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Cryogenic carbon capture

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SUSTAINABLE ENERGY SOLUTIONS

Cryogenic Carbon Capture

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Outline

- Cryogenic Carbon Capture™ (CCC) Overview
- Status and Highlights of Recent Tests
- CCC Enabling Low-CO_2 Fossil Systems, Renewables, Energy Storage, and Grid Stability

An Optimistic Message

Cryogenic Carbon Capture™ (CCC) represents a promising pathway for global CO_2 reduction with minimal cost and energy consumption.

CCC addresses the largest issues in both fossil and renewable energy.

CCC reduces fossil CO_2 emissions and reliably stores renewable energy. It is a realistic pathway to achieving a 2 °C global temperature rise.

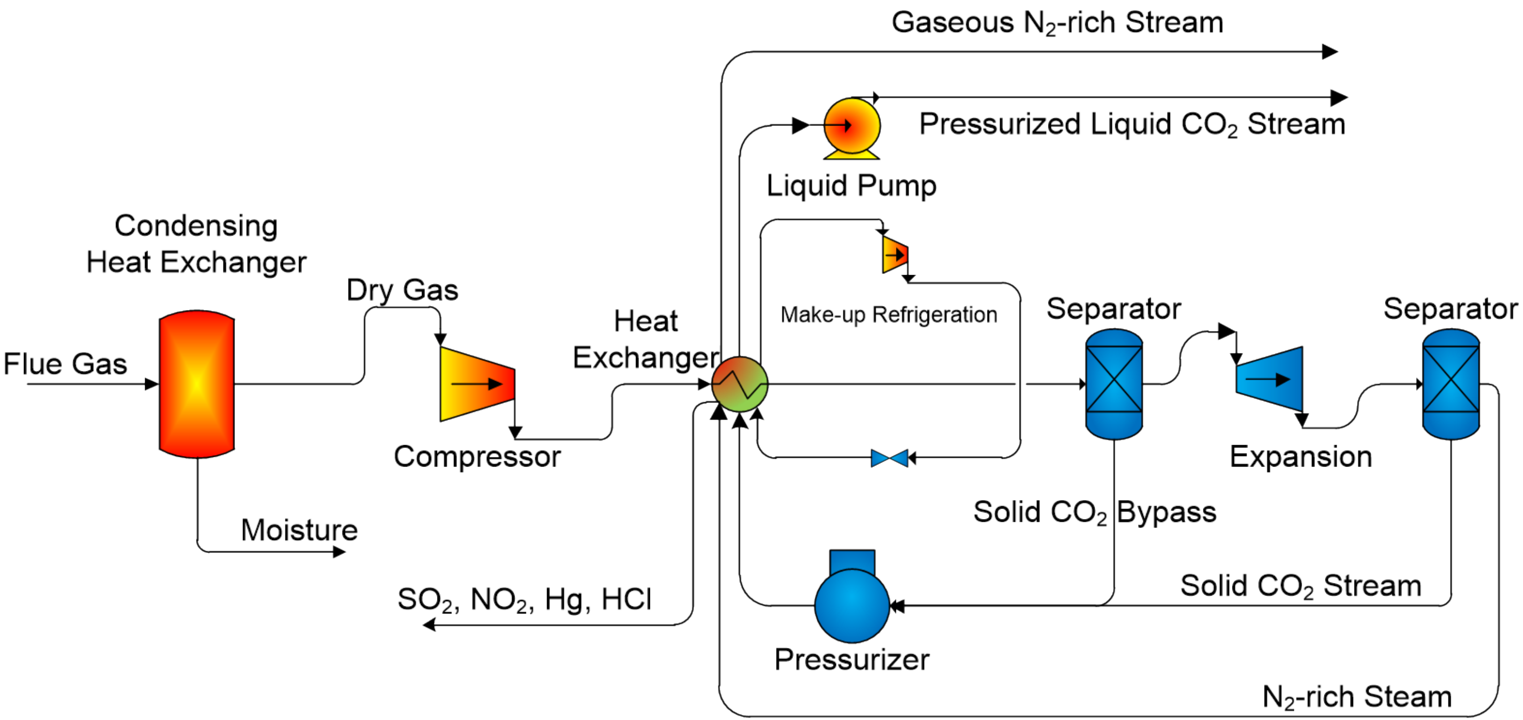
CCC Value Proposition

- Energy efficient CO_2 capture (about ½ amine)
- Cost effective CO_2 capture (about ½ amine)
- Enables adoption of renewables through rapidly responding, large-scale energy storage
- Bolt-on technology (ideal retrofit or greenfield)
- Widely deployable (NG, refineries, coal …)
- Multipollutant process (Hg, SO_x, HC, $PM_{2.5}$, …)
- Consumes no additional water

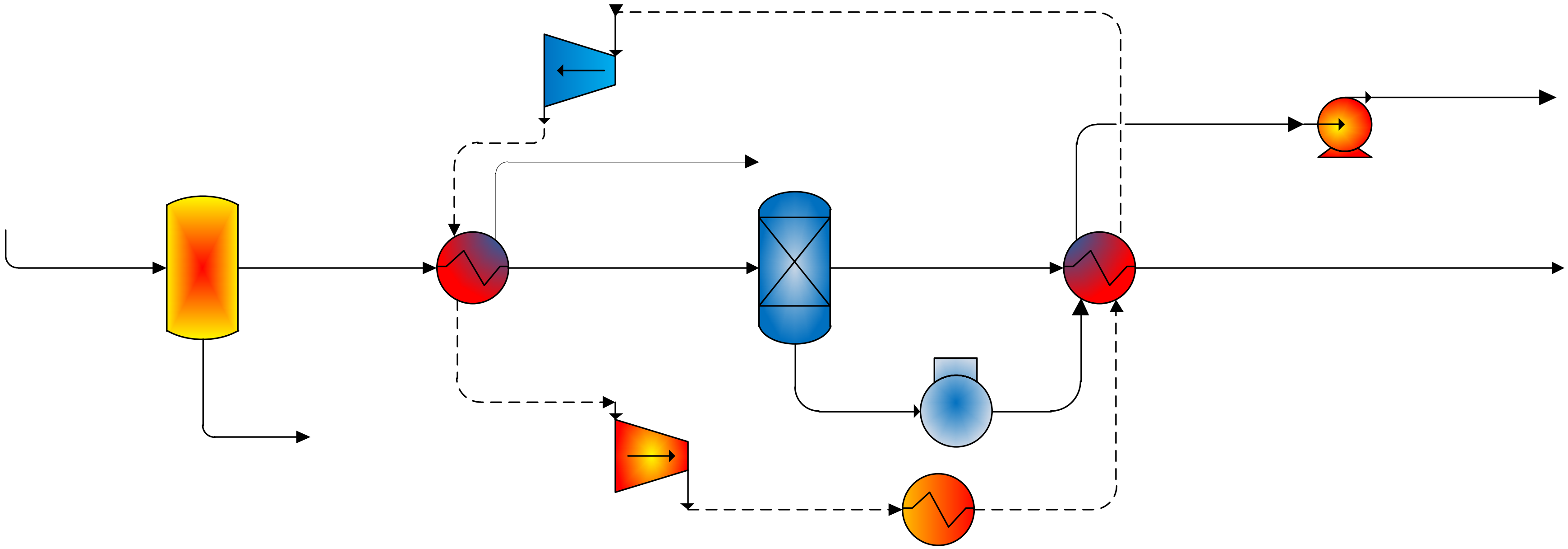
Completed Skid-scale Demonstrations

- Fuels
  - Coals (subbituminous and bituminous)
  - Natural gas
  - Biomass
  - Municipal waste, tires
- Technologies
  - Utility power plants
  - Industrial heat plants
  - Cement plant kilns
  - Large pilot-scale reactor
- Pre-combustion/NG Processing (lab scale)

