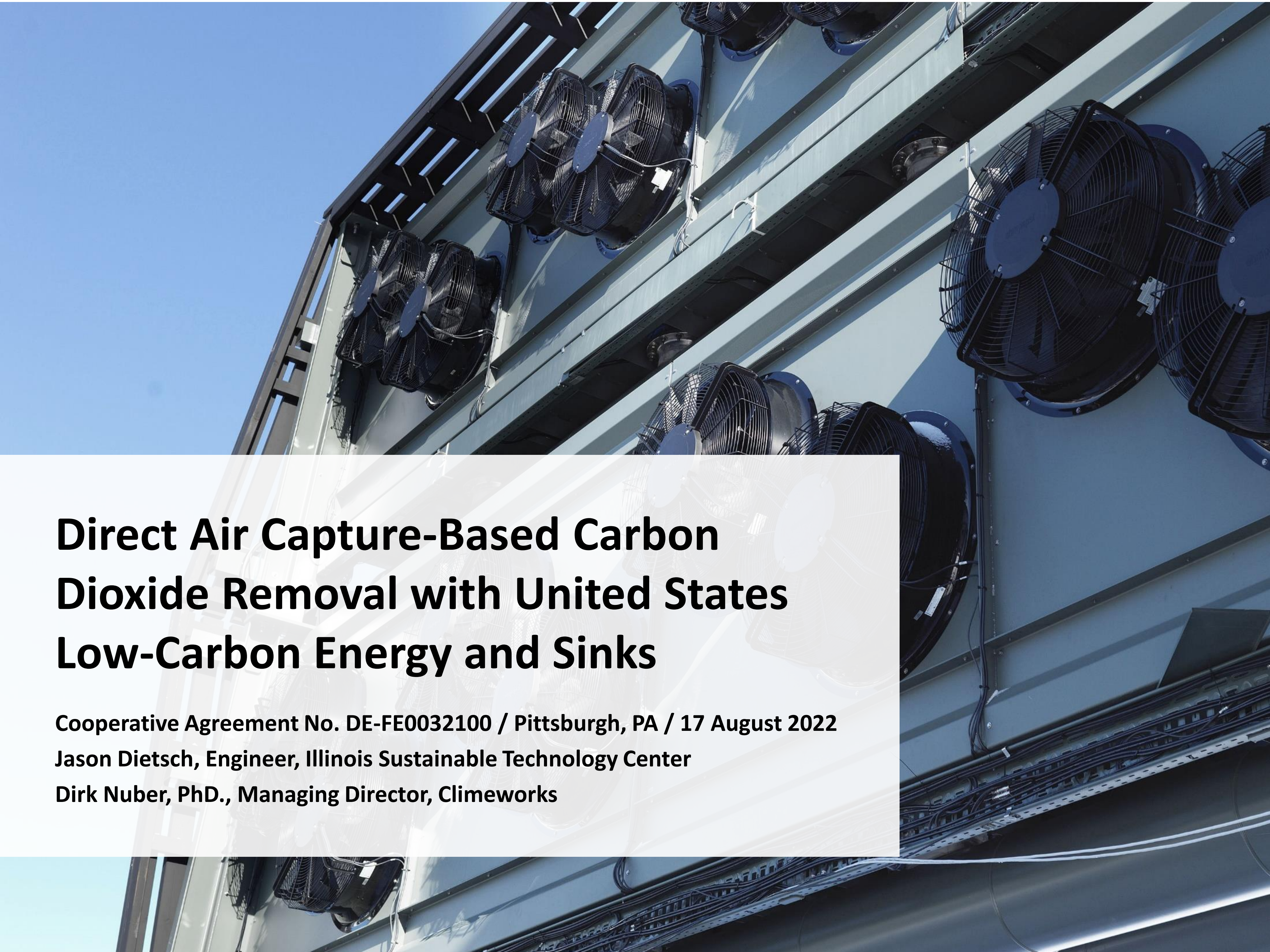


Direct Air Capture-Based Carbon Dioxide Removal with United States Low-Carbon Energy and Sinks

