Direct Air Capture-Based Carbon Dioxide Removal with United States Low-Carbon Energy and Sinks

Cooperative Agreement No. DE-FE0032100 / Pittsburgh, PA / 31 August 2023

Jason Dietsch, Engineer, Illinois Sustainable Technology Center

Karina Veloso, Project Manager Development Projects, Climeworks

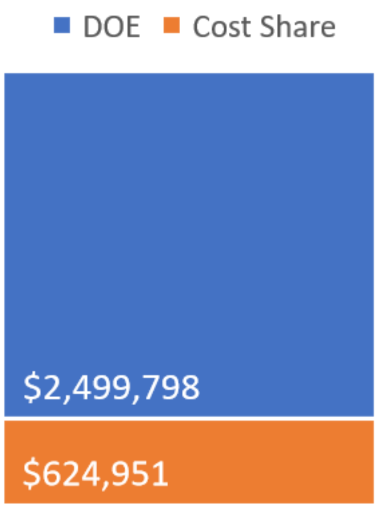
Disclaimer

Project & Technology

Operators

Energy & Storage

Project Overview



Funding: $3,124,749
DOE: $2,499,798
20% Cost Share: $624,951
Work Period: 1 Oct 2021 – 31 Mar 2023
Work Extension: 1 Apr 2023 – 31 Dec 2023

Project objectives

The overall objective of this Energy And SInks (EASI) project is to complete an initial design of a commercial-scale, Carbon Capture and Storage system for Direct Air Capture (DAC) that separates and stores a minimum of 100,000 tonnes/year (mt/yr.) net CO_2 from air. Three diverse host sites have been identified and will be used to determine the impact of different climates on the design of the DAC systems. In addition, the impact of using different low-carbon energy sources will also be evaluated. The focus of this project is the geological storage of CO_2, rather than utilization of the CO_2.

Project Team Management Structure

ILLINOIS
PROJECT LEAD
University of Illinois (UIUC)
Dr. Kevin C. OBrien, PI
Jason Dietsch
Project Management ; TEA / LCA; EH&S; Business Case

SUBAWARDEE
climeworks *(Zurich)*
TECHNOLOGY PROVIDER
Dr. Dirk Nuber, co-PI
Dr. Daniel Sutter
Karina Veloso
ISBL System Design

SUBCONTRACTOR
Kiewit
ENGINEERING, PROCUREMENT, CONSTRUCTION
James Mitchum
Ron Mihordin
OSBL, BOP, Costing

Host Site #1 : California
Lawrence Livermore National Laboratory
Dr. Roger Aines
Dr. William Bourcier
Dr. Wenqin Lee
OSBL : Geothermal / CO2 Storage

SENTINEL PEAK RESOURCES
Marc Whitezell
Host Site #1 Owner

ORMAT
Bob Sullivan
Geothermal Expertise

Host Site #2 : Louisiana
GULF COAST SEQUESTRATION
Secure Sustainable Storage
Colin Williams
Host Site #2 Owner