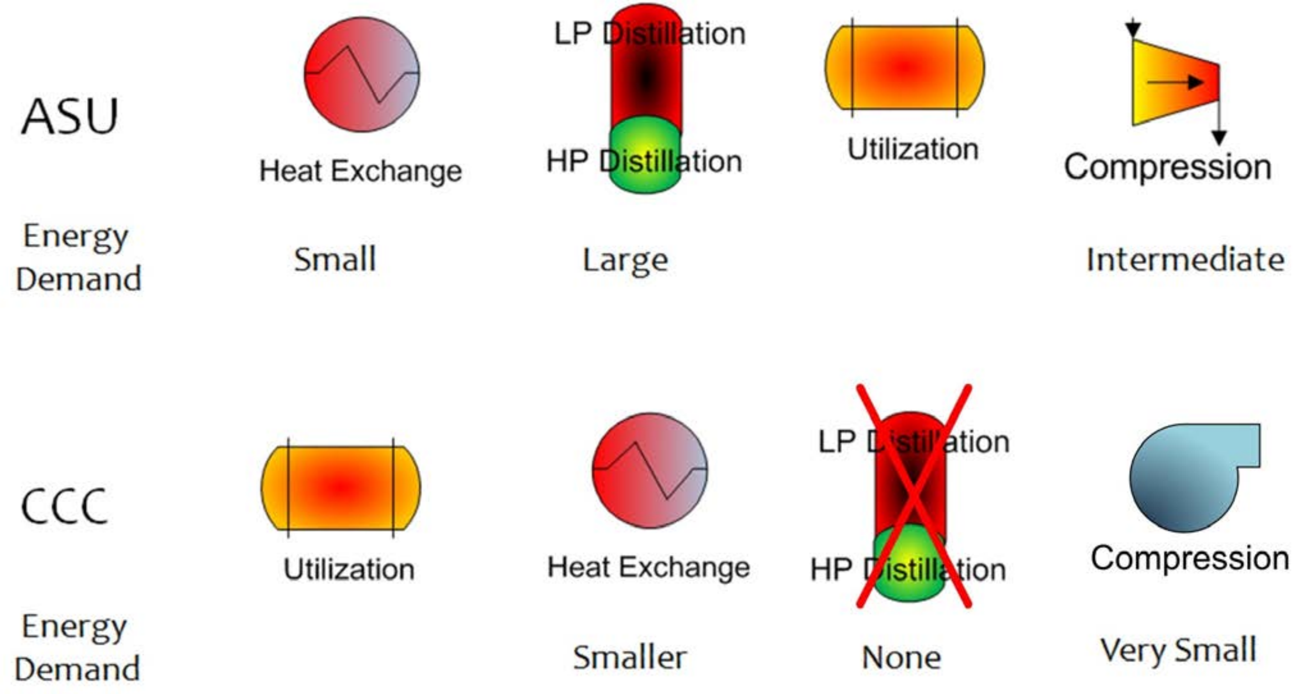
Simplified Flow Diagram (CFG)



Simplified Flow Diagram (ECL)

