Project DE-FE0032148
Cryogenic Carbon Capture From Cement Production

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Cooler By Design.™

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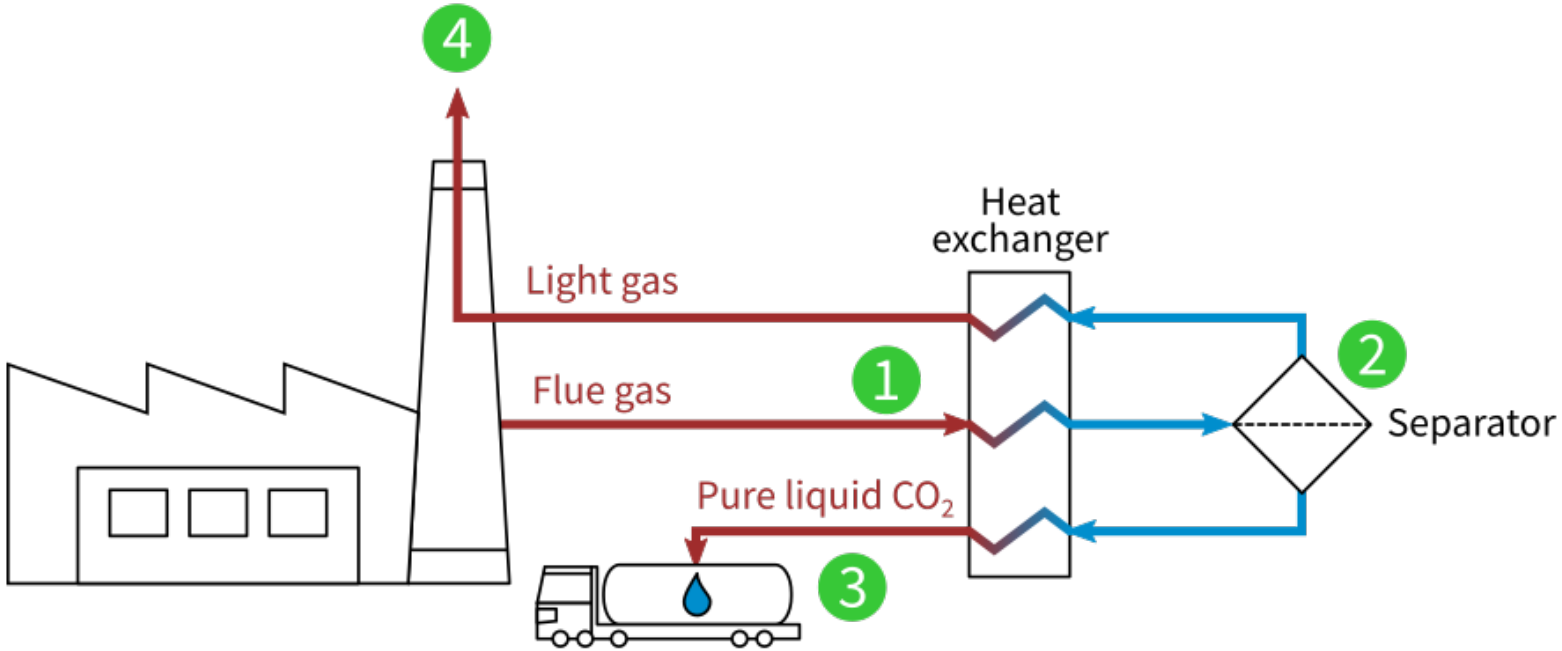
CCC Process Overview

