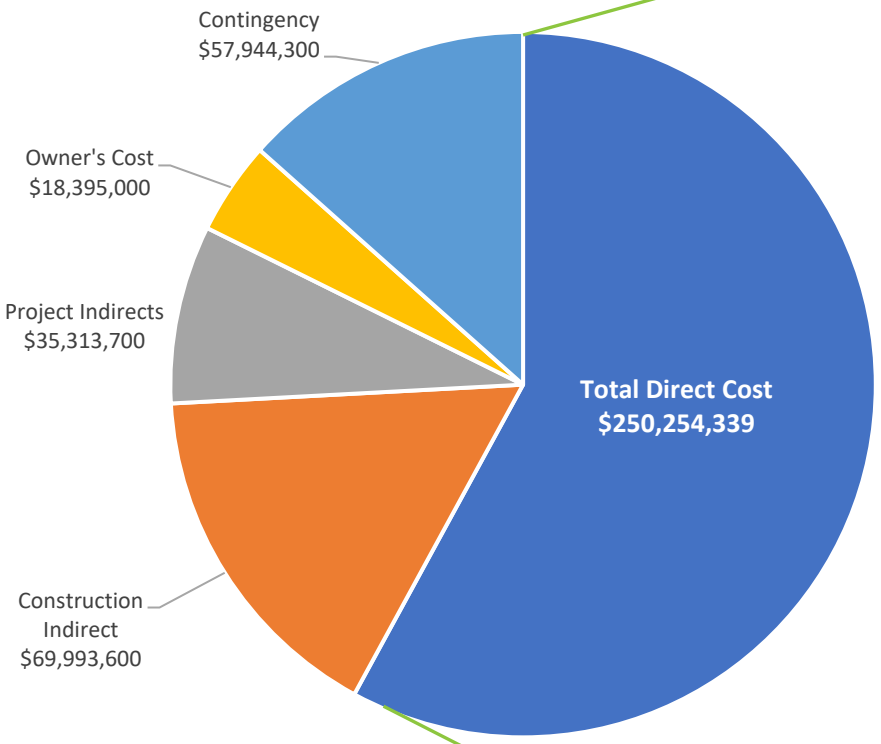
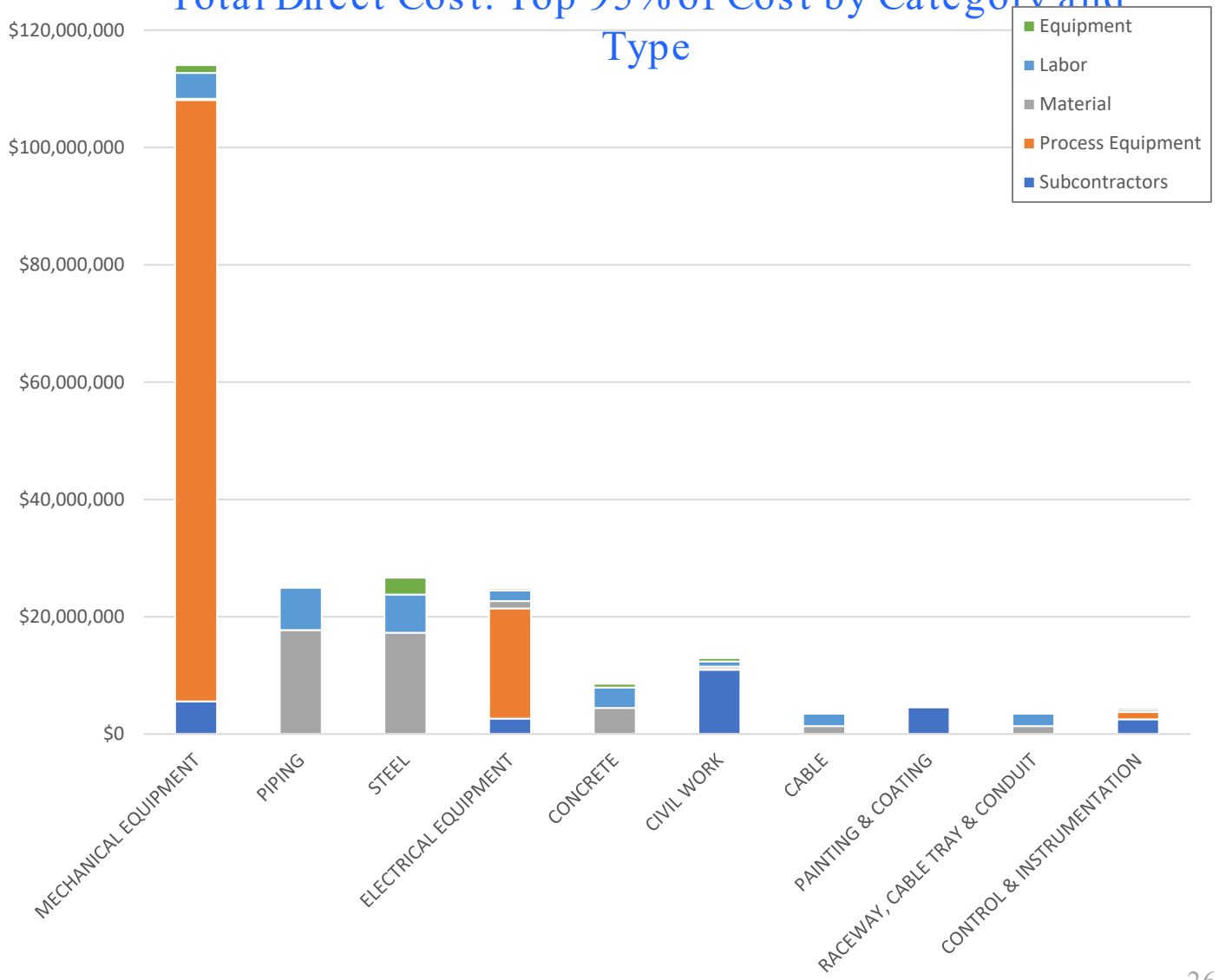
Capital Cost Breakdown

Total Project Cost ($432 million 2022$)



Total Direct Cost: Top 95% of Cost by Category and Type



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