Large Pilot CAER Heat Integrated Post-combustion CO_2 Capture Technology for Reducing the Cost of Electricity

Award Number DE-FE0026497

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http://www.caer.uky.edu/powergen/home.shtml

Summary

- Formed a cohesive stable project team
- Reached host site agreement
- Completed ISBL and OSBL design and cost estimate
- Identified no significant EH&S risks
- Provided preliminary TEA
- Completed the sensitivity study on packing materials and solvents
- Submitted technology gap analysis

Project Organization and Participants

UKy-CAER

0.7 MWe Project Team Members (DE-FE0007395)

- Koch Modular Process Systems – Original Process Equipment Manufacturer (OPEM)
- Worley Parsons – Economic Analysis, Cost Verification
- EPRI – TEA, Process & Equipment Modeling, and 3rd Party Verification
- Smith Management Group – EH&S
- CMTA – Owner's Engineering Firm
- LG&E and KU – Host Site

10 MWe Project Team Members (DE-FE00024697)

- Koch Modular Process Systems – PI&D Process Design and Cost Estimation
- Worley Parsons – PI&D BOP Design and Cost Estimation, Economic Analysis
- EPRI – Process & Equipment Modeling, TEA, and BOP Consultation
- Smith Management Group – EH&S
- CMTA – In-house Engineering Support
- LG&E and KU – Host Site

Project Overview

- 10 MWe advanced post-combustion CO_2 capture large pilot including two heat-pump loops, enhanced absorber and water wash design
- Designed as hybrid free-stand and modular configuration
- Host site at Louisville Gas and Electric Company's, Trimble County Generating Station, approximately 80 miles from UKy-CAER

Project Goal and Objectives

Goal

- Develop a pathway to meet the DOE post-combustion CCS targets and bridge the gap to commercialization by showcasing the unique UKy-CAER process, advancing it from TRL 5/6 to 7/8, and to provide a platform to boost public awareness and confidence in CCS technology.