TotalEnergies
Brian Meichtry
Solar expertise

Host Site #3 : Wyoming
NSE | NORTH SHORE ENERGY
Steve Swanson
Host Site #3 Owner

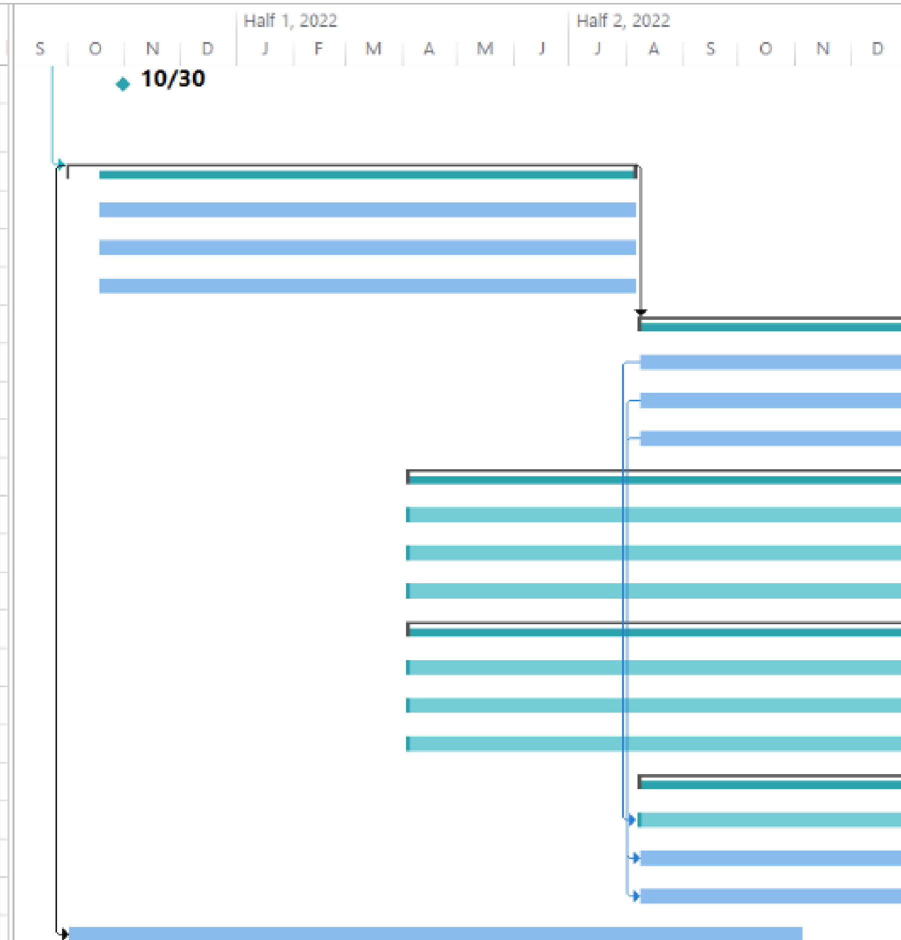
Project Tasks

Task #	Task
1.0	Overall Project Management
2.0	Initial Engineering Design
3.0	Costing Estimate
4.0	Techno-Economic Analysis (TEA)
5.0	Life Cycle Analysis (LCA)
6.0	Business Case Assessment
7.0	Environmental Health and Safety (EH&S) Analysis

Project Timeline

1 October 2021 – 31 December 2022

	Task Name	Start	Finish
4	1.1. Project Management Plan	10/1/21	10/30/21
5	DOE Review	10/1/23	12/31/23
6	**2.0 Initial Engineering Design**	**10/1/21**	**8/5/22**
7	2.1 Engineering Design Host Site #1	10/18/21	8/5/22
8	2.2 Engineering Design Host Site #2	10/18/21	8/5/22
9	2.3Engineering Design Host Site #3	10/18/21	8/5/22
10	**3.0 Cost Estimation**	**8/8/22**	**3/1/23**
11	3.1 Cost Estimate Host Site #1	8/8/22	3/1/23
12	3.2 Cost Estimate Host Site #2	8/8/22	3/1/23
13	3.3 Cost Estimate Host Site #3	8/8/22	3/1/23
14	**4.0 Technoeconomic Analysis (TEA)**	**4/4/22**	**9/30/23**
15	4.1 TEA Host Site #1	4/4/22	9/30/23
16	4.2 TEA Host Site #2	4/4/22	3/31/23
17	4.3 TEA Host Site #3	4/4/22	3/31/23
18	**5.0 Life Cycle Analysis (LCA)**	**4/4/22**	**3/1/23**
19	5.1 LCA Host Site #1	4/4/22	3/1/23
20	5.2 LCA Host Site #2	4/4/22	3/1/23
21	5.3 LCA Host Site #3	4/4/22	3/1/23
22	**6.0 Business Case Analysis**	**8/8/22**	**9/30/23**
23	6.1 Business Case Host Site #1	8/8/22	9/30/23
24	6.2 Business Case Host Site #2	8/8/22	3/31/23
25	6.3 Business Case Host Site #3	8/8/22	3/31/23
26	**7.0 Environmental Health & Safety Analysis**	10/1/21	11/4/22