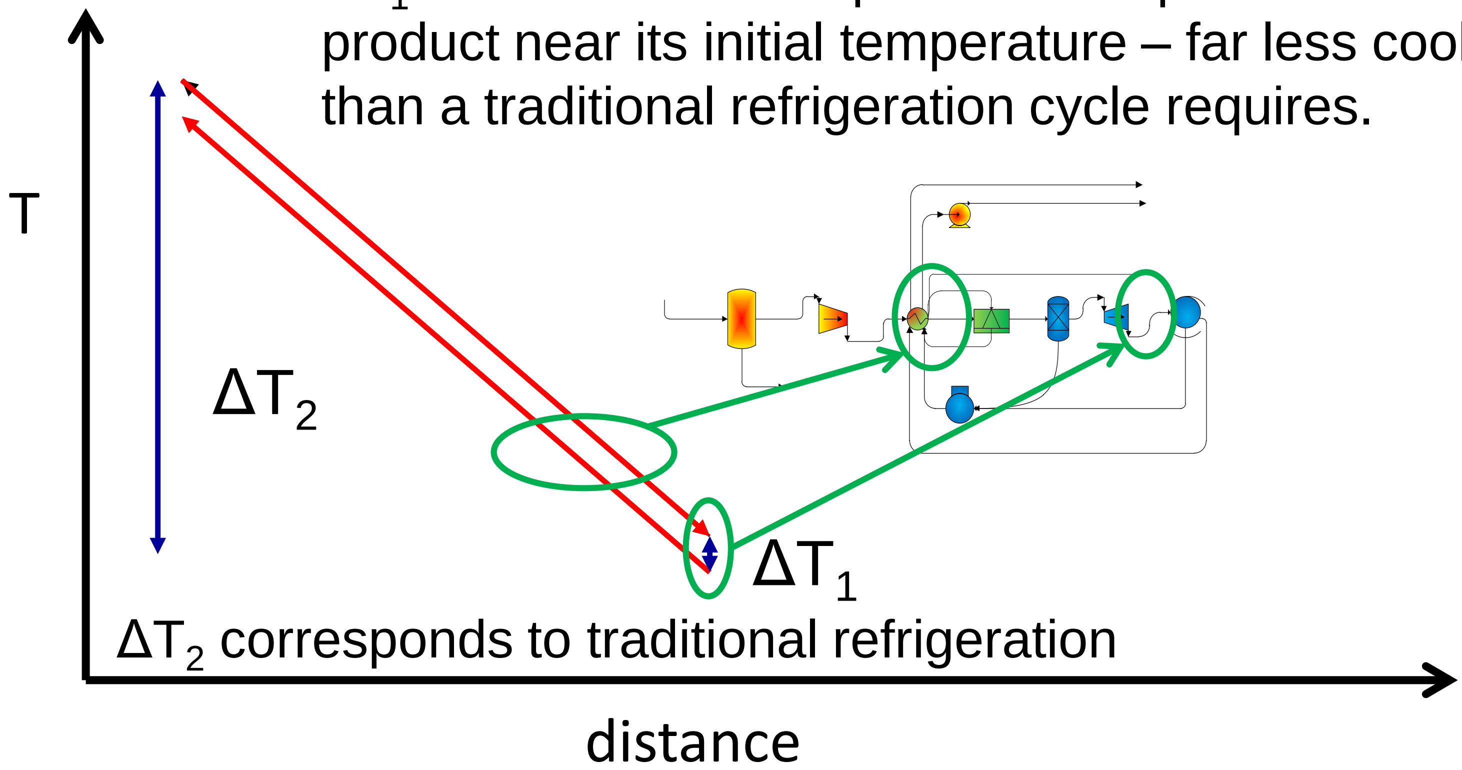


ASU Comparisons

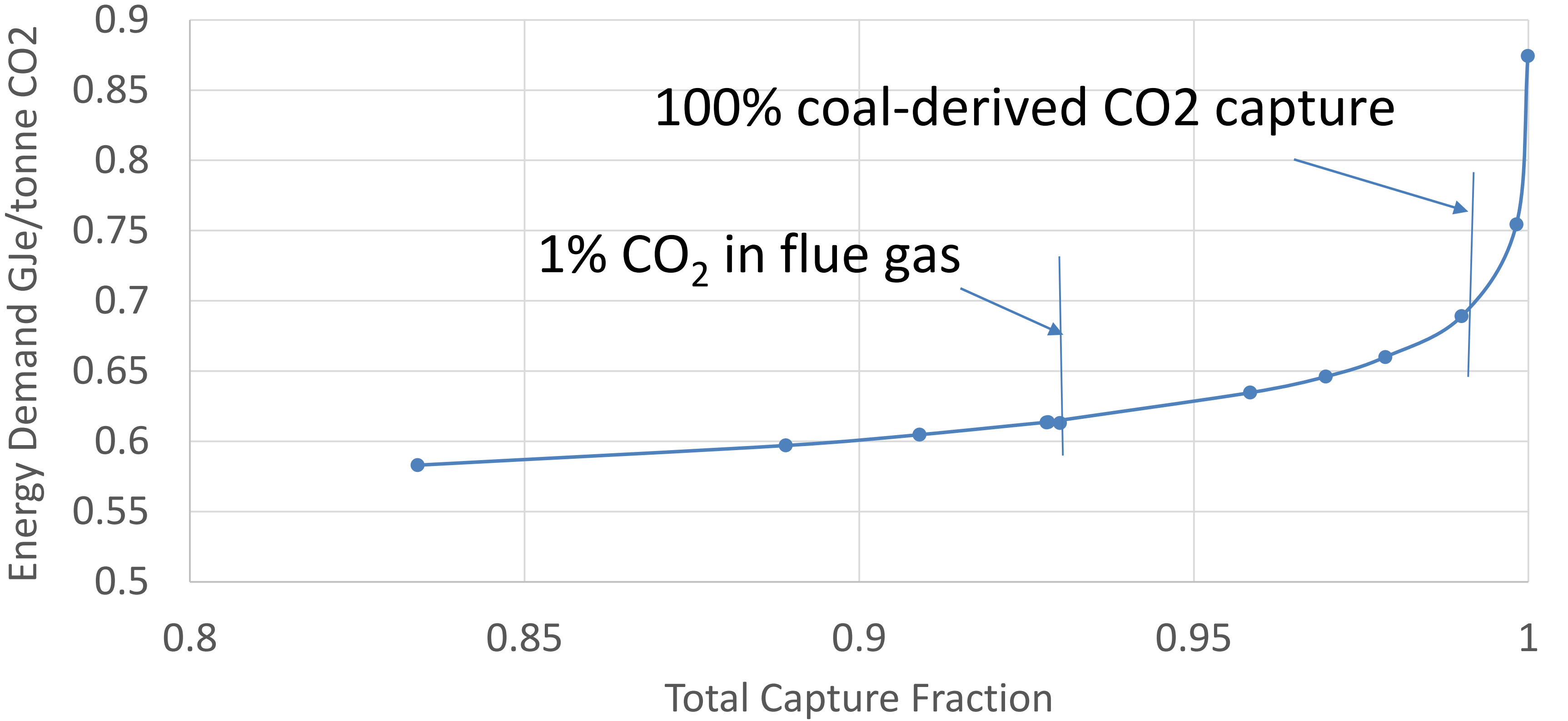


Basic Principles

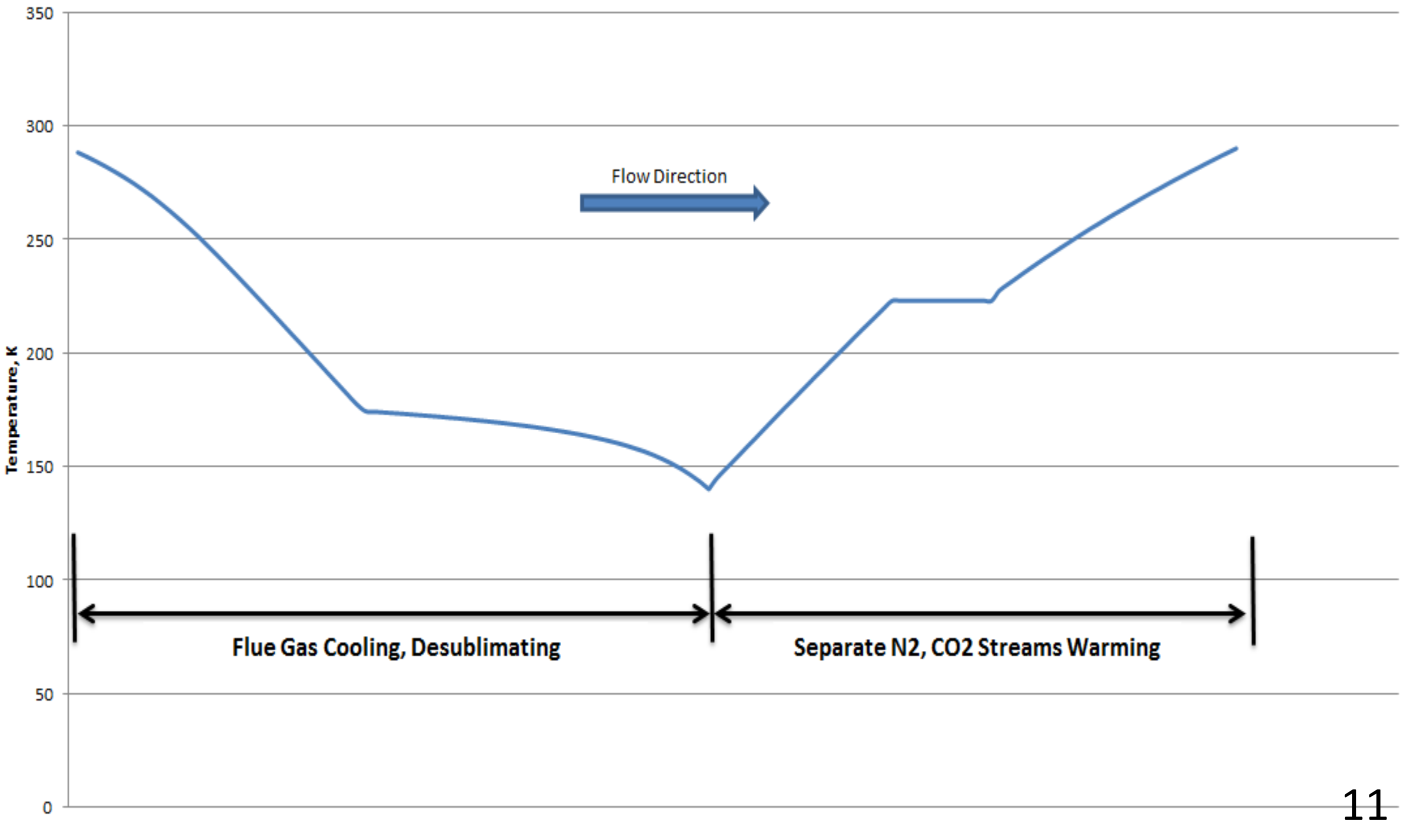
ΔT_1 suffices to drive a process that produces a product near its initial temperature – far less cooling than a traditional refrigeration cycle requires.



