

Future Energy Systems Center

Cost-Performance Analysis and Benchmarking of CO₂ Capture Systems for Hard-to-Abate Industries

Project Updates

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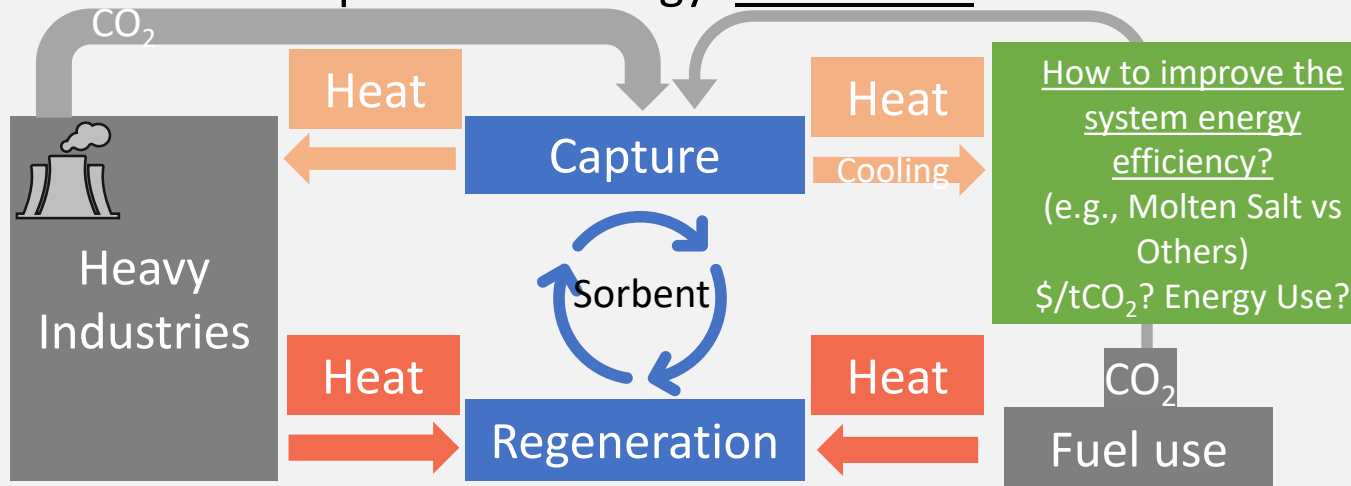
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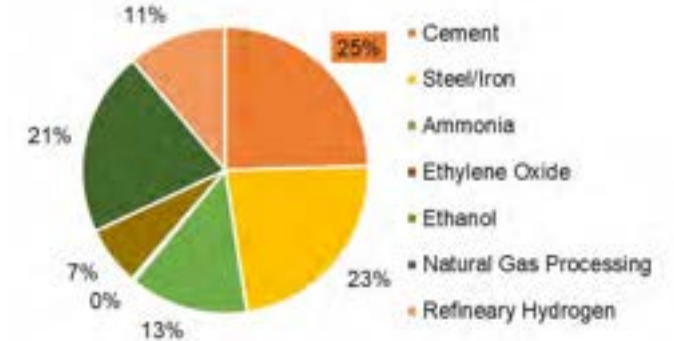
Project motivation and objectives

Motivation

- ~25% of CO₂ emissions are from hard-to-abate industries: cement, iron/steel, ethylene, hydrogen, and others, with variable emissions characteristics: concentration (CO₂ %), temperature (~300 - ~1500 °C), flow rate, etc.
- The most industrially mature processes based on temperature-swing separation with amines are optimized for ~40-120 °C. Cost and system efficiency are major challenges.
- Molten salts capture technology: 600-650 °C