Project Timeline

1 January 2023 – 31 December 2023

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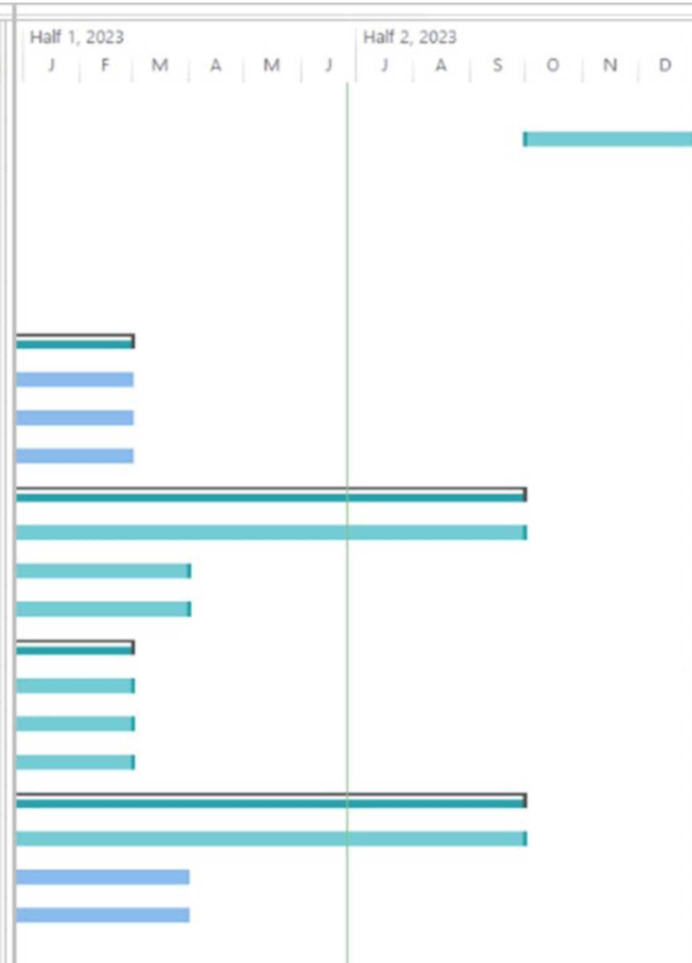
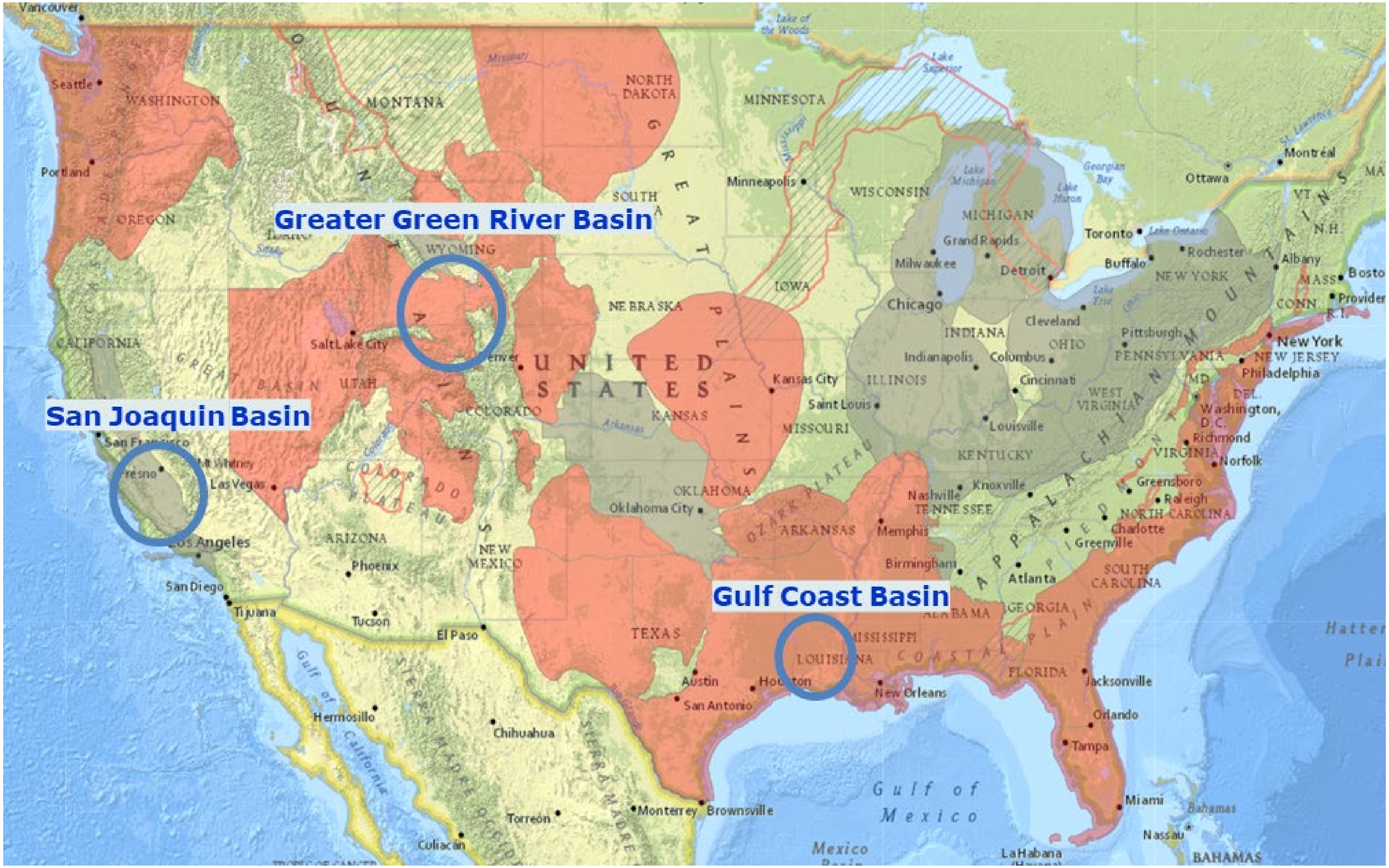