Cooperative Agreement No. DE-FE0032100 / Pittsburgh, PA / 17 August 2022

Jason Dietsch, Engineer, Illinois Sustainable Technology Center

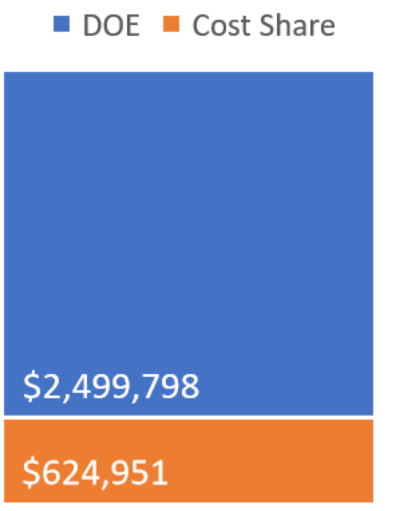
Dirk Nuber, PhD., Managing Director, Climeworks

Disclaimer

Project & Technology

Operators

Energy & Storage



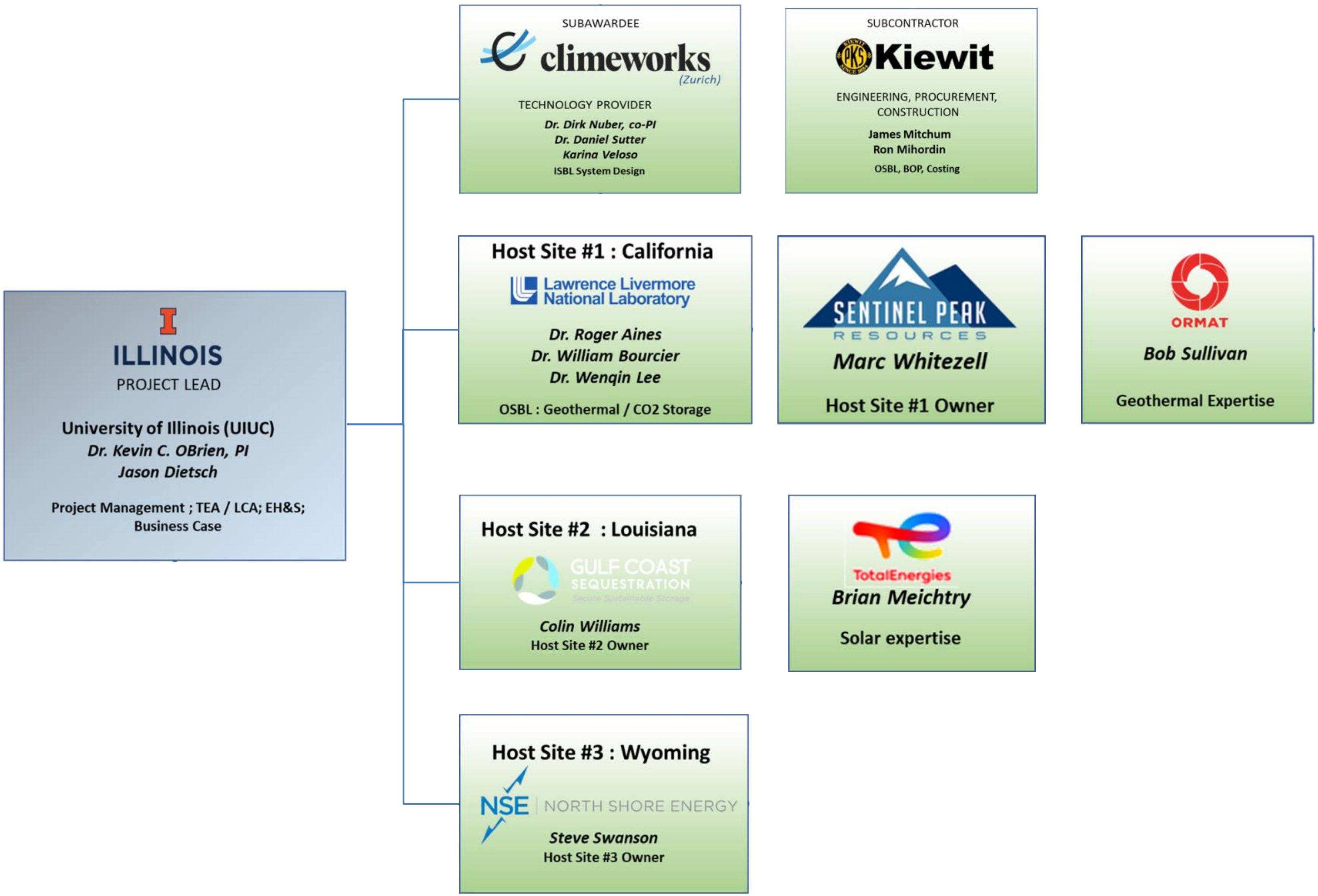
Project Overview

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

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.

