Direct Air Capture Recovery of Energy for CCUS Partnership (DAC RECO2UP)

Project Number: DE-FE0031961

Joshua Miles, Aircapture

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 29th, 2023

Project Overview

Period of Performance:

10/1/2020 – 01/31/2024

Project Funding:

Federal Share: $2,500,000

DOD: $1,000,000

DOE: $1,500,000

Non-Federal Share: $635,805

Total: $3,135,805

Project Team Members:

Southern States Energy Board

Aircapture LLC

Synapse Product Development

Crescent Resource Innovation

National Carbon Capture Center

Southern Company

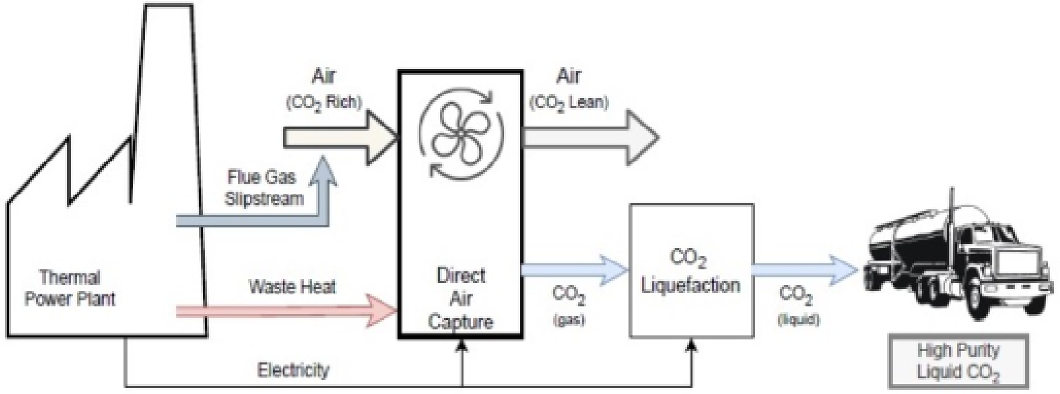
Global Thermostat LLC

Project Goal:

Decrease the cost of capture through testing of existing DAC materials in integrated field units that produce concentrated CO2 stream of at least 95% purity.

Project Objectives and Program Alignment

DAC RECO2UP seeks to advance laboratory-tested DAC materials in a commercially relevant embodiment and environment with a system fidelity that, if successful, will lower the cost of DAC and demonstrate TEA and LCA suitable for commercial applications at the scale tested. The proposal will explore multiple configurations of a single embodiment allowing for future prototypical designs to be tailored for specific commercial applications. Demonstrating the economic viability of DAC in various configurations while demonstrating a decreased cost and preliminary LCA will validate DAC as a commercially viable and scalable negative emission technology as identified by the National Academies and referenced in this Program. Further, the multidisciplinary team and involved stakeholder network will assist in the knowledge dissemination of the project and help to validate the technology for commercial applications.



Project Objectives and Program Alignment

Stated Program Goals (FOA 2188 AOI-2):

Decrease the cost of capture through testing of existing DAC materials in integrated field units that produce concentrated CO_2 stream of at least 95% purity.

Conduct in-field testing of integrated systems allowing for continued development of the process and opportunities to identify optimization options.

Fully develop the techno-economics of these DAC configurations and their overall CO_2 impact through life cycle analysis (LCA).

DAC RECO2UP Project Objectives:

Objective 1. Conduct applied research and development to decrease the cost of DAC from atmospheric air and mixtures of air and simulated industrial gases available in a test bay at the National Carbon Capture Center (NCCC).

Objective 2. Develop and scale-up an integrated system utilizing energy recovery at the NCCC.

Objective 3. Increase the integrated system's fidelity by validating and demonstrating operations in a simulated commercial environment by maximizing capital efficiency, energy efficiency.

Objective 4. Identify and address key technical barriers, within a representative operating environment, in support of DAC technology commercialization.

Objective 5. Perform a pre-screening techno-economic analysis (TEA) and life cycle analysis (LCA) to determine the environmental sustainability (amount of carbon negativity) and economic viability (cost impacts) of the integrated DAC system.

Project Team Facilities

- 9,000 SQ FT of design, fabrication, manufacturing and laboratory space
  - power, water, steam, natural gas, vacuum
- Testing Facilities
  - FAT, analysis in Berkeley
  - Integrated Systems at the NCCC in Wilsonville, Alabama
- Laboratories

Synapse Build Labs
(Seattle, SF)

AirCapture Manufacturing, Laboratory & Fabrication Facilities
(Berkeley, CA)