Conceptually Simple Process



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

Simplified CCC PFD

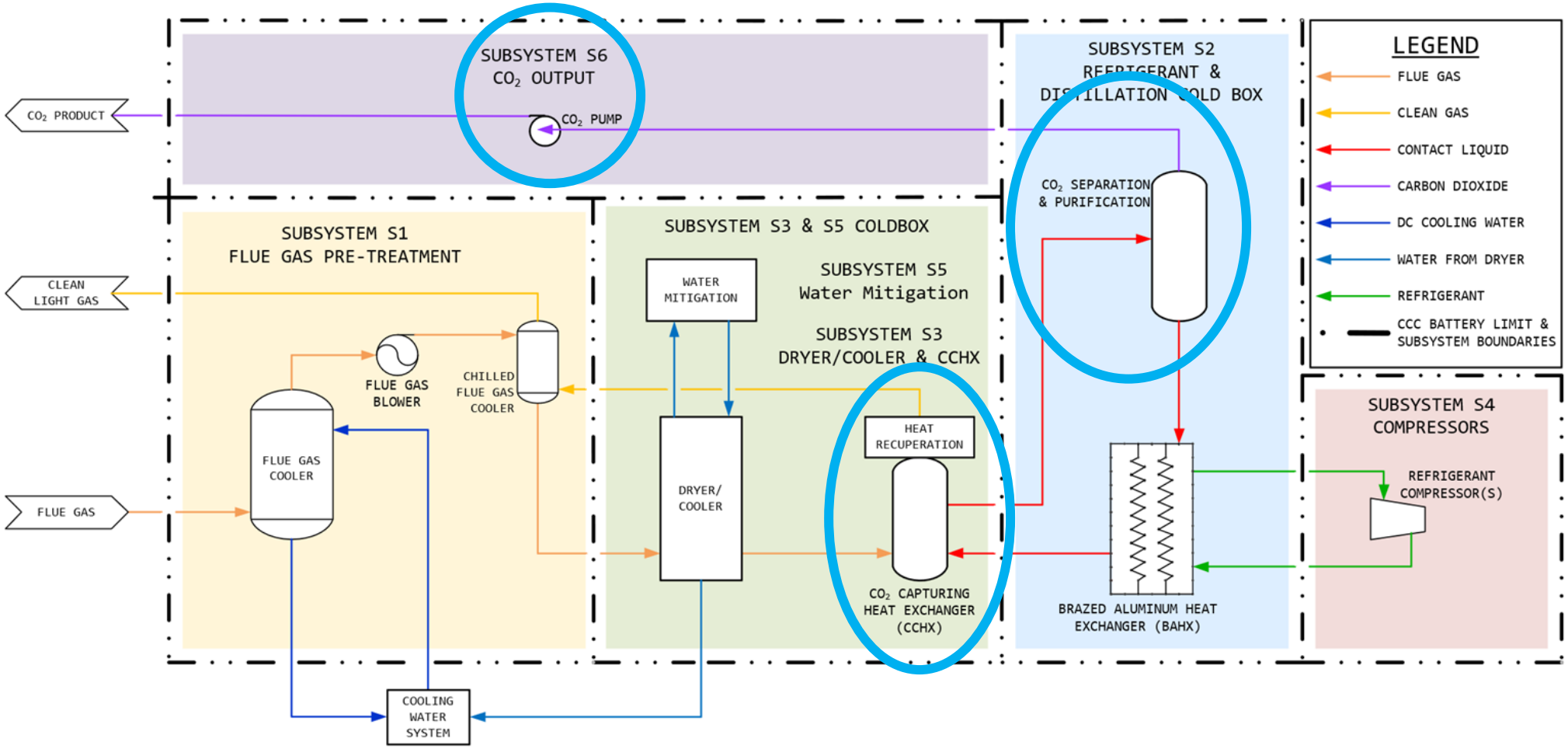
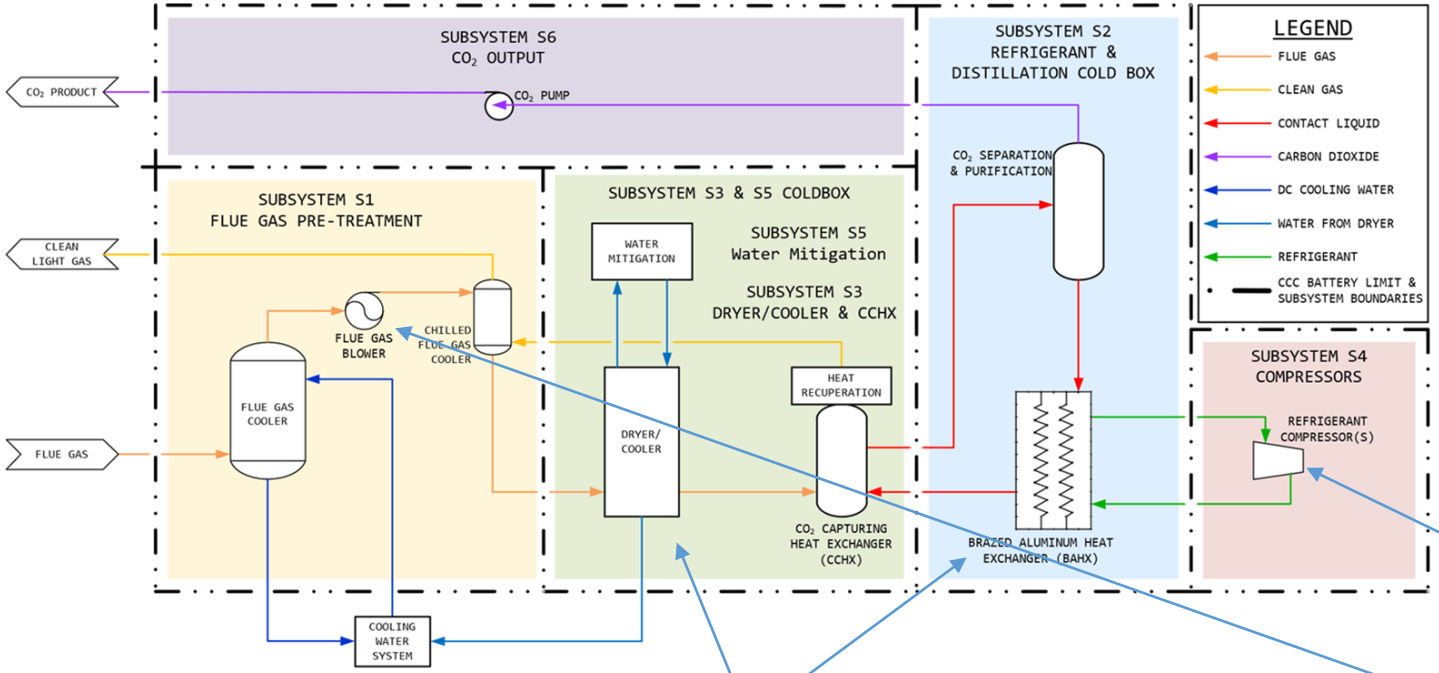