Energy Demand at High Capture



Actual Gas Temperature Profiles

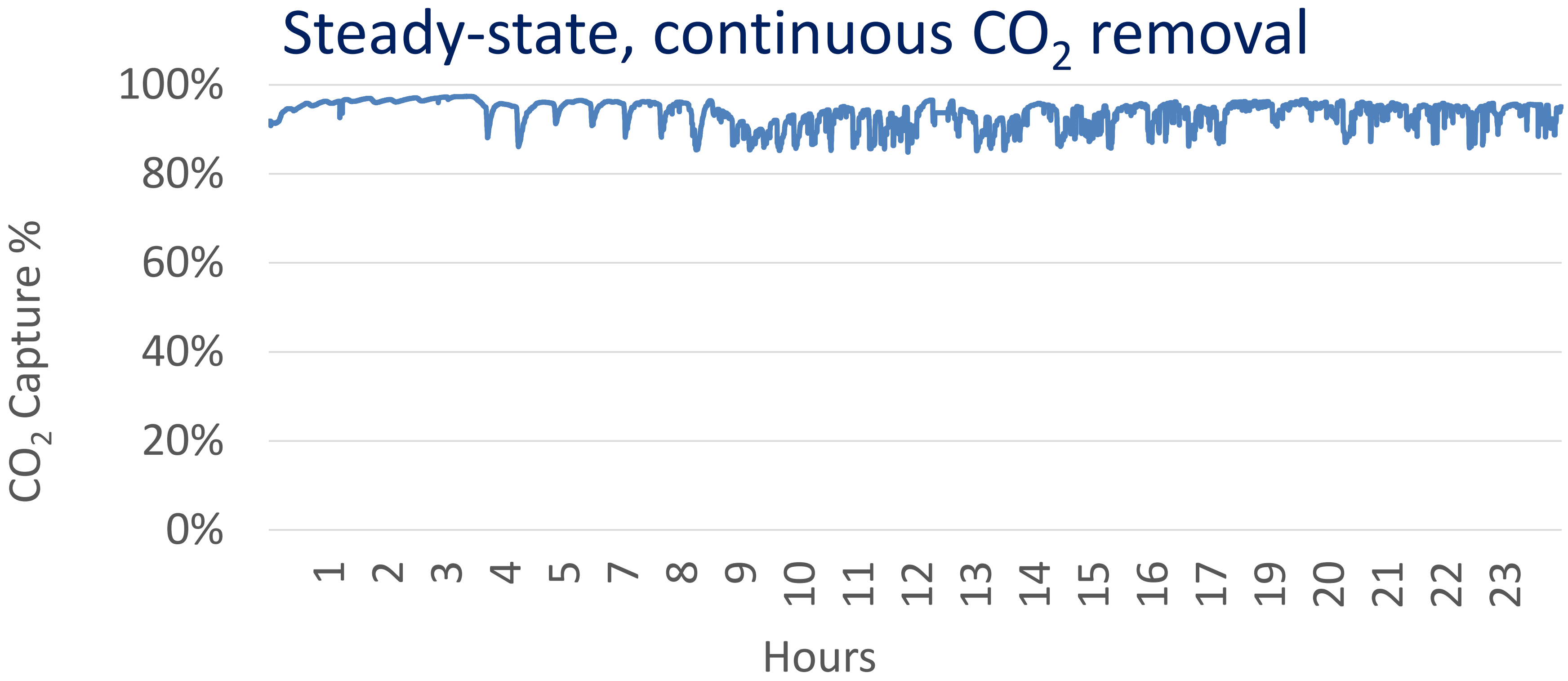


Utility Power Plant Skid Test

Wyoming Skid Photos

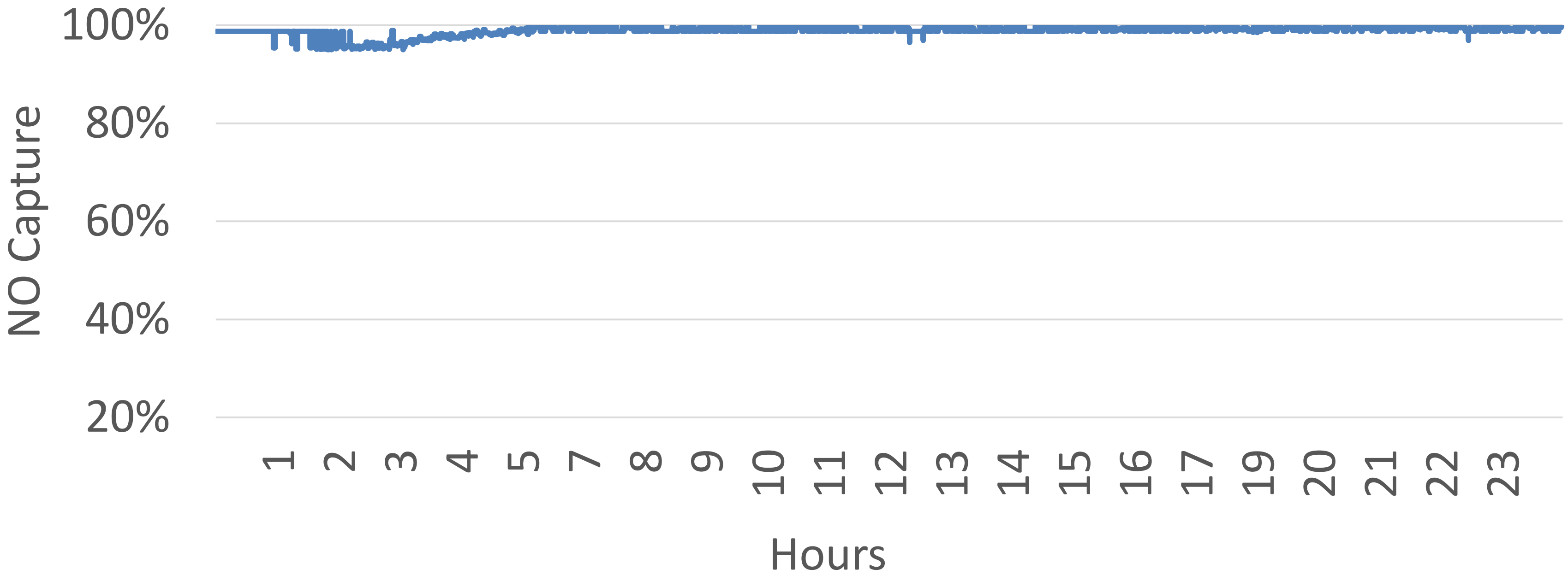
