Project DE-FE0032148
Cryogenic Carbon Capture From Cement Production

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Sustainable Energy Solutions, a Chart Industries Company

Cooler By Design.™

- Project Introduction
- CCC Technology Overview
- Previous CCC Demonstrations
- Progress and System Design

Project Introduction

Project Overview – Cryogenic Carbon Capture From Cement Production

30 TPD CCC Pilot

Design based off field-tested 1 TPD unit

Location at Sugar Creek Cement Plant near Kansas City, Missouri

Skid-based design that can be built mostly off-site with limited integration

Project Start: Feb. 1, 2022

Project End: April 30, 2025

Three Phases of one year each

Partnership with National Energy Technology Laboratory (NETL)

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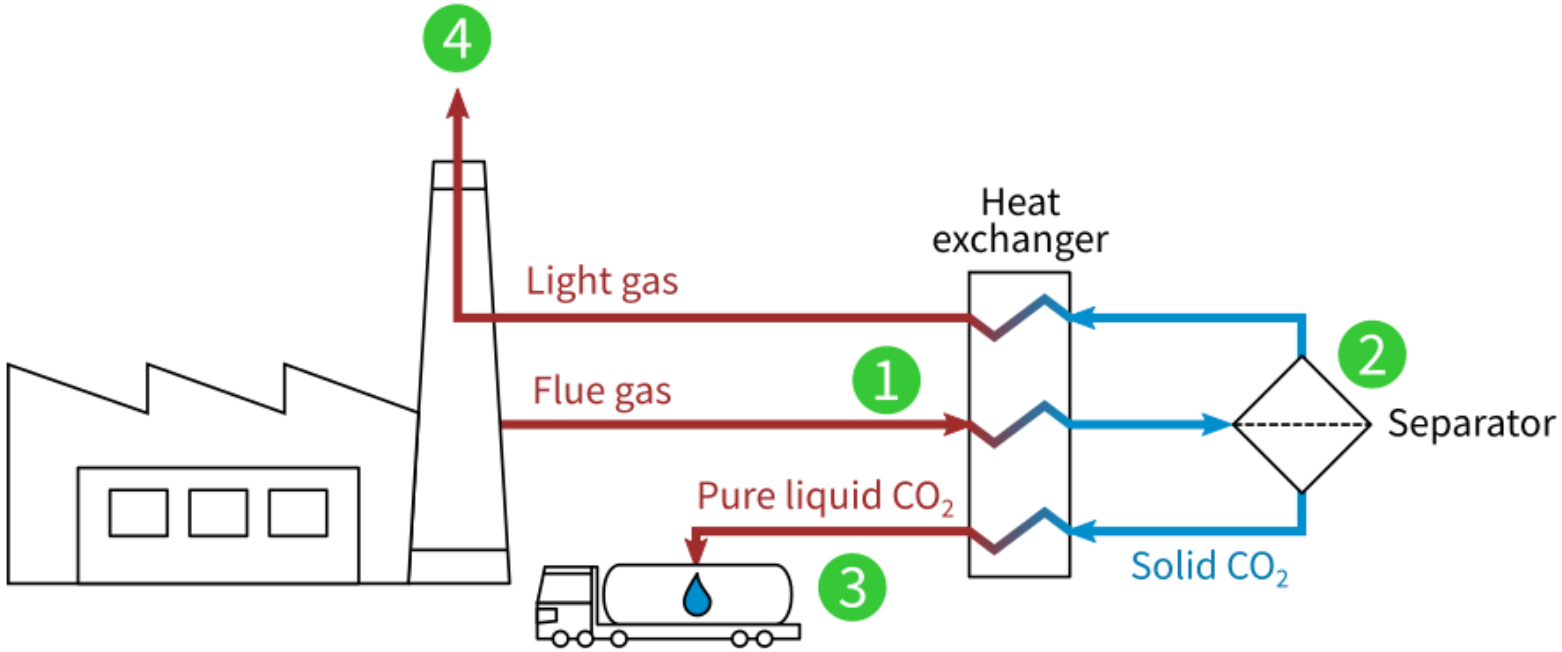
Project Team

Success Criteria

Decision Point	Date	Success Criteria
Completion of Phase 1	1/31/2023	– The remaining cost of plant construction, operation, and decommissioning is less than or equal to the proposed remaining budget of Phases 2 and 3 as determined by the final plant design. – The lead-times provided by the vendors allow for sufficient time to complete construction and commissioning by the end of Phase II, as determined by the construction plan provided by the EPC.
Completion of Phase 2	1/31/2024	– All operating and environmental approvals finalized. – Detailed construction plan implemented.
Completion of Phase 3	1/31/2025	**Commissioning** Subsystems all certified, including: – The ability to cool the gas to at least -117° C – The multi-stream heat exchanger achieving 5°C minimum approach temperature Startup, shutdown, emergency, and standard operating procedures finalized. **Testing** – Complete continuous testing for a minimum of 2 months – Capture during the testing at 1.22 mol% CO_2 in outlet stream (i.e., 95% capture with 19.8 mol% CO_2 on a dry basis) and 95% CO_2 purity at 30 tonnes/day CO_2. **Decommissioning** – Complete decommissioning of plant per the decommissioning plan **TEA** – Full-scale TEA showing energy of CO_2 captured less than 0.83 MJ_e/kg CO_2

CCC Process Overview

Conceptually Simple Process



1. Flue gas is cooled
2. CO_2 is separated as a solid from the light gases
3. CO_2 is melted and prepared for transport
4. Light gases are reheated and released to atmosphere