Storage Host Sites Overview



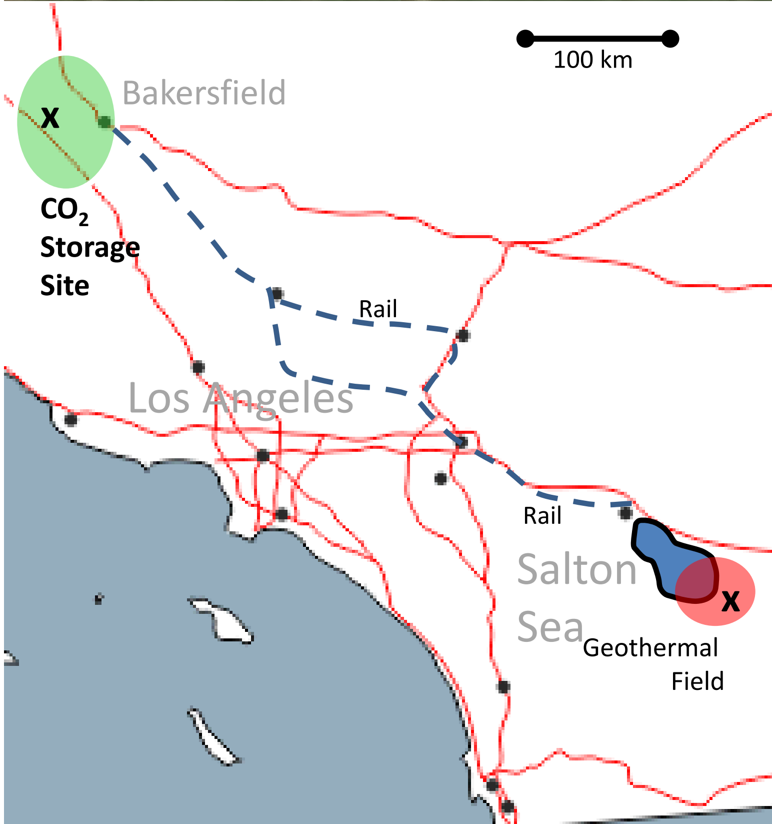
California

Climate
Hot and dry
Avg High 89°F
Avg Low 55°F
3.13” rain/year

Heat source
East Mesa Power Plant
27MW Geothermal, Binary plant (ORC)
Ormat Technologies, Inc. – Operator

Storage site
Saline aquifer, San Joaquin Basin near Buttonwillow, CA
Sentinel Peak Resources - Operator

Transport to storage
Truck, Rail, or Pipeline



Louisiana

Climate
Wet & hot summers (Avg High/Low 91°F/76°F)
Wet & warm winters (Avg High/Low 65°F/45°F)
Avg 63.82” Rain/year

Power Source
Electricity Generated via Solar Power
TotalEnergies SE

Operator: Gulf Coast Sequestration

Storage Site
Deep Subsurface Rock Formations
Between the Sabine River and Lake Charles, LA

Transport to storage
Power source and storage are co-located

Wyoming

Climate
Dry & warm summers (Avg High/Low 84°F/57°F)
Dry & cold winters (Avg High/Low 30°F/15°F)
Avg 8.56” Rain/year
Avg 48” Snow/year

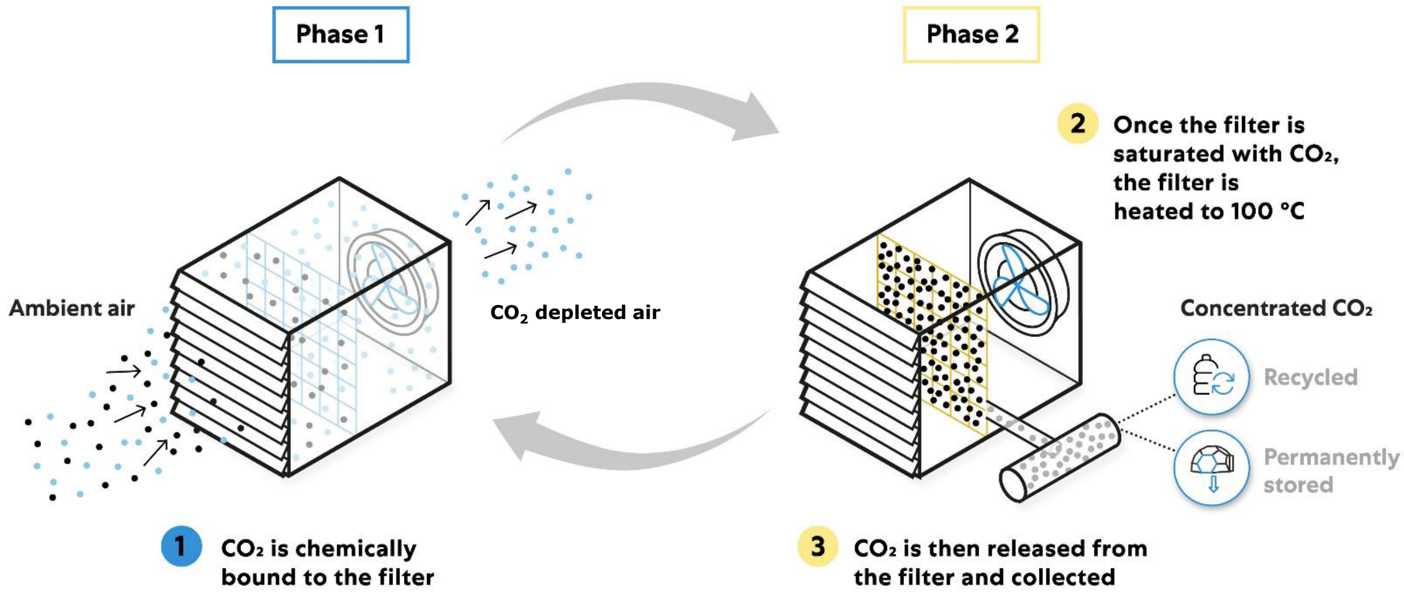
Heat Source
Painter Gas Plant
Hot Water & Compressor Waste Heat