National Carbon Capture Center
https://www.nationalcarboncapturecenter.com

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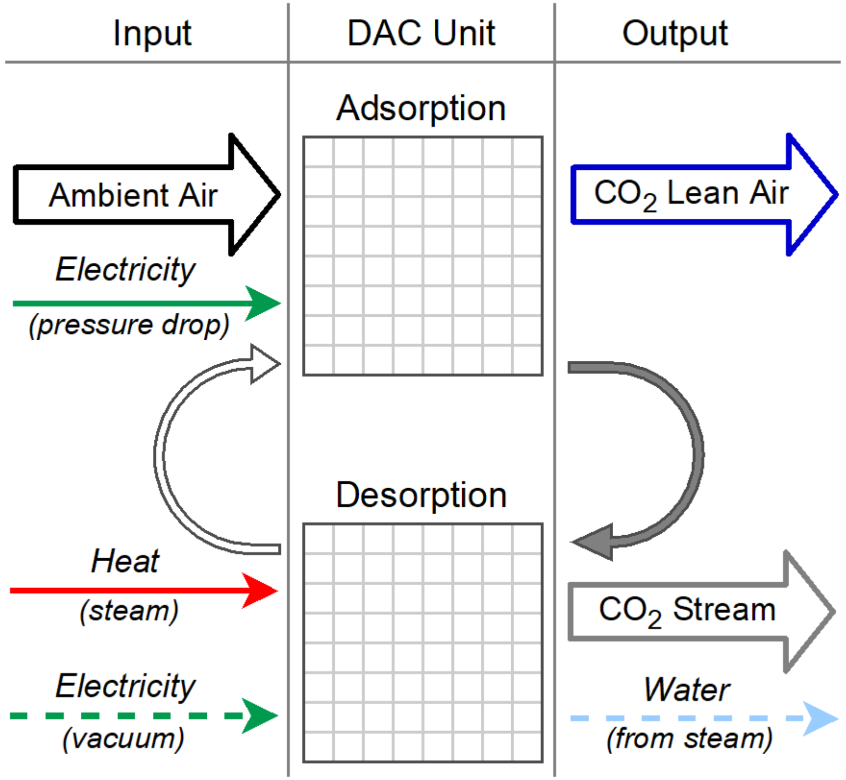
Technology Background

Step 1 (Capture): CO2 is collected by moving air or mixtures of air and CO2 rich gases across a proprietary contactor which adsorbs CO2.

Step 2 (Regeneration): The contactor is moved into a regeneration box where low-temperature steam flows across the contactor, removing CO2 from the contactor, and the CO2 is collected.



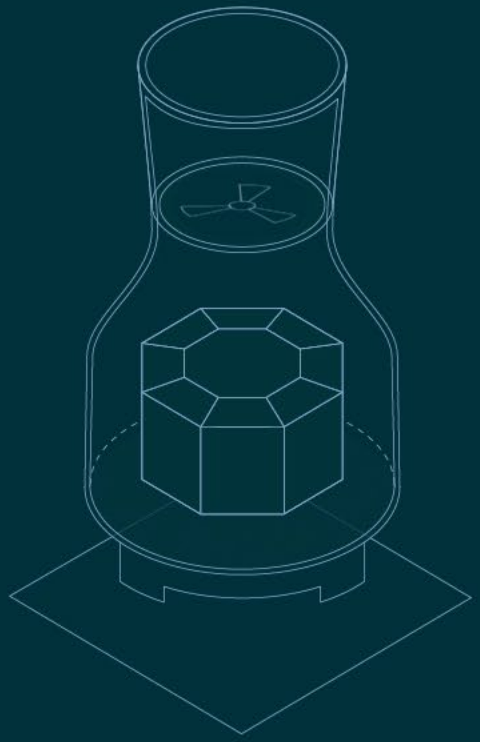
Polymeric Amine Sorbent

- Monolithic Contactor
- Low pressure drop
- Low thermal mass
- High geometric surface area
- Compatible with various construction methods

Adsorption
- 900 seconds / monolith in ambient air

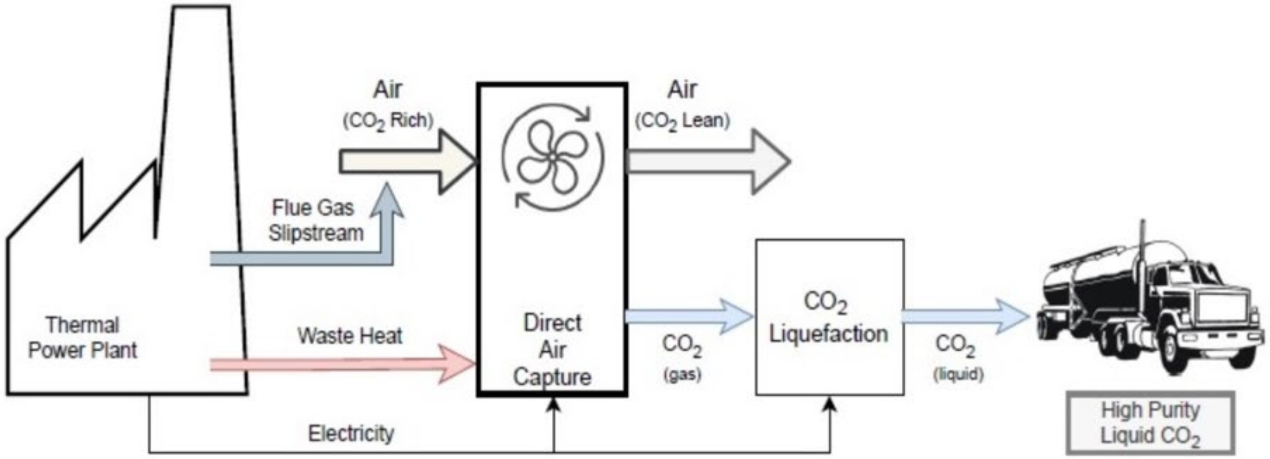
Desorption
- Saturated Steam in less than 90 seconds

