# Scaleup and Site-Specific Engineering Design for Air Capture Technology

DE-FE0032101

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2023 Carbon Management Research Project Review Meeting
August 28 – September 1, 2023

# Project Overview

- Funding
  - Govt. Share: $2,808,243.00
  - Cost Share: $702,100.00
  - Total: $3,510,343.00
- Overall Project Performance Dates
  - Conditional Project Award: 10/01/2021
  - Final Award: 11/29/2021
  - Project Kickoff Meeting: 12/13/2021
  - Final Report: December 31, 2024

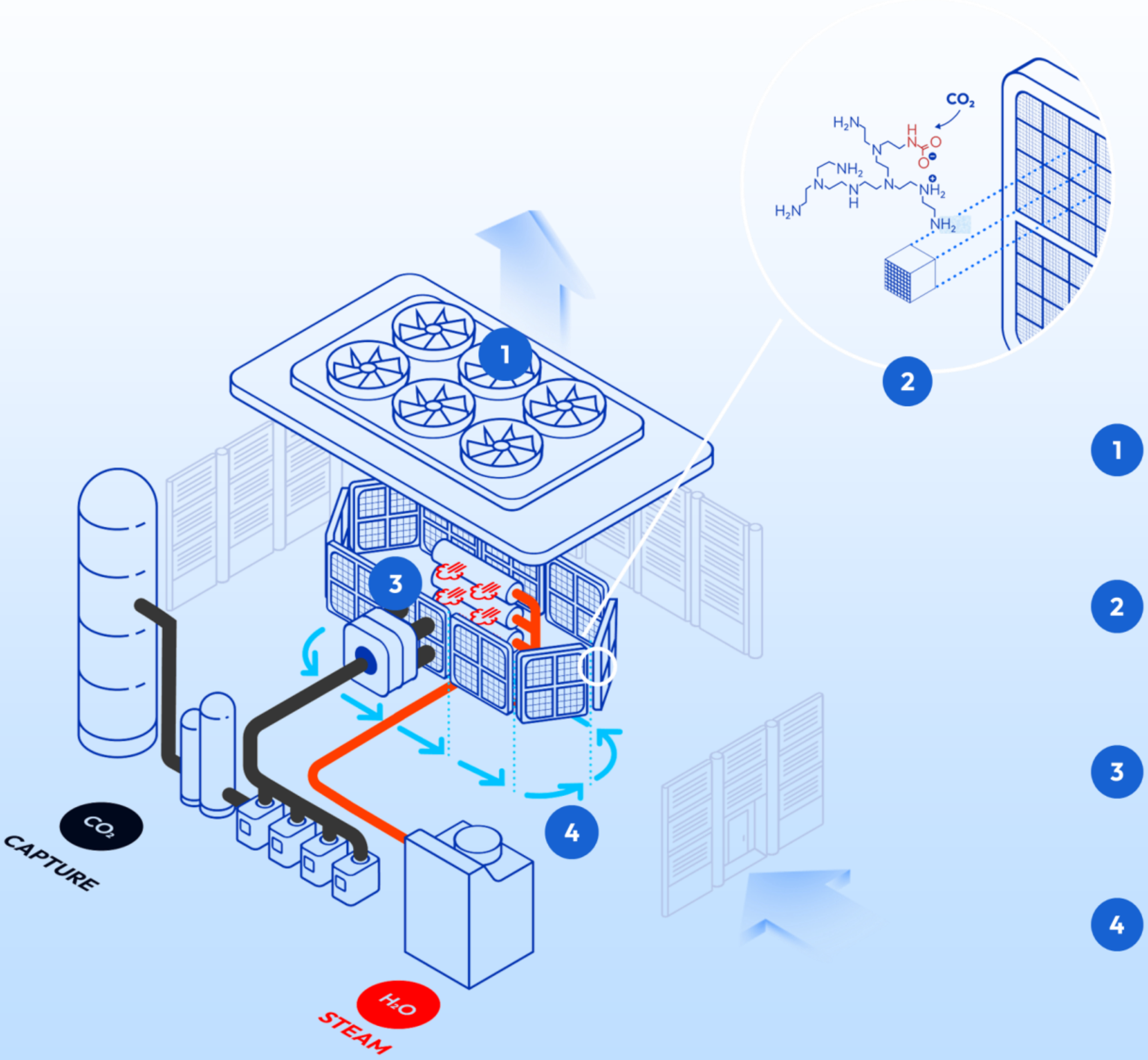
# Project Overview

- Project Participants
  - Lead Organization: Black & Veatch Corporation
  - Partner Organizations: Global Thermostat, Sargent & Lundy, ExxonMobil
  - Host sites: Southern Company, Elysian Ventures

# Project Overview

- Overall Project Objectives:  Completion of an initial design of a commercial-scale, Carbon Capture, Utilization, and Storage Direct Air Capture (CCUS-DAC) system that captures a net of at least 100,000 tonne per year (TPY) carbon dioxide (CO2) from the atmosphere and sequesters through pipeline transportation to different geological storage sites.

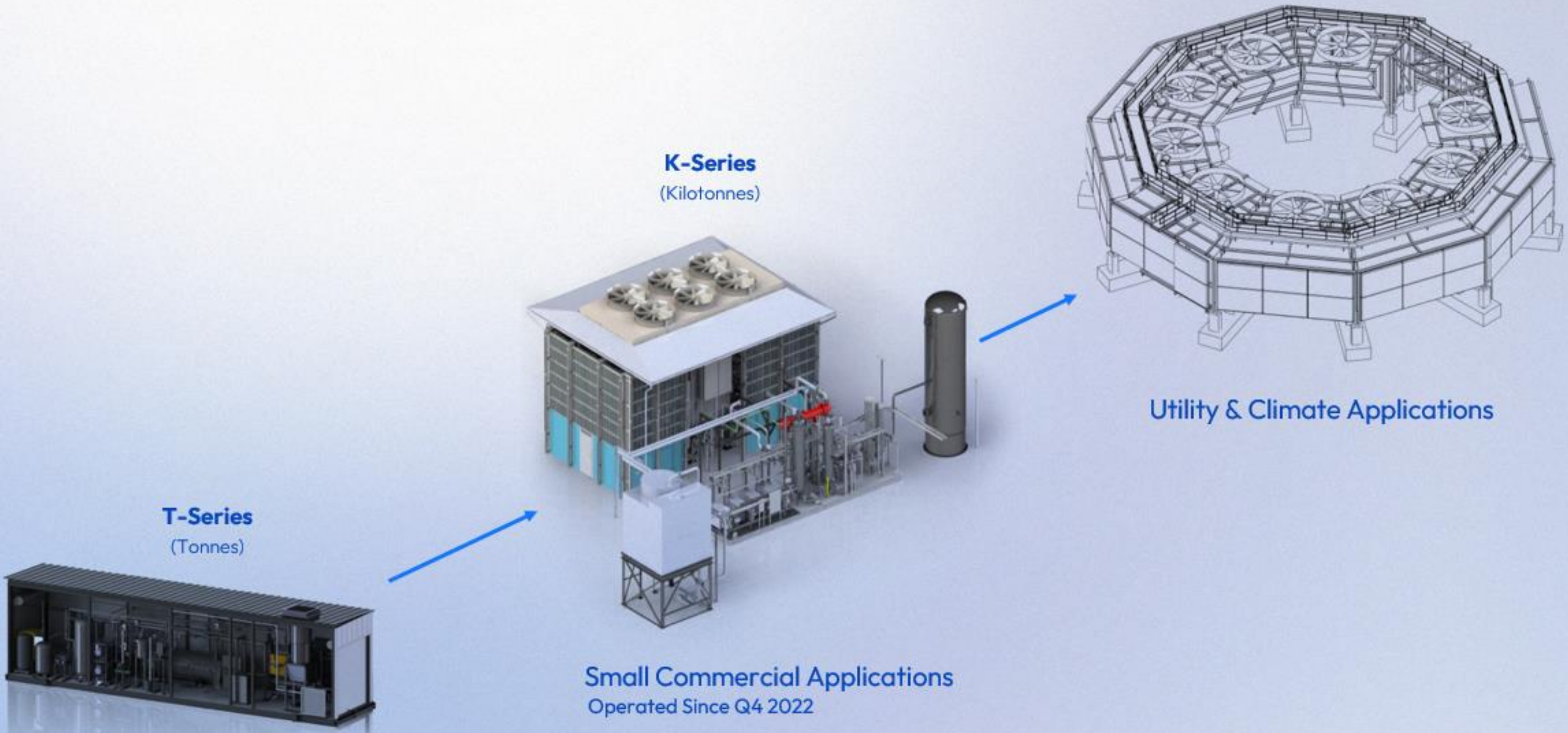
# Global Thermostat DAC Platform



### A Low Temperature, Solid Adsorbent Process

1. Air is pulled through our custom-designed contactors via high-efficiency, cooling-tower style fans
2. CO2 molecules are selectively trapped by proprietary amine sorbent embedded in our ultra-high surface area, low pressure drop contactors
3. Low temperature steam directly injected onto the contactor rapidly releases the $CO_2$, concentrating it for collection, use, or storage
4. The regenerated contactor panel reenters airflow to capture more $CO_2$, restarting the cycle