1 tonne/day CO_2 capture

Utility Power plant

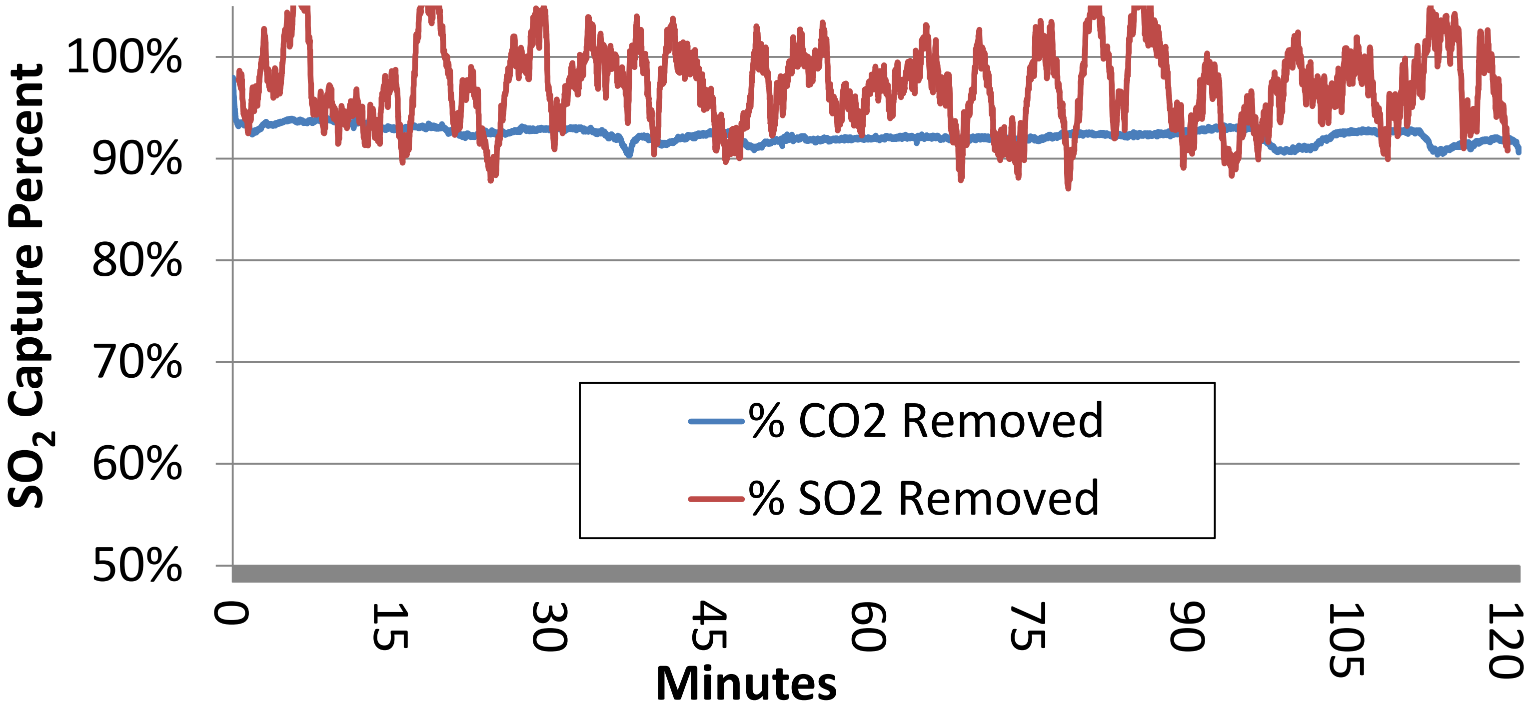


Pollutant Removal

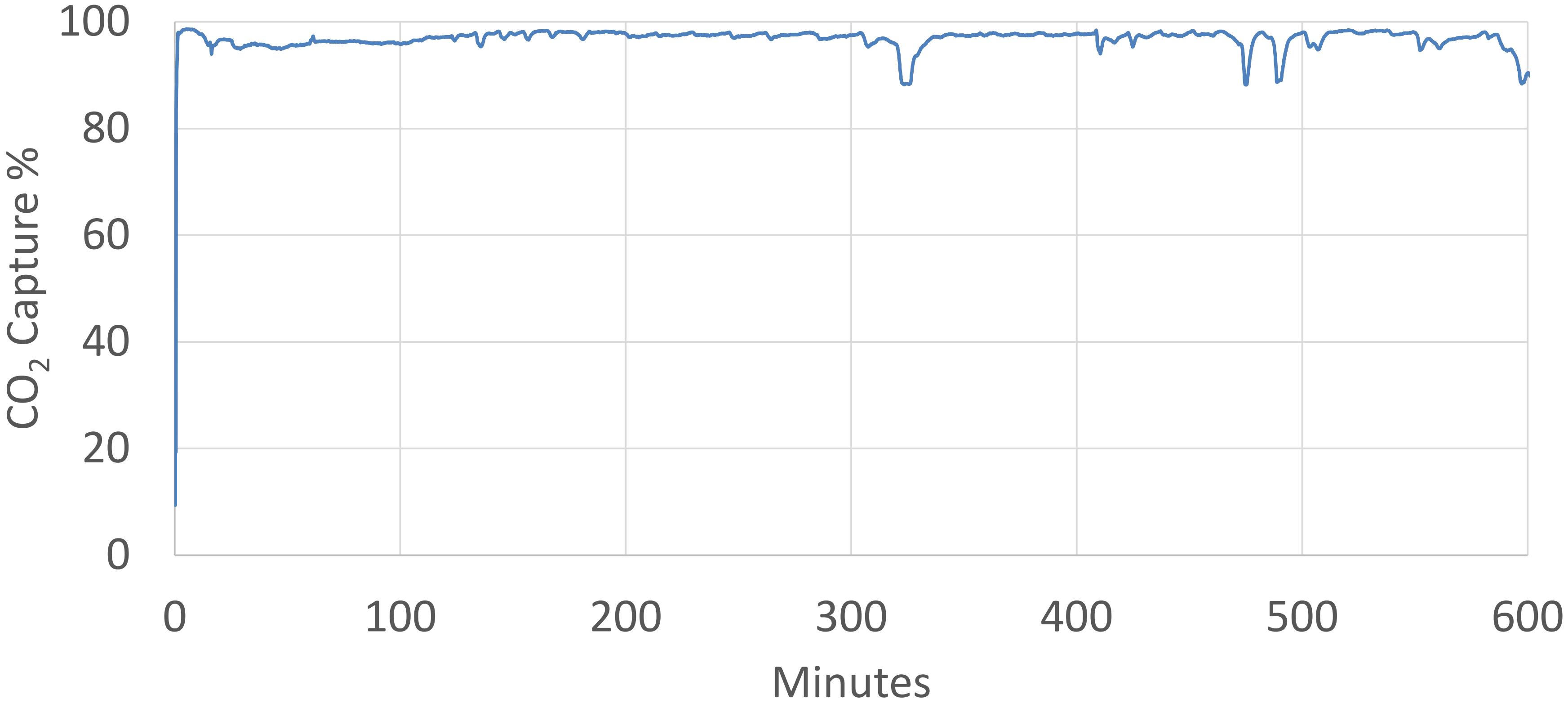
- NO - Captured at very high rates, likely reacted to NO_2