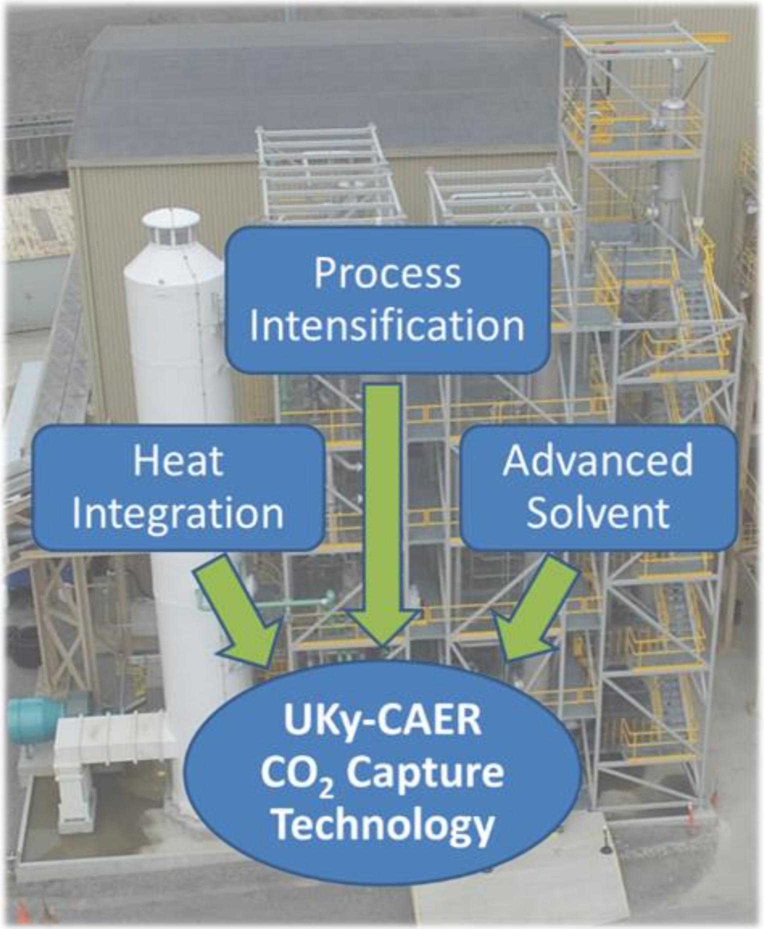
Objectives

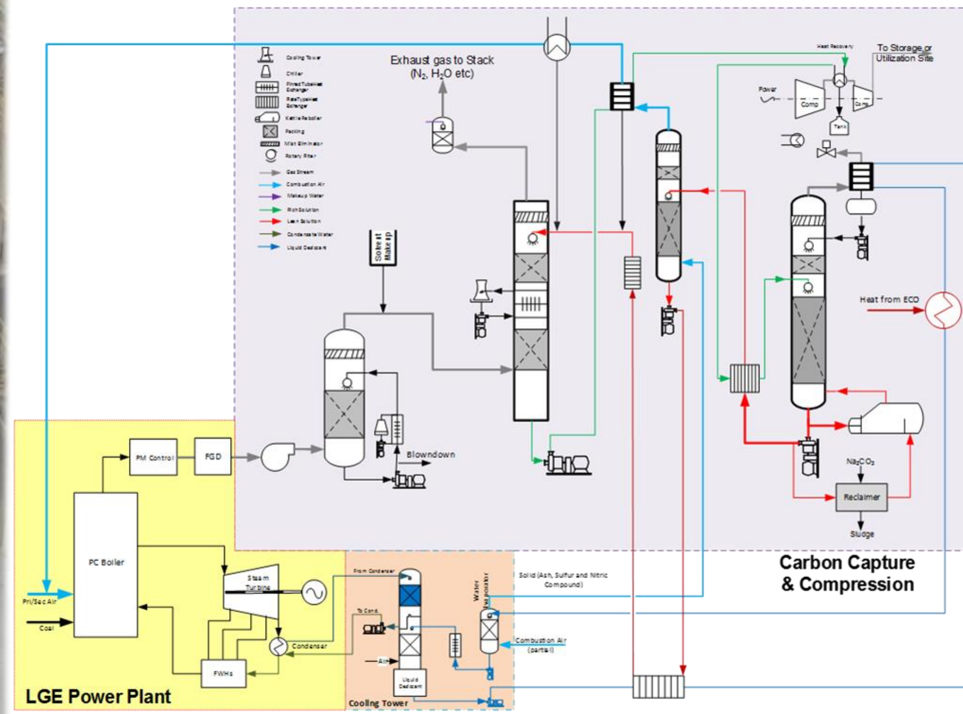
1) Detailed the design associated with capture facility including site preparation and utilities to validate the UKy-CAER mass transfer intensification and heat integration techniques for improved CCS performance, which can be applied to any advanced solvent;

2) Sensitivity study on packing and solvent to select appropriate column internals and operating parameters;

3) Identified ten Technology Gaps identified that currently hinder commercial application of CCS technology;

Process Description





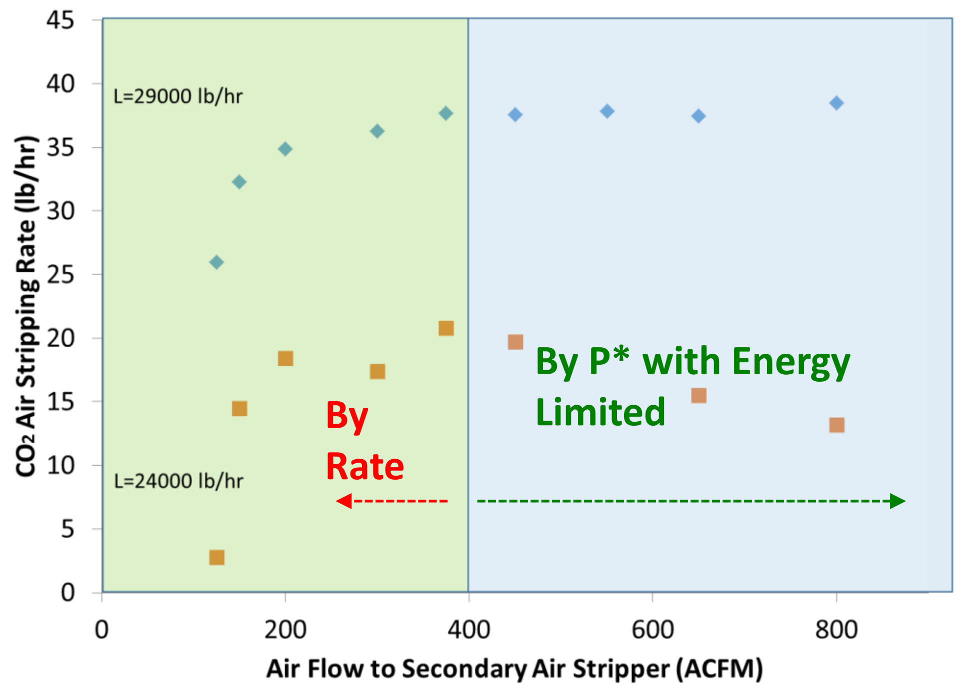
DE-FE0026497 Close-out Meeting, Pittsburgh, PA, October 27, 2017