# Scalable Modules for All Markets



**T-Series**
(Tonnes)

Value Chain Pilots
Built & Operated Continuously, Semi-Autonomously since 2021

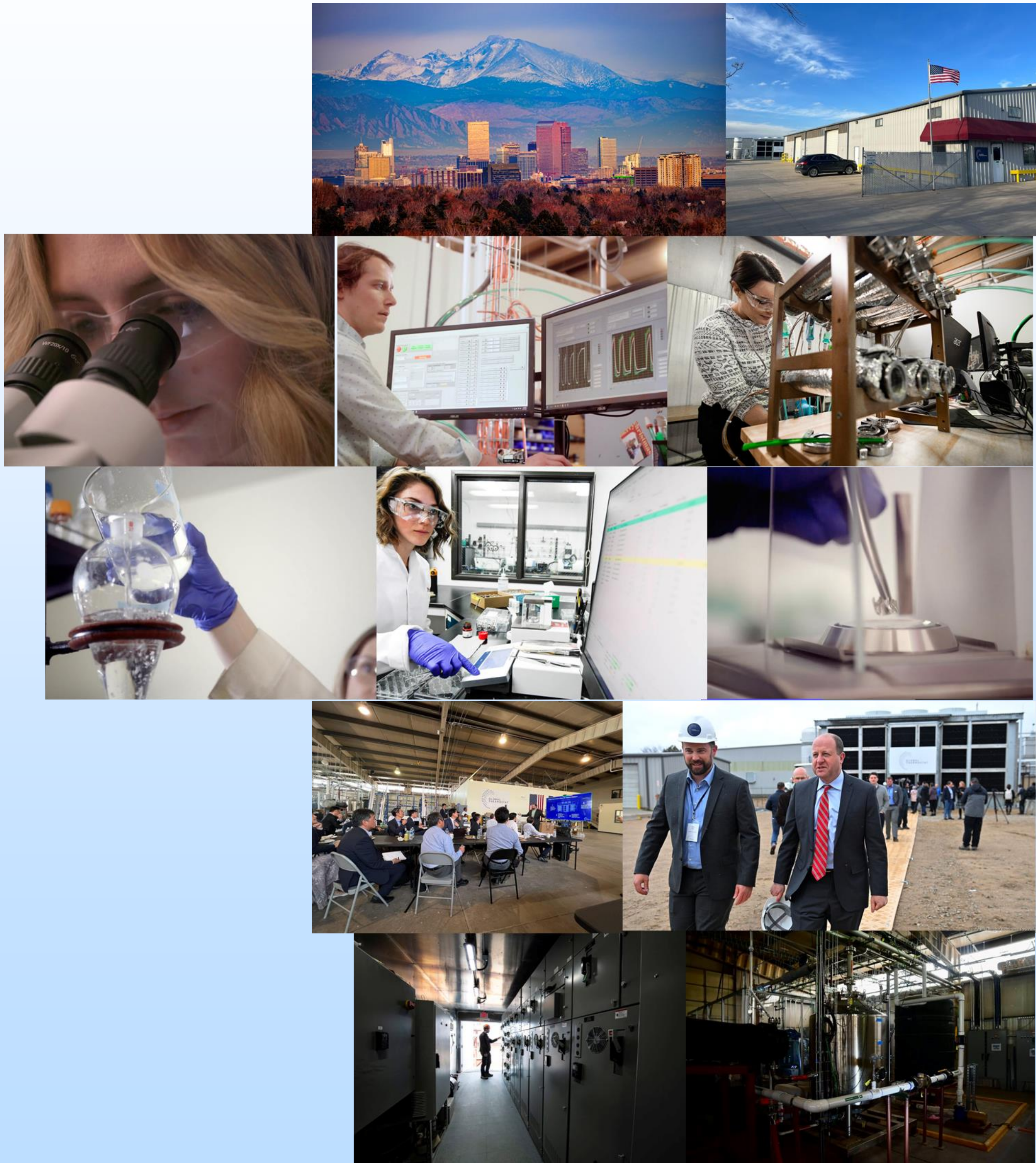
**K-Series**
(Kilotonnes)

Small Commercial Applications
Operated Since Q4 2022

**M-Series**
(Megatonnes)

Utility & Climate Applications

# GT Accelerated Development & Pilot Campus



Advanced R&D and integrated pilot campus at GT HQ near Denver, Colorado enables at-scale operation and rapid development cycles.

- 2+ Acre Facility
- State-of-the Art Analytical & Materials Labs
- Bench, Pilot & Commercial Scale Testing Facilities
- Fabrication & Prototyping Shop

# Kilotonne-scale GT DAC Demonstration

Operating since Q4 2022

- For 100+kta deployments, increase size of DAC module (scale up), duplicate DAC module (scale out), and centralized shared components

# Project Scope & Approach

- Identify three DAC plant locations of different climates, nearby to active sequestration.
- Complete FEED study and cost estimate for standalone DAC installation, including utilities and compression, capable of >100,000 tonnes/year *net* CO2 removal at the lead location.
  - Due to lack of reliable renewables at the sites, assume natural gas as the baseline energy source -- design CHP with packaged PCC amine system
  - DAC plant: GT, S&L
  - BOP/utilities: B&V
- Modify the lead location plant design for the subsequent two locations to adapt to the site specifics (climate, civil, etc.).
- TEA, LCA, EH&S assessment, business case assessment for each

# Project Sites

## Factors Affecting DAC Deployments at the Three Sites

- Differentials in productivity and energy demand due to climate (temperature and humidity) – rely on GT pilot-scale database
- Differentials in winterization requirements due to climate – use predictions based on GT experience in Colorado
- Differentials due to air quality – use predictions based on Colorado database
- Differences in energy costs (natural gas) and fixed costs (labor, maintenance, tax, and insurance) – input from host site partners
- All offer close by opportunities for sequestration

Site 1: Bucks, AL
Hot / Humid Climate

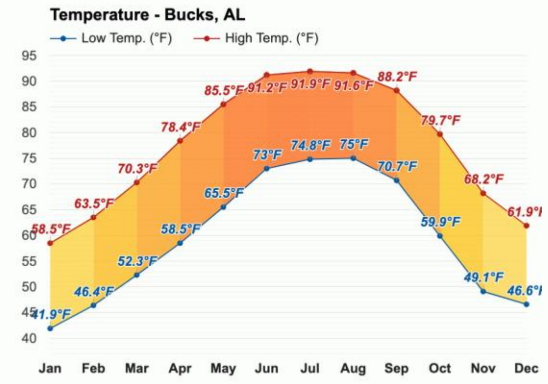
Site 2: Odessa, TX
Hot / Dry Climate

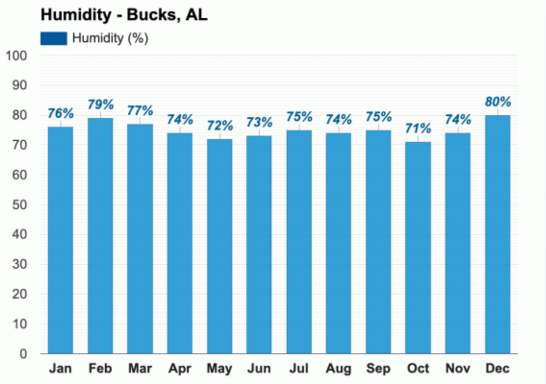
Site 3: Goose Creek, IL
Mid-Continental Climate