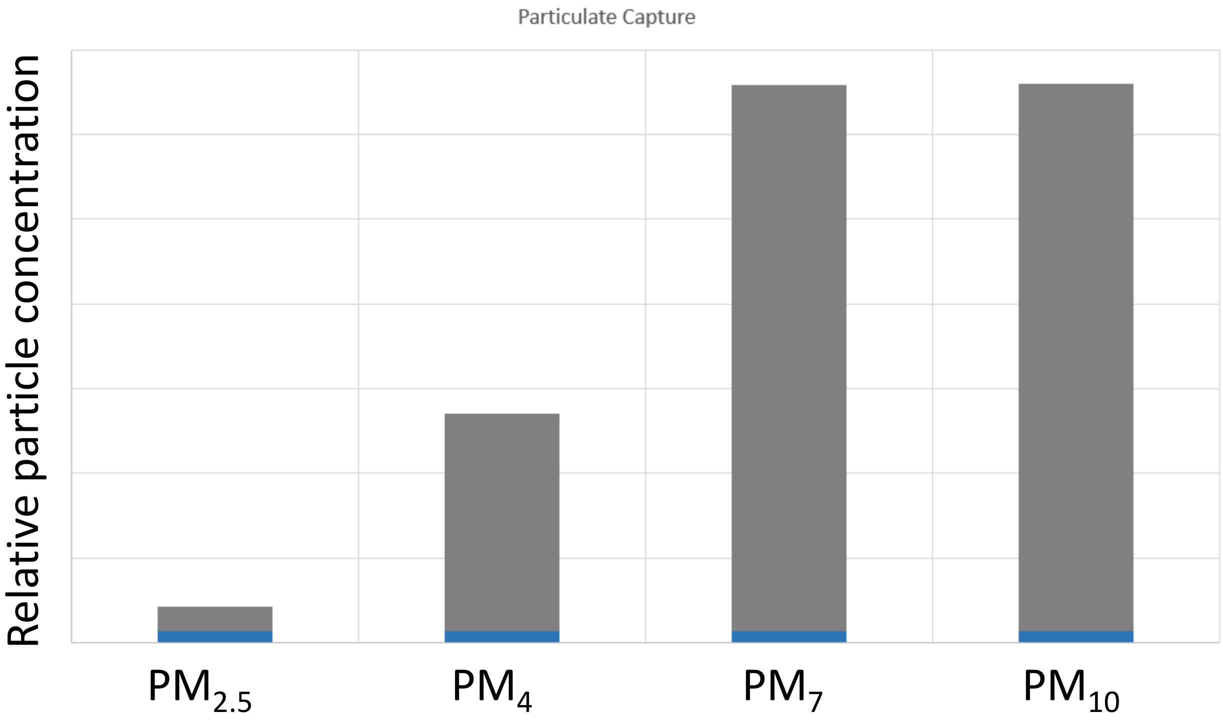
Pollutant Capture Data



Cement Kiln



Particulate Capture

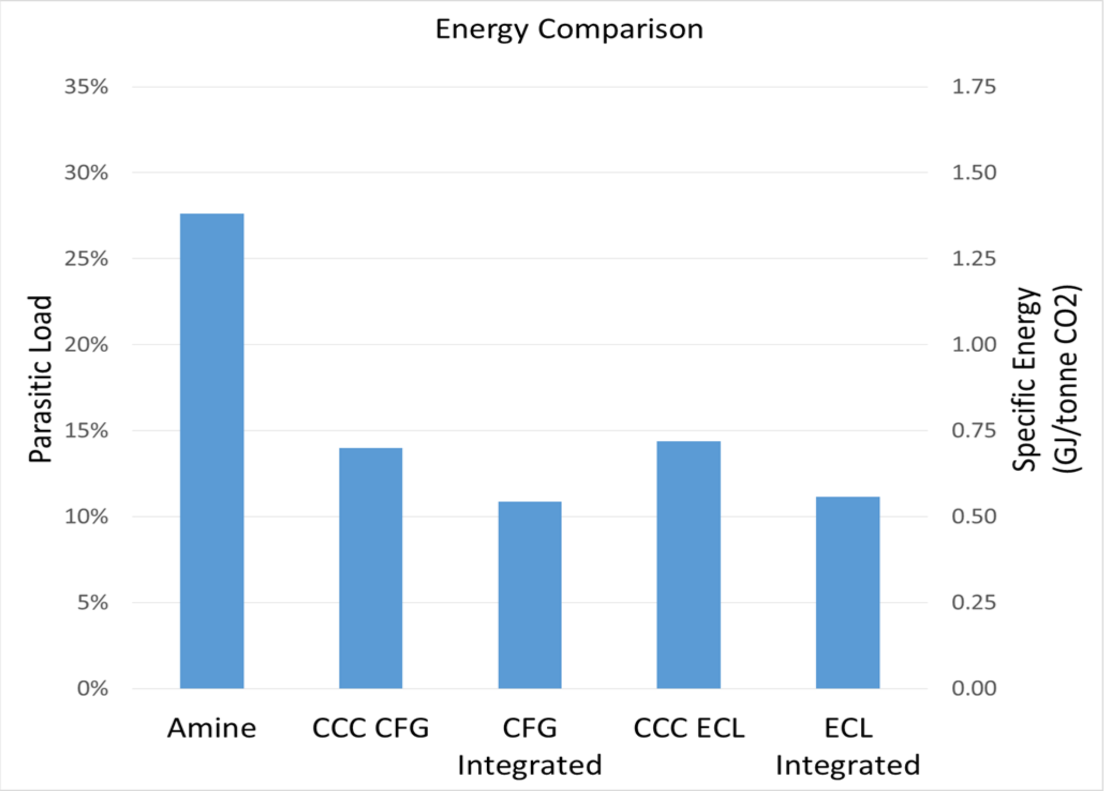


Mercury Testing

- Field test at utility power plant
- Inlet 735 ppt, or 5.77 μg/m^3 (after wet scrubber)
- Outlet below detection limit, which is 1 ppt, or 0.01 μg/m^3 for 99.9%+ capture.
- Actual concentrations predicted to be far below atmospheric levels (1-2 ng/m^3).

Energy Penalty

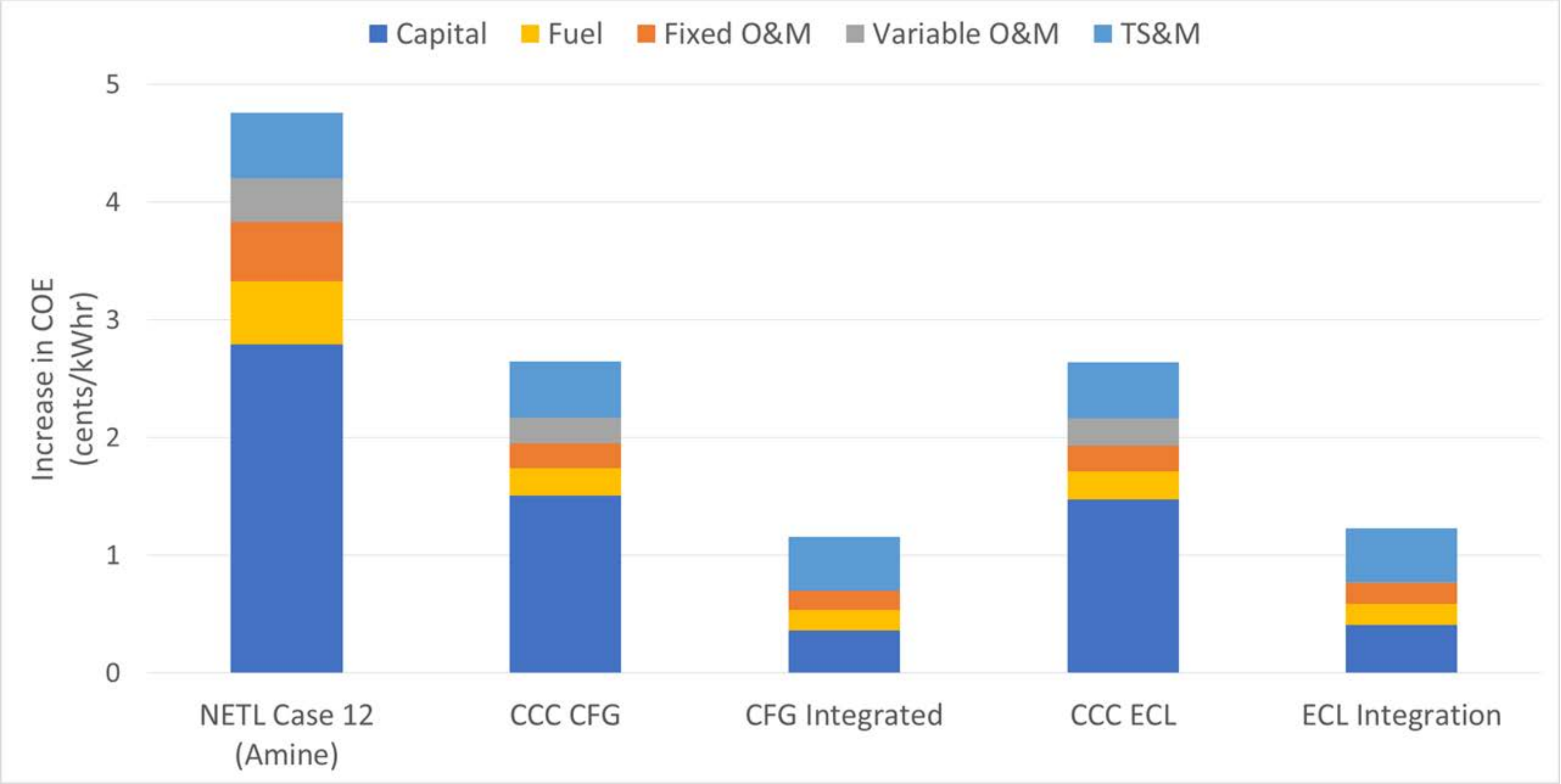
CCC nearly eliminates emissions while consuming half the energy of alternatives