U.S. Industrial CO₂ emissions by Industry
Total: 268.95 MT-CO₂/yr

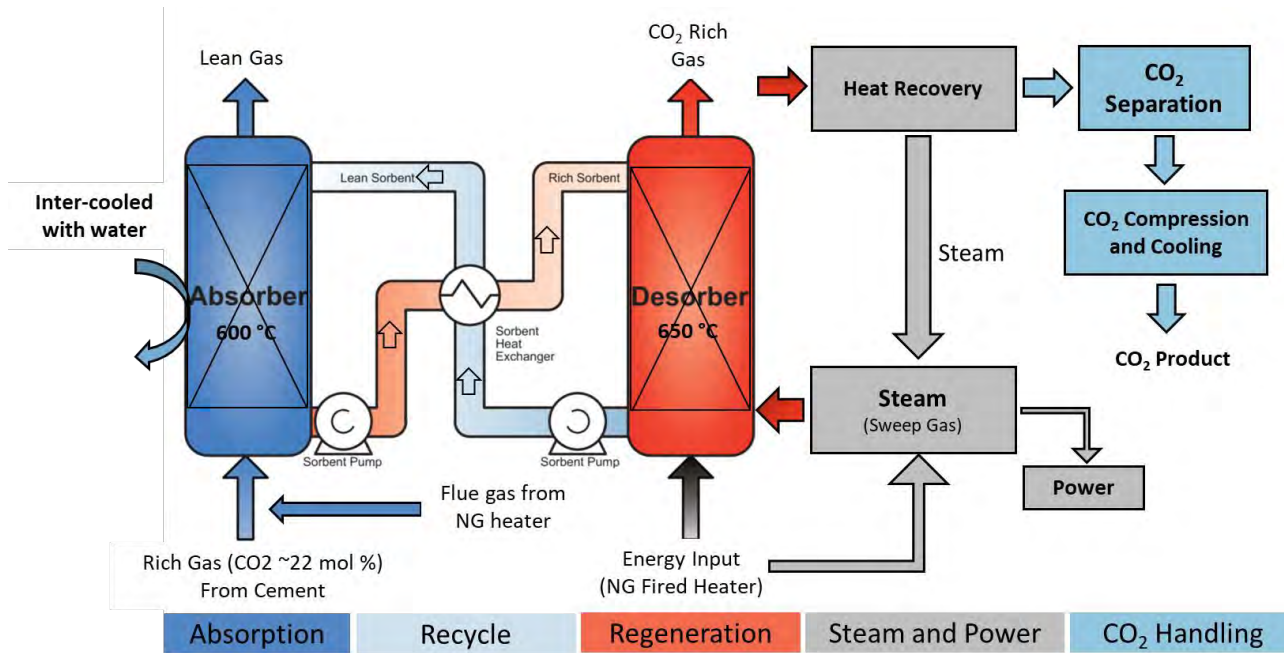


Objectives

1. What are the emissions, efficiency, and cost impacts of temperature-matched capture?
2. Develop a universal framework to cross-compare across different emissions types and capture technologies.
3. Use model outputs to assess greatest potential for impact (efficiency/emissions savings x scale of industry) that can guide future technology development.

Capture CO₂ from Cement Plant

- Case study: Cement plants decarbonization using Molten Salt carbon capture



- “Temperature-Swing” carbon capture
- Desorption needs high-quality heat by NG fired heater
- Steam is used as a sweep gas for desorption
- High-quality heat can be recovered to generate steam and power (byproduct)

Aspen HYSYS Model

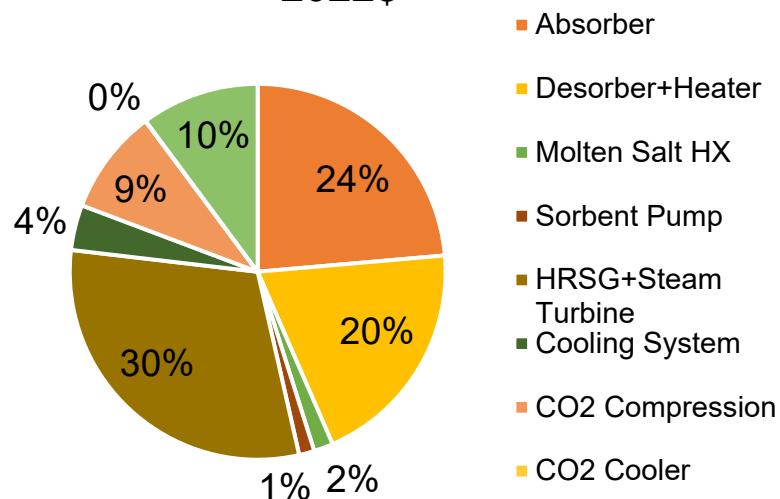
Base case: Capturing CO₂ from Cement plant flue gas

Process Evaluation		Note
CO ₂ Emissions, M tonnes/yr	1.61	75% from Cement, 25% NG fired heater
CO ₂ Capture Rate, %	90	/
NG HHV Thermal Input, MW _t	224	1.35 kWh _t /kgCO ₂
Total Gross Power, MW _e	35	0.21 kWh _e /kgCO ₂
Net Power, MW _e	19	0.11 kWh _e /kgCO ₂
Total Auxiliary Power, MW _e	16	0.098 kWh _e /kgCO ₂
Pumps, MW _e	4	0.025 kWh _e /kgCO ₂
Compression, MW _e	12	0.073 kWh _e /kgCO ₂

The simulation results were based on molten salt data from Mantle Carbon Co.