Chart and Howden Manufactured Equipment Make up Majority of Plant



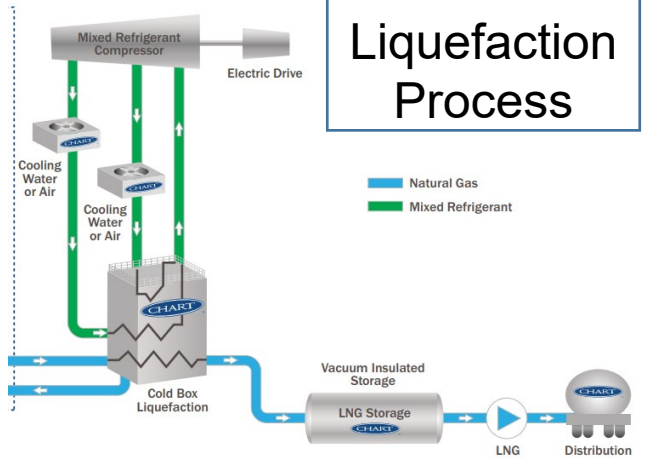


Chart Gas Liquefaction Process

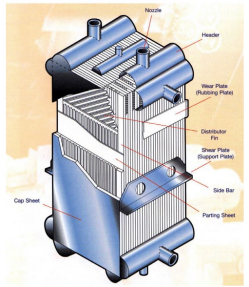


Chart Brazed Aluminum Heat Exchangers and Cold Boxes

Howden Blowers and Compressors

Independent Validation

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

-Howard Herzog, MIT Energy Initiative

CCC Benefits

Lowest energy and cost retrofit technology

Easiest retrofit carbon capture technology

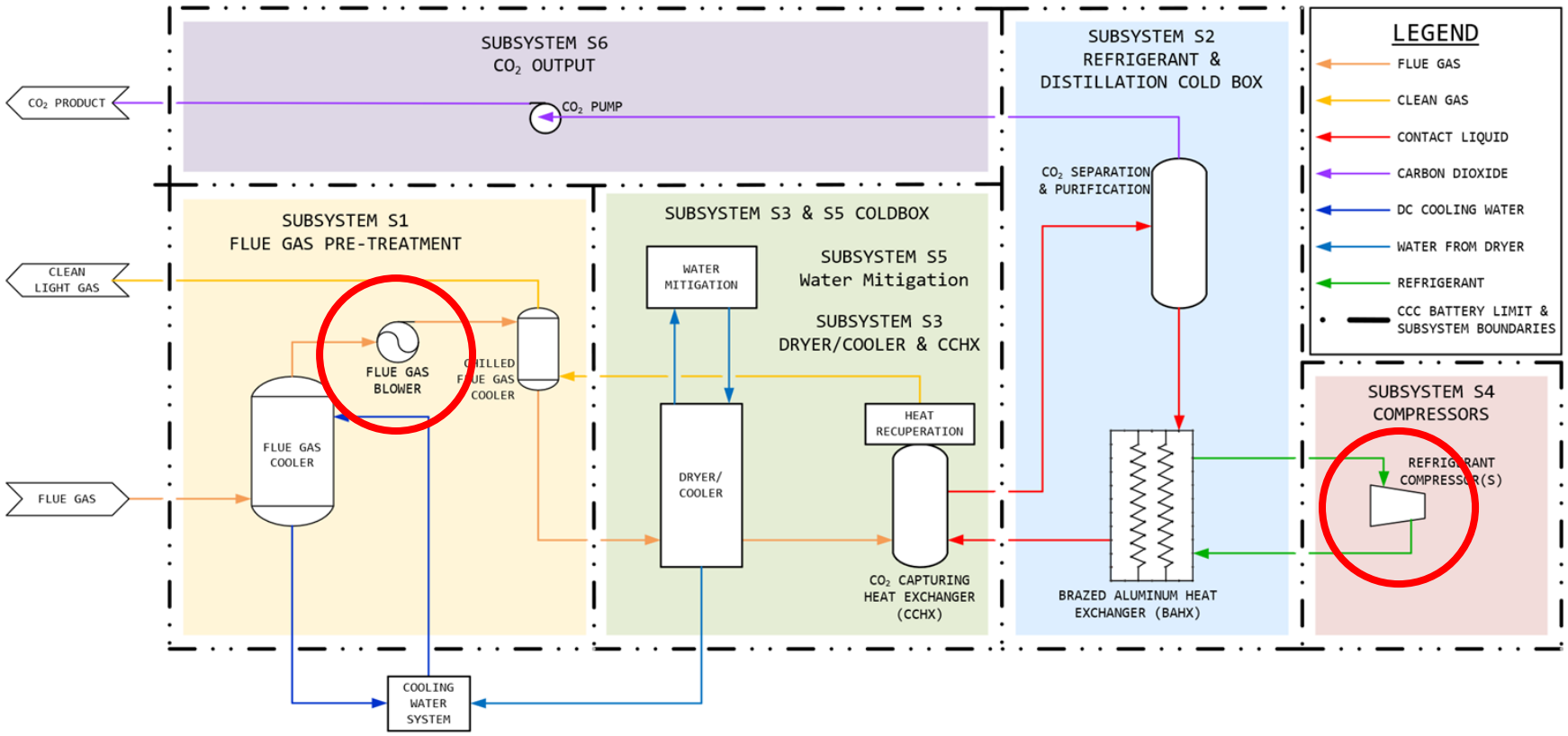
Robust to pollutants and captures most criteria pollutants