Operator
North Shore Exploration & Production, LLC

Storage Site
Depleted Oil & Gas Reservoir
Nugget/Weber Formation, South Brady Federal Unit.
North Shore Exploration & Production, LLC

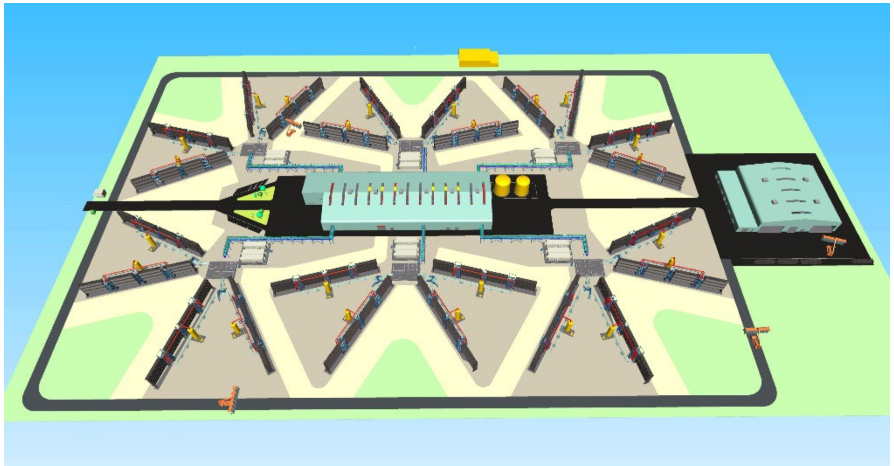
Transport to storage
Heat source and storage are co-located