Techno-Economic Analysis

TPC (\$758 MM)
2022\$



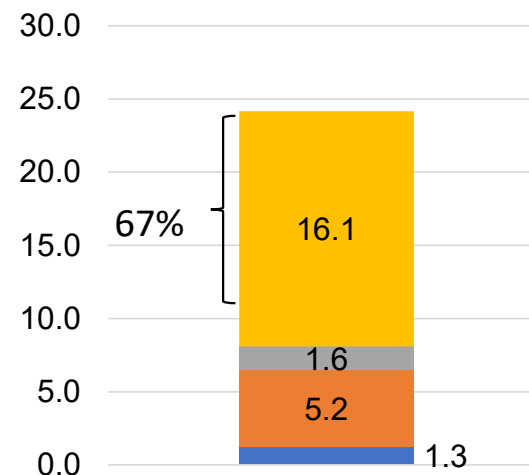
Major Drivers

- Capture System (Absorber+Desorber w/ Heater): 24+20 = 44%
- HRSG+Steam Turbine: 30%

Key Takeaways

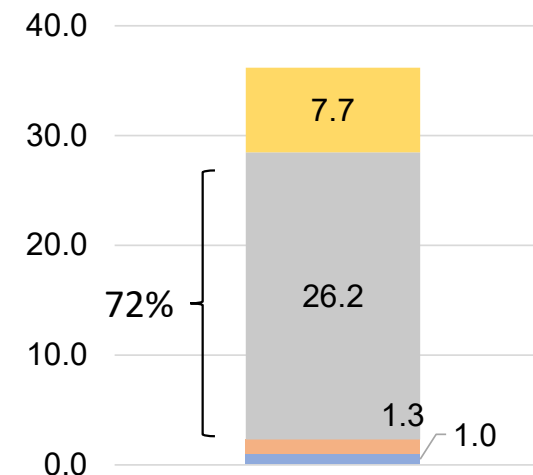
- TPC for molten salt capture system: \$758 MM (\$470/tCO₂/year)
- The system is **capital-intensive**, approximately equivalent to 1/3 of TPC for a 770-MW NGCC power plant (\$2,300 MM).
- The use of HRSG + Steam Turbine to improve overall energy efficiency

Fixed Operating Costs
(\$24 MM)



- Property Taxes and Insurance
- Admin and Support Labor
- Maintenance Labor
- Operating Labor

Variable Operating Costs
(\$36 MM)



- Maintenance Material
- NG Use
- Water
- Sorbent Replacement

- Fixed OPEX: \$24 MM/year
Main driver: Property Taxes and Insurance (2% of TPC), followed by Maintenance Labor (0.65% of TPC)
- Variable OPEX: ~\$36 MM/year
Main driver: NG Consumption, followed by Regular Maintenance Material (0.96% of TPC) and Sorbent Replacement Cost

TEA Results

COC: Cost of CO₂ Capture

COA: Cost of CO₂ avoided

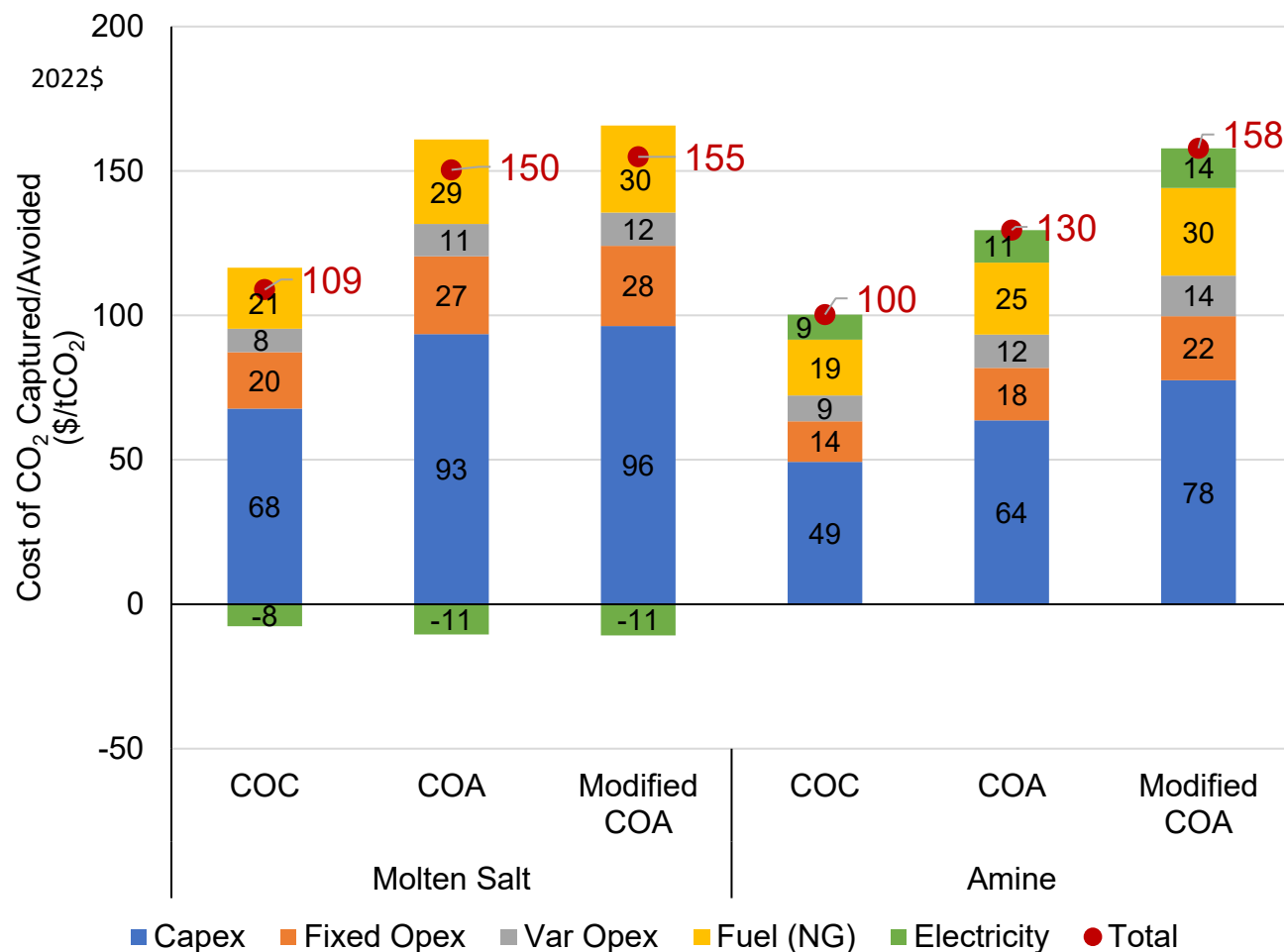
Modified COA: well-to-gate system boundary