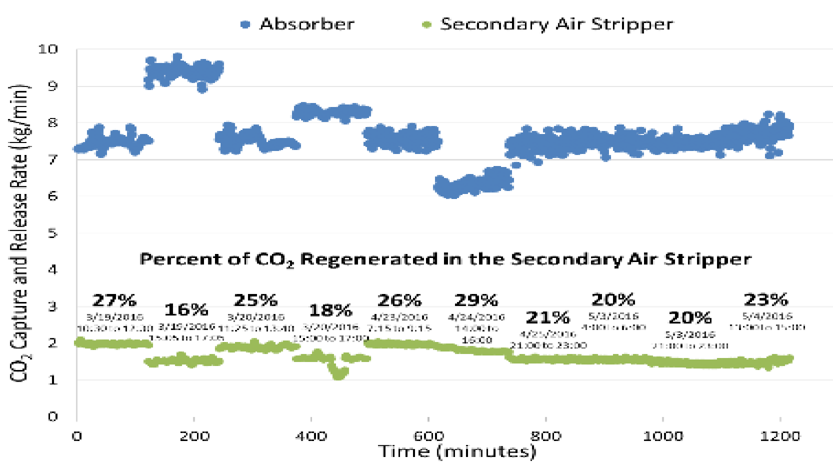
A Robust Process for Advanced Solvents

Performance Compared to 30 wt% MEA	Hitachi H3-1	CAER	CCSL
Energy Penalty	27% savings	20-25% savings	~30% savings
Solvent Circulation Rate	~35% reduction	~30% reduction	~40% reduction
Cyclic Capacity	~1.5X	~1.5X	~2X
Viscosity	2.5 – 3X	~1.5X	3 – 3.5X
Surface Tension	~0.6X	~1.0X	-1.1X
Degradation Products	Low	Low	Low
Solvent Regeneration Energy Measured at NCCC 0.5 MWe Unit (Btu/lb CO_2)	1240		1170
Solvent Regeneration Energy Measured at Uky-CAER CCS	1022 Btu/lb CO_2 on 0.7 MWe Small Pilot, 61% of MEA on 0.1 MWth Bench	1070 BTU/lb CO_2 on 0.7 MMWe, 68% of MEA on 0.1 MWth Bench	52% of MEA on 0.1 MWth Bench