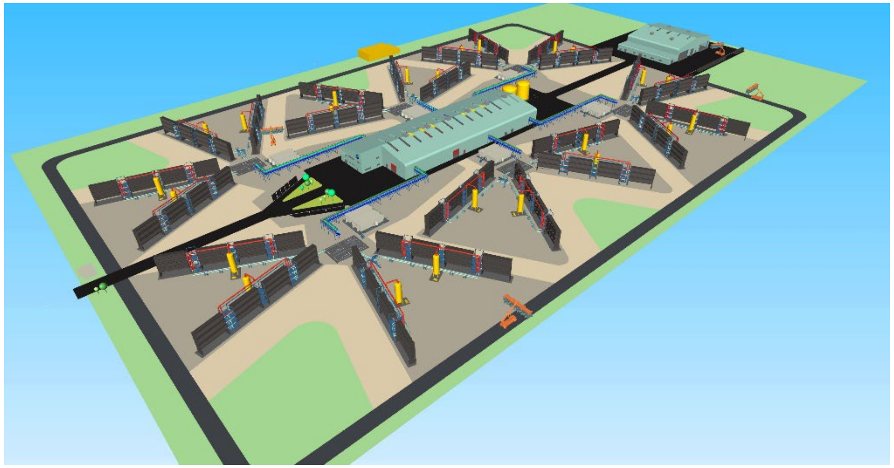
How Climeworks technology works

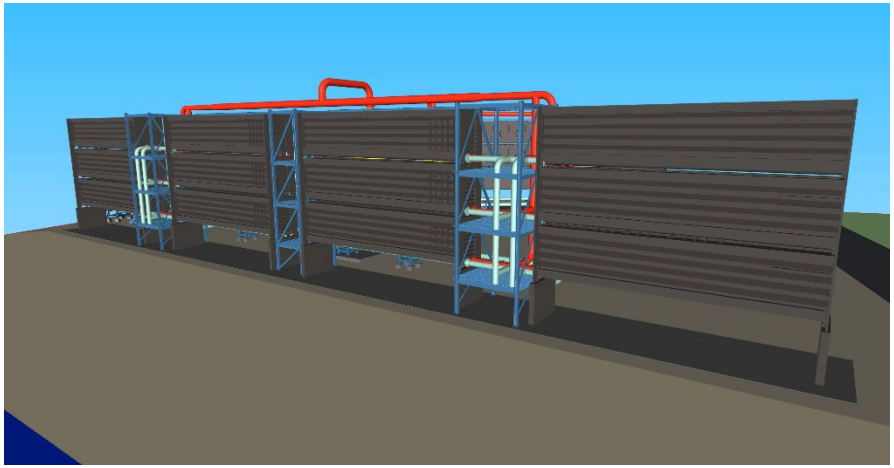


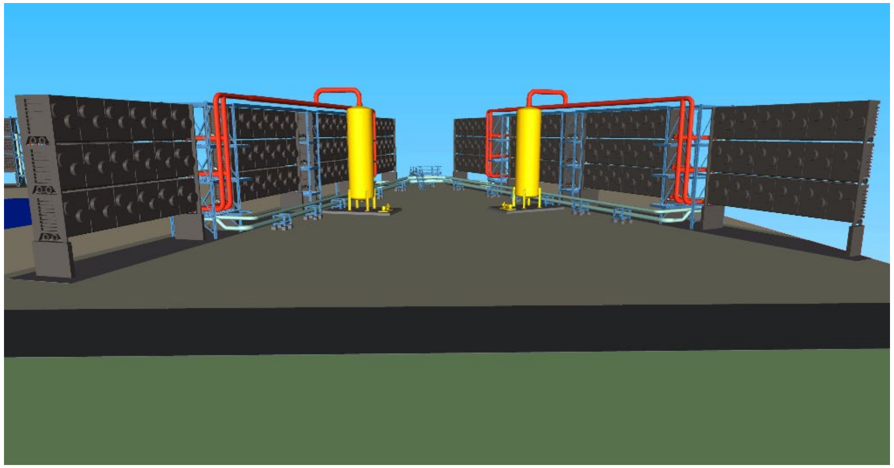
1. Air is drawn into the CO_2 collector containers through a fan, where it passes through a filter material located inside the collector that captures the CO_2 molecules. Air with a reduced CO_2 concentration is released back into the atmosphere.
2. Once the filter is completely full of CO_2, the collector closes, and the filter is heated to around 212°F. The captured CO2 is then prepared for storage and the capture cycle starts again.
3. The CO_2 removed by our facilities is then injected deep into geologic storage areas by our storage partners.

DAC Facility Layout







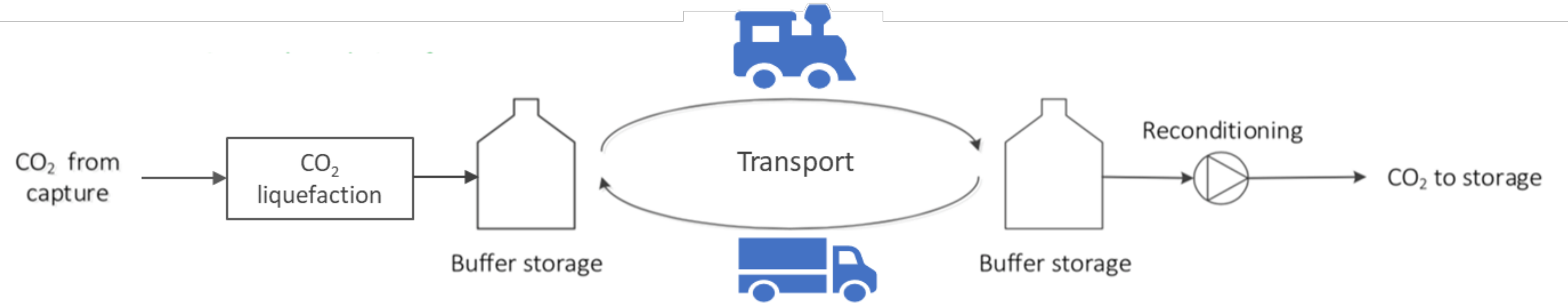


Engineering Design

- Climeworks' technology performance evaluated under different climates
  - Sorbent indicates better performance under cold and humid conditions
- Minimal design changes are needed by the DAC facility to connect with different types of energy sources
  - Modular and flexible design

	Units	California	Louisiana	Wyoming
Net CO_2 Removed from Air	Tonne/y	138,391	149,050	155,952
Footprint	m^2	142,515		
	Acres	35		
Electrical Source		Geothermal	Solar PV	Grid
Heat Source		Geothermal	Solar PV (electric heaters)	Waste heat (High-Temp Heat Pump)
Distance DAC-storage	miles	~ 350	< 5	< 5
Method of CO_2 Transport Evaluated		Truck / Train / Pipeline	Pipeline	Pipeline

Transportation of CO_2 from DAC to Storage Site #1



<u>Transport by Truck (including reconditioning + buffer storage cost)</u>

- 361 miles (one way)
- Between \$126 - \$247 / net tonne CO_2 (dependent on potential optimizations)