Produces high-purity, liquid CO_2

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

Integrated grid-scale energy storage

Energy



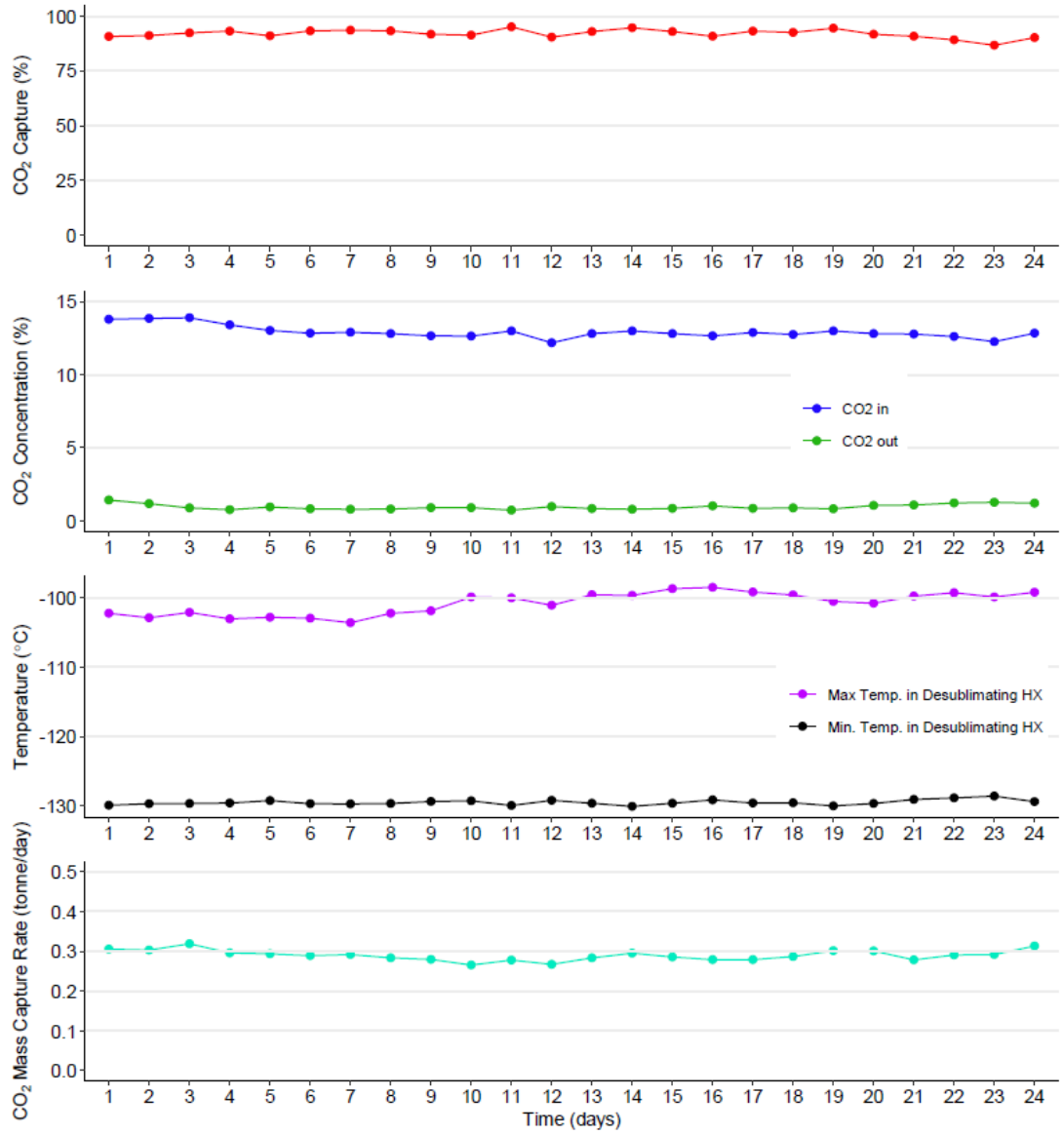
- 90% of energy is from compressors and blower
- 30 TPD Pilot ~1.16 MJ_e/kg or 320 kWh_e/tonne
  - 60% compressor efficiency
- Industrial facilities that can use high-efficiency compressors can be 0.8 MJ_e/kg or 220 kWh_e/kg or better
  - 85% compressor efficiency
- 13.0% CO2 on a wet basis, 16.6% on a dry basis
- Includes compression and liquefaction

Robust Operation and Pollutants

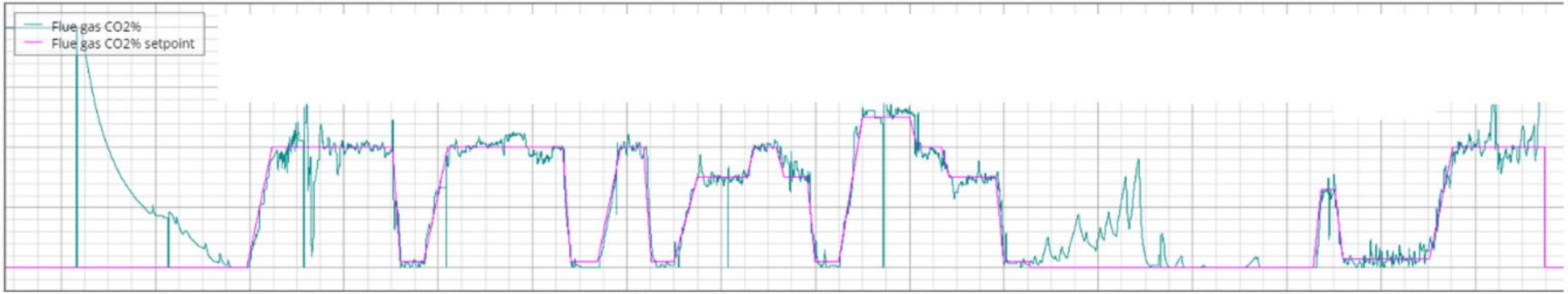
- Physical process means it is robust to particulates, pollutants, and oxygen
- Inert contact liquid and low temperature means no oxidation or chemical reactions
- Thermodynamic co-capture of any compound that is less volatile than CO_2
- Temperature dependent, composition dependent
- Indicative capture assuming inlet SO_x and NO_x greater than 100 ppm
  - SO_x capture of 95%+; outlet typically has single digit ppm
  - NO_2 capture of 95%+; outlet typically has to single digit ppm
  - NO capture of ~33%
- 100%+ Hg removal and other metals (gas leaving has less Hg than the air entering, verified experimentally)
- Outlet PM lower than inlet due to wet processes (verified experimentally)
- Most VOCs captured (anything less volatile than CO_2)
- Pollutants and particulates can be removed via filtration or distillation, depending on where they condense