Molten Salt capture technology appears to be comparable with the Amine capture technology under the same TEA assumptions

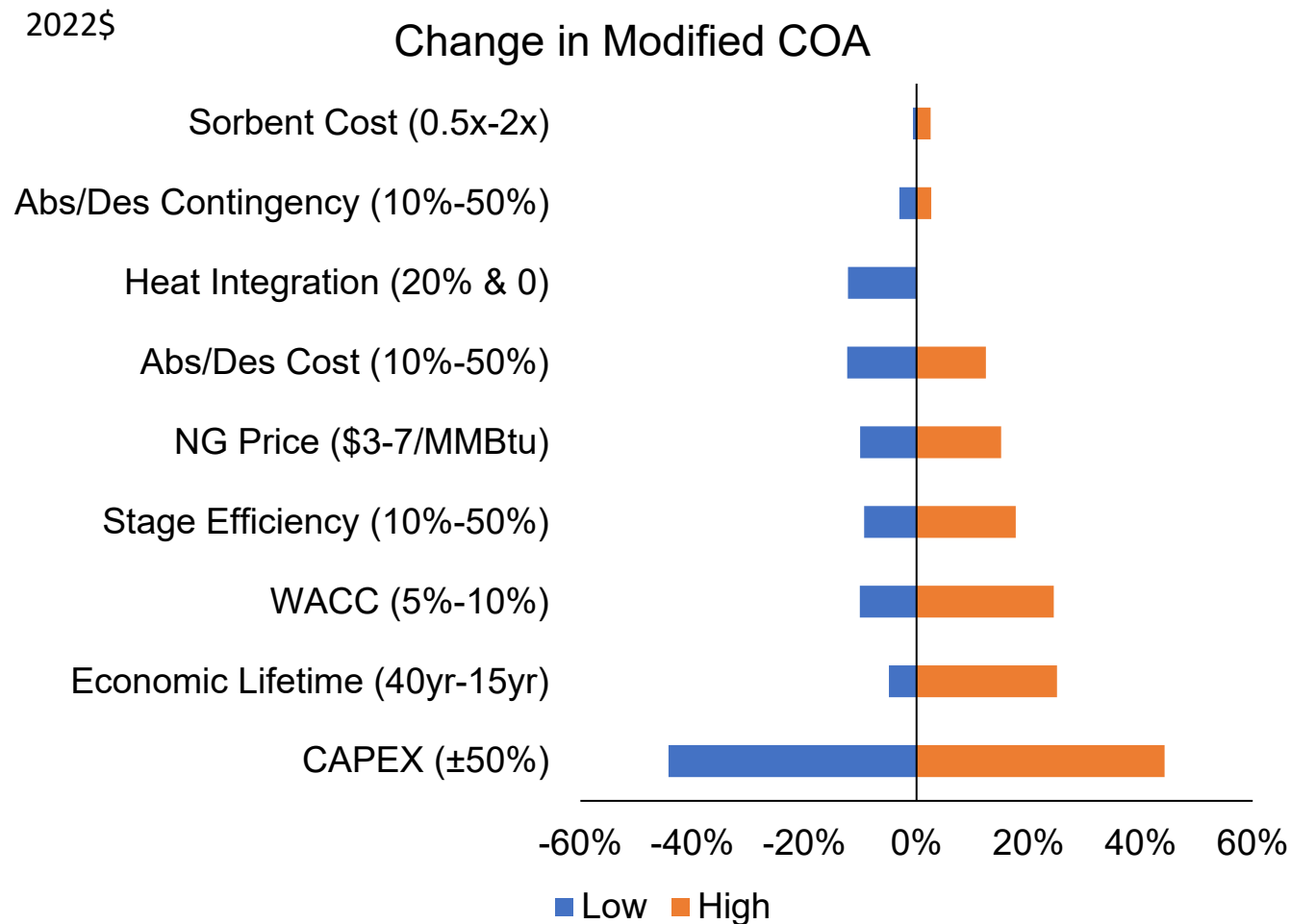
$$\text{COC} \left(\frac{\$}{\text{tonne CO}_2} \right) = \frac{\text{CAPEX} + \text{Fixed OPEX} + \text{Var OPEX} + \text{Fuel} + \text{Power}}{\text{tonnes CO}_2 \text{ captured per year}} \quad (\text{onsite})$$