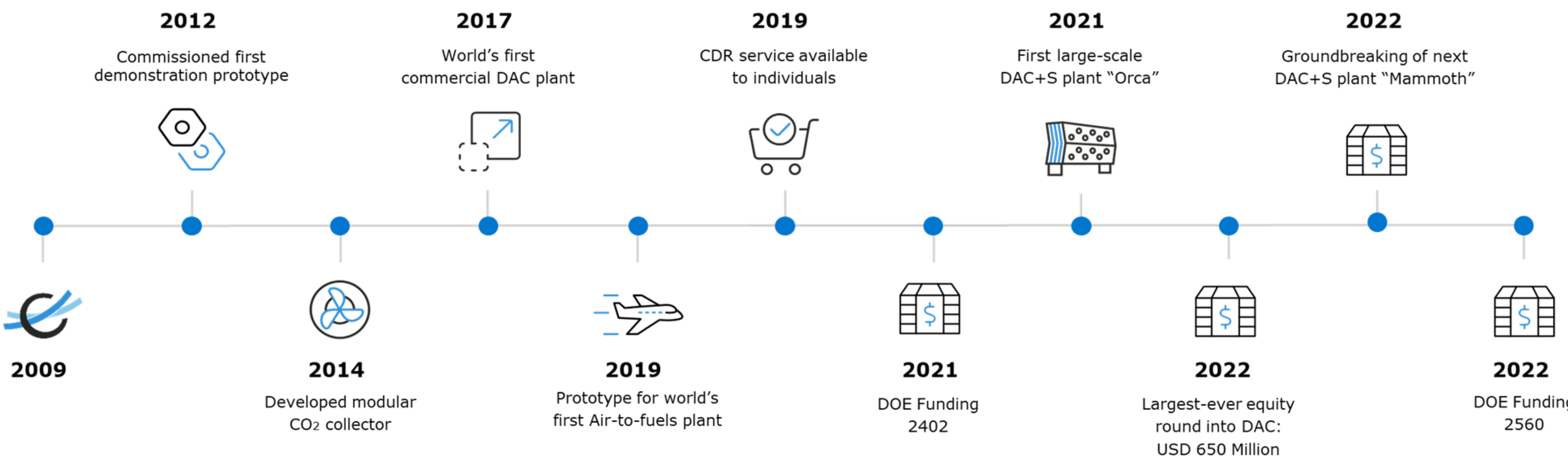
Project Team Management Structure



Background on capture technology

Technology Development Timeline

Climeworks history & milestones



Technology Development Timeline

Iceland
Hellisheiði

Orca
4’000 tons
per year

~10x scale-up

Iceland
Hellisheiði

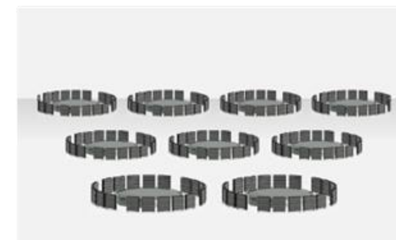
Mammoth
36’000 tons
per year

~10x scale-up

Global

> 400’000 tons
per year

Global



Multi-mega ton range

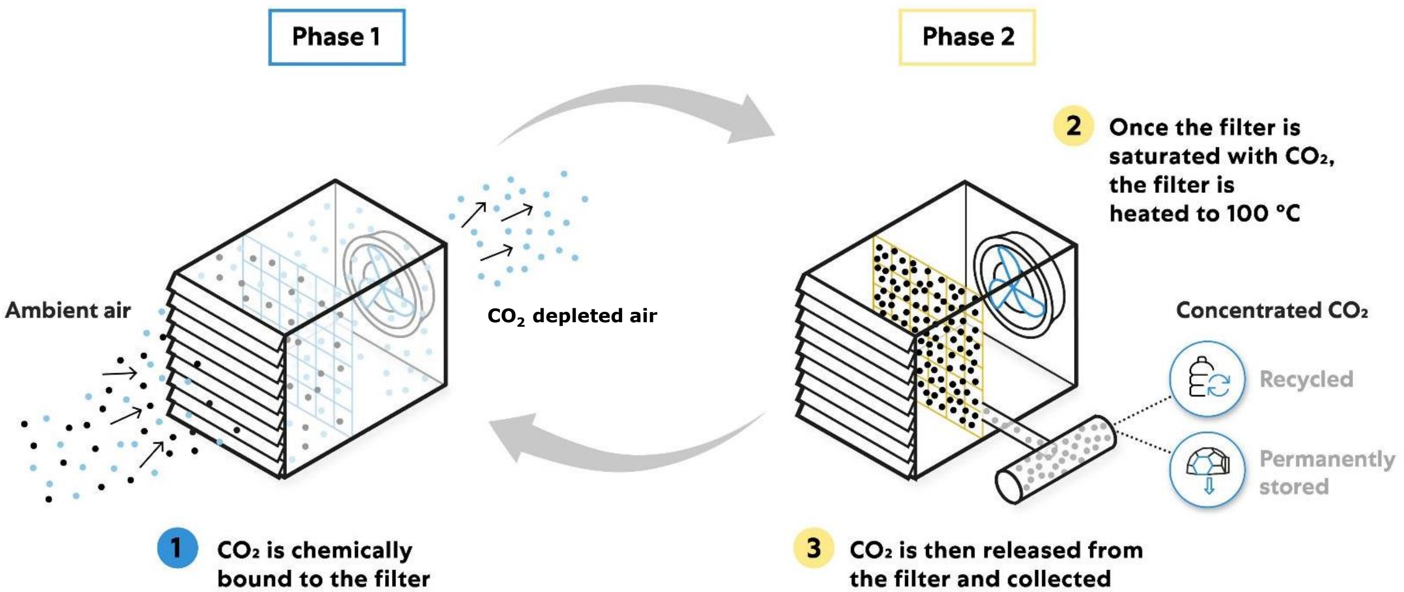
2021
Enable scale-up

2024
Volume production

By 2030
Scale-up acceleration

2030s
Global roll-out

How Climeworks technology works



1. Air is drawn into the collector with a fan. Carbon dioxide is captured on the surface of a highly selective filter material that sits inside the collectors.

2. After the filter material is full with carbon dioxide, the collector is closed and we increase the temperature to between 80 and 100 °C - this releases the carbon dioxide.