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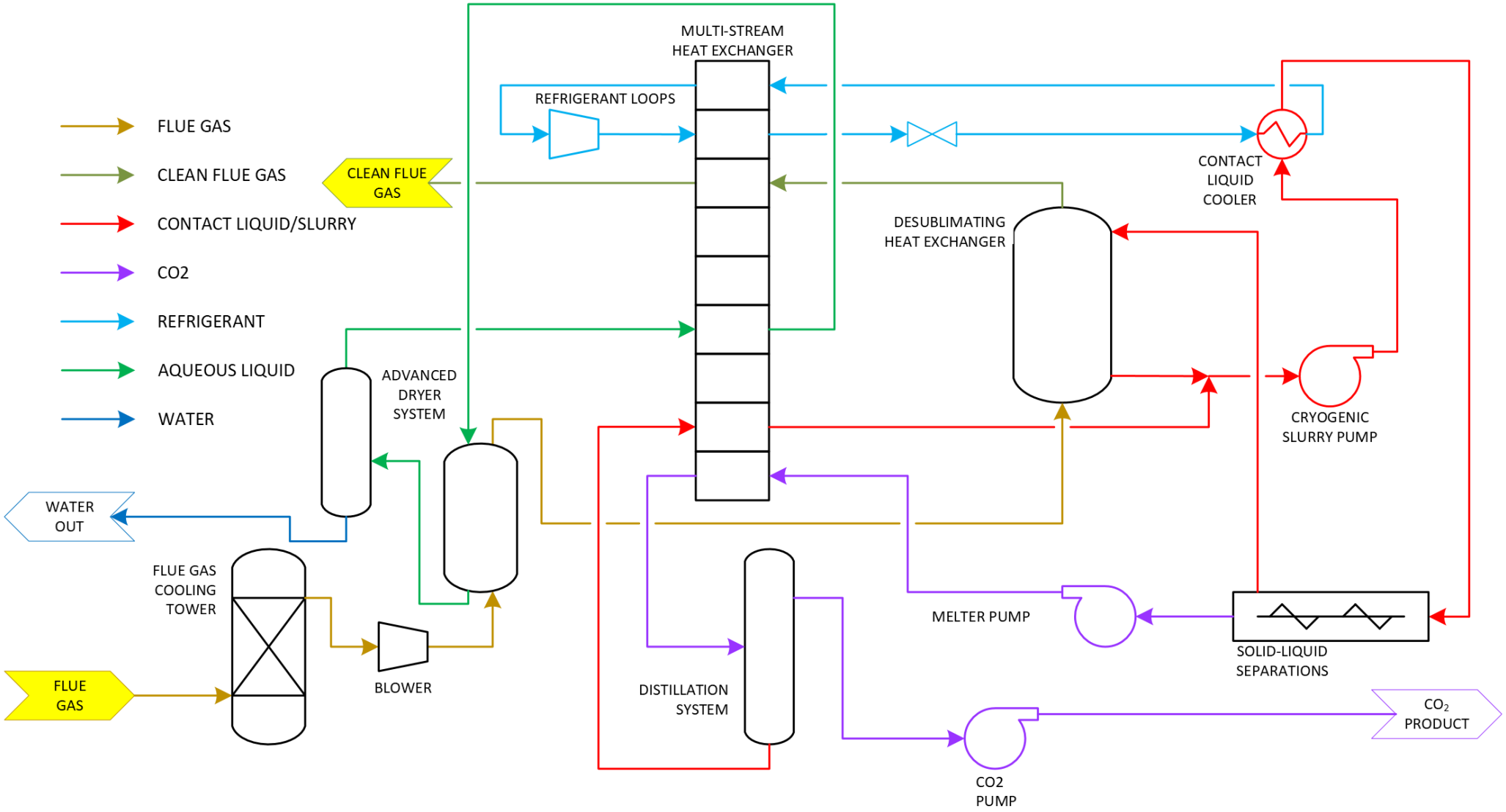
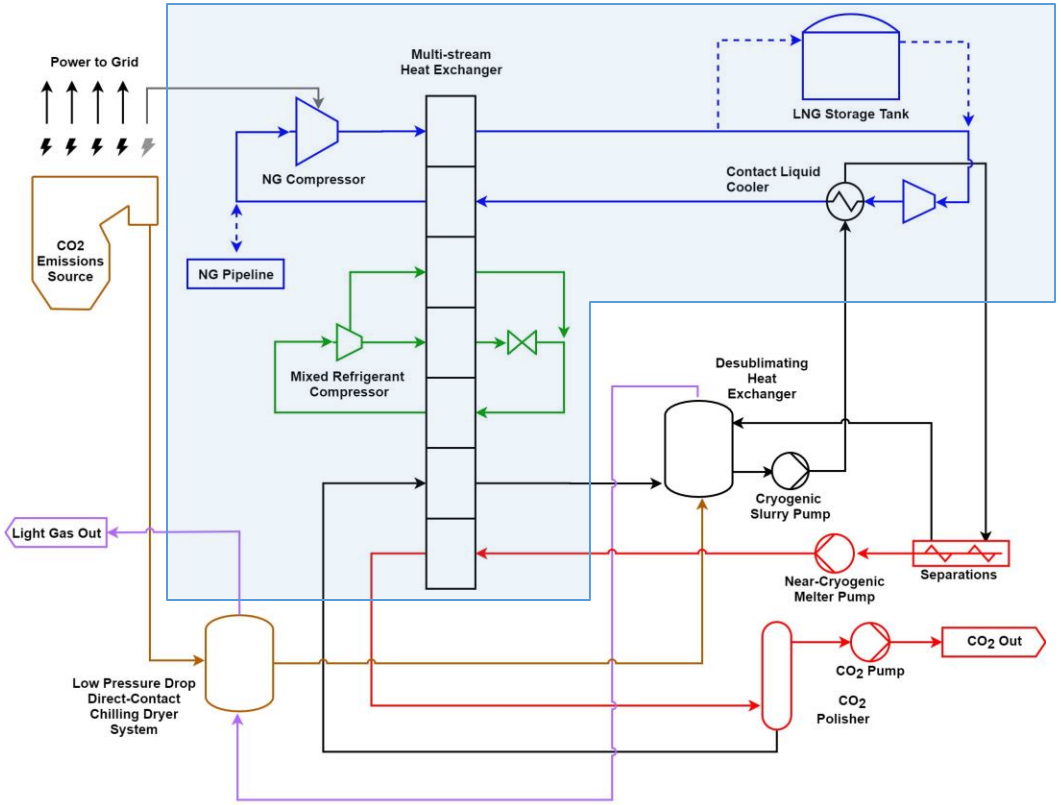
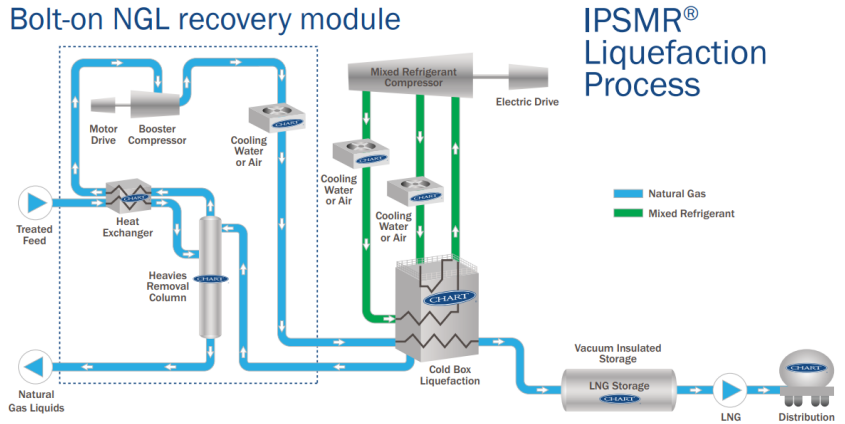
Preliminary Simplified CCC PFD