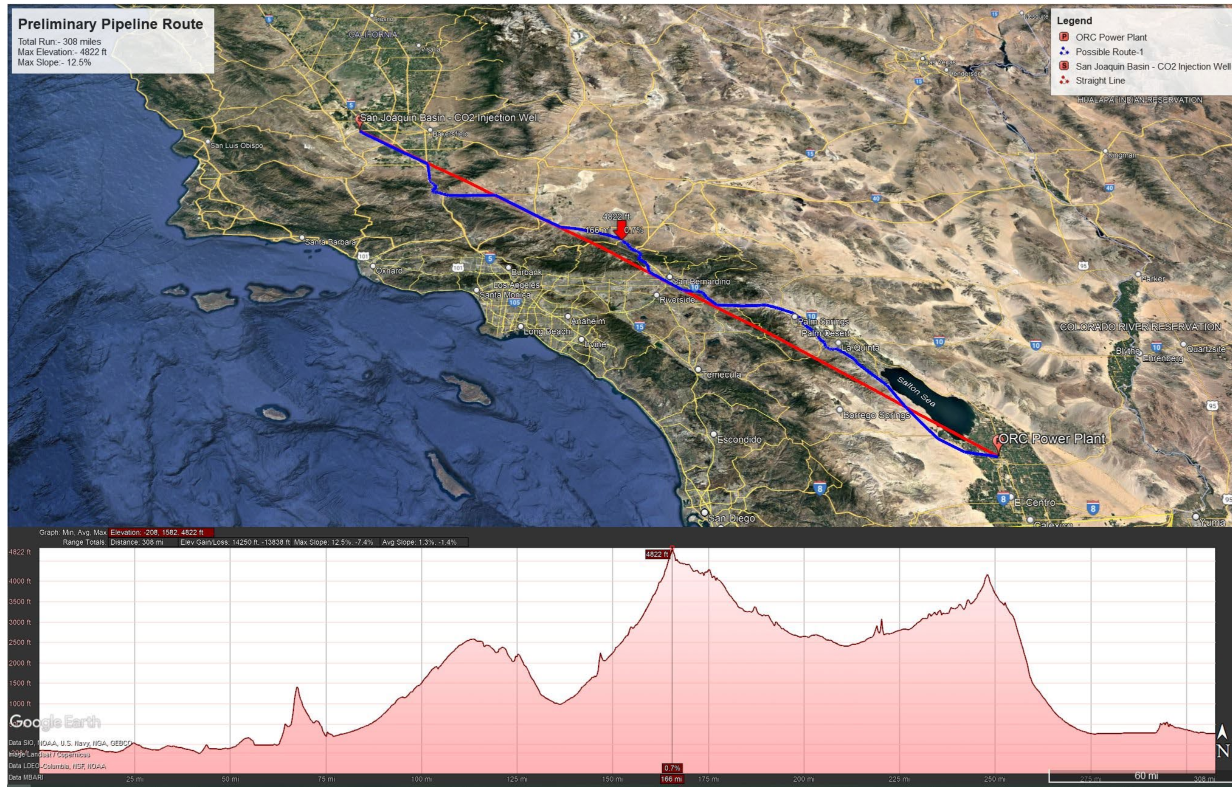
<u>Transport by Rail (including reconditioning + buffer storage cost)</u>

- \$154 / net tonne CO_2 (Negotiation with rail companies may lead to lower quote)

Transportation of CO_2 from DAC to Storage Site #1

<u>Pipeline:</u>

- 4'' (NPS) pipeline would be minimum required
- \$275 / tonne CO_2
- To achieve comparable transportation rates of NG or Crude oil pipelines
  - 1 Million tonnes of CO_2/y
  - Locate storage within 35-mile radius of the DAC unit



Project Cost Estimation

- Class 4 estimate for Capital Costs (-30% to +50%)
  - Includes civil works (foundations, concrete, grading) & buildings
  - Mechanical Equipment & Piping
  - Electrical & Instrumentation
- Operational costs
  - Labor rates were obtained from the US Bureau of Labor Statistics
- Energy costs
  - Electricity costs obtained from EIA.gov
- Transport costs
  - Co-location of energy and storage site (within 35-mile radius) is necessary for economic viability

Normalized per capture amount	California	Louisiana	Wyoming
Capital Costs	Base	Base - 2%	Base + 5%
Operational Costs	Base	Base - 6%	Base - 6%
Energy & heat costs	Base	Base - 25%	Base - 72%
Transport	Base	Base - 90%	Base - 90%

Techno-economic Analysis & Business Case

- Techno-eco evaluation indicates that the Wyoming site has the lowest cost of capture:
  - Highest CO_2 capture rate (best climate conditions)
  - Use of industrial heat leads to lower energy costs
  - Low labour costs
  - Storage and energy source are co-located

- Evaluated using the 45Q tax credit for revenue for each of the DAC systems
  - $180 per tonne of CO_2 Stored