Demonstrated Advantages of Technology

Mature plant design, experience in construction & operations	• Experience operating full-system prototypes as well as up to 4,000 tCO2/y units. • Experience in site preparation, construction, process engineering & selection of industrial components.
Modular design	• The modular design of the DAC plants enables Climeworks to scale rapidly.
Process & sorbent technology	• Learnings from numerous laboratory test stands, mid- and full-scale prototypes as well as installations in Switzerland, Italy, Germany, and Iceland. • The DAC collectors' modular nature and the flexibility of the integrated contactor structures ensure that future developments in sorbent technology can be easily integrated into existing hardware.

Host sites studied for the project

California

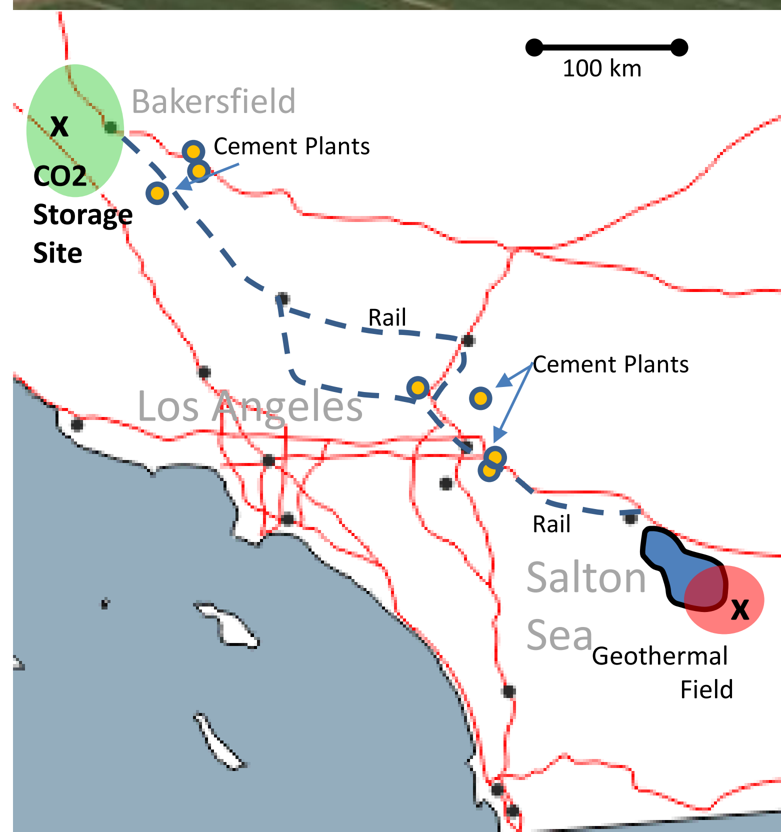
Climate
Hot and dry
Avg High 89°F
Avg Low 55°F
3.13” rain/year