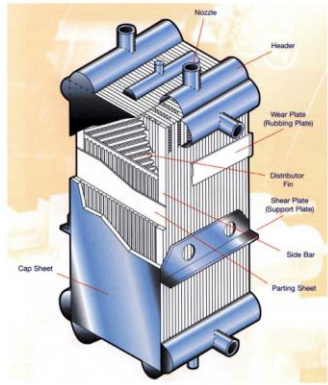


SES-Chart Collaboration

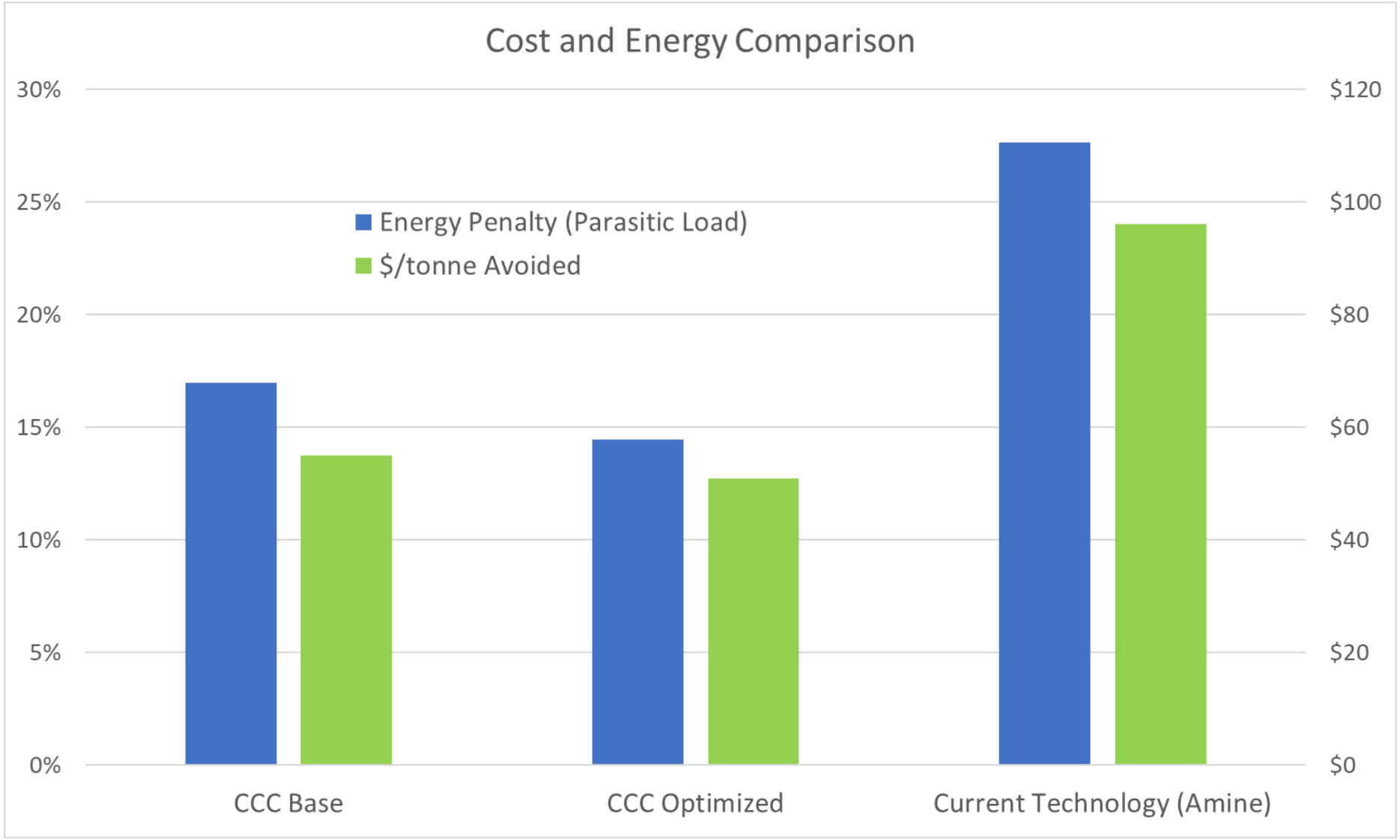
- SES acquired by Chart in 2020
- High degree of overlap in equipment used for CCC Process







Cost and Energy Savings



Based on Rev 2a Baseline NETL Study with Updated Costs. Additional value and revenues could be gained from CO_2 sales and energy storage.

CCC Benefits

Low energy and cost retrofit technology

Easy retrofit carbon capture technology

Robust to pollutants and captures most criteria pollutants

Produces high-purity, liquid CO_2

Very high capture rates, up to negative emissions (99%+)

Integrated grid-scale energy storage

Independent Validation

"Of all these [carbon capture] processes, I regard the CCC process to have the greatest potential"