# Project Site 1 – Bucks, AL

- Baseline Site: JM Barry Power Plant

Southern
Company

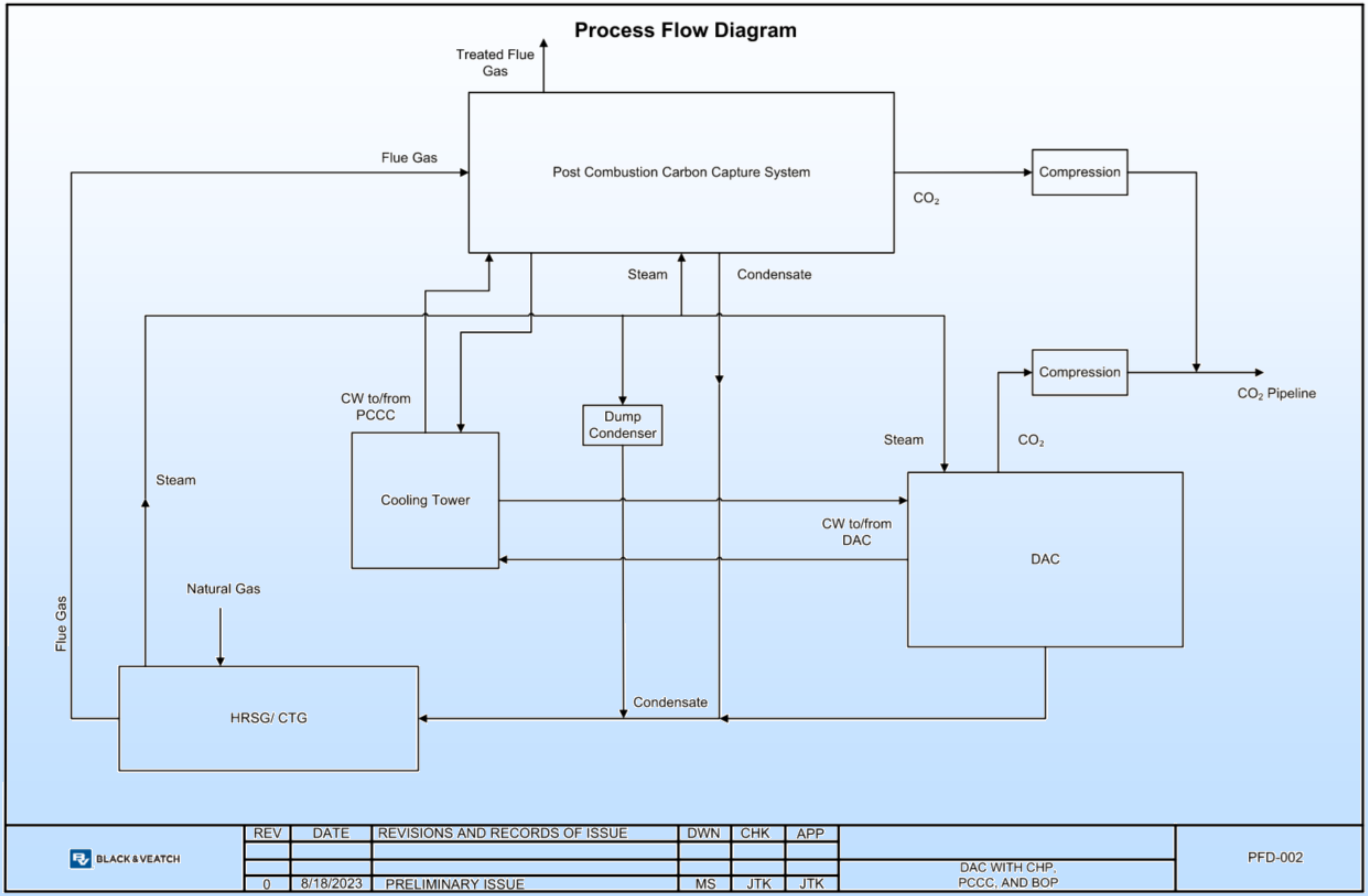




<u>Climate considerations</u>:

Hot, Humid
Lower delta T for regeneration
Higher thermal mass due to water content
Favorable kinetics for adsorption
Slower monolith dehumidification during transition
No winterization/subfreezing operation considerations

# Conceptual Block Flow



| REV | DATE | REVISIONS AND RECORDS OF ISSUE | DWN | CHK | APP |
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| 0 | 8/18/2023 | PRELIMINARY ISSUE | MS | JTK | JTK |

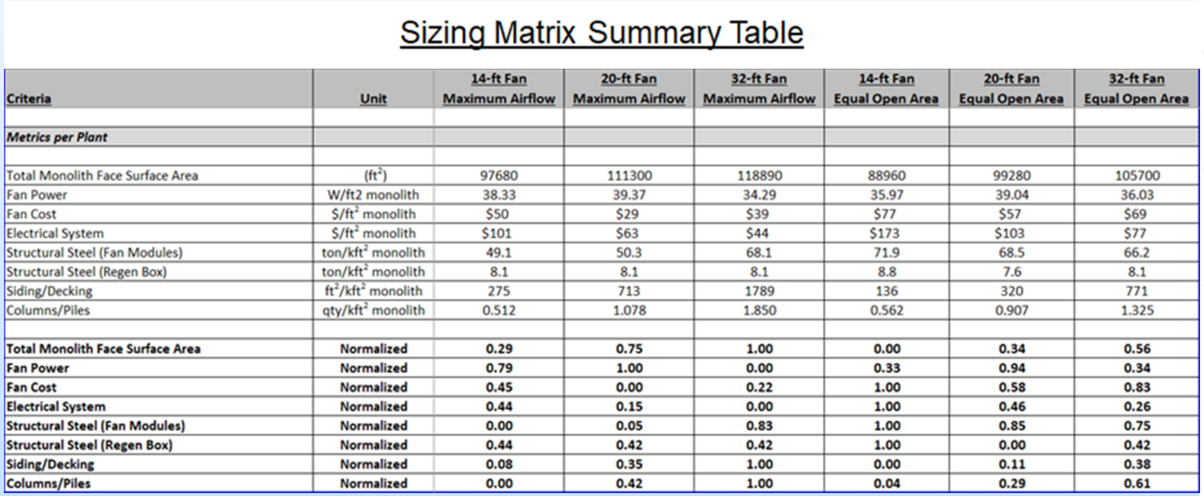
DAC WITH CHP,
PCCC, AND BOP

# Scale-Up Approach

- Build off of kilotonne-scale DAC plant
  - Retain concepts for movement system, regen box, seals, intake manifold, contactor cartridging, etc.
  - Retain 9:1 ratio of adsorption to desorption
  - Apply the same process steps
- Ring-shaped DAC module consisting of ten independent segments (wedges) and circular track
  - Each adsorption wedge compartmentalized but identical
- Develop size comparison matrices to evaluate capital & operating cost trends vs. segment size
- Down-select size based on efficiency, constructability, cost, commercial equipment availability
- Confirm and iterate viability of segment geometry for airflow uniformity and system pressure drop via CFD

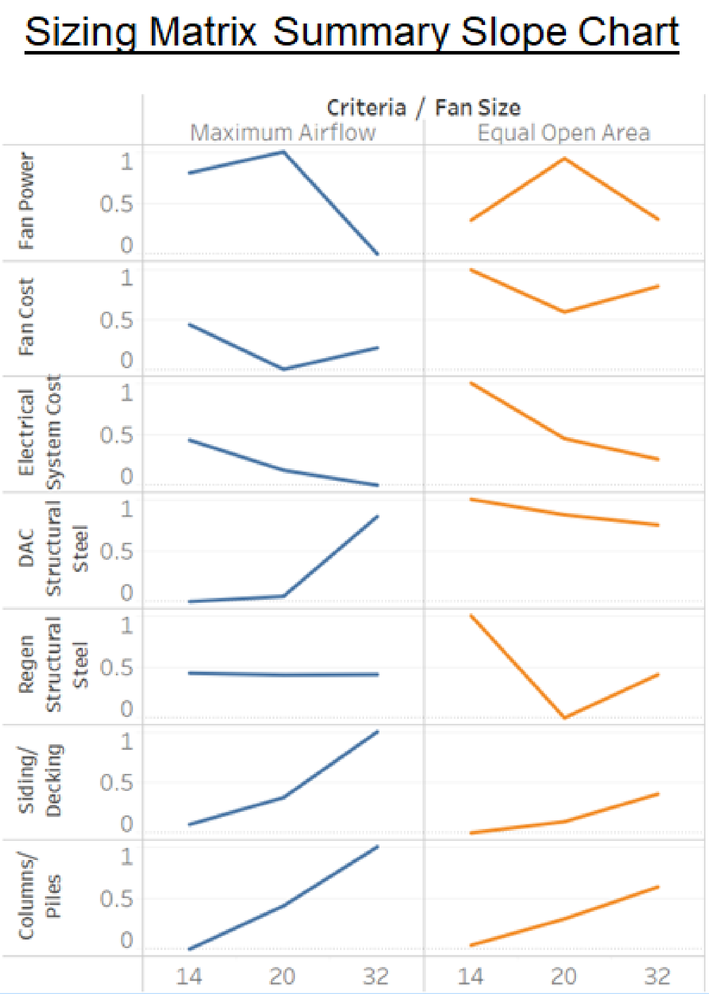
# Sizing Matrix Example

- Evaluate 14’ vs 20’ vs 32’ CT fans correlated to two different contactor amounts:
  - “Equal Area” – Contactor frontal area sized to equal fan sweep area
  - “Maximum Airflow” – Contactor frontal area sized to accommodate airflow capability at the specified static pressure