Heat source
East Mesa Power Plant
27MW Geothermal, Binary plant (ORC)

Operator
Ormat Technologies, Inc.

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 site co-located at the same location.

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 site are co-located.

Technical Approach / Project Scope

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 Progress

Overall Project Management

- On going

Initial Engineering Design

- Design basis completed
- ISBL design completed
- OSBL / BOP design is ongoing

Costing Estimate

- Gathering quotes from vendors

Project Progress

Techno-Economic Analysis (TEA)

- On going. Pending Costing

Life Cycle Analysis (LCA)

- On going. Pending Costing

Business Case Assessment

- On going. Pending Costing

Environmental Health and Safety (EH&S)

- On going

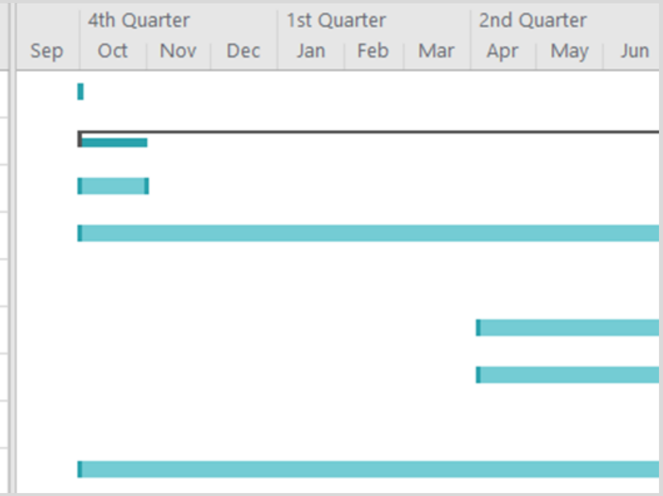
Deliverables

Task #	Deliverable Title	Due Date
1.1	~~Project Management Plan~~	~~Update due 30 days after award. Revisions to the PMP shall be submitted as requested by the NETL Project Manager.~~
2.0	Initial Engineering Design	Due at project completion. A draft shall be submitted to the NETL Project Manager 90 days before project completion.
3.0	Costing Estimate	
4.0	Techno-Economic Analysis (TEA)	
5.0	Life Cycle Analysis (LCA)	
6.0	Business Case Assessment	
7.0	Technology EH&S Risk Assessment	

Project Timeline

1 October 2021 – 30 June 2022

Task Name	Start	Finish
Project Start	10/1/21	10/1/21
1.0 - Project Management	10/1/21	3/31/23
1.1 - Project Management Plan	10/1/21	10/31/21
2.0 - Initial Engineering Design	10/1/21	3/31/23
3.0 - Cost Estimation	7/1/22	11/4/22
4.0 - Techno-economic Analysis (TEA)	4/4/22	3/3/23
5.0 - Life Cycle Analysis (LCA)	4/4/22	3/31/23
6.0 - Business Case Analysis	7/25/22	3/31/23
7.0 - Enviromental Health & Safety Analysis	10/1/21	11/4/22



1 July 2022 – 31 March 2023

Task Name	Start	Finish
Project Start	10/1/21	10/1/21
1.0 - Project Management	10/1/21	3/31/23
1.1 - Project Management Plan	10/1/21	10/31/21
2.0 - Initial Engineering Design	10/1/21	3/31/23
3.0 - Cost Estimation	7/1/22	11/4/22
4.0 - Techno-economic Analysis (TEA)	4/4/22	3/3/23
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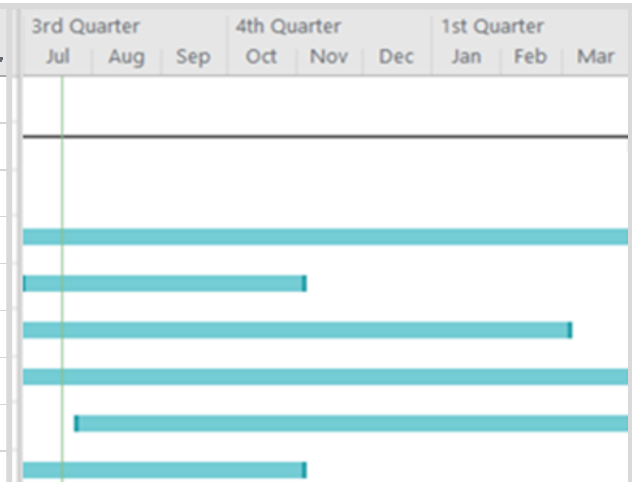