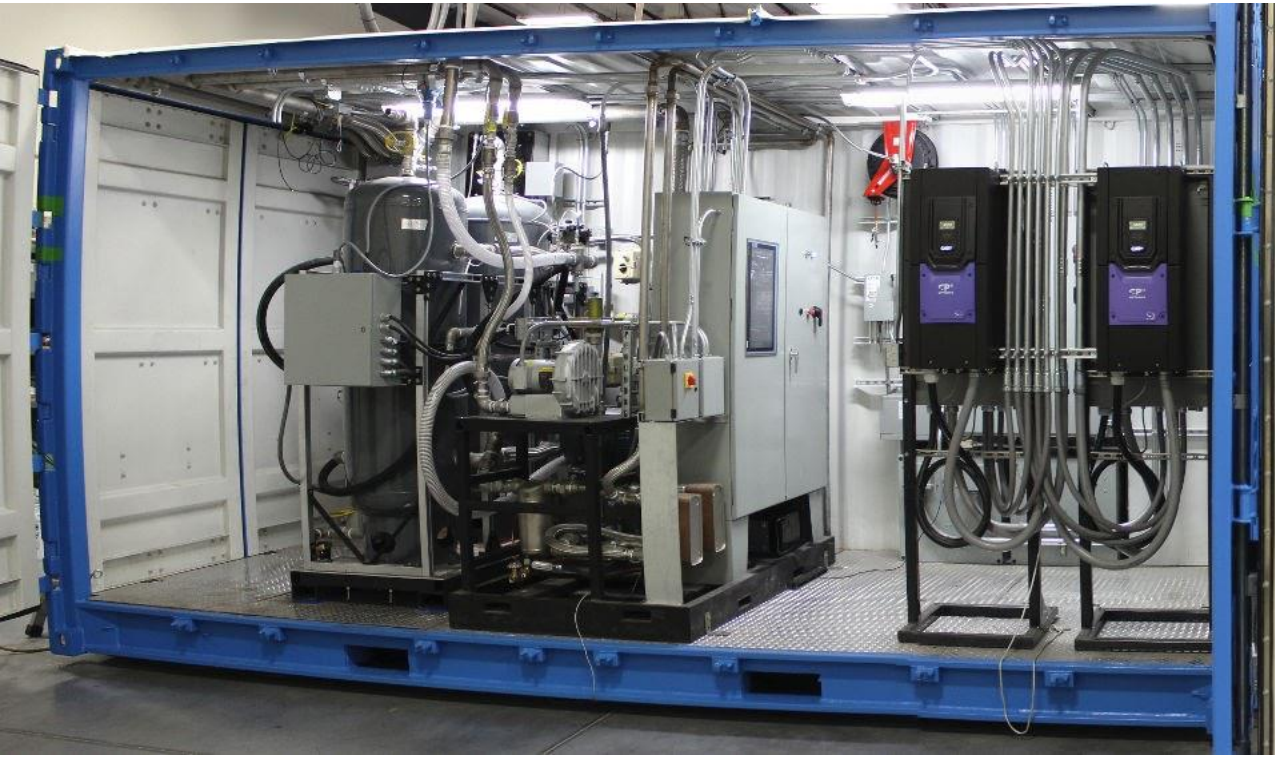
-Howard Herzog, MIT Energy Initiative

Previous Demonstrations

1 Ton/day Demo


Storage and Utility Skid
Pre-Treatment and Electrical Skid
Cryogenic Carbon Capture Skid