$$\text{COA} \left(\frac{\$}{\text{tonne CO}_2} \right) = \frac{\text{CAPEX} + \text{Fixed OPEX} + \text{Var OPEX} + \text{Fuel} + \text{Power}}{\text{tonnes CO}_2 \text{ captured per year} - \text{tonnes CO}_2 \text{ emitted by NG Use}} \quad (\text{onsite})$$

$$\text{Modified COA} \left(\frac{\$}{\text{tonne CO}_2^e} \right) = \frac{\text{CAPEX} + \text{Fixed OPEX} + \text{Var OPEX} + \text{Fuel} + \text{Power}}{\text{tonnes CO}_2 \text{ captured per year} - \text{tonnes CO}_2 \text{ emitted by NG Use} - (\text{Tonnes CO}_2^e \text{ by NG} + \text{Tonnes CO}_2^e \text{ by electricity})} \quad (\text{well-to-gate system boundary})$$



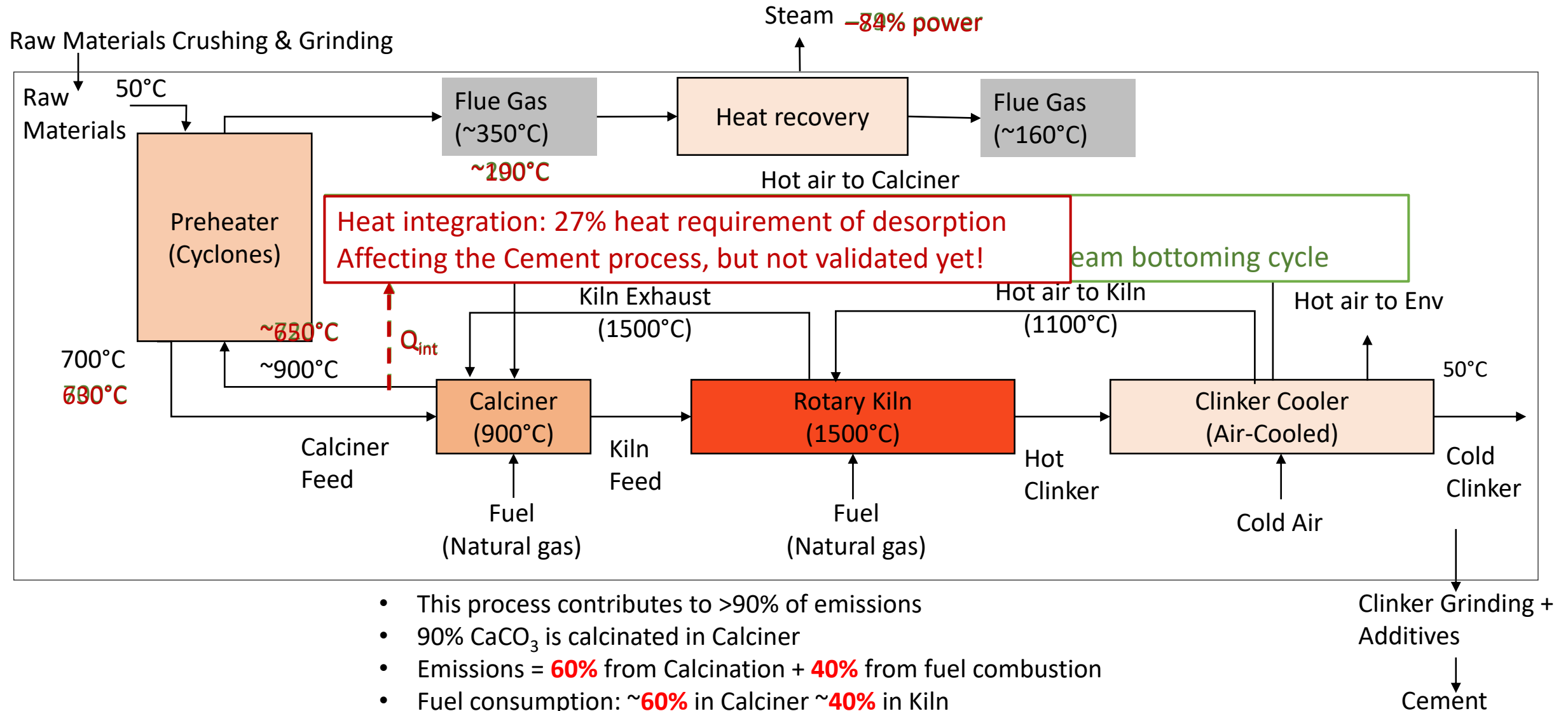