Risk & Mitigation Strategy

	Risk Rating : L,M,H			
Perceived Risk	Probability	Impact	Overall	Mitigation and Response Strategy
Financial				
Cost share for project not obtained or insufficient	L	H	L	•Cost share commitment letters obtained. •All entities providing cost share are financially sound.
Results from business cases indicate that DAC is not immediately financially attractive in the USA	M	H	M	•Business case analysis will also explore future projections and highlightted actions required to make this apporach attractive in the USA.
Cost/Schedule				
Project costs and/or schedule overruns	L	H	L	•Team has previous experience conducting DOE projects on budget and on time.
Tasks require significantly more time than expected	L	H	M	•Preliminary results from Climeworks provide good basis and understanding. •Prior scale-up projects by Climeworks provide a good basis of understanding.
Technical / Scope				
Delays in selection of energy supply	L	H	M	•Selection Process launched early in collaboration with partners. •Active dialogue with stakeholders and energy providers. •Weekly progress monitoring.
Availability of energy supply (i.e. sufficient waste heat from existing host site)	L	H	M	•Selection Process launched early in collaboration with partners. •Options developed for multiple energy sources should primary source be unavailable for full project demand.
Delayed supply of equipment offers for estimate	L	M	M	•Procurement review started in a timely manner allowing for some delays in response time without affecting critical part of project. •Active dialogue with key suppliers to ensure that timeline is kept.
External Factor				
Issues related to COVID-19 delay execution	M	H	M	•Team has worked virtually for months. •Communication process currently in place that uses remote work tools, e.g. Microsoft Teams.
Perturbations in the energy market create financial hardships for host sites, thus reducing their interest / ability to participate	M	M	M	•Host sites view DAC as a strategically important tchnology for their future business plans.

Risk & Mitigation Strategy cont.

	Risk Rating : L,M,H			
Perceived Risk	Probability	Impact	Overall	Mitigation and Response Strategy
Management, Planning, and Oversight				
Unrealistic planning base/assumptions in project schedule may result in delays of project implementation	L	M	M	•Clear and carefully planned timeline created in collaboration with designers and engineers. •Scenario-based planning, using conservative assumptions and adequate contingency time for activities on the critical path of the project. •Bottom-up planning of individual activities.
Deficient project management may result in inefficiencies and delays	L	M	M	•Integrated, holistic project management set up. •Adequate allocation of experienced/qualified personnel to project management. •Detailed milestone planning. •Structured meeting, monitoring, and reporting structure to ensure real-time transparency. •Defined decision-making structures and processes.
Availability of key personnel for project	L	M	L	•Commitment received from partner organizations.
Uncertainty of permitting agencies and timelines	L	L	L	•Agencies and timelines known based on previous experience with similar host sites.
Delays in host site selection	L	M	M	•Selection process launched early in collaboration with partners. •Active dialogue with stakeholders and planning authorities. •Quality, detail and conciseness of data and reports submitted ensured. •Weekly progress monitoring.
Unable to meet USA equipment sourcing requirements	L	M	L	•Tasks included in the SOPO to achieve this requirement. •Key personnel dedicated to achieving this goal.
Unable to achieve USA labor sourcing requirements	L	M	L	•Actions already taken to achieve requirement.
EH&S				
Handling large volumes of sorbents creates new issues from an EH&S perspective	M	M	M	•Existing projects outside the US required managing larger volumes of sorbents and addressing regeneration.