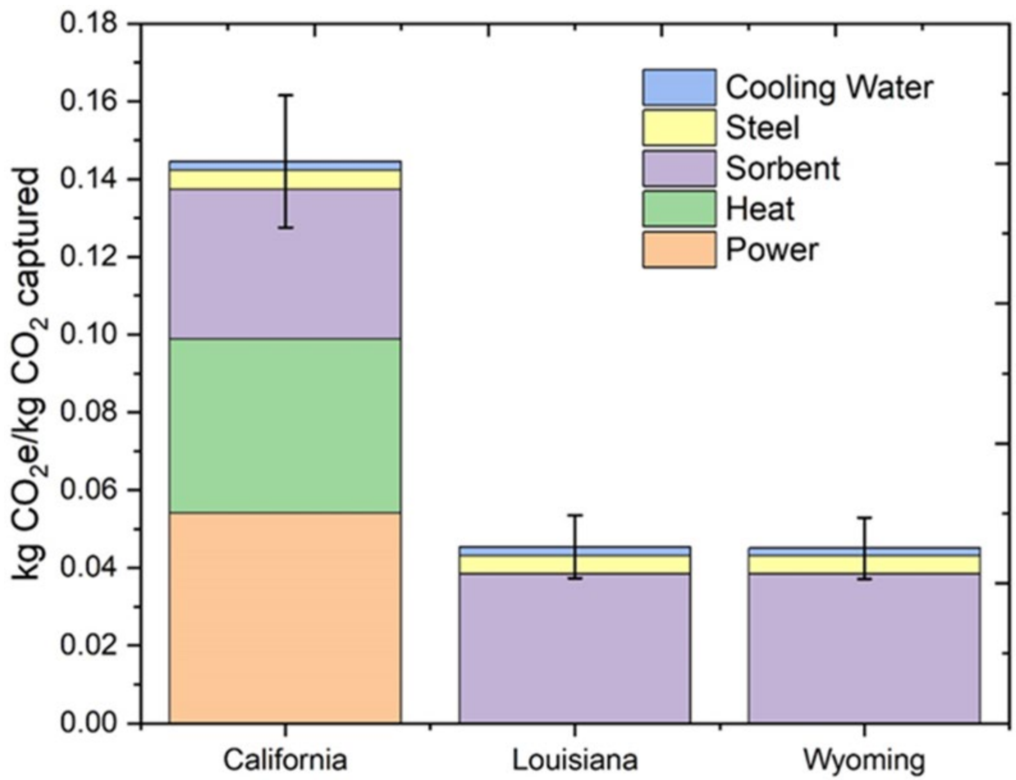
	California	Louisiana	Wyoming
Gross Revenue, $/y	24,910,380	26,829,000	28,071,360

Technology EH&S Risk Assessment

- The environmental friendliness and safety of the Climeworks Direct Air Capture (DAC) system was assessed:
  - All potential ancillary or incidental emissions (air, water, solid wastes) were identified, and magnitude estimated
  - Evaluation of toxicological effects of any identified substances
- An evaluation of the compliance and regulatory requirements to operate a DAC plant was performed
- EH&S concluded:
  - None of the liquid, gas or solid emissions are toxic or pollutants
  - Sorbent material used is chemically stable and nonreactive with other materials
  - Risk and Safety Mitigations have been implemented in the Design

Life Cycle Analysis (LCA)

- Global Warming Potential comparison of DAC system at different locations
- Grey emissions accounted for the construction (material and transport) and operational phase:
  - Biggest contributors are seen in the operational phase with energy usage (heat + electricity) and sorbent replacement
- Louisiana & Wyoming consider 0 kg CO_2e/kg CO_2 captured as solar & wind are considered as electrical source



Project Main Conclusions

- Climeworks’ technology can be used in different climates with minimal impact to performance
  - Wyoming has the highest CO_2 capture rate
- DAC facility can be connected to different types of energy sources with minimal design changes
  - Modular and flexible DAC design
- Co-location of DAC system to energy and storage site is an important selection criteria
  - Distance between energy source and storage site should be < 35 miles
- California has highest energy, transportation, and labour costs
- Wyoming has highest capital costs (Civil and heat integration system to plant waste heat)
- Wyoming has the lowest energy costs due to the use of waste heat

Acknowledgements & Questions

Acknowledgements

Name	Organization
Zachary Roberts	National Energy Technology Laboratory / US Department of Energy
Daniel Sutter, Karina Veloso	Climeworks AG
Kevin OBrien, Chinmoy Baroi	Prairie Research Institute / University of Illinois
Matt Thomas, James Mitchum, Ron Mihordin	Kiewit Engineering Group Inc.
Steve Swanson, Mark Fordney	North Shore Energy
Colin Williams	Gulf Coast Sequestration
Brian Meichtry	TotalEnergies SE
Roger Aines, Bill Bourcier, Wenqin Li	Lawrence Livermore National Laboratory
Bob Sullivan	Ormat Technologies Inc.
Marc Whitezell	Sentinel Peak Resources