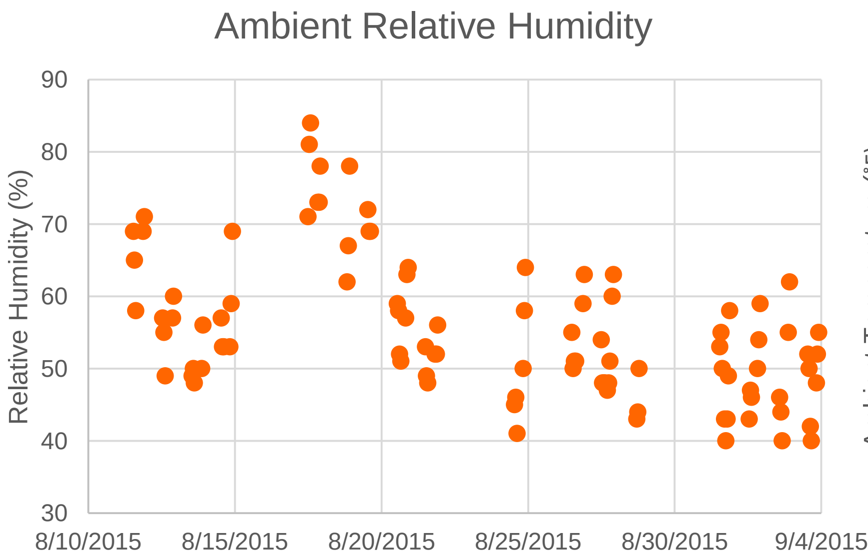
Foundation – Secondary Air Stripper

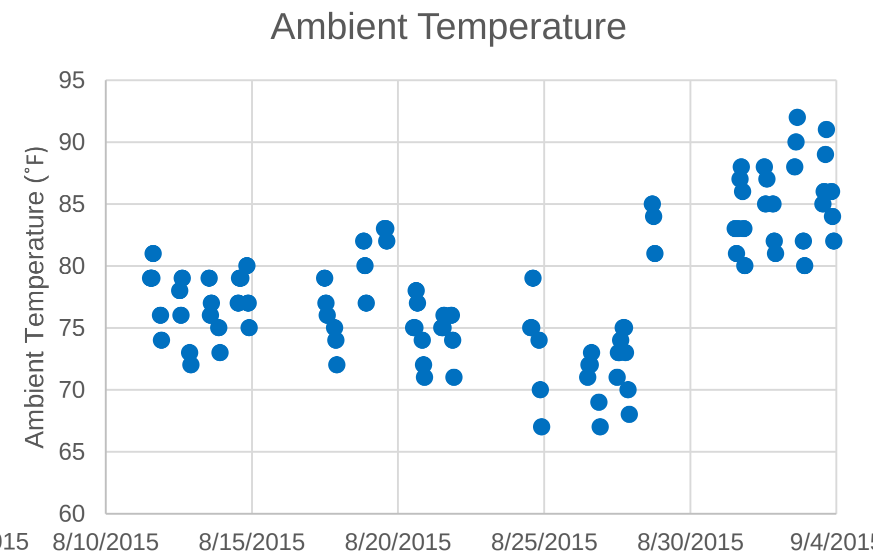
- Given:
  - Flue Gas: 1400 acfm
  - CO_2: 16.0%
  - Stripper pressure: 36 psia
  - Solvent feed to air stripper temp: 195 F
  - Alkalinity = 3.26 mol/kg