Pre-Treatment and Electrical Skid



Cryogenic Carbon Capture Skid

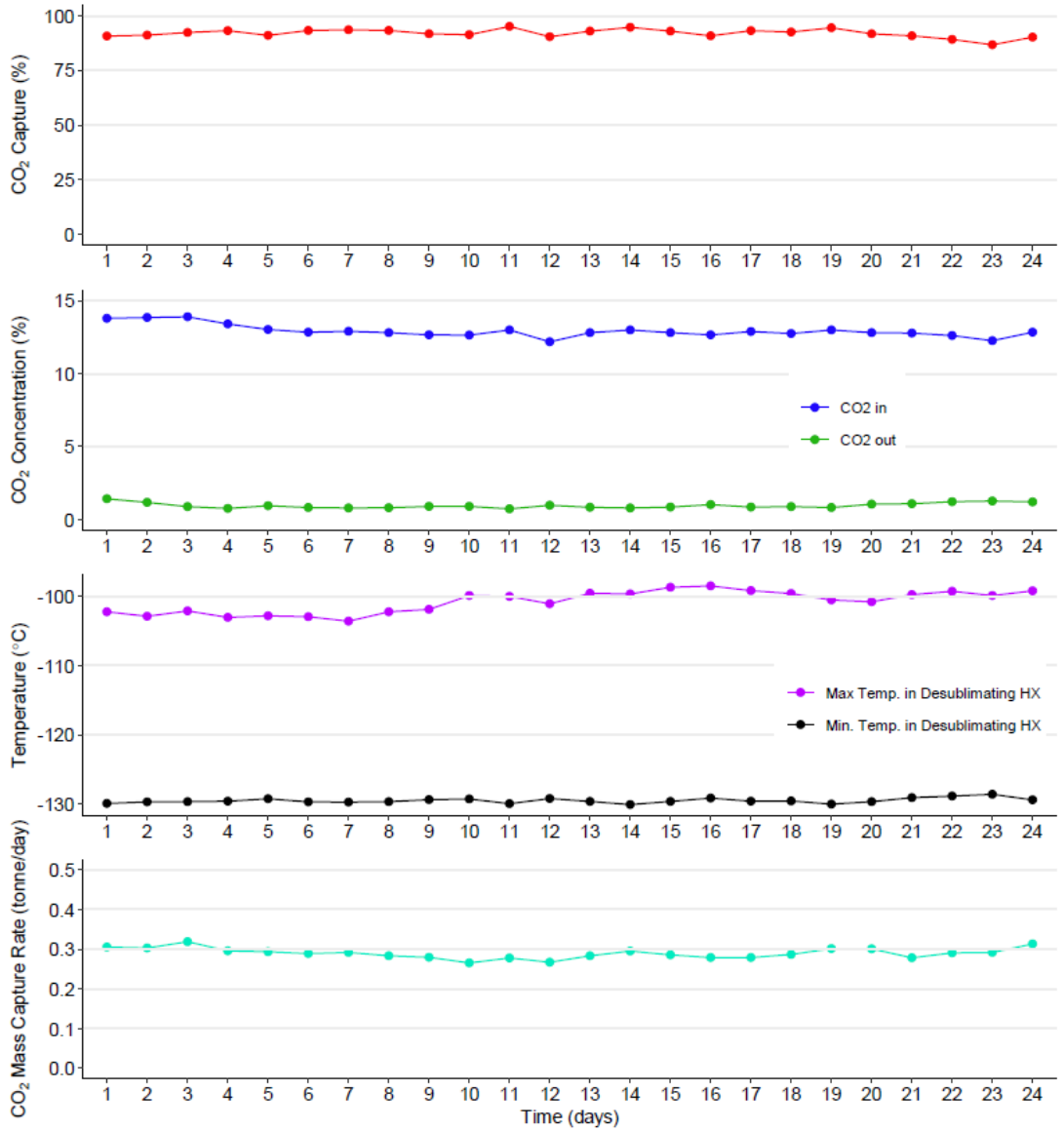
Capture at Cement Plant

Small Pilot Operated by SES

Use in Concrete

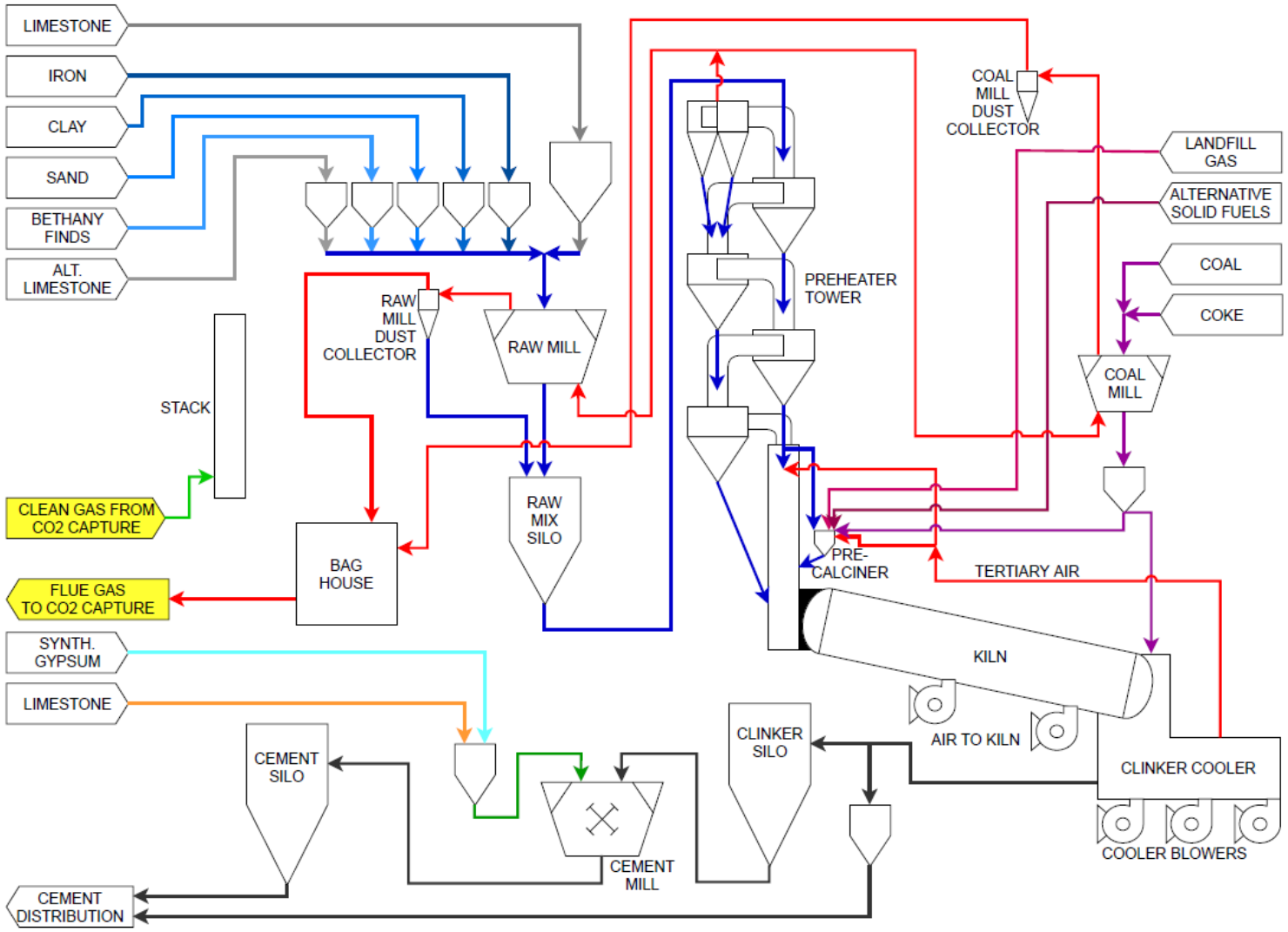
CarbonCure Utilization Partner

Continuous Testing



Preliminary Plans for CCC Pilot at Sugar Creek

PFD of Sugar Creek Cement Plant



CCC Pilot/Small Commercial-Scale Preliminary Layout

SES INNOVATION

CHART

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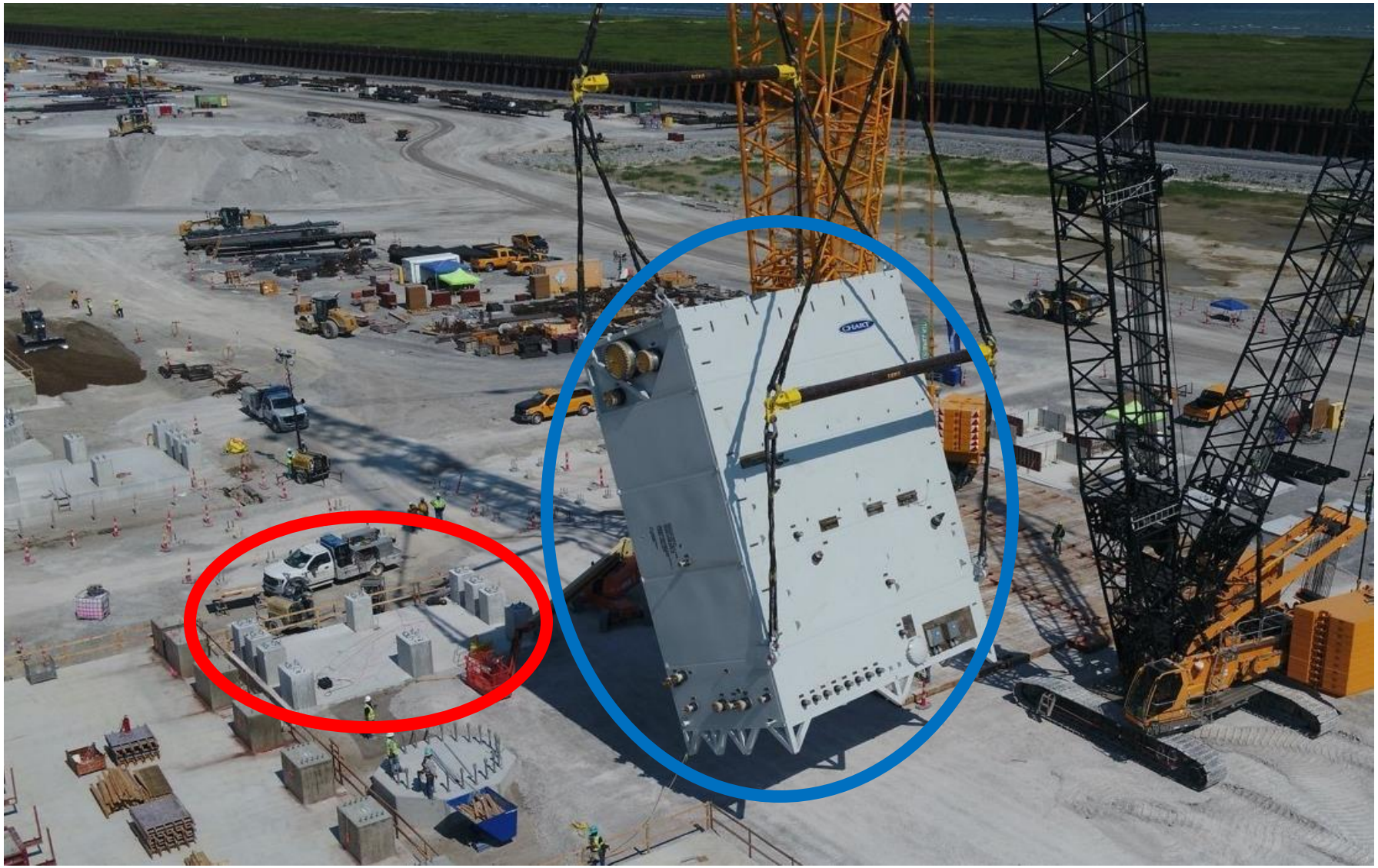
Skid-Based System Design