Design basis

Design basis

OSBL and ISBL Design Basis - Conditions for the design basis are set

CO_2 Product Specification - CO_2 product conditions for each of the host sites has been set to match the type of sequestration available

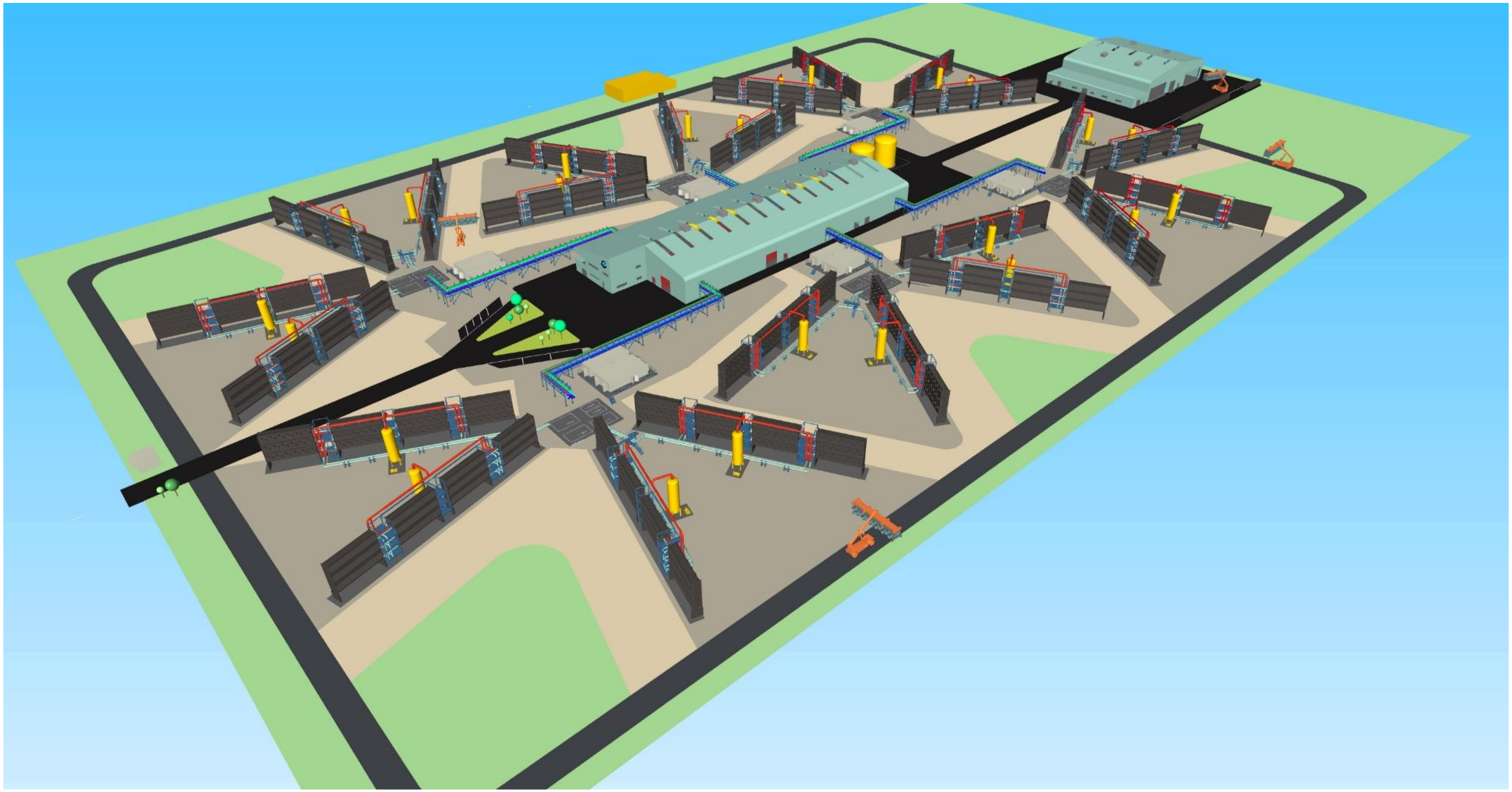
- California: 1,700 psig, >95% CO_2
- Louisiana: 2,000 psig, >95% CO_2
- Wyoming: 1,500 psig, >95% CO_2

Process Emissions and Effluents - Identification of components of emissions that could present potential environmental consequences