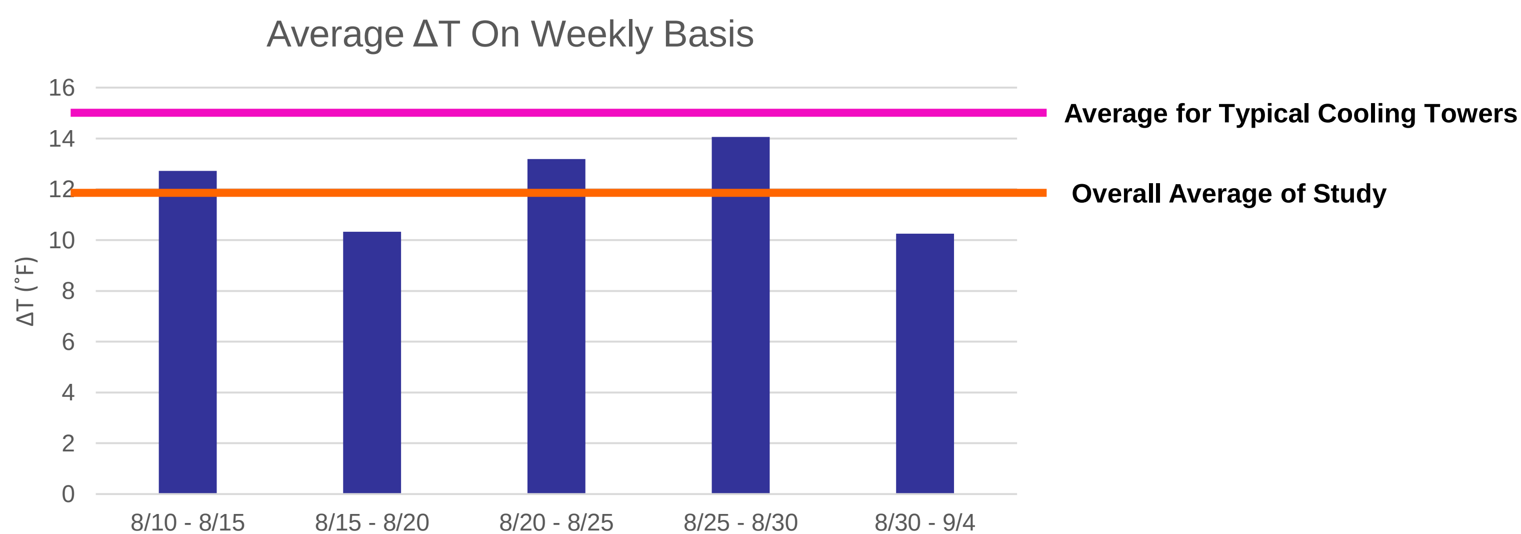




Heat Integrated Cooling Tower

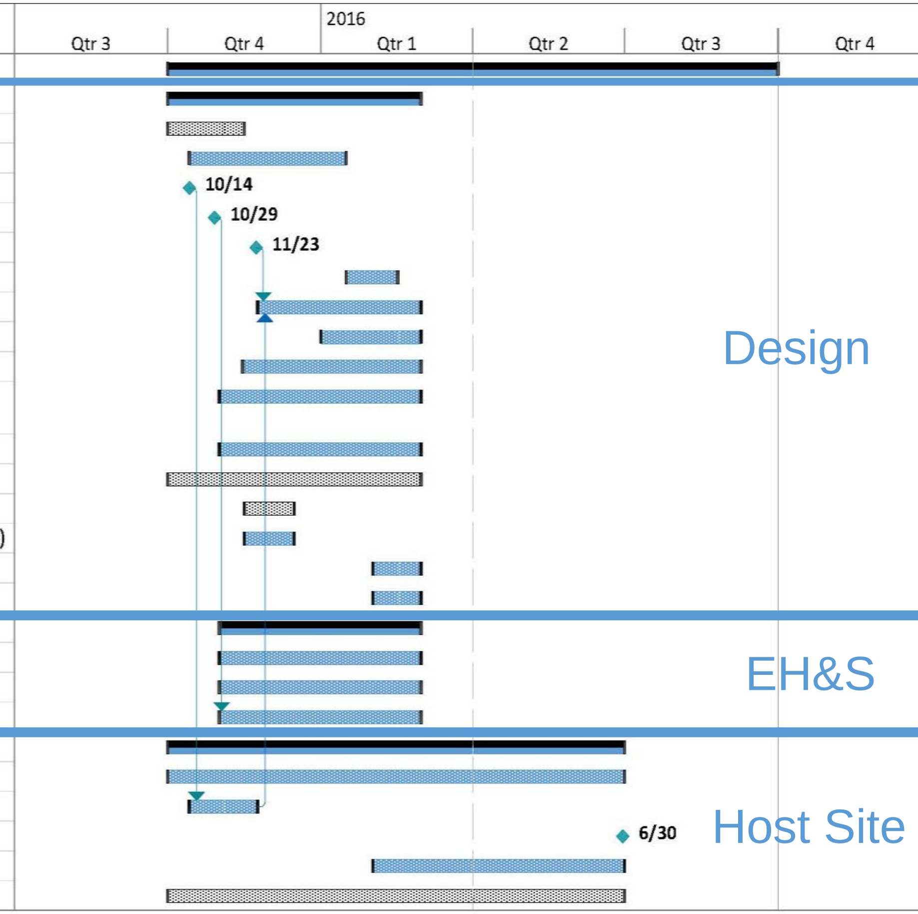






Phase 1: Project Schedule

ID	Task Name
1	1 Budget Period 1 Project Management and Planning
5	2 Basic Process Specification and Design
6	2.1 Aspen modeling of base case at 10MWe scale (UKy Lead)
8	2.2 Preliminary carbon capture system design (KMPS Lead)
9	*2.2.1 KMPS to provide approximate land requirement to UKy/WP*
10	*2.2.2 KMPS to provide general system volumes to UKy/SMG*
11	*2.2.3 KMPS to provide approximate system weights to UKy/WP*
12	2.3 Major equipment identification and selection (KMPS Lead)
14	2.4 Host site survey and general arrangement design (WP, UK and LG&E-KU)
15	2.5 Phase 2 cost estimate (KMPS and WP Lead)
16	2.6 Techno economic analysis (TEA) (EPRI and WP Lead)
18	2.7 Continuously update and revise the TEA with data collected from 0.7MW UKy-CAER small-pilot (UKy, EPRI and WP):
19	2.8 Identification of EPC candidates (WP, UKy and LG&E-KU)
20	2.9 Technology gap analysis (UKy Lead)
22	2.10 Sensitivity study - solvent selection (UKy Lead)
23	2.11 Sensitivity study - absorber column internal configuration determination (UKy and KMPS)
24	2.12 CO2 compression equipment selection (UKy and WP)
25	2.13 Steam supply selection (UKy and WP)
26	3 Complete EH&S Evaluation
27	3.1 Evaluation of Host Site Emission Permitting and Acquire Permit (if Necessary)
28	3.2 Complete Environtmental Questionnaire for Phase 2 (SMG Lead)
30	3.3 EH&S Assessment (SMG Lead)
32	4 Host Site Selection and Financial Agreements
33	4.1 Host Site Agreement Complete (UKy Lead)
34	*4.1.1 Host Site Selection (LG&E-KU)*
35	*4.1.2 Host Site Agreement*
36	4.2 Prepare Host Site Preparation/Integration Plan (UKy, KMPS and LG&E-KU)
37	4.3 Finalize Project Cost-Share Agreements (UKy Lead)