Conceptual Module Design

Conceptual Module Design

Cold Box Examples

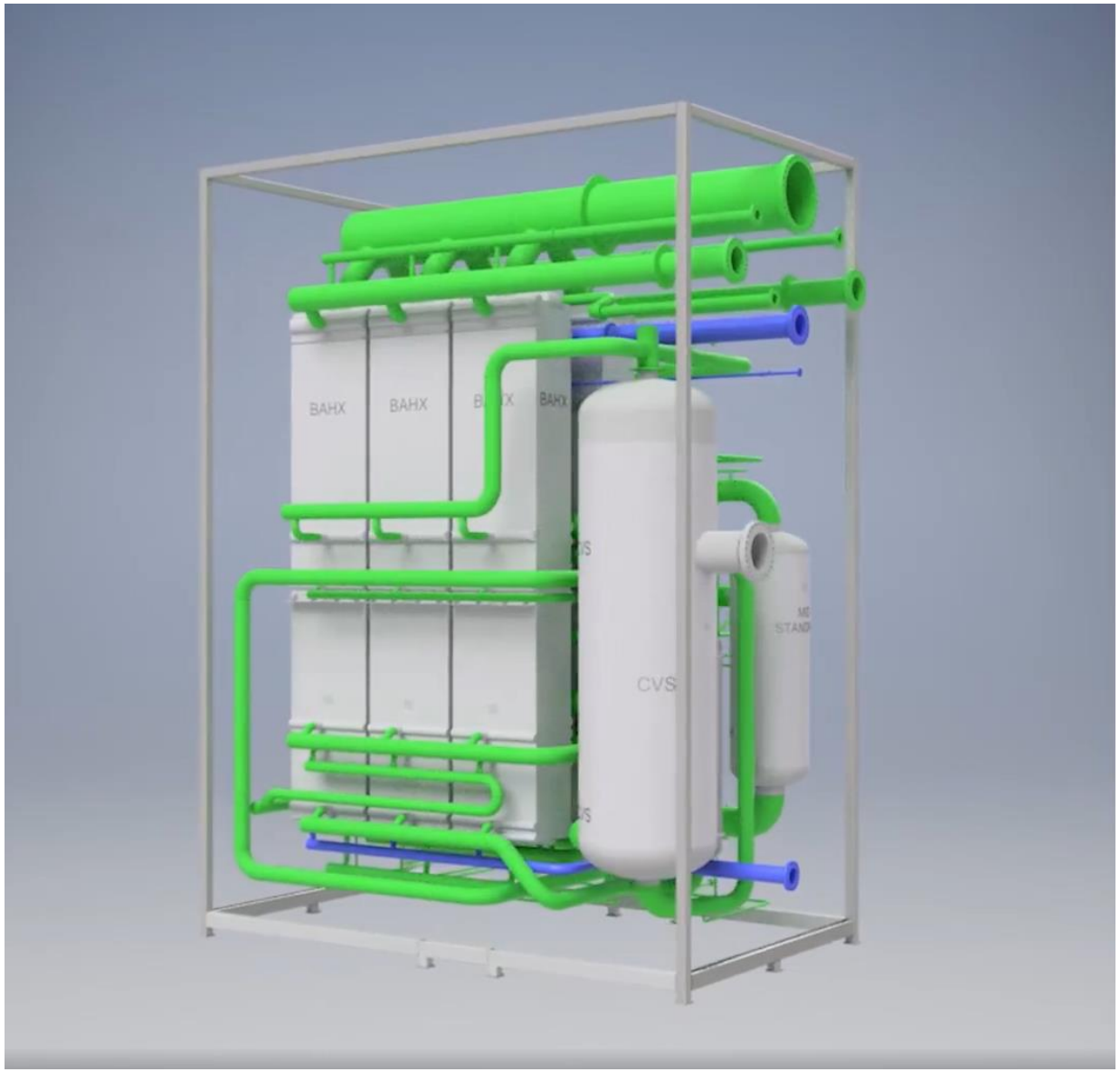


- This image shows an example of an enclosed chart cold box module (blue).
- Eagle Materials CCC cold box will be similar but much smaller.
- Constructed by Chart and will include everything except for the concrete foundations (red).

Example M-3 Style Cold box

This is a Chart cold box being placed at a site, the cold box for this system will be smaller

Coldbox Internals



An example of the internals of a chart cold box are shown here. All of the internal equipment, piping and structural supports will be built into the box with exterior ports showing for process interconnects

Summary

- CCC Benefits
  - Lowest energy and cost retrofit technology
  - Easiest retrofit carbon capture technology
  - Produces high-purity, liquid CO2
  - Very high capture rates, up to negative emissions (99%+)

- Project Specifics
  - Nominally 30 TPD pilot on modern cement plant in Sugar Creek, Missouri
  - Design based off extensively field and in-house tested 1 TPD capture unit
  - Skid-based design that can be built mostly off-site with limited integration

Acknowledgments

- Thank you to the companies and organizations that are contributing to this project.