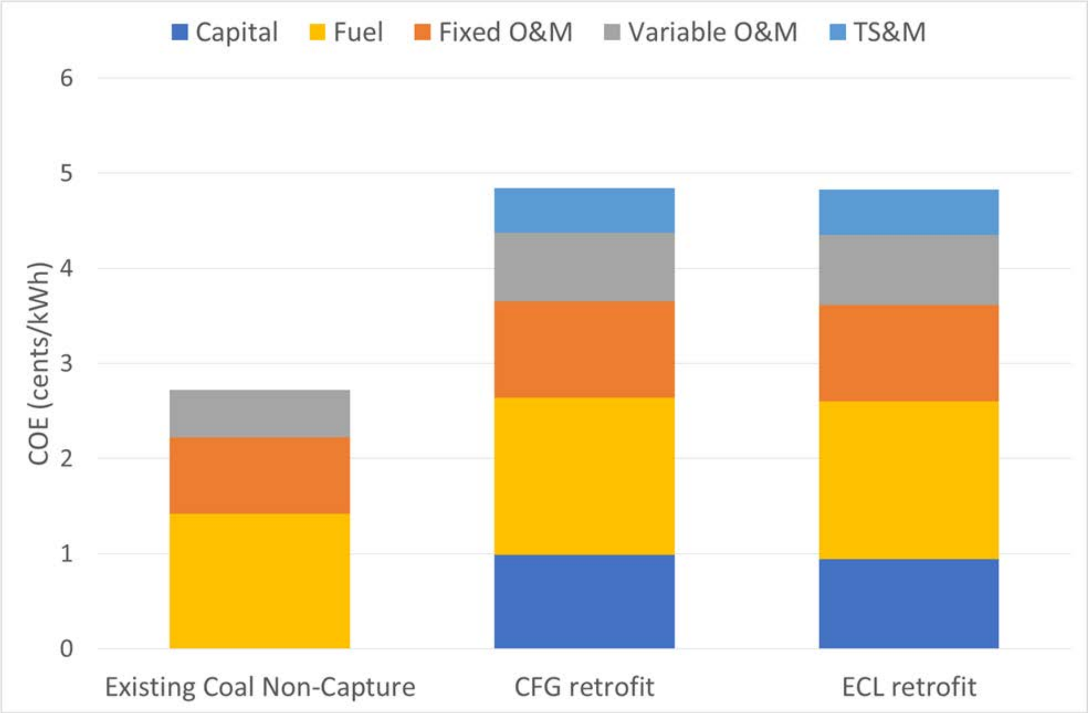
Energy Costs

	No Capture	Amine	CCC	Integrated CCC
Net Power (GJ/tonne CO_2)	0	1.38	0.714	0.555
Net HHV Heat Rate (BTU/kWh)	8687	12002	10144	9776
Parasitic Load	0.00%	27.6%	14.4%	11.1%

Cost of Electricity



Retrofit Costs



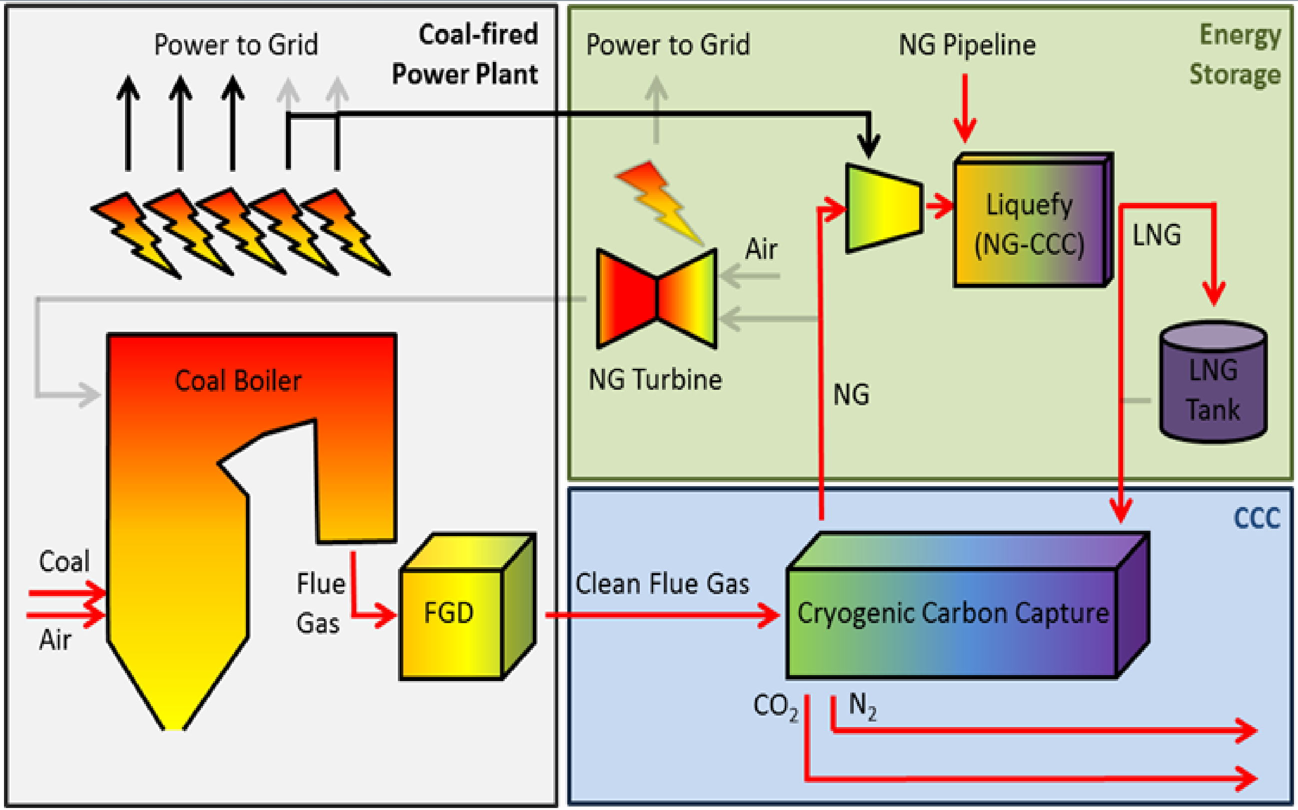
Energy Storage

- Grid-scale energy storage
  - Intermittent renewable sources
  - Load leveling
  - High efficiency (95%+)
  - Low cost

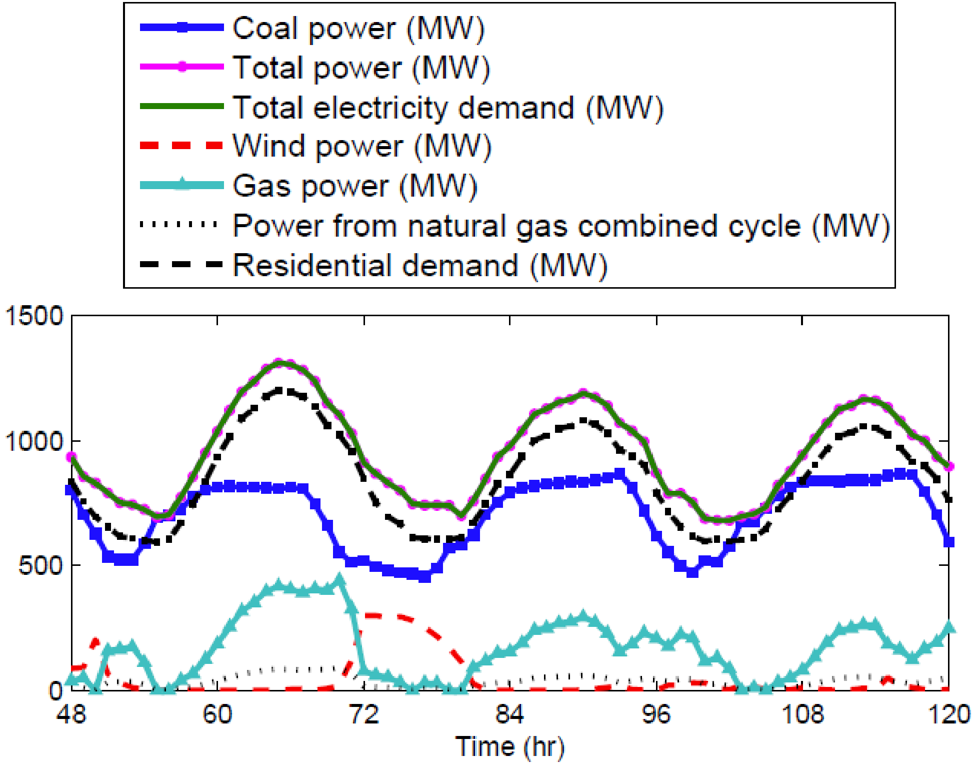
CCC ECL Energy Consumption by Source

Energy Source	Percent of Total
Flue Gas Blower	11.6%
Refrigerant Compression	83.0%
Separations Compression	2.1%
Condensed-phase Pumping	3.3%
Total	100%