Sizing Matrix Summary Table

| Criteria | Unit | 14-ft Fan Maximum Airflow | 20-ft Fan Maximum Airflow | 32-ft Fan Maximum Airflow | 14-ft Fan Equal Open Area | 20-ft Fan Equal Open Area | 32-ft Fan Equal Open Area |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| ***Metrics per Plant*** | | | | | | | |
| | | | | | | | |
| Total Monolith Face Surface Area | ($\mathrm{ft}^2$) | 97680 | 111300 | 118890 | 88960 | 99280 | 105700 |
| Fan Power | W/ft2 monolith | 38.33 | 39.37 | 34.29 | 35.97 | 39.04 | 36.03 |
| Fan Cost | $\$/\mathrm{ft}^2$ monolith | \$50 | \$29 | \$39 | \$77 | \$57 | \$69 |
| Electrical System | $\$/\mathrm{ft}^2$ monolith | \$101 | \$63 | \$44 | \$173 | \$103 | \$77 |
| Structural Steel (Fan Modules) | $\mathrm{ton/kft}^2$ monolith | 49.1 | 50.3 | 68.1 | 71.9 | 68.5 | 66.2 |
| Structural Steel (Regen Box) | $\mathrm{ton/kft}^2$ monolith | 8.1 | 8.1 | 8.1 | 8.8 | 7.6 | 8.1 |
| Siding/Decking | $\mathrm{ft}^2/\mathrm{kft}^2$ monolith | 275 | 713 | 1789 | 136 | 320 | 771 |
| Columns/Piles | $\mathrm{qty/kft}^2$ monolith | 0.512 | 1.078 | 1.850 | 0.562 | 0.907 | 1.325 |
| | | | | | | | |
| **Total Monolith Face Surface Area** | **Normalized** | **0.29** | **0.75** | **1.00** | **0.00** | **0.34** | **0.56** |
| **Fan Power** | **Normalized** | **0.79** | **1.00** | **0.00** | **0.33** | **0.94** | **0.34** |
| **Fan Cost** | **Normalized** | **0.45** | **0.00** | **0.22** | **1.00** | **0.58** | **0.83** |
| **Electrical System** | **Normalized** | **0.44** | **0.15** | **0.00** | **1.00** | **0.46** | **0.26** |
| **Structural Steel (Fan Modules)** | **Normalized** | **0.00** | **0.05** | **0.83** | **1.00** | **0.85** | **0.75** |
| **Structural Steel (Regen Box)** | **Normalized** | **0.44** | **0.42** | **0.42** | **1.00** | **0.00** | **0.42** |
| **Siding/Decking** | **Normalized** | **0.08** | **0.35** | **1.00** | **0.00** | **0.11** | **0.38** |
| **Columns/Piles** | **Normalized** | **0.00** | **0.42** | **1.00** | **0.04** | **0.29** | **0.61** |

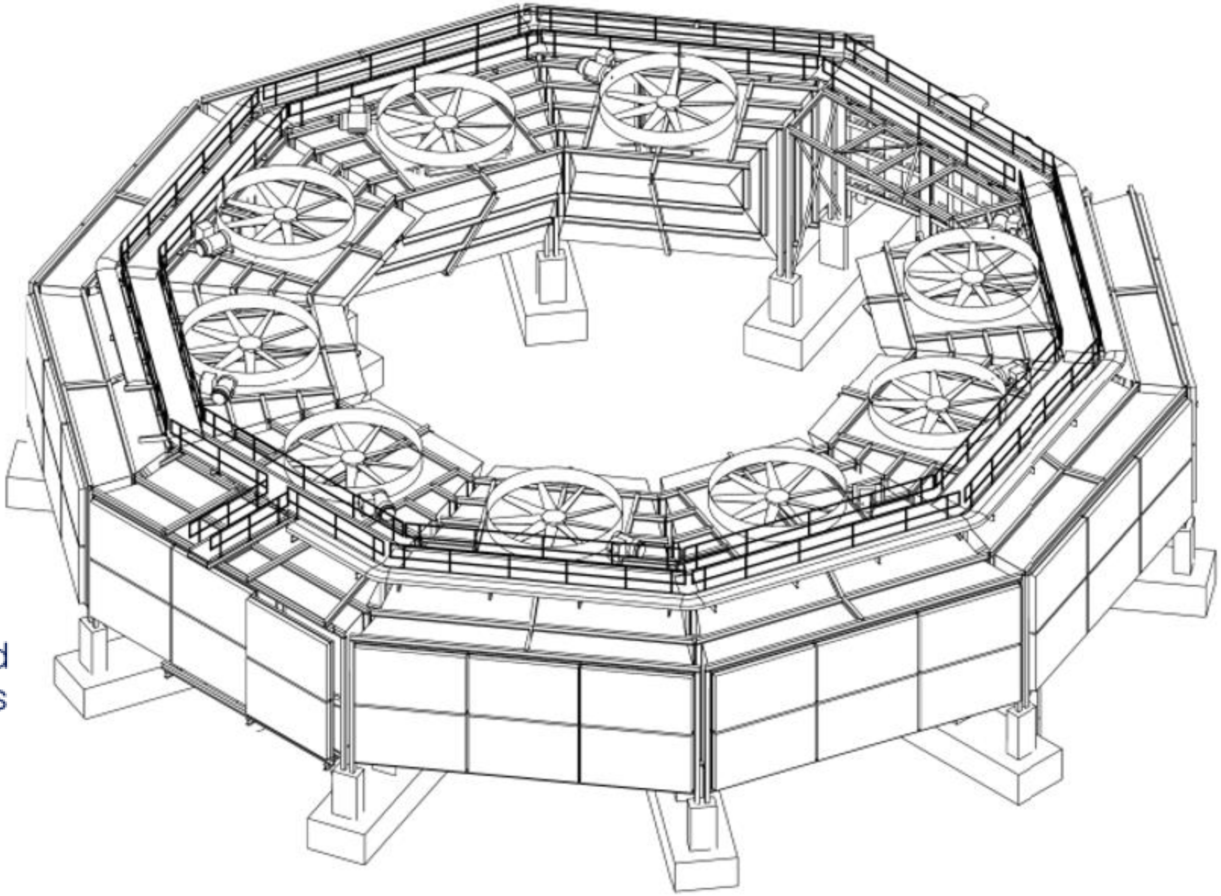


Sizing Matrix Summary Slope Chart

- Selected 15’ diameter fan with a monolith area to fan open area ratio of 2:1
- While the fan power and electrical system costs scaled favorably as the fan diameter increased, the structural design aspects scaled poorly
- Smaller DAC segments and regeneration boxes result in better constructability and maximizes shop fabrication

# DAC Module Design

- 9x Air Adsorption Modules, each with 15' diameter axial fans
  - Each includes filters and louvers
  - Each independent and isolated
- 1x Regeneration Module
- Circular monolith movement system rotates 30 track-guided contactor panel assemblies
- One Air Adsorption Module is fitted with barn door to facilitate access