FLSmidth

Eagle Materials

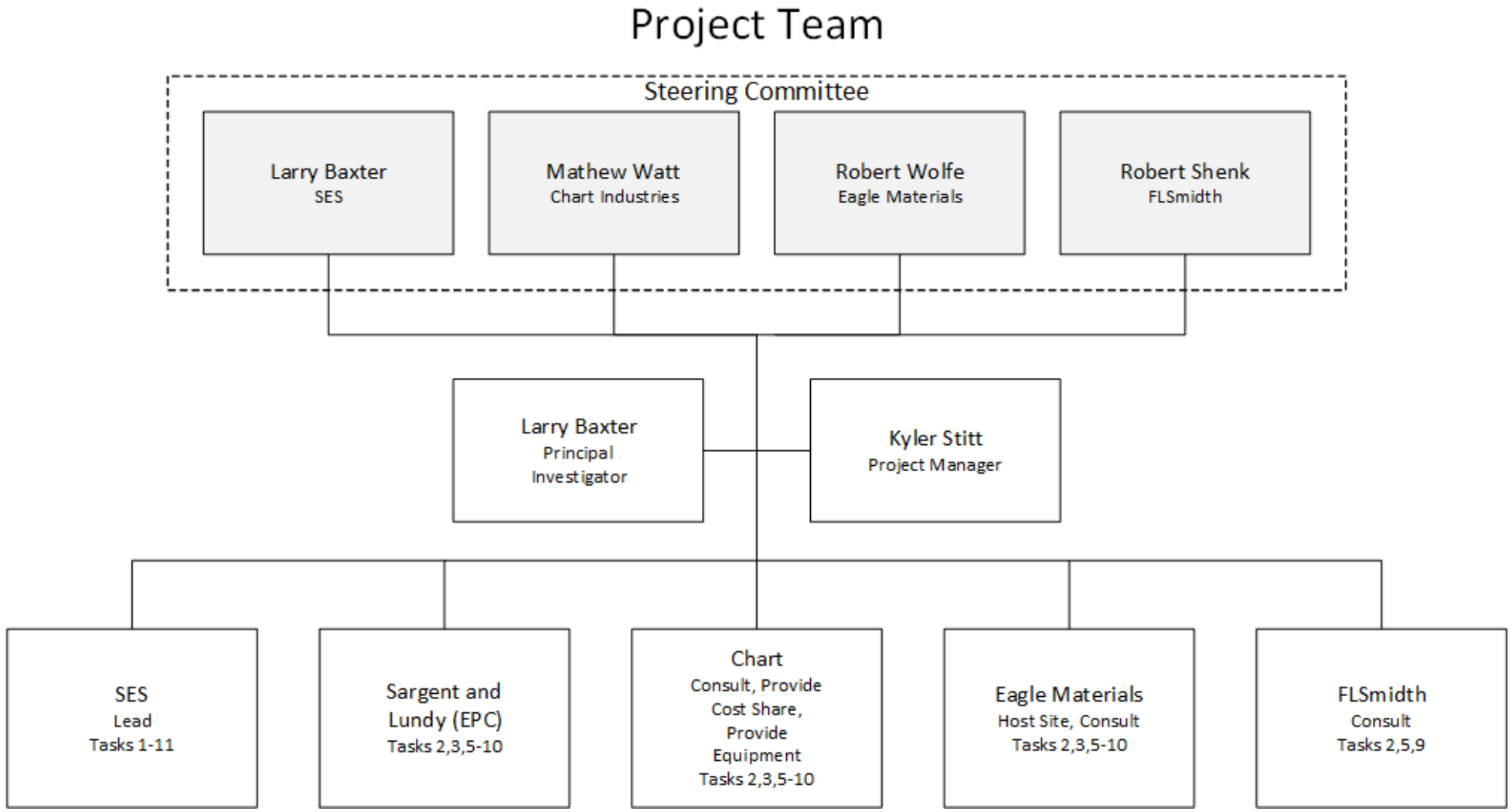
National Energy Technology Laboratory

CHART

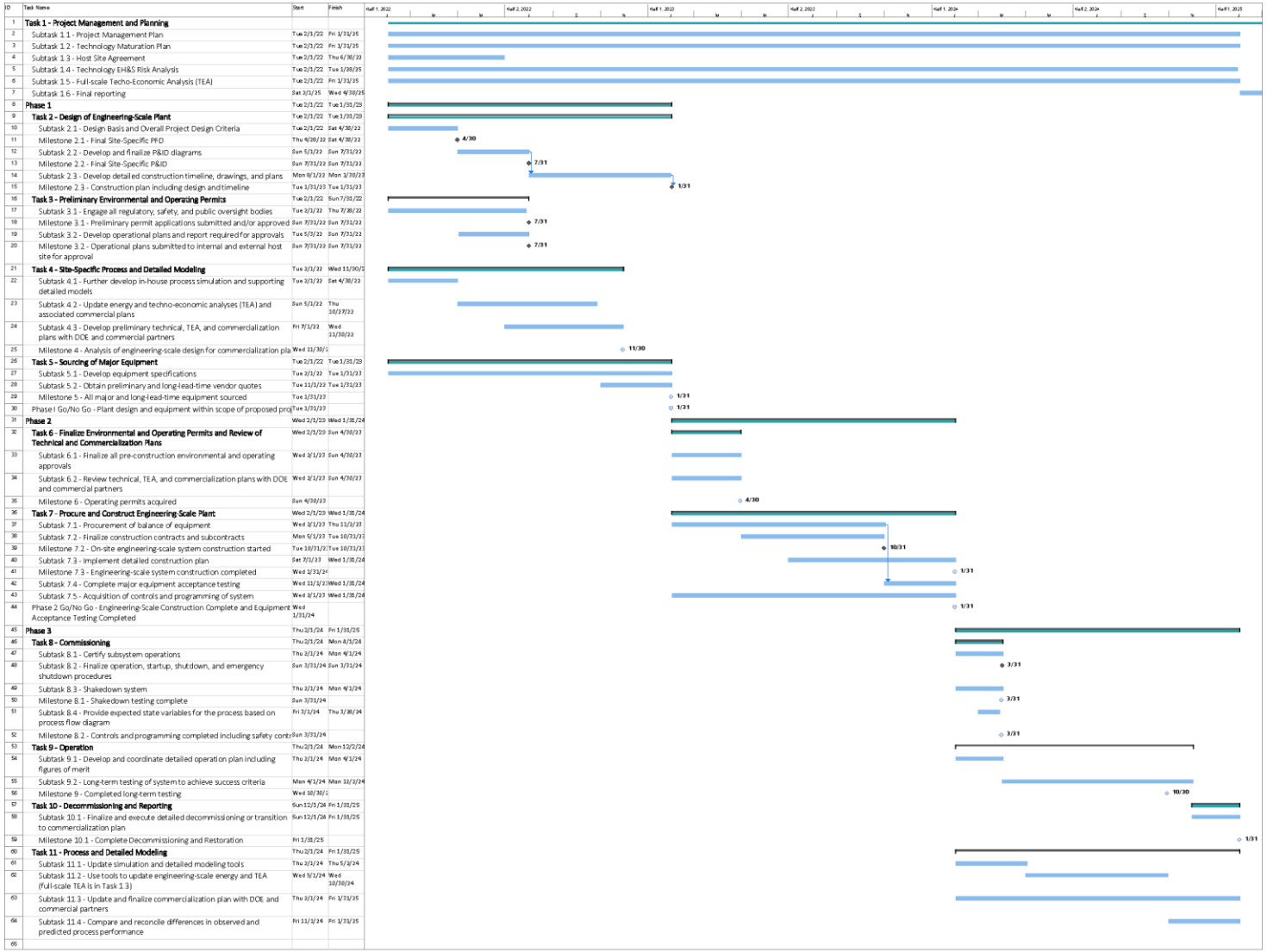
Sargent & Lundy

Appendix Slides

Organizational Chart



Gantt Chart



ID	Task Name	Start	Finish
1	**Task 1 - Project Management and Planning**		
2	Subtask 1.1 - Project Management Plan	Tue 2/1/22	Fri 1/31/25
3	Subtask 1.2 - Technology Maturation Plan	Tue 2/1/22	Fri 1/31/25
4	Subtask 1.3 - Host Site Agreement	Tue 2/1/22	Thu 6/30/22
5	Subtask 1.4 - Technology EH&S Risk Analysis	Tue 2/1/22	Tue 1/28/25
6	Subtask 1.5 - Full-scale Techo-Economic Analysis (TEA)	Tue 2/1/22	Fri 1/31/25
7	Subtask 1.6 - Final reporting	Sat 2/1/25	Wed 4/30/25
8	**Phase 1**	Tue 2/1/22	Tue 1/31/23
9	**Task 2 - Design of Engineering-Scale Plant**	Tue 2/1/22	Tue 1/31/23
10	Subtask 2.1 - Design Basis and Overall Project Design Criteria	Tue 2/1/22	Sat 4/30/22
11	Milestone 2.1 - Final Site-Specific PFD	Thu 4/30/22	Sat 4/30/22
12	Subtask 2.2 - Develop and finalize P&ID diagrams	Sun 5/1/22	Sun 7/31/22
13	Milestone 2.2 - Final Site-Specific P&ID	Sun 7/31/22	Sun 7/31/22
14	Subtask 2.3 - Develop detailed construction timeline, drawings, and plans	Mon 8/1/22	Mon 1/30/23
15	Milestone 2.3 - Construction plan including design and timeline	Tue 1/31/23	Tue 1/31/23
16	**Task 3 - Preliminary Environmental and Operating Permits**	Tue 2/1/22	Sun 7/31/22
17	Subtask 3.1 - Engage all regulatory, safety, and public oversight bodies	Tue 2/1/22	Thu 7/28/22
18	Milestone 3.1 - Preliminary permit applications submitted and/or approved	Sun 7/31/22	Sun 7/31/22
19	Subtask 3.2 - Develop operational plans and report required for approvals	Tue 5/3/22	Sun 7/31/22
20	Milestone 3.2 - Operational plans submitted to internal and external host site for approval	Sun 7/31/22	Sun 7/31/22
21	**Task 4 - Site-Specific Process and Detailed Modeling**	Tue 2/1/22	Wed 11/30/22
22	Subtask 4.1 - Further develop in-house process simulation and supporting detailed models	Tue 2/1/22	Sat 4/30/22
23	Subtask 4.2 - Update energy and techno-economic analyses (TEA) and associated commercial plans	Sun 5/1/22	Thu 10/27/22
24	Subtask 4.3 - Develop preliminary technical, TEA, and commercialization plans with DOE and commercial partners	Fri 7/1/22	Wed 11/30/22
25	Milestone 4 - Analysis of engineering-scale design for commercialization pla	Wed 11/30/22	
26	**Task 5 - Sourcing of Major Equipment**	Tue 2/1/22	Tue 1/31/23
27	Subtask 5.1 - Develop equipment specifications	Tue 2/1/22	Tue 1/31/23
28	Subtask 5.2 - Obtain preliminary and long-lead-time vendor quotes	Tue 11/1/22	Tue 1/31/23
29	Milestone 5 - All major and long-lead-time equipment sourced	Tue 1/31/23	
30	Phase I Go/No Go - Plant design and equipment within scope of proposed proj	Tue 1/31/23	
31	**Phase 2**	Wed 2/1/23	Wed 1/31/24
32	**Task 6 - Finalize Environmental and Operating Permits and Review of Technical and Commercialization Plans**	Wed 2/1/23	Sun 4/30/23