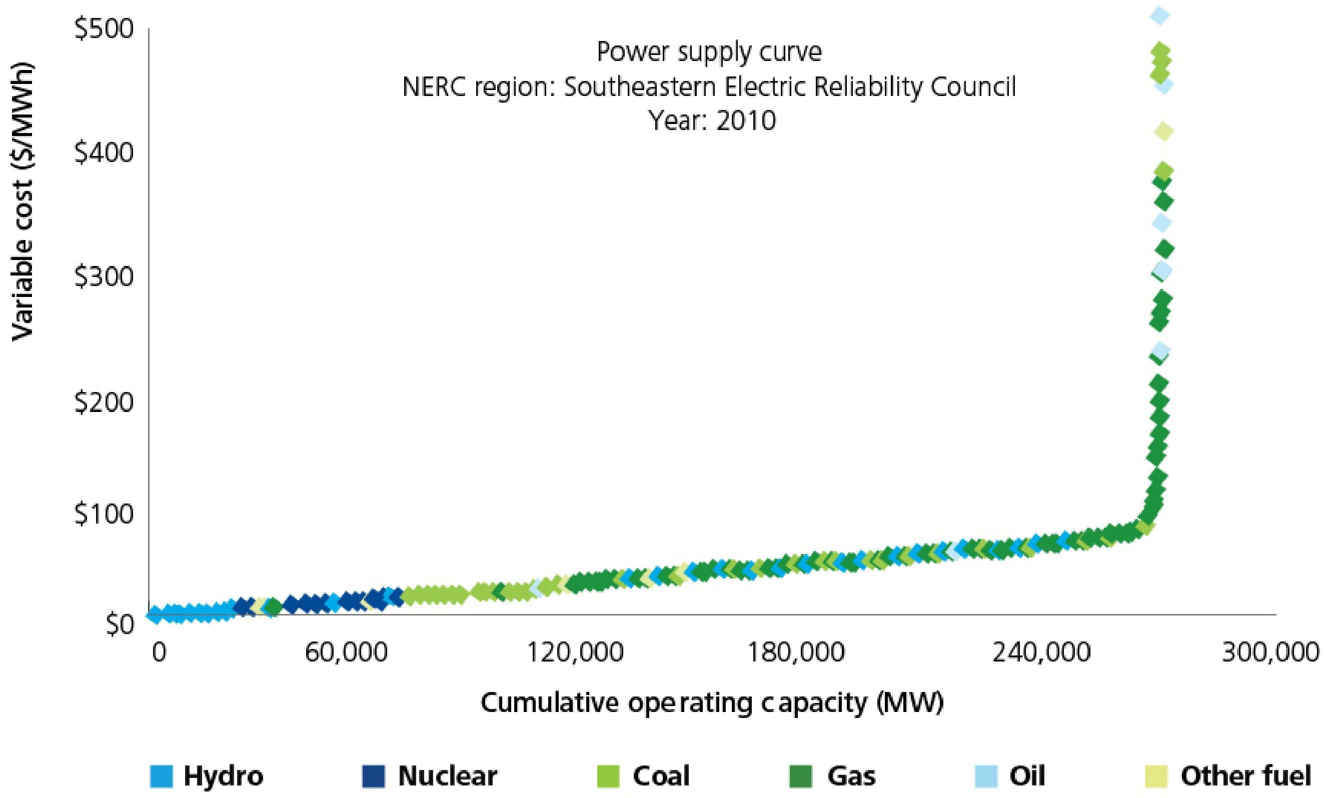
Energy Storing



Diverse Power Sources



Actual Supply Curve

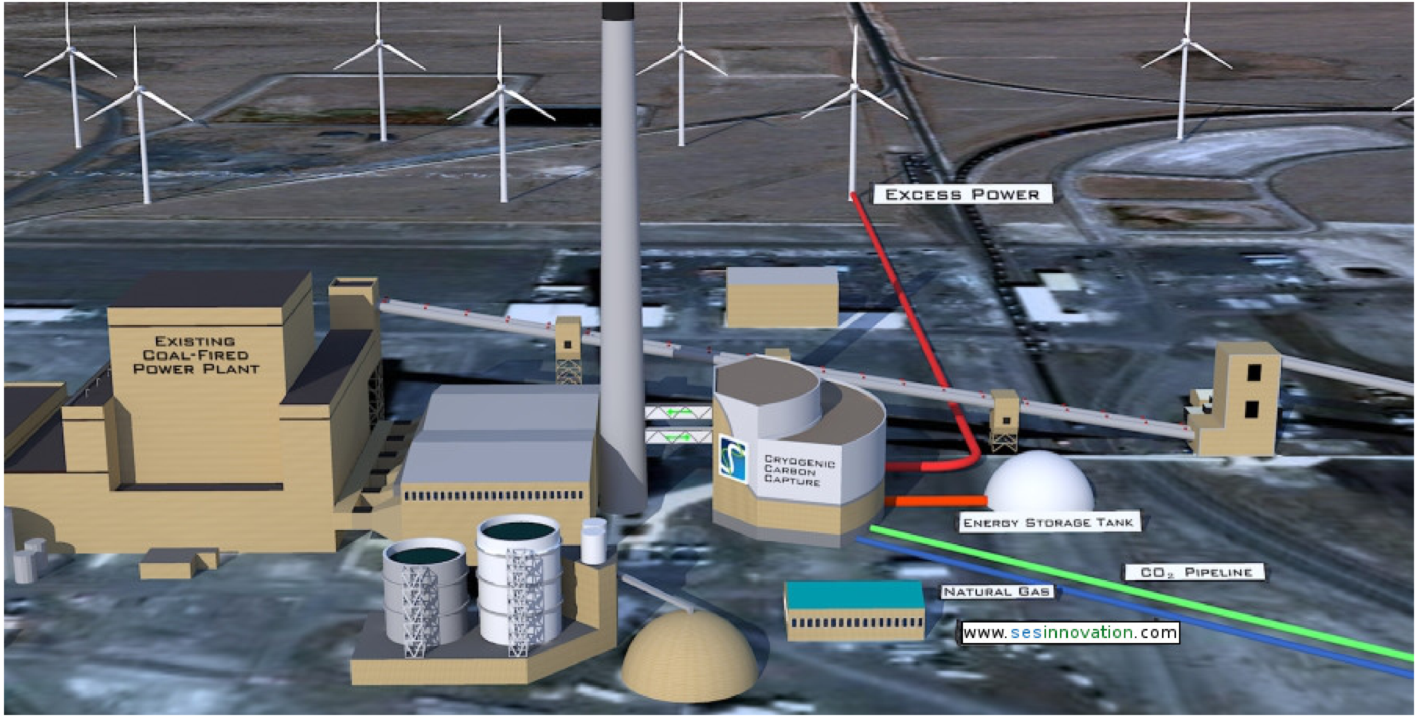


Source: Deloitte Center for Energy Solutions & Deloitte MarketPoint, Made in America: The economic impact of LNG exports from the United States, Jan. 25, 2013

Results

- An 800 MW_e power plant with CCC stabilized +/- 400 MW_e grid surges associated with periodic demand cycles and intermittent renewable availability with no need for spinning reserves or other supplementary power.
- Power demand cycles, wind availability, and general costs taken from actual grid data (southern California).
- 250 MW_e surge in wind power that occurs in the evening, as power demand generally is in rapid decrease, was effective absorbed by CCC and delivered the next day during peak power.
- Similar load following with coal being constant is possible, but requires larger storage tank and NG replacement rate.

Integrated System



Pilot Facility

100 tonne/day, 5 MW_e pilot system

Acknowledgements

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- Dave Frankman and Kyler Stitt are engineering managers. Substantial contributions from all SES team members
- Power plants, cement plants, and other host facilities
- Details at www.sesinnovation.com