Continuous Testing – High Capture

- 1 TPD testing results
- 25-day test
- 90%+ capture
- DAC feasible



Variable Operation



- 28-hour test on 1 TPD unit
- Variable CO_2 composition and flue gas composition
- 95%+ capture for the entire test
- No process upsets
- Variable CO_2 rejection and steady-state CO2 rejection

30 TPD Pilot

Project Overview – Cryogenic Carbon Capture From Cement Production

30 TPD CCC Pilot

Design based off field-tested 1 TPD unit

30 TPD (nominally 11,000 TPA)

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: Originally April 30, 2025, now May 31, 2026

No-Cost Time Extension

Project Funding: $17,140,929

Success Criteria

Decision Point	Success Criteria
Completion of Phase 1	– 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	– All operating and environmental approvals finalized. – Detailed construction plan implemented.
Completion of Phase 3	**Commissioning** Subsystems all certified, including: – The ability to cool the gas to at least -100° 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

Skid-Based CCC System Design at Sugar Creek

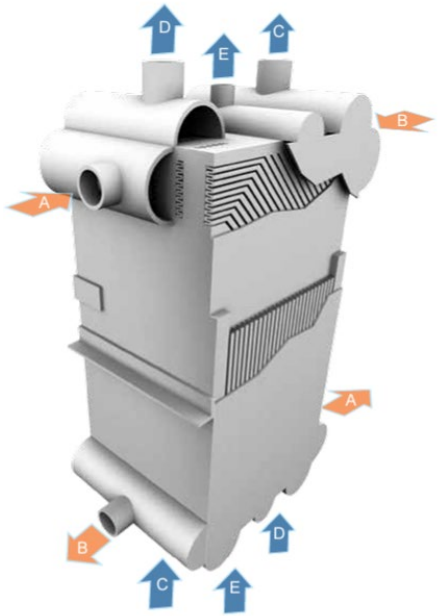
Conceptual Overhead View

Front-end Treatment

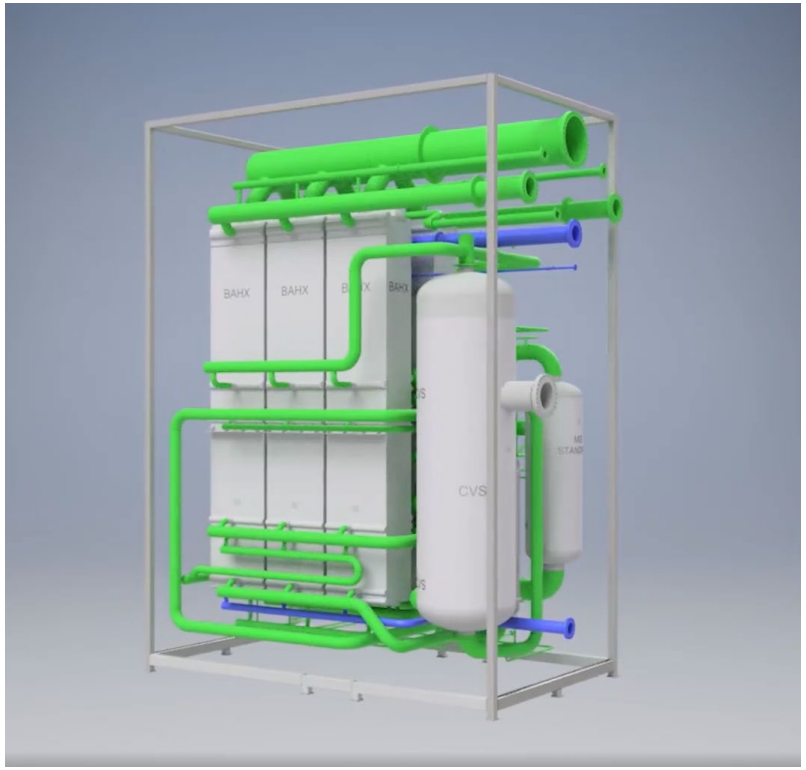
- Key Unit Operations
  - Flue gas cooling
  - Initial flue gas drying
  - Blower to overcome pressure drop
  - Light gas heat recovery
- Manufactured to SES specifications by Koch Engineered Solutions