LG&E Trimble County Unit #1

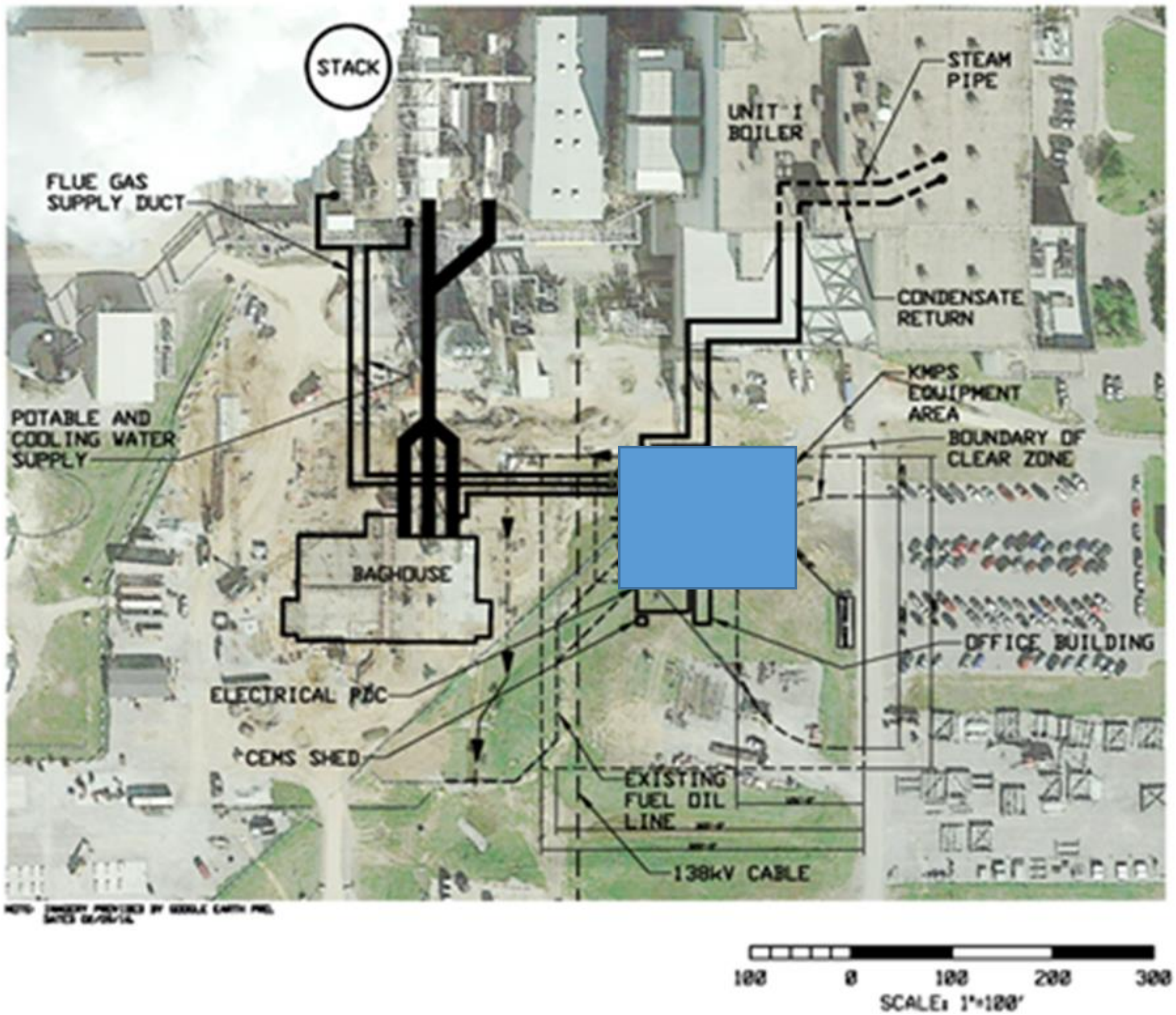
- TC 1 came on-line in 1990
- Lowest cost coal fired unit in LG&E/KU territory and provides base load power
- The capacity factor (2016) – 77%
- 493 Mwe (net) Unit
  - Low NOx burners
  - SCR
  - Wet FGD
  - Dry ESP
  - Lime Injection
- ***Host Site Agreement Signed***