Monoliths & sorbents provided by Global Thermostat



Project Design

Goal: Develop integrated DAC system design with thermal recovery and downstream processing to increase overall system fidelity and demonstrate in commercially relevant field testing at NCCC.



3 skids:

- Heat Integration/Recovery
- DAC
- CO2 Liquefaction

Heat skid will enable simulation of varying qualities of industrial waste heat

DFM DAC will run in multiple modes of operation to demonstrate integration

CO2 processing skid will produce CO2 in varying qualities for testing

Integrated process will demonstrate economics, LCA and product carbon footprint.

Project Schedule

✓ Design Phase I (BP1)
- 10/1/20 – 10/31/21

✓ Construction Phase II (BP2)
- 11/1/21 – 10/31/22

➢ Integrated Systems Testing Phase III (BP3)
- 11/1/22 – 1/31/24

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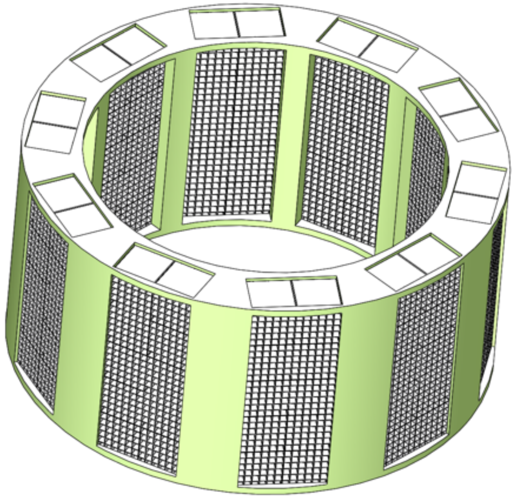
DAC Conceptual Design

Goal: Evaluate a number of conceptual designs for contactor configuration.

Considerations: Minimize pressure drop, sealing mechanisms, system volume, moment of inertia, equipment availability, etc.

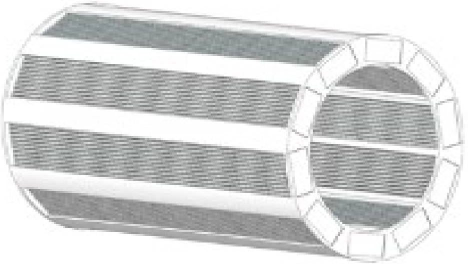
Modular, Scalable, DFM



2x5 Contactor Arrangement (100 tonne/yr)

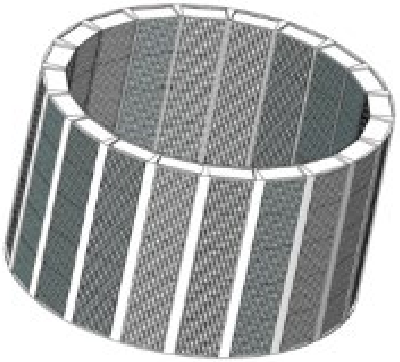
1 X 10 Flat

- Air Flows from the inside
- Air Flows out the outside
- Reference Volumes
  - Outer = 5.48 m^3
  - Net = 2.53 m^3
- Brick I = 220 kg*m^2
- Pros
  - Smallest OD = 1500mm
  - 2 choices for Steam Chamber
    - Steam chamber seals on Inside and Outside length of Cylinder. Cylinder rotates
    - Steam chamber moves along
- Cons
  - Over 10 feet long



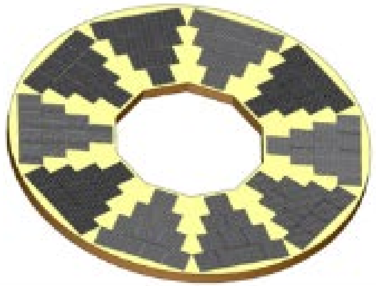
5 x 20 ring

- Air Flows from the inside
- Air Flows out the outside
- Steam chamber seals on inside and outside of Cylinder
- Reference Volumes
  - Outer = 6.72 m^3
  - Net = 1.85 m^3
- Brick I = 616 kg*m^2
- Pros
  - Direct air flow
  - Low net volume
  - Lots of room in the middle for stuff
- Cons
  - Large OD, 2500 mm (7.7 feet)