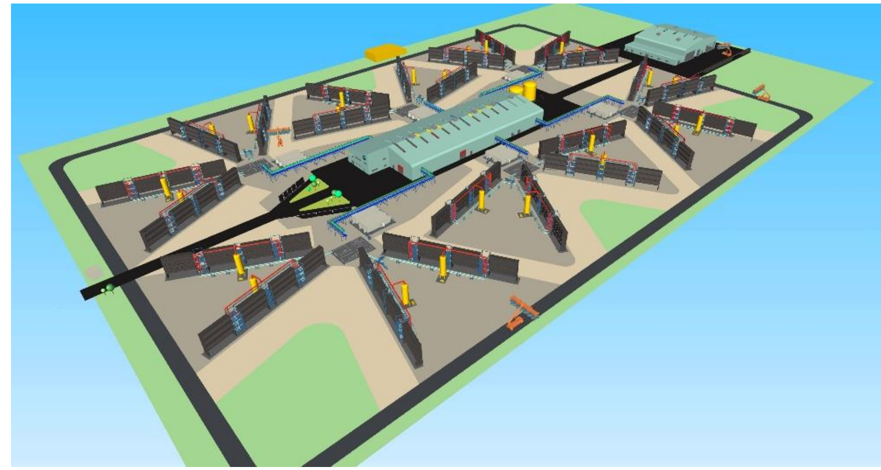
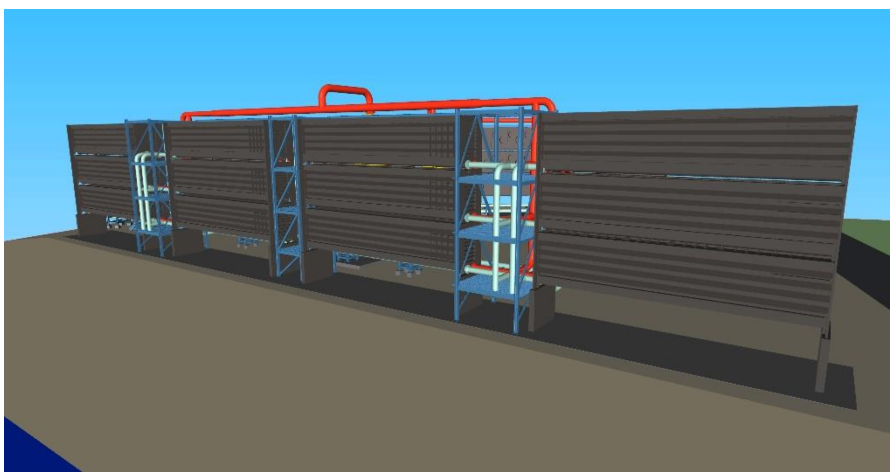
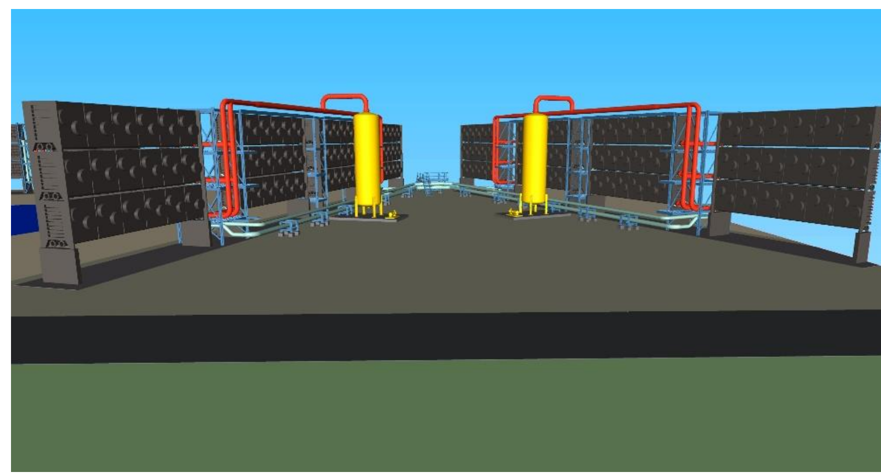
Steam and Electric Sourcing Study

- California: Geothermal heat and electricity
- Louisiana: Solar power, Electric steam generation
- Wyoming: Wind based grid power, Waste heat from host site

3D Model



3D Model

Next steps & Acknowledgements

Moving forward

- Completion of ISBL / OSBL Detailed Engineering
- Develop Overall Project Capital Cost Estimate
- Perform a Preliminary Techno-Economic Analysis
- Perform a Preliminary Life Cycle Analysis
- Completion of all Project Deliverables

Acknowledgements

Name	Organization
Krista Hill, Zachary Roberts	National Energy Technology Laboratory / US Department of Energy
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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