33	Subtask 6.1 - Finalize all pre-construction environmental and operating approvals	Wed 2/1/23	Sun 4/30/23
34	Subtask 6.2 - Review technical, TEA, and commercialization plans with DOE and commercial partners	Wed 2/1/23	Sun 4/30/23
35	Milestone 6 - Operating permits acquired	Sun 4/30/23	
36	**Task 7 - Procure and Construct Engineering-Scale Plant**	Wed 2/1/23	Wed 1/31/24
37	Subtask 7.1 - Procurement of balance of equipment	Wed 2/1/23	Thu 11/2/23
38	Subtask 7.2 - Finalize construction contracts and subcontracts	Mon 5/1/23	Tue 10/31/23
39	Milestone 7.2 - On-site engineering-scale system construction started	Tue 10/31/23	Tue 10/31/23
40	Subtask 7.3 - Implement detailed construction plan	Sat 7/1/23	Wed 1/31/24
41	Milestone 7.3 - Engineering-scale system construction completed	Wed 1/31/24	
42	Subtask 7.4 - Complete major equipment acceptance testing	Wed 11/1/23	Wed 1/31/24
43	Subtask 7.5 - Acquisition of controls and programming of system	Wed 2/1/23	Wed 1/31/24
44	Phase 2 Go/No Go - Engineering-Scale Construction Complete and Equipment Acceptance Testing Completed	Wed 1/31/24	
45	**Phase 3**	Thu 2/1/24	Fri 1/31/25
46	**Task 8 - Commissioning**	Thu 2/1/24	Mon 4/1/24
47	Subtask 8.1 - Certify subsystem operations	Thu 2/1/24	Mon 4/1/24
48	Subtask 8.2 - Finalize operation, startup, shutdown, and emergency shutdown procedures	Sun 3/31/24	Sun 3/31/24
49	Subtask 8.3 - Shakedown system	Thu 2/1/24	Mon 4/1/24
50	Milestone 8.1 - Shakedown testing complete	Sun 3/31/24	
51	Subtask 8.4 - Provide expected state variables for the process based on process flow diagram	Fri 3/1/24	Thu 3/28/24
52	Milestone 8.2 - Controls and programming completed including safety contr	Sun 3/31/24	
53	**Task 9 - Operation**	Thu 2/1/24	Mon 12/2/24
54	Subtask 9.1 - Develop and coordinate detailed operation plan including figures of merit	Thu 2/1/24	Mon 4/1/24
55	Subtask 9.2 - Long-term testing of system to achieve success criteria	Mon 4/1/24	Mon 12/2/24
56	Milestone 9 - Completed long-term testing	Wed 10/30/24	
57	**Task 10 - Decommissioning and Reporting**	Sun 12/1/24	Fri 1/31/25
58	Subtask 10.1 - Finalize and execute detailed decommissioning or transition to commercialization plan	Sun 12/1/24	Fri 1/31/25
59	Milestone 10.1 - Complete Decommissioning and Restoration	Fri 1/31/25	
60	**Task 11 - Process and Detailed Modeling**	Thu 2/1/24	Fri 1/31/25
61	Subtask 11.1 - Update simulation and detailed modeling tools	Thu 2/1/24	Thu 5/2/24
62	Subtask 11.2 - Use tools to update engineering-scale energy and TEA (full-scale TEA is in Task 1.3)	Wed 5/1/24	Wed 10/30/24
63	Subtask 11.3 - Update and finalize commercialization plan with DOE and commercial partners	Thu 2/1/24	Fri 1/31/25
64	Subtask 11.4 - Compare and reconcile differences in observed and predicted process performance	Fri 11/1/24	Fri 1/31/25
65			