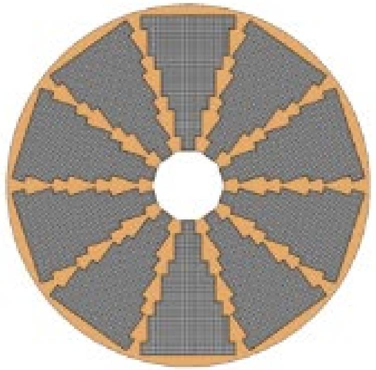
12 inch brick flat

- Air comes in the bottom
- Air goes out the top
- Steam chamber seals on top and bottom face
- Reference Volumes
  - Outer = 5.38 m^3
  - Net = 4.50 m^3
- Brick I = 1724 kg*m^2
- Pros
  - Best layout for airflow
  - Thinnest
- Cons
  - Large OD 4700mm (Over 15 feet)
  - Largest moment of Inertia
  - Difficult Sealing



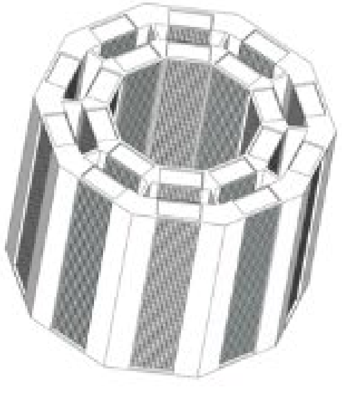
6 inch brick flat

- Air comes in the bottom
- Air goes out the top
- Steam chamber seals on top and bottom face
- Reference Volume
  - Outer = 4.09 m^3
  - Net = 3.94 m^3
- Brick I = 1089.002 kg*m^2
- Pros
  - Best layout for airflow
  - Thinnest
- Cons
  - Needs 6 x 6 inch bricks
  - Large OD 4100mm (Over 13 feet)
  - Large moment of Inertia
  - Difficult Sealing



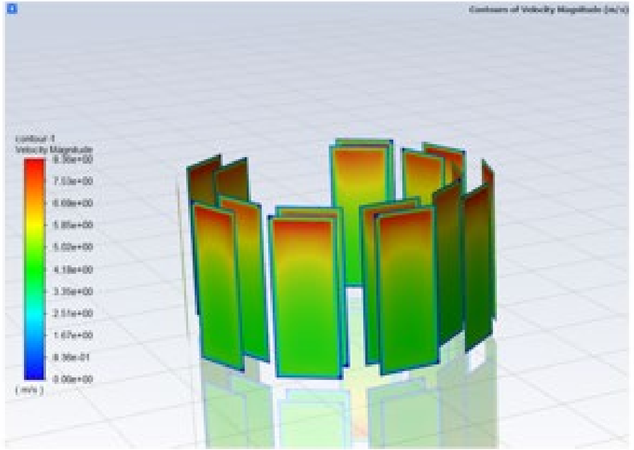
Dual Ring

- Air flows in between inner and outer ring of bricks
- Air Flows out the interior and exterior of Ring
- Steam chamber seals on top, Inside, and outside of cylinder
- 2000mm OD
- Reference Volumes
  - Outer = 4.87 m^3
  - Net = 3.65 m^3
- Brick I = 312 kg*m^2
- Pros
- Cons
  - Complicated ducting to get air between rings.
  - 3 sealing surfaces