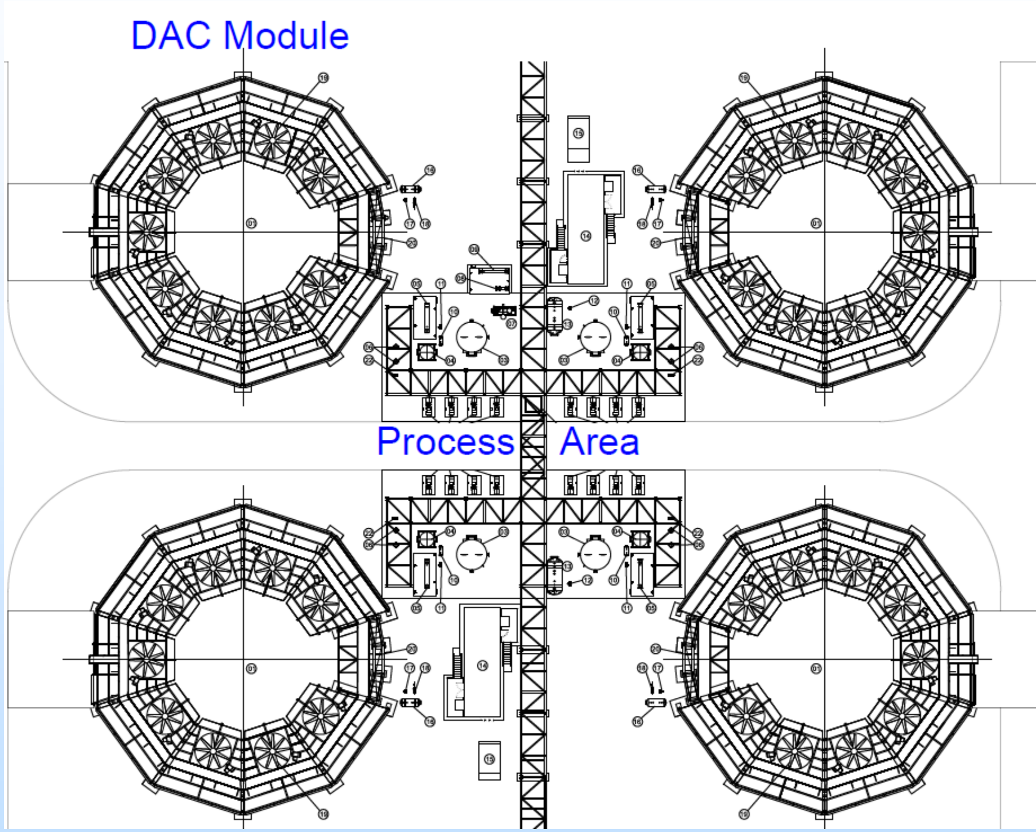


DAC MODULE

ISOMETRIC

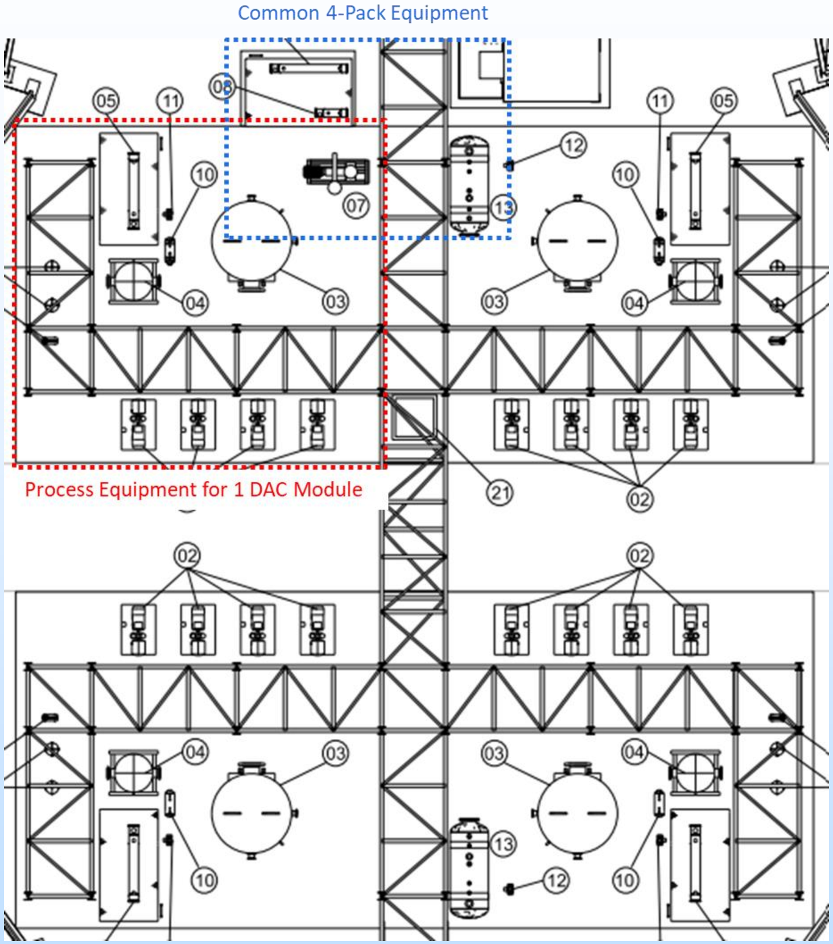
# “4-Pack” Repeat Unit

- DAC Module Diameter is 120’
- DAC Modules create 4-Pack Clusters
- Common 4-Pack Process Area
- Plant aggregate capacity scales by increasing the number of 4-Packs
- Centralized plant utilities
- Centralized plant CO2 compression



# Process Area

- Per DAC Module:
  - Product Separator
  - Product Condenser
  - Steam Capacitance Vessel
  - Air Evacuation/Harvest Vacuum Pumps
- Per 4-Pack:
  - Product Coolers and Blower
  - Condensate Collection
  - 2x PDCs: switchgear, MCCs, VFDs, UPS, DCS