Anticipated Large Pilot 10MWe CCS Location

CCS Design Basis

Type	Proposed 10 MWe Pilot	Current 0.7 MWe Slipstream Amount	Units
	Out of Plant		
Land	1-2 acres		
Electric Design Load	1,500	150	kW
Flue Gas Feed	100,000	6,871	lbs/hr
Plant Water	25	1.5	gpm
Superheated Steam	42,000	3,000	lbs/hr
Instrument Air	500	100	scfm
Plant Air	Not significant during normal operation		
	Return to Plant		
Flue Gas Condensate/Soda Ash Waste	40	2.8	gpm
Flue Gas to Stack	160,000	11,000	lbs/hr
Steam Condensate Return	42,000	3,000	lbs/hr
	Miscellaneous		
Solvent Supply	6	0.3	lbs/hr
Solid Waste	150		kg/day
Air Emissions (absorption reagent)	5		lbs/hr

BOP Design



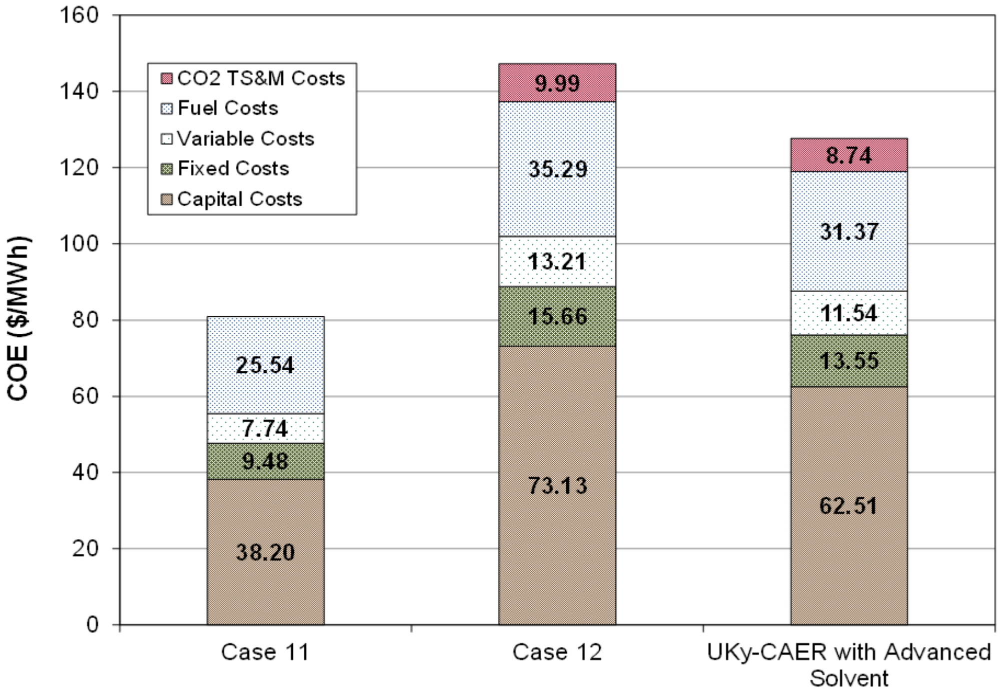
Boundaries of BOP Design:

- Tie-ins to the plant services, ducts and power plant piping
- Tie-ins to the KMPS modules
- Wiring to major pieces of equipment including pumps and fans

Items included in the BOP:

- Spill containment foundation
- Steam and condensate piping with reducing valve and regulator (supports included)
- Flue gas supply and return ducts and duct support structures
- Process and potable water service/piping
- Tie into electrical service and supporting electrical equipment
- Process control system, and
- Mobile control room/lab/maintenance area

Techno-economic Analysis



- EPRI conducted simulation, generated HMB Stream Tables
- WP did sizing and cost estimate
  - Absorber: 118 ft packing
  - Primary Stripper: 95 ft packing
  - Secondary Stripper: 72 ft packing

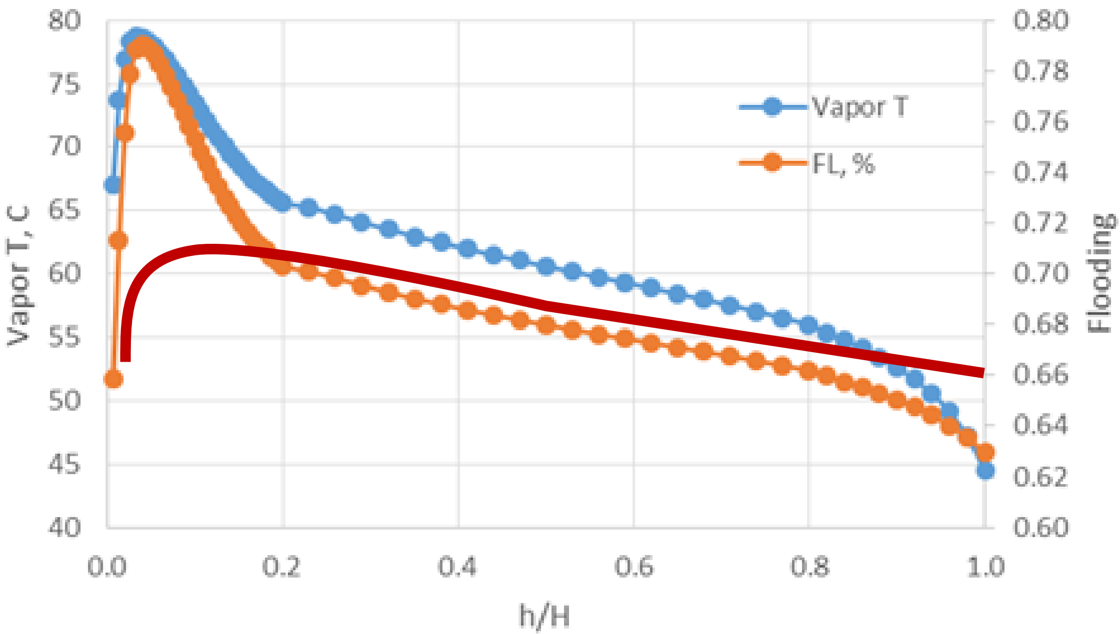
<u>Advantage of the UKy-CAER Process using an Advanced Solvent :</u>

- Overall Plant Efficiency: 32.0%
- A lower COE by $19.6/MWh, a 13.3% reduction, equivalent to a 29.5% incremental reduction.
- A lower LCOE by $24.81/MWh, also a 13.3% reduction.
- $43.54/tonne CO_2 captured (excluding TS&M), lower cost of CO_2 captured by $12.96/tonne CO_2, a 19.5% reduction.

Knowledge Gained from 0.7 MWe Scale

- Absorber is rate-limited, but 40 HETP is plenty for advanced 2^{nd} or beyond solvent
- Stripper (primary and secondary) is equilibrium controlled, less than 20 HETP is enough to regenerate solvent to reach 90% CO_2 capture
- In the view of energy penalty, the L/R heat exchanger plays a significant role for energy saving compared to absorber packing height for richer carbon loading
- Process control is a challenge if 90% of capture is the only target

Advanced Absorber – Packing



Packed Tower Internals. Bulletin KGMTIG-1. Rev. 3-2010. 2003-2010. Koch-Glitch, LP.

Increasing Capacity ← → Increasing Efficiency

FLEXIPAC® Structured Packing Surface Area											
ft²/ft³	17	25	34	47	68	77	90	106	129	152	220
m²/m³	55	80	110	155	225	250	295	350	420	500	725
Inclination Angle 45°	4Y	3.5Y	3Y	2.5Y	2Y	250Y	1.6Y	1.4Y/350Y	1Y	500Y	700