Sensitivity Analysis



Key Takeaways

- Base modified COA: \$155/tCO₂e
- The uncertainty on CAPEX leads to a large change in COA varying from -44% to +44%
- Followed by financial parameters like economic lifetime and WACC
- Absorber column stage efficiency uncertainty could cause large variation in COA
- Integrating excess heat from cement plant can lead to some savings.

Heat Integration with Cement Plant



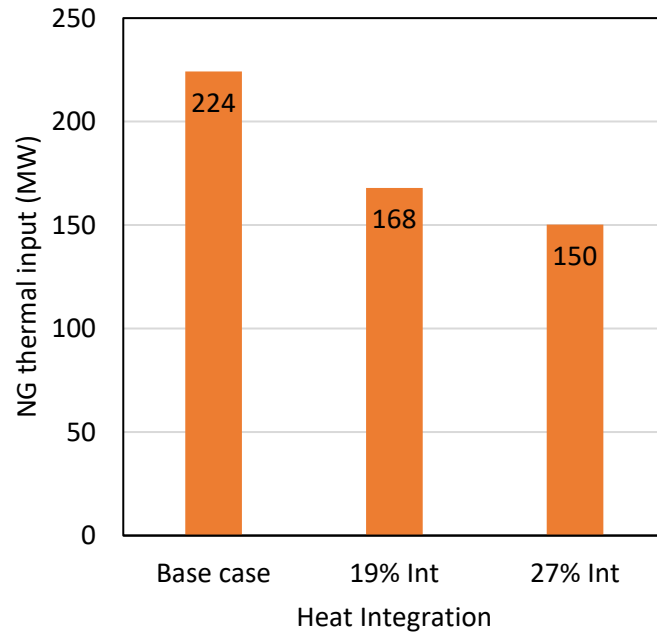
Reference: Atsonios et al. 2015. Fuel

Benhelal et al, 2012. Energy Science and Technology

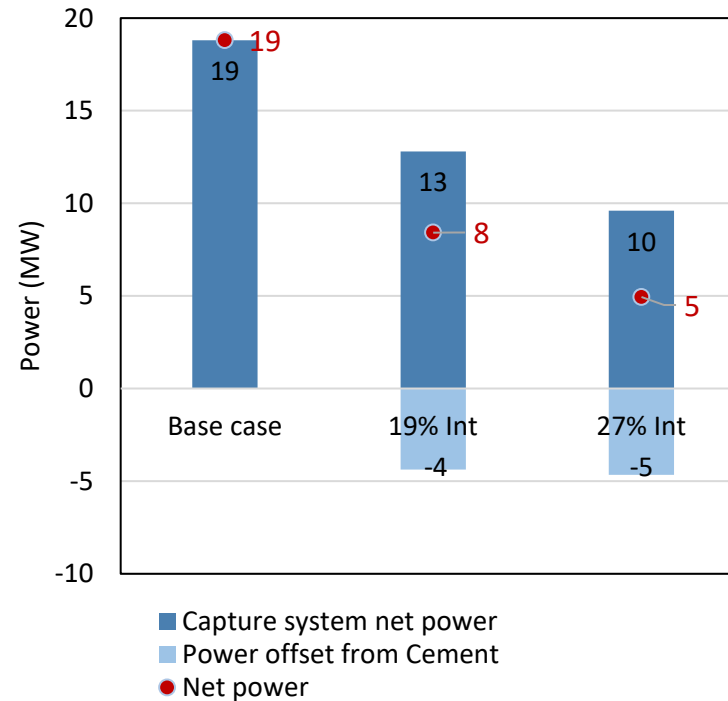
Nwaoha et al. 2018. International Journal of Greenhouse Gas Control