Common 4-Pack Equipment

Process Equipment for 1 DAC Module

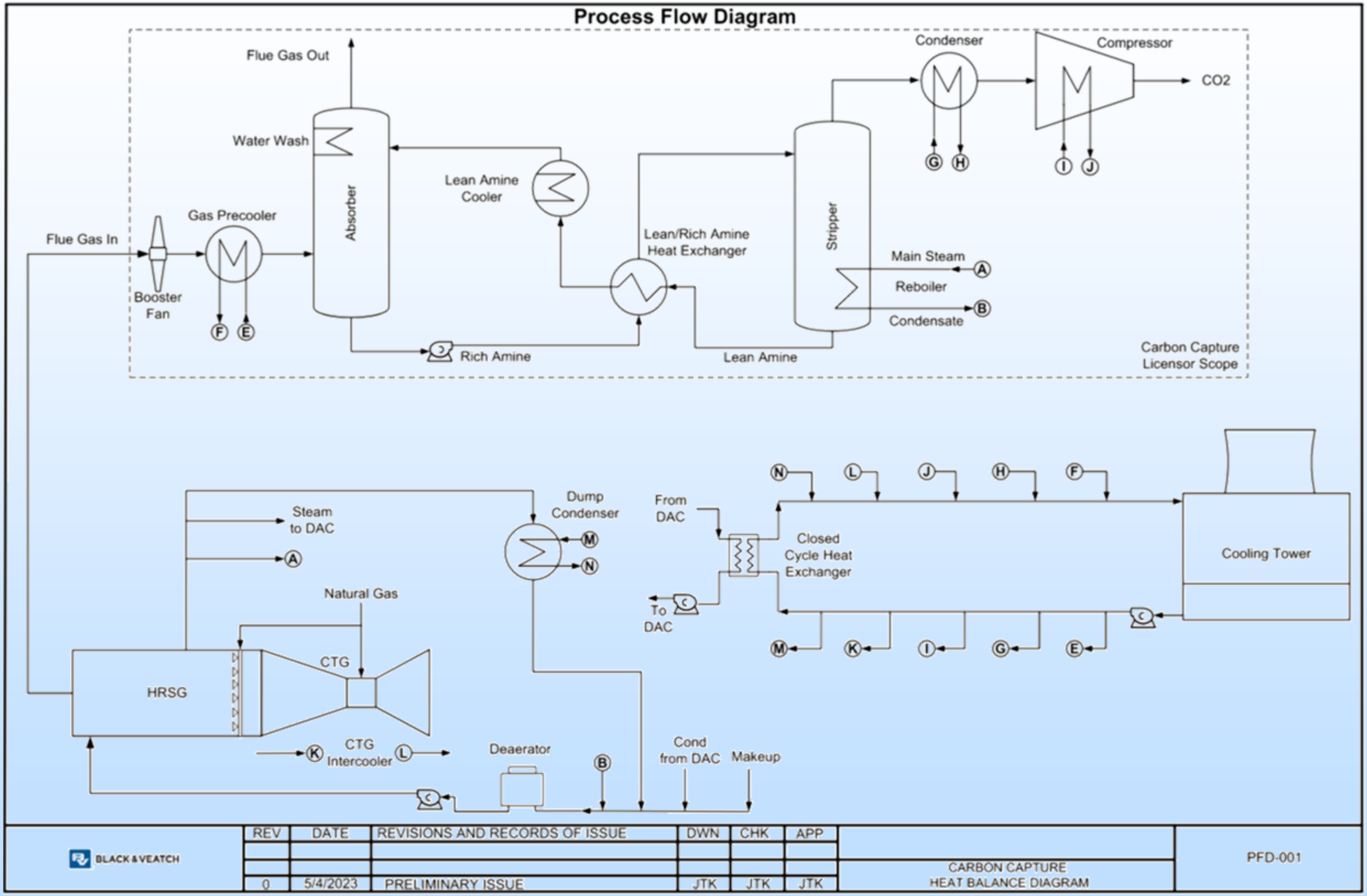
# DAC Modules

# Full DAC Plant

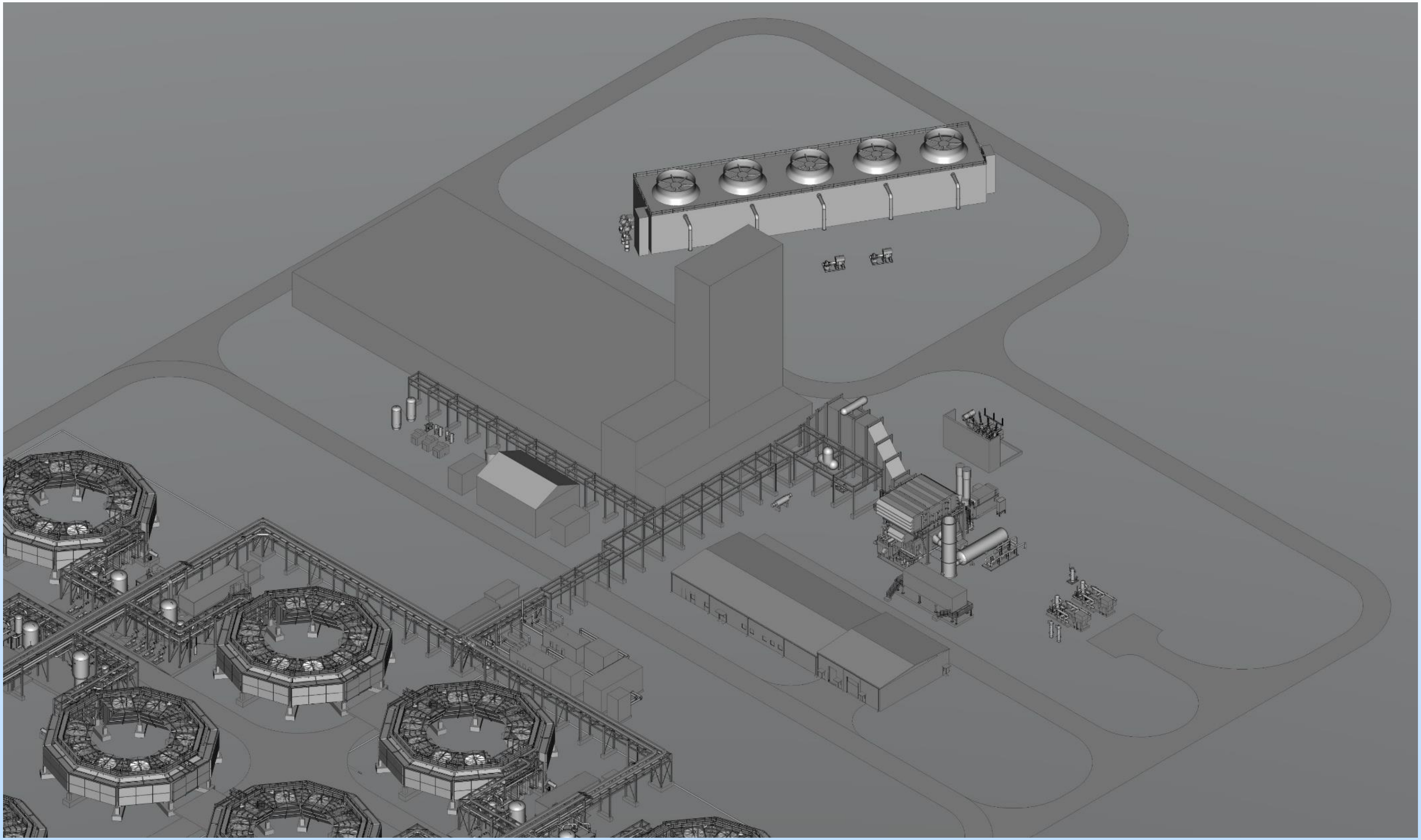
# Plant Utilities

- CHP
  - Single CTG/HRSG configuration
  - No STG to maintain flexibility and reduce complexity
  - Single pressure HRSG
    - SCR and CO catalyst for $NO_x$ and CO reduction, respectively
    - Supplemental duct firing to increase steam production and control
  - High efficiency, even at part load
  - High power (~115 MW) results in plenty of output margin
  - Low minimum CTG load of 20% while maintaining emissions compliance minimizes grid draw and startup durations
  - Post combustion carbon capture (PCCC) based on amine technology included to capture 95% of $CO_2$ emissions produced by the CHP.
- Auxiliary boiler
  - Will only be used for startup warming of the PCCC system and will not be utilized during steady state operation.

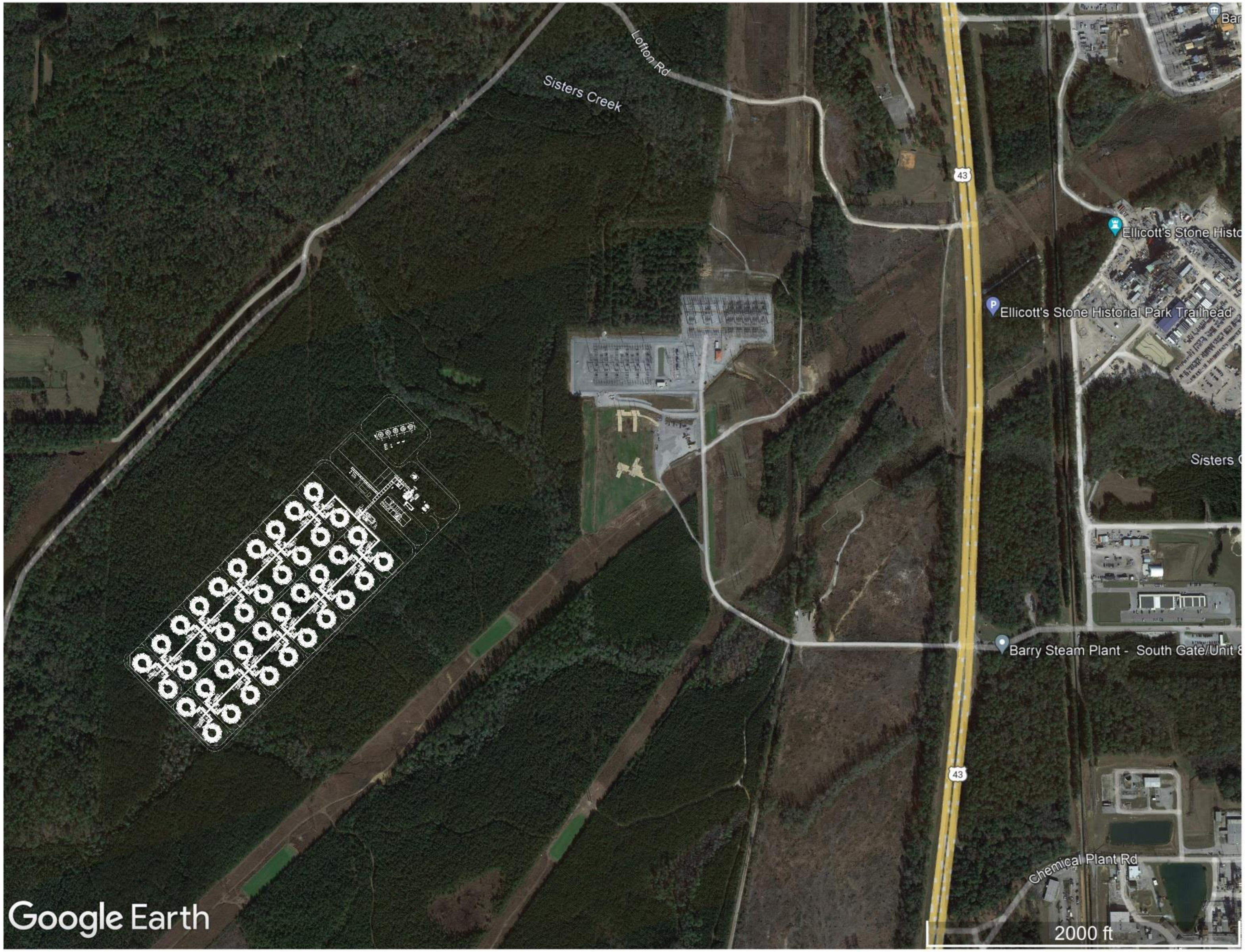
# Plant Utilities PFD



# Plant Utilities Rendering



# Bucks AL Conceptual Location



# Lessons Learned

- General size of the CHP facility and DAC power requirements have changed significantly since the initiation of the project. The auxiliary power for $CO_2$ compression was not initially included.
- Startup requirements and sequence for the CHP, PCCC, and DAC systems were developed.
    - Startup and shutdown events were sequenced to minimize natural gas combusted, electricity drawn from the grid, and CHP run time without the PCCC operating.
- Bigger is not always better – non-linear civil & structural costs create an optimization between DAC module scale and construction cost
- Cascading DAC modularity creates implicit redundancy

# Plans for future testing/development/ commercialization

a. Current project
   - Large scale DAC module designed to FEL2 level with Class 4 estimate
   - DAC plant designed for >100 kta net capture from the atmosphere – complete TEA and LCA

b. Next phase – after this project complete
   - Finalize the building block design for a climate-relevant plant; take to FEL3 design / Class 2 estimate
   - Construct the large-scale DAC module

# Summary Slide

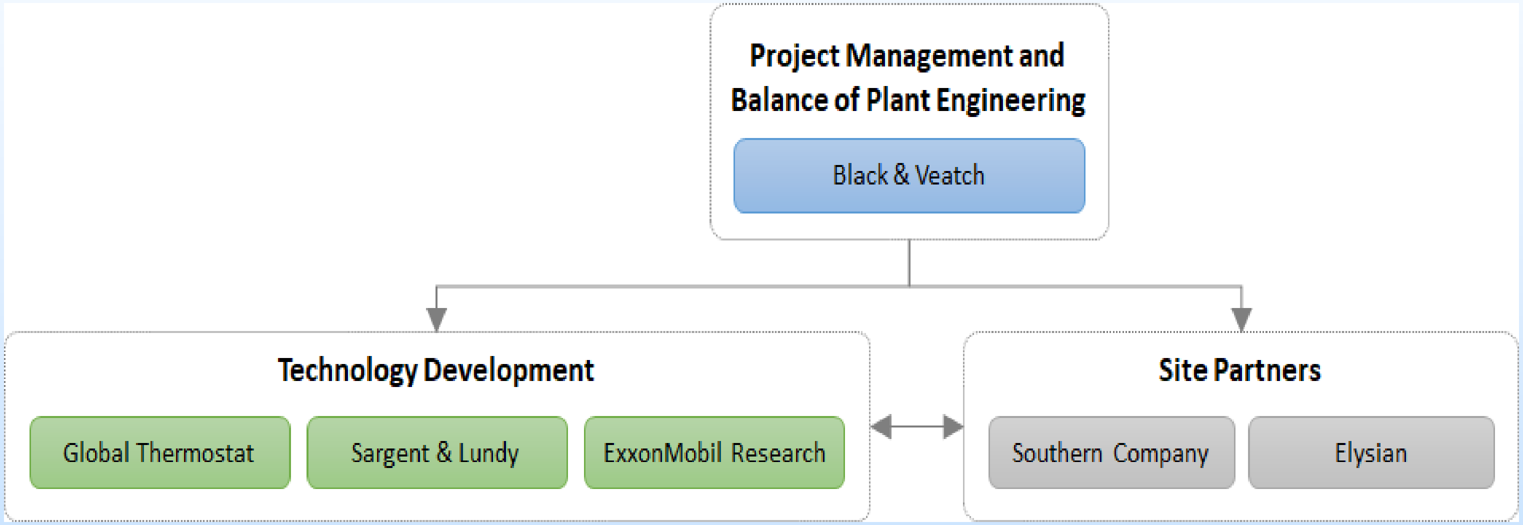
- DAC module designed for balance of scale and constructability
- Cascading modularity in overall DAC plant design:
  - › Centralized utilities, servicing
    - › Distributed process areas, each servicing
      - › Four-packs of DAC modules, each comprised of
        - › Nine identical adsorption wedges, each containing
          - › Three contactor panels, each populated with
            - › Hundreds of active contactor bricks
- Modifications to primary Bucks AL plant design, cost, productivity in progress
  - Odessa TX - Hot & Dry: Lower energy requirement
  - Goose Creek IL - Cold & Wet: Winterization

# Thank You

# Appendix

- These slides will not be discussed during the presentation but are mandatory.

# Organization Chart



**Project Management and Balance of Plant Engineering**

Black & Veatch

**Technology Development**

Global Thermostat

Sargent & Lundy

ExxonMobil Research

**Site Partners**

Southern Company

Elysian

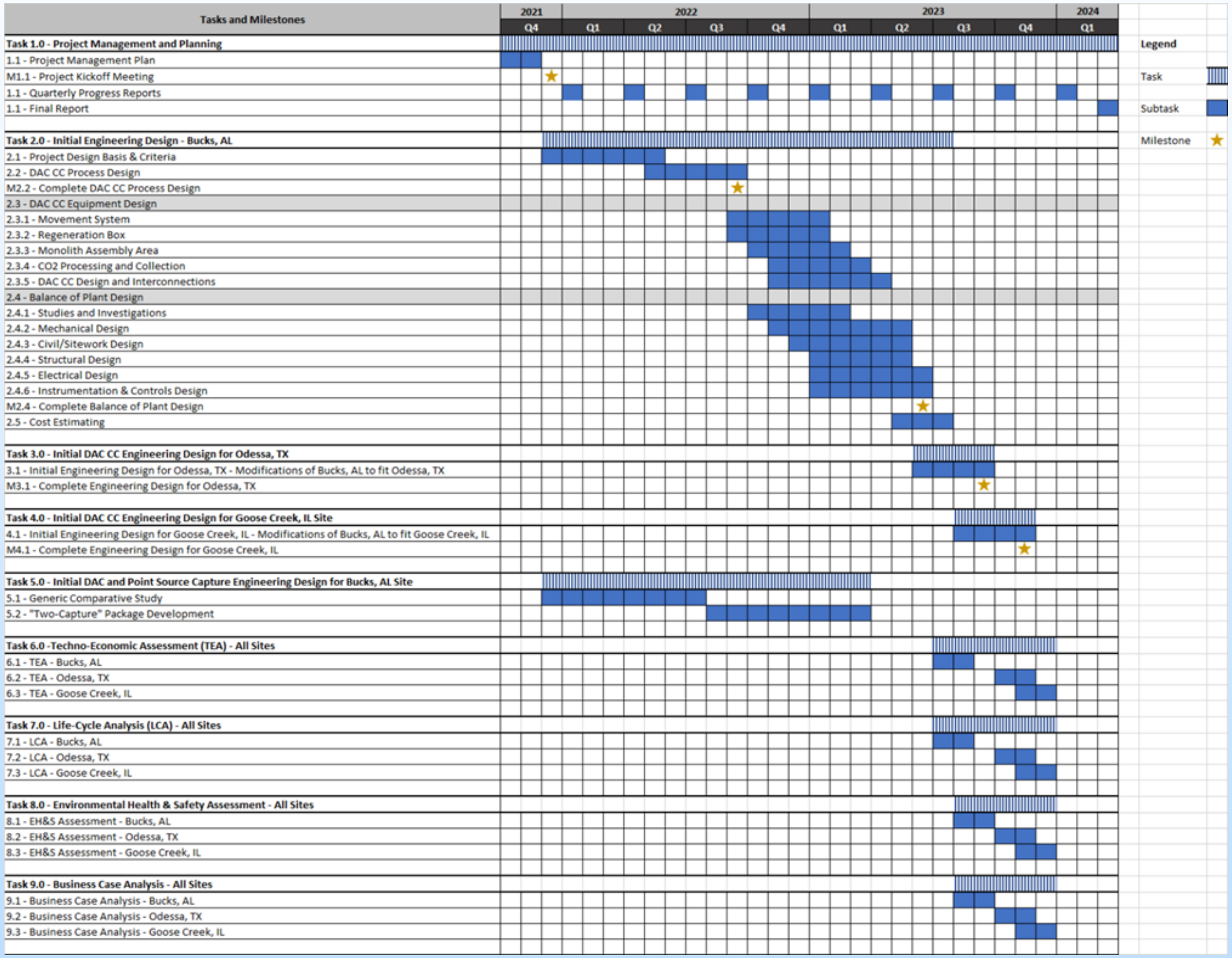
# Project Team

- Black & Veatch
  - Mark Steutermann – Project Manager
  - Algert Prifti – Technology Manager
  - Dave Oldham – BOP Engineering Manager
- Global Thermostat
  - Dr. Eric Ping – VP, Process & Operations
  - Dr. Steph Didas – Director, Special Projects
  - Dr. Miles Sakwa-Novak – VP, Materials
  - Brianna Atherton, P.E. – VP, Plant Design & Manufacturing
  - Jed Pruett – Director, Process Development
  - Zachary Foltz – Development Engineer

# Project Team (cont.)

- Sargent & Lundy
  - Kevin Lauzze – VP and Project Director
  - Nick Kutella – Project Manager
  - Cheryl Goodenough – Engineering Manager
  - Bill Sheeren – Process & Mechanical Engineer
- ExxonMobil Technology & Engineering (EMTEC)
  - Rustom Billimoria – Distinguished Scientific Advisor
  - Justin Federici – Project Manager
- Southern Company
  - John Carroll – Project Engineer
- Elysian
  - Bret Logue – Principal Elysian Ventures, LLC

# Gantt Chart



| Tasks and Milestones | 2021 | | | 2022 | | | | | | | | | | | | 2023 | | | | | | | | | | | | 2024 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q4 | | | Q1 | | | Q2 | | | Q3 | | | Q4 | | | Q1 | | | Q2 | | | Q3 | | | Q4 | | | Q1 | | |
| **Task 1.0 - Project Management and Planning** |▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|
| 1.1 - Project Management Plan |■|■| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| M1.1 - Project Kickoff Meeting | | |★| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.1 - Quarterly Progress Reports | | | |■| | |■| | |■| | |■| | |■| | |■| | |■| | |■| | |■| | |
| 1.1 - Final Report | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |■|
| **Task 2.0 - Initial Engineering Design - Bucks, AL** | | |▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥| | | | | | | | |
| 2.1 - Project Design Basis & Criteria | | |■|■|■|■|■|■| | | | | | | | | | | | | | | | | | | | | | |
| 2.2 - DAC CC Process Design | | | | | | | |■|■|■|■|■| | | | | | | | | | | | | | | | | | |
| M2.2 - Complete DAC CC Process Design | | | | | | | | | | | |★| | | | | | | | | | | | | | | | | | |
| 2.3 - DAC CC Equipment Design | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.3.1 - Movement System | | | | | | | | | | | |■|■|■|■|■| | | | | | | | | | | | | | |
| 2.3.2 - Regeneration Box | | | | | | | | | | | |■|■|■|■|■| | | | | | | | | | | | | | |
| 2.3.3 - Monolith Assembly Area | | | | | | | | | | | | |■|■|■|■|■| | | | | | | | | | | | | |
| 2.3.4 - CO2 Processing and Collection | | | | | | | | | | | | | |■|■|■|■|■| | | | | | | | | | | | |
| 2.3.5 - DAC CC Design and Interconnections | | | | | | | | | | | | | |■|■|■|■|■|■| | | | | | | | | | | |
| 2.4 - Balance of Plant Design | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.4.1 - Studies and Investigations | | | | | | | | | | | | |■|■|■|■|■| | | | | | | | | | | | | |
| 2.4.2 - Mechanical Design | | | | | | | | | | | | | |■|■|■|■|■|■|■| | | | | | | | | | |
| 2.4.3 - Civil/Sitework Design | | | | | | | | | | | | | | |■|■|■|■|■|■| | | | | | | | | | |
| 2.4.4 - Structural Design | | | | | | | | | | | | | | | |■|■|■|■|■| | | | | | | | | | |
| 2.4.5 - Electrical Design | | | | | | | | | | | | | | | |■|■|■|■|■|■| | | | | | | | | |
| 2.4.6 - Instrumentation & Controls Design | | | | | | | | | | | | | | | |■|■|■|■|■|■| | | | | | | | | |
| M2.4 - Complete Balance of Plant Design | | | | | | | | | | | | | | | | | | | | |★| | | | | | | | | |
| 2.5 - Cost Estimating | | | | | | | | | | | | | | | | | | | |■|■|■| | | | | | | | |
| **Task 3.0 - Initial DAC CC Engineering Design for Odessa, TX** | | | | | | | | | | | | | | | | | | | | |▥|▥|▥|▥| | | | | | |
| 3.1 - Initial Engineering Design for Odessa, TX - Modifications of Bucks, AL to fit Odessa, TX | | | | | | | | | | | | | | | | | | | | |■|■|■|■| | | | | | |
| M3.1 - Complete Engineering Design for Odessa, TX | | | | | | | | | | | | | | | | | | | | | | | |★| | | | | | |
| **Task 4.0 - Initial DAC CC Engineering Design for Goose Creek, IL Site** | | | | | | | | | | | | | | | | | | | | | | |▥|▥|▥|▥| | | | |
| 4.1 - Initial Engineering Design for Goose Creek, IL - Modifications of Bucks, AL to fit Goose Creek, IL | | | | | | | | | | | | | | | | | | | | | | |■|■|■|■| | | | |
| M4.1 - Complete Engineering Design for Goose Creek, IL | | | | | | | | | | | | | | | | | | | | | | | | | |★| | | | |
| **Task 5.0 - Initial DAC and Point Source Capture Engineering Design for Bucks, AL Site** | | |▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥|▥| | | | | | | | | | | | |
| 5.1 - Generic Comparative Study | | |■|■|■|■|■|■|■|■| | | | | | | | | | | | | | | | | | | | |
| 5.2 - "Two-Capture" Package Development | | | | | | | | | | |■|■|■|■|■|■|■|■| | | | | | | | | | | | |
| **Task 6.0 -Techno-Economic Assessment (TEA) - All Sites** | | | | | | | | | | | | | | | | | | | | | |▥|▥|▥|▥|▥|▥| | | |
| 6.1 - TEA - Bucks, AL | | | | | | | | | | | | | | | | | | | | | |■|■| | | | | | | |
| 6.2 - TEA - Odessa, TX | | | | | | | | | | | | | | | | | | | | | | | | |■|■| | | | |
| 6.3 - TEA - Goose Creek, IL | | | | | | | | | | | | | | | | | | | | | | | | | |■|■| | | |
| **Task 7.0 - Life-Cycle Analysis (LCA) - All Sites** | | | | | | | | | | | | | | | | | | | | | |▥|▥|▥|▥|▥|▥| | | |
| 7.1 - LCA - Bucks, AL | | | | | | | | | | | | | | | | | | | | | |■|■| | | | | | | |
| 7.2 - LCA - Odessa, TX | | | | | | | | | | | | | | | | | | | | | | | | |■|■| | | | |
| 7.3 - LCA - Goose Creek, IL | | | | | | | | | | | | | | | | | | | | | | | | | |■|■| | | |
| **Task 8.0 - Environmental Health & Safety Assessment - All Sites** | | | | | | | | | | | | | | | | | | | | | | |▥|▥|▥|▥|▥| | | |
| 8.1 - EH&S Assessment - Bucks, AL | | | | | | | | | | | | | | | | | | | | | | |■|■| | | | | | |
| 8.2 - EH&S Assessment - Odessa, TX | | | | | | | | | | | | | | | | | | | | | | | | |■|■| | | | |
| 8.3 - EH&S Assessment - Goose Creek, IL | | | | | | | | | | | | | | | | | | | | | | | | | |■|■| | | |
| **Task 9.0 - Business Case Analysis - All Sites** | | | | | | | | | | | | | | | | | | | | | | |▥|▥|▥|▥|▥| | | |
| 9.1 - Business Case Analysis - Bucks, AL | | | | | | | | | | | | | | | | | | | | | | |■|■| | | | | | |
| 9.2 - Business Case Analysis - Odessa, TX | | | | | | | | | | | | | | | | | | | | | | | | |■|■| | | | |
| 9.3 - Business Case Analysis - Goose Creek, IL | | | | | | | | | | | | | | | | | | | | | | | | | |■|■| | | |

| **Legend** | |
|---|---|
| Task | ▥ |
| Subtask | ■ |
| Milestone | ★ |