CCC-Specific Equipment

- Detailed design and Fabrication by Chart
- Key Unit Operations
  - CO_2 separation and purification
  - Contact liquid distillation
  - Additional heat integration
  - Pumps and circulation



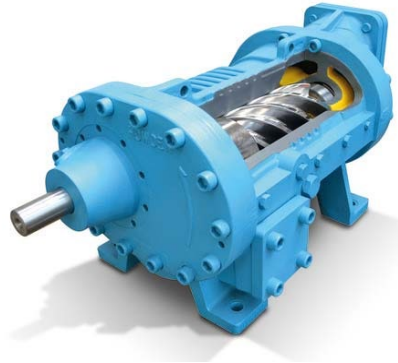
Representative BAHX

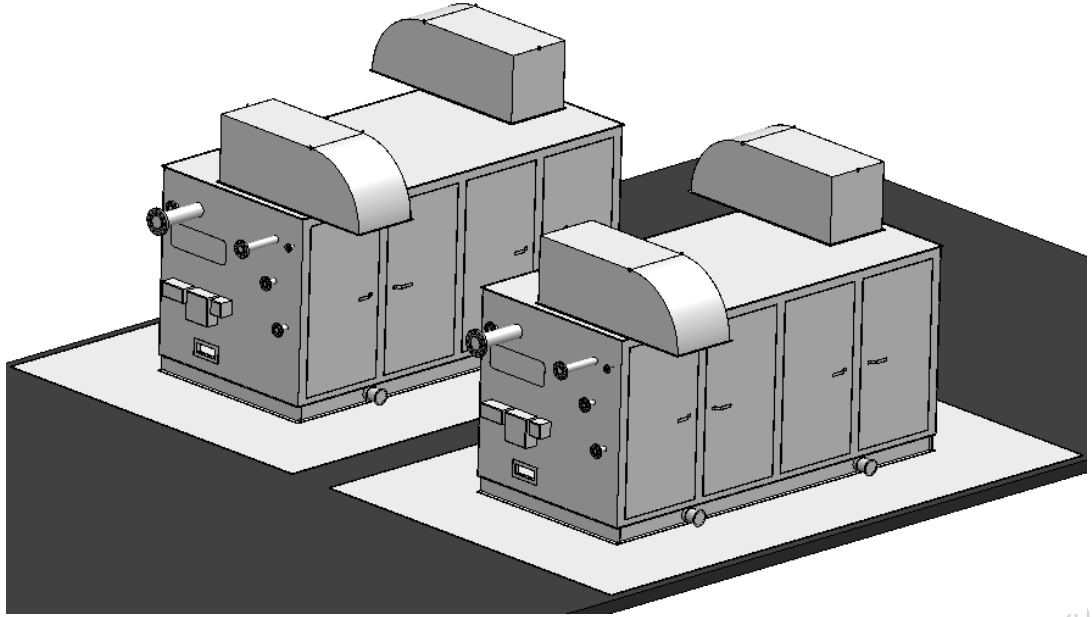


Representative Cold Box Internals

Refrigerant Compressors

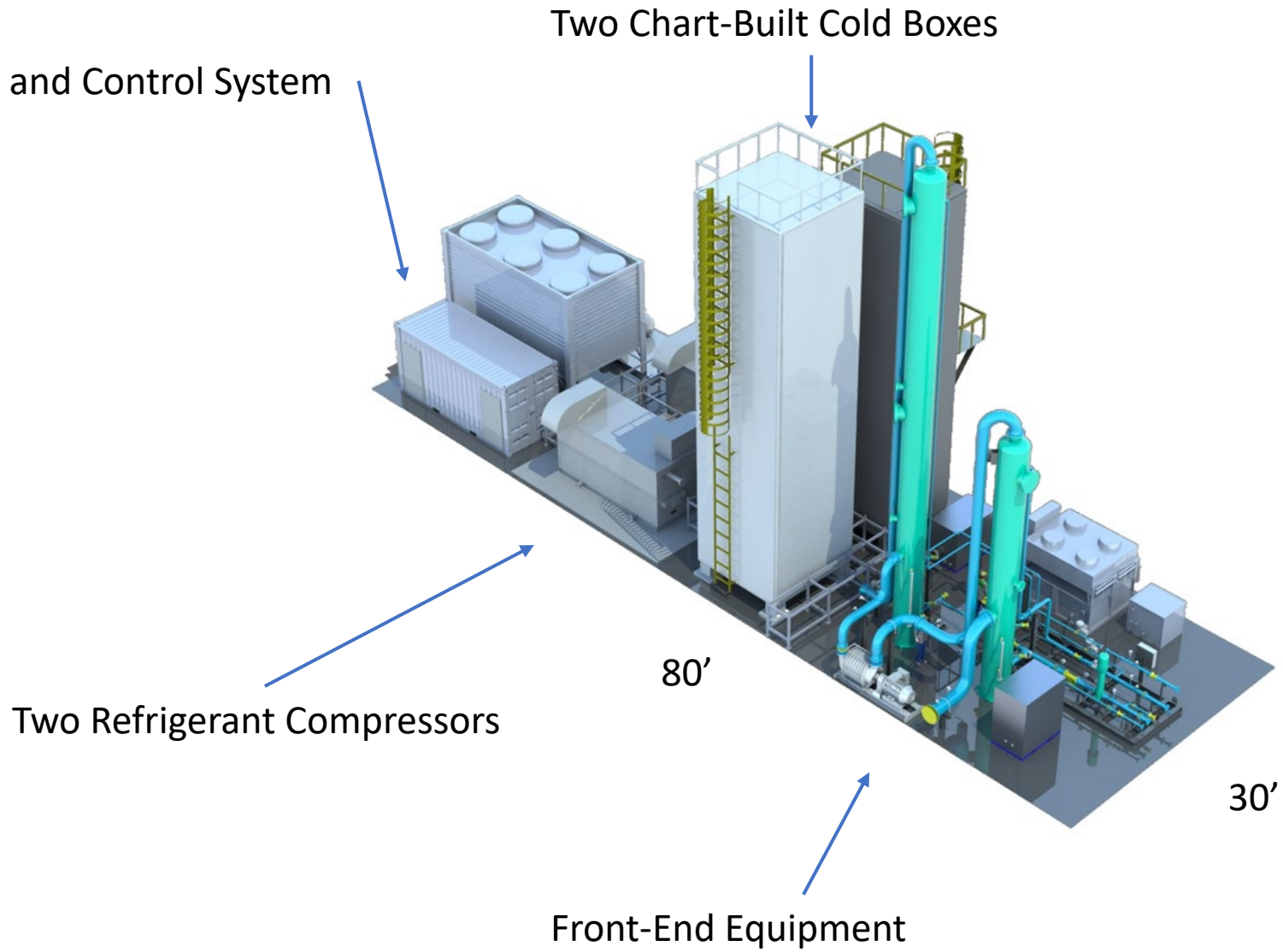
- Howden Compressors (now a part of Chart Industries) will provide oil-injected screw compressors.
- Skid-mounted and easily integrated on site.
- Robust under various operating conditions.





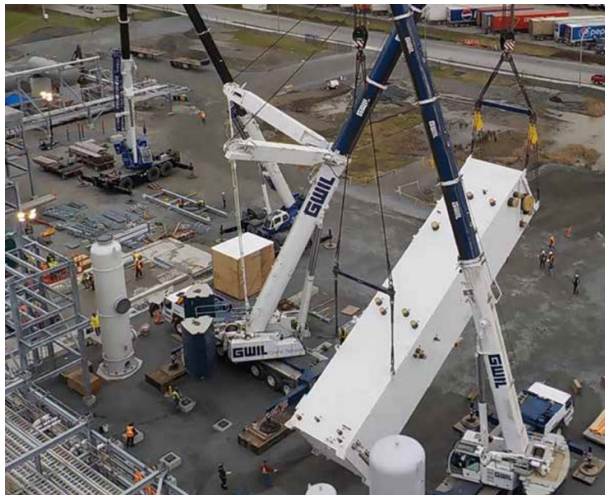
Plot Plan Isometric

- Skid-based design
- Minimal integration with host site (electricity, flue gas, minimal makeup water)
- On-site integration by Sargent & Lundy
- Can be easily relocated to other sites for testing



Scaling – Similar to Existing Processes

Similar to 30 TPD Plant Scale



- Actively looking for follow-on projects
- Commercial feasibility, pre-FEED, and FEED studies ranging from 100 TPD – 10,000 TPD
- Chart has capabilities and experience building cold boxes that are the same scale as full-scale coal-fired power plants

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
  - 30 TPD pilot on modern cement plant in Sugar Creek, Missouri
  - Design based off extensively in-house and field 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.