Heat Integration with Cement Plant

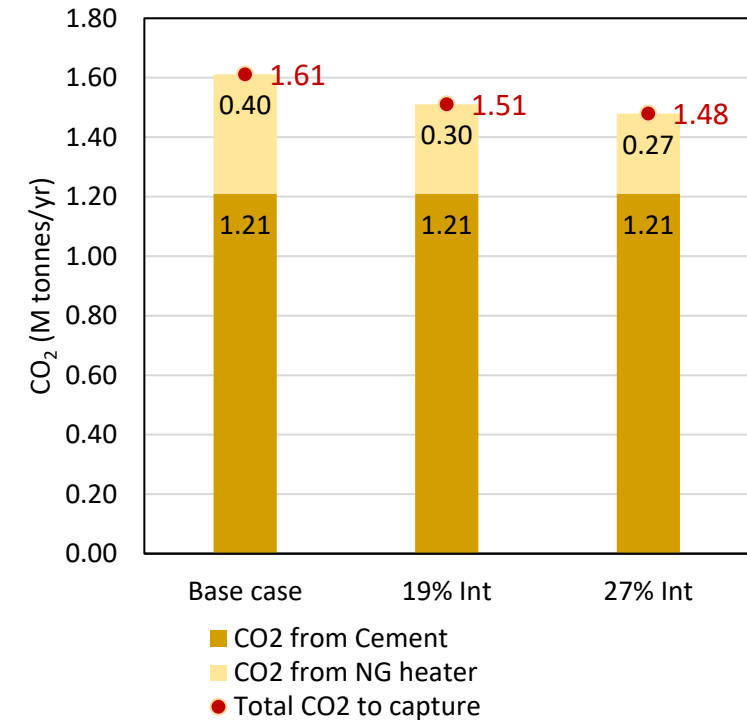
NG consumption



Power production



CO₂ to capture

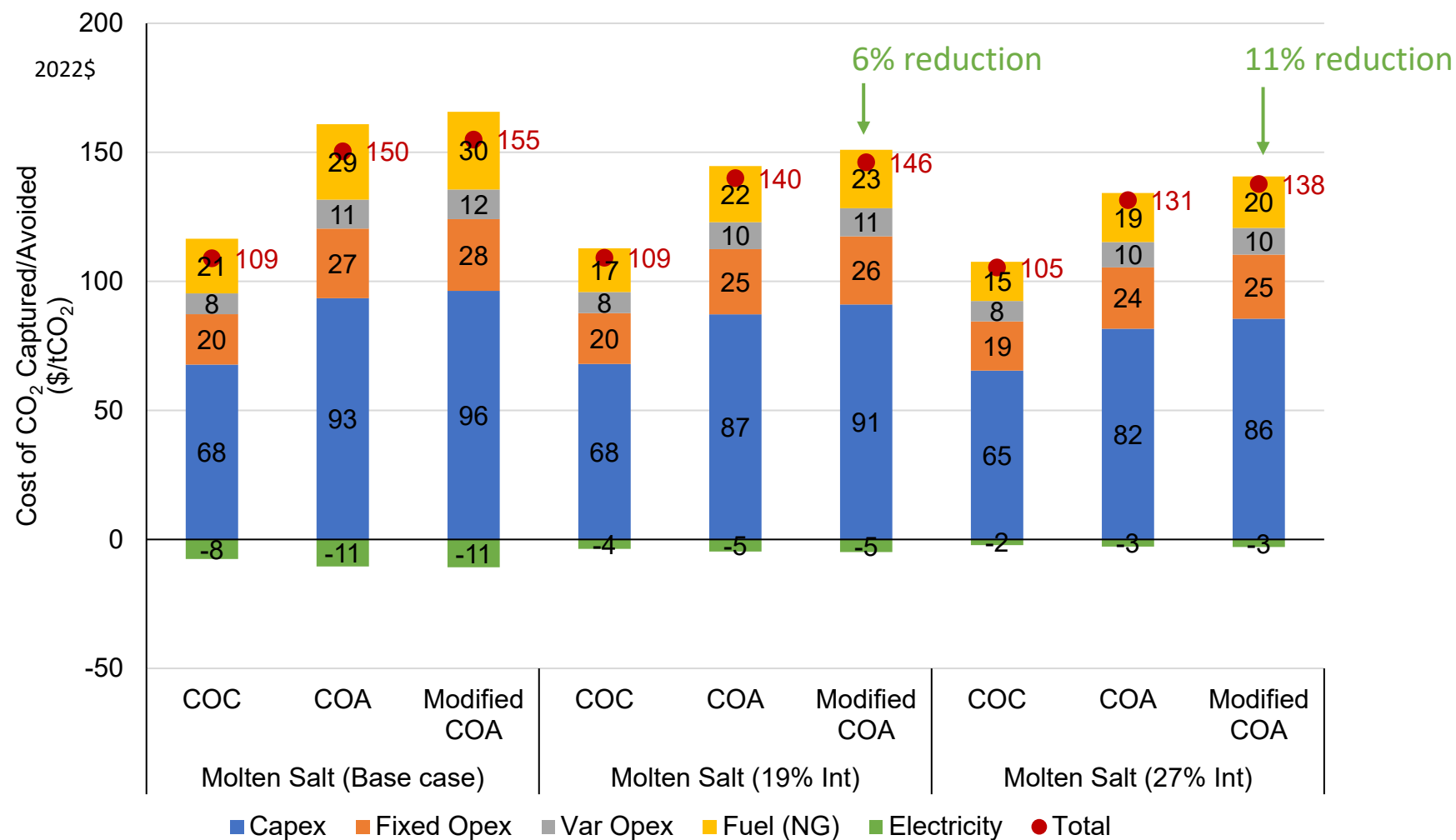


For the Molten Salt capture process with heat integration with Cement Plant:

- NG consumption reduced
- Power production reduced (further reduced to offset the power loss in Cement plant)
- Amount of CO₂ to capture reduced

Note: 27% integration has not yet been validated

TEA for Heat Integration



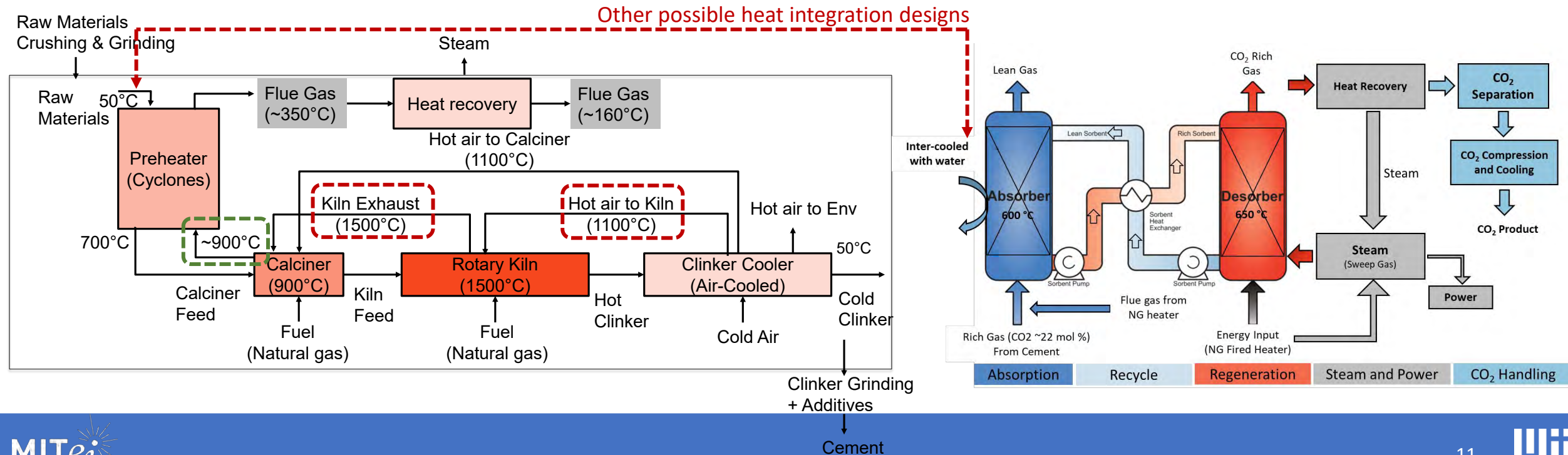
Assumptions:

- Only heat integration: taking heat from the calciner outlet flue gas stream
- TEA for the Molten salt capture system only, not including changes in the Cement plant (e.g., steam bottoming cycle)
- Account for power loss in the Cement plant (as extra auxiliary load in the capture process)
- 19% integration doesn't affect the Cement main process, but 27% integration would need validation

Note: 27% integration has not yet been validated

Takeaways and Future Work

- Molten Salt capture technology appears to be comparable with the Amine capture technology under the same TEA assumptions
- Heat integration can reduce energy consumption and reduce costs
- Identify other possible heat integration designs
- Develop a rigorous Cement process model to explore heat integration designs
- Apply Molten Salt capture system to other industries (e.g. steel process)



Q&A and Project Discussions

Backup Slides