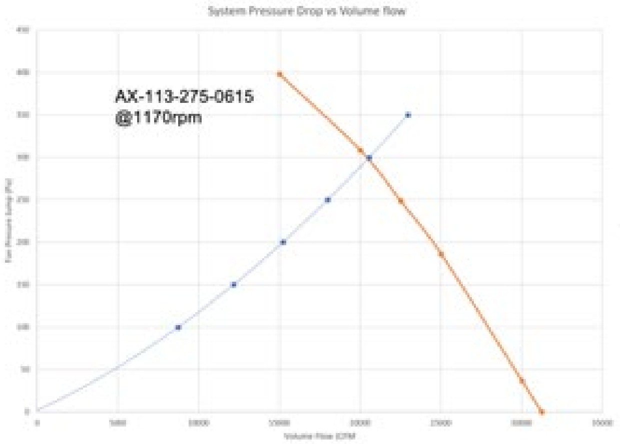


BP1 Adsorption CFD Results

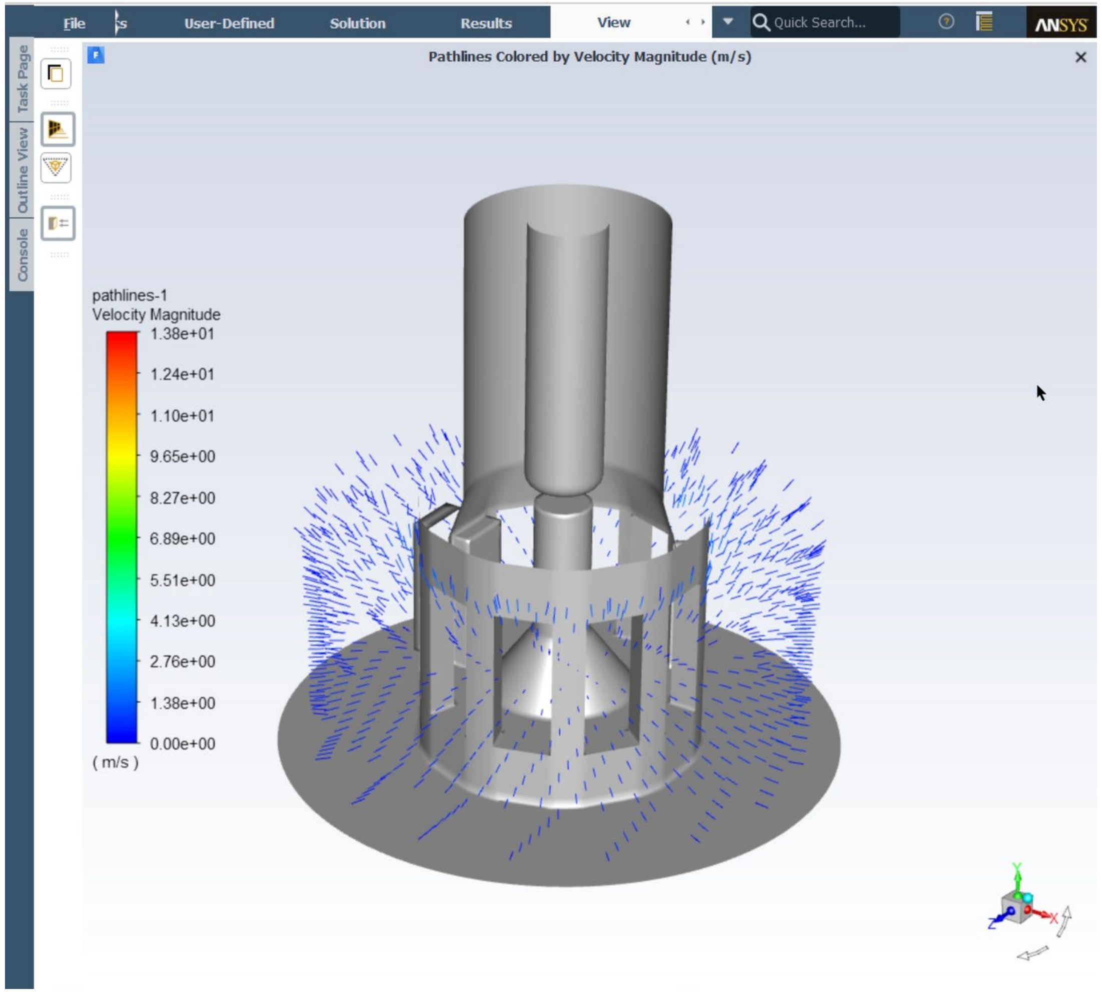
- Detailed CFD analysis of 100 contactor circular / radially oriented design basis
- CFD results lead to basic design configuration with internal taper, fan diffuser, preferred orientation of fan inlet to contactor arrangement
- Acceptable flow distribution and airspeed velocities across contactors
- Overall system pressure drop is within energy budget
- System air flowrate ~23,000 CFM, 350Pa Pd Target



Velocity distribution through bricks



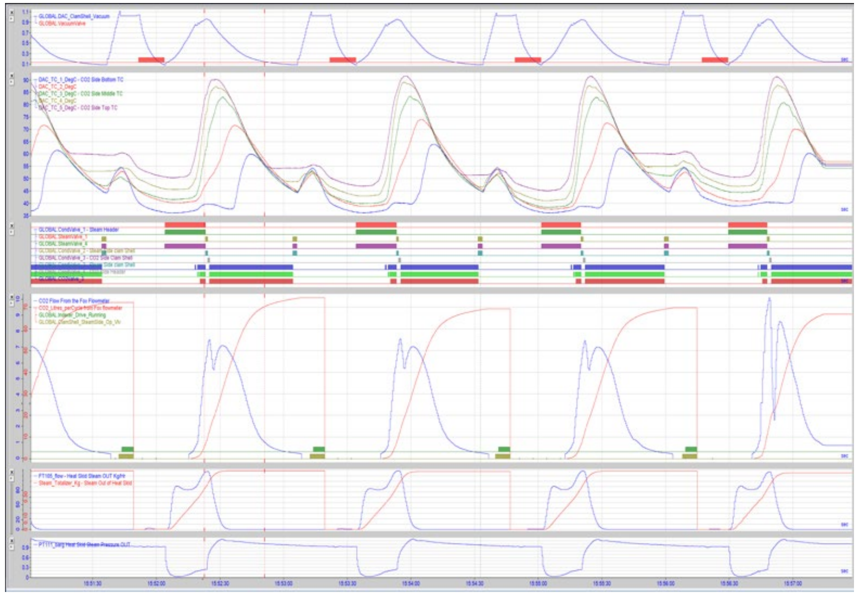
System Pressure drop vs Volume Flow



BP2 Milestones

- ➢ Project is on schedule and budget
- ✓ Milestone 4.1.a. Initiate Construction of Skids – 2/15/22
- ✓ Milestone 4.1.b. Finish Construction of Skids – 7/31/22
- ✓ Milestone 1.3.b. NCCC Technology Collaboration Agreement– 10/31/22
- ✓ Milestone 4.3.a. Phase II Commissioning Report and Test Matrix– 10/31/22

Completed Multi-mode Heat Integration Skid



Automated data traces from integrated PLC (DAC & Heat Skid)

100 tpy DAC SN1 & Heat Skid

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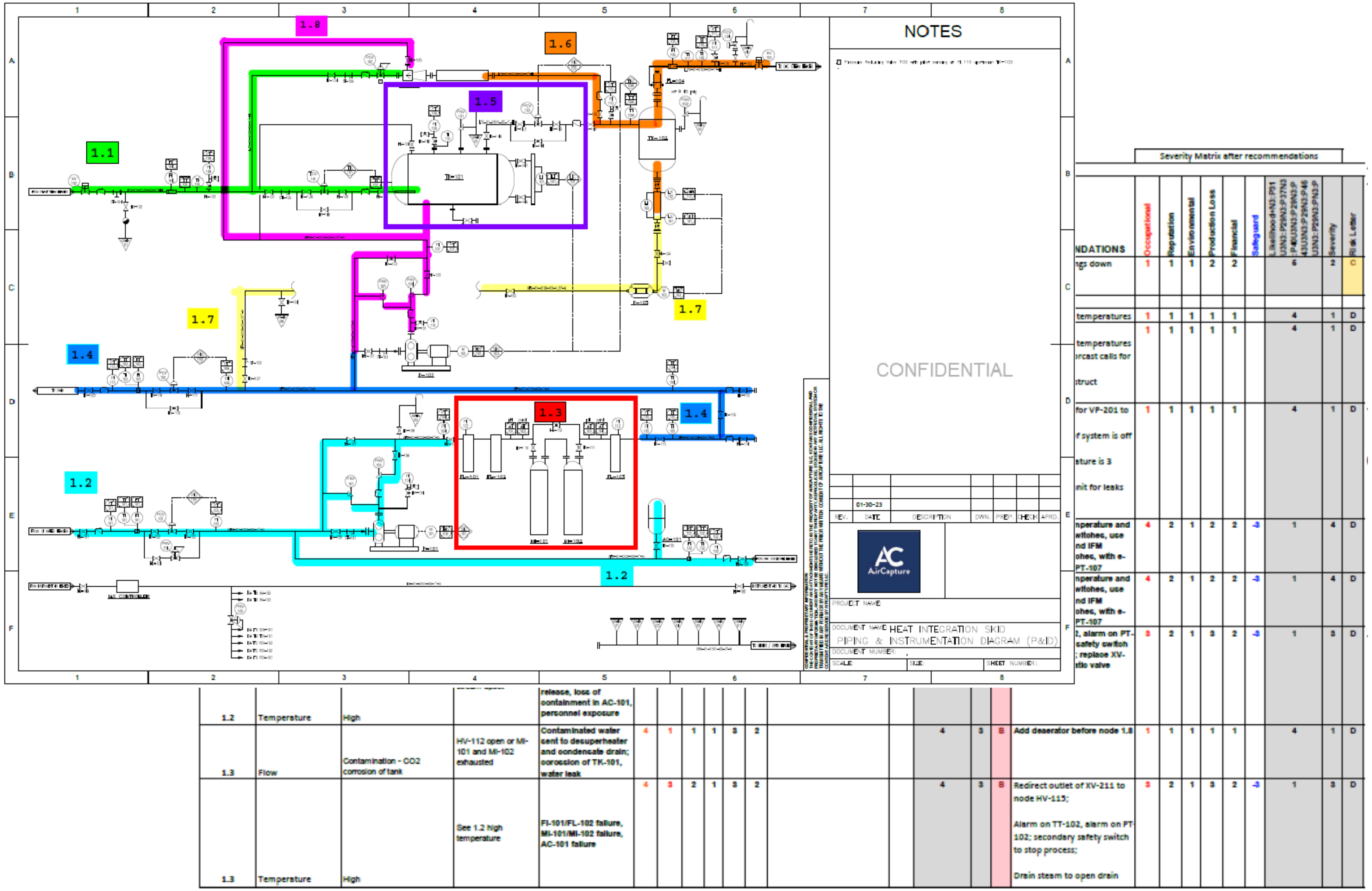
BP III - Integrated Systems Testing (Q1 2023 – Ongoing)

- ✓Milestone 2.3 Pre-operational risk workshop and operational HAZOPs review – 1/30/2023

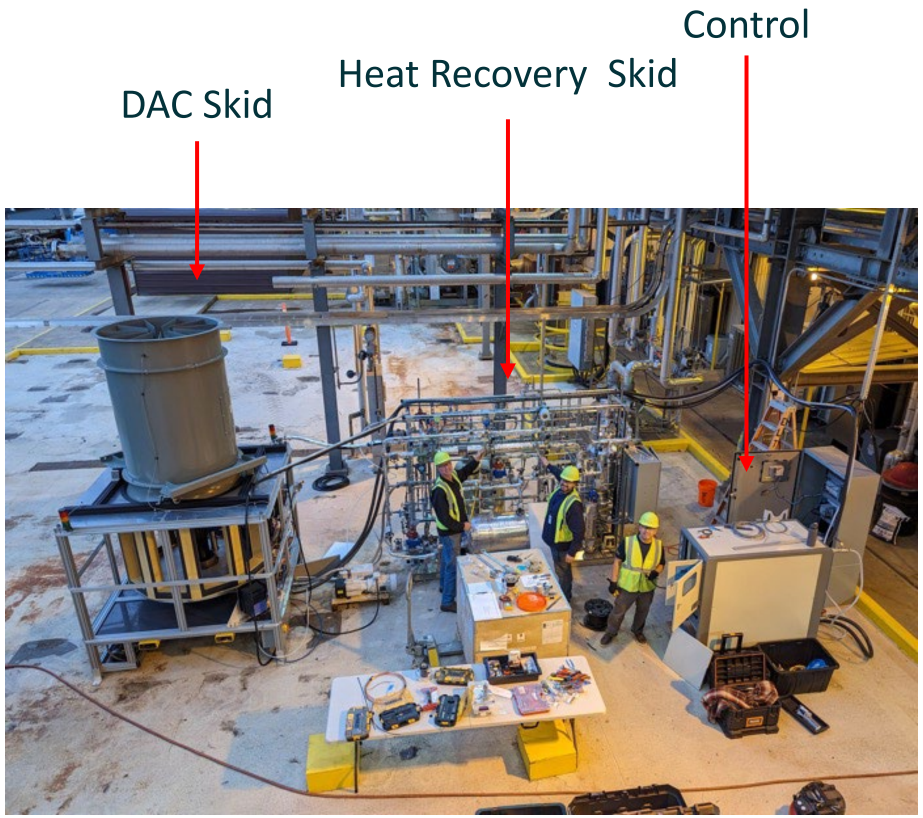


BP III - Integrated Systems Testing (Q1 2023 – Ongoing)

✓ Milestone 5.1.a. Skids Transported to NCCC – 2/7/23

Shipment to NCCC

NCCC Pilot Bay Test Area



Installation at NCCC

BP III - Integrated Systems Testing (Q1 2023 – Ongoing)

✓ Milestone 5.1.b. Completed Site Commissioning at NCCC – 5/12/23

DAC Skid (left)
Heat Skid (right)

Aircapture Commissioning Engineers at NCCC

Start of automated operations at NCCC

First DAC Produced CO_2 at NCCC

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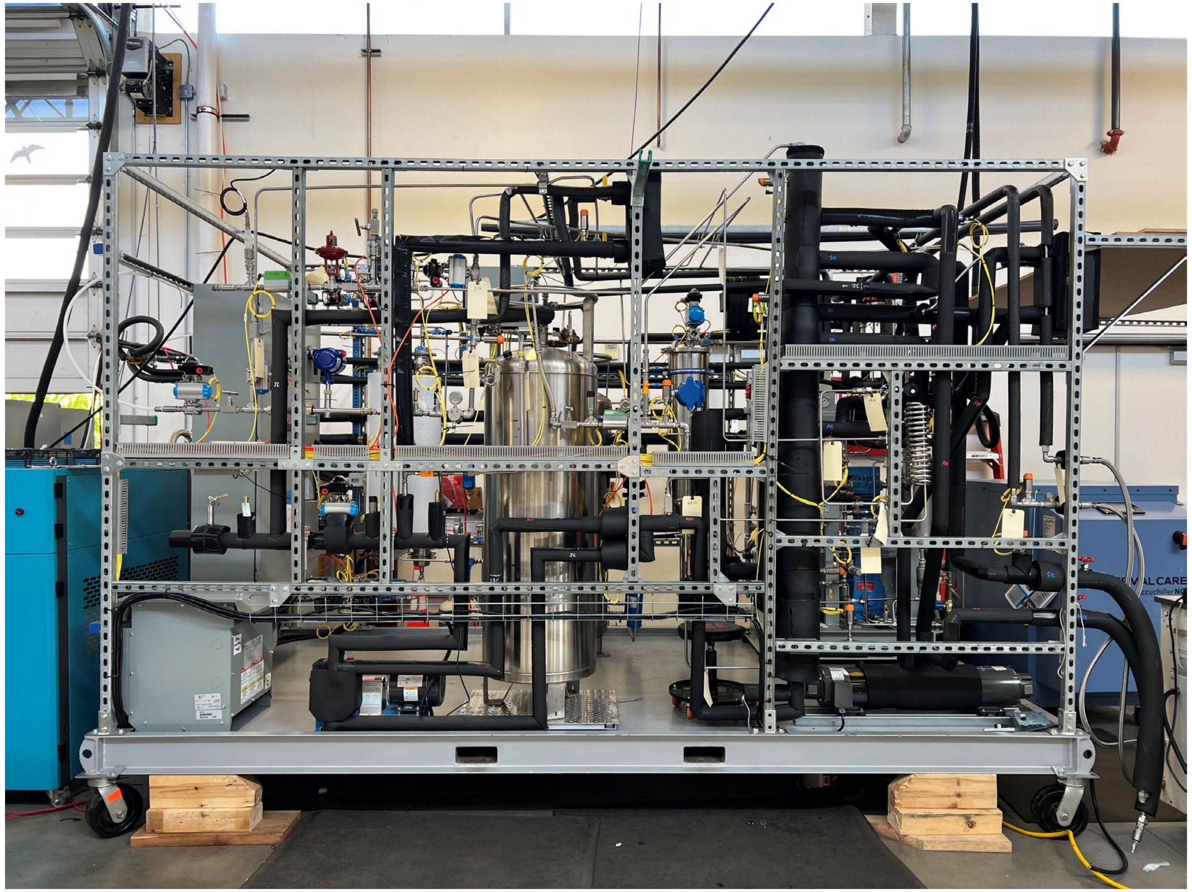
BP III - Integrated Systems Testing (Q1 2023 – Ongoing)

- **Testing Campaigns**
- AirCapture with support from NCCC will conduct three long-term testing campaigns over 6 months
- Campaign 1 is finishing up this week 9/29 with over 35,000 cycles on site
- Campaign 2 to begin in September, Campaign 3 integrating liquification to occur Q4 2023.
- **Decommissioning**
- AirCapture & NCCC will decommission skids and remove from host site.
- **Data Analysis, TEM & LCA, EH&S**
- Ongoing data analysis throughout testing campaign followed by Pre-Screening Technical Economic Analysis & Lifecycle Analysis with support from Amy Landis, Ph.D. (TEA/LCA) & Ron Hunsinger, Ph.D. (Toxicology)
  - TEA to provide final price per tonne of CO_2 from air from operational data and commercial assumptions for both gross and net CO_2 removal
  - LCA to be completed with respect to approach and boundaries of the fate of CO_2 for both pipeline ready and productized CO_2



Liquefaction Skid

Performance Attributes and Requirements

Performance Attribute	Performance Target	Current Status / Test Range	Comments / Justification for Performance Requirement
Capture Efficiency	>50%	30-60%	Dependent on contactor, airspeed, environmental conditions. Ideal economic case may be below 50% depending on environmental conditions and local energy costs.
Gas CO_2 Purity	>95%	> 97%	Purity ranges between 95-99% have been achieved. Depends on process control set points for desorption rough down.
Liquefaction efficiency	> 95%	TBD	Liquefaction efficiency should be above 95% to avoid excessive product losses which increase overall cost. 95% is a suitable target based on preliminary TEA work.
Liquid CO_2 purity	99.9%	TBD	Liquid CO_2 purity should exceed the proposed target to achieve minimum purity required by various industries.
Desorption Temperature	80 – 110°C	80-95°C	Acceptable range for desorption given the technology. Waste heat available from a large number of industrial sources in this temperature range. Utilization of low-grade waste heat in this range will reduce overall CO_2 production costs.
Adsorption:Desorption Cycle Time	900s : 90s	Achieved, Various	9:1 adsorption to desorption ratio. Timing model flexible due to system design. Efficiency maximization depends on contactor performance.
Remote Operations	Uninterrupted Remote Operations	Remote operations achieved	No specific performance targets for uninterrupted performance stated as MTBF is unknown for FOAK. Aspirational target of ~1 month uninterrupted operations at NCCC. From commissioning start, current interrupts have been due to planned downtime of heat availability from NCCC and BOP maintenance issue (chiller).

* Confidential, Business Sensitive Performance Attributes of the project excluded from this presentation (e.g., energy utilization).

Wrap Up

- Project target TRL 5 has been achieved.
- System design has completed over 90,000 desorption cycles across both operating units.
- Long-term testing at NCCC is ongoing, required to demonstrate mechanical reliability, operational parameters in real-world environment.
- Goal is to rapidly advance through commercial TRLs.
- Critical ongoing factor is contactor performance and sorbent lifetime.
- Project will demonstrate LCA, TEA of CO_2 gas and liquid.
- System platform designed for increased technology advancement (i.e., heat recovery integration to decrease thermal demand).
- Modular DAC approach optimized for cost reduction and learning curve.

DAC-100 SN2 (Berkeley, CA)

Acknowledgements

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Southern States Energy Board

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NCCC + Southern Company

Cost Share Partners:

Aircapture

Southern States Energy Board

Synapse

Crescent Hill Resources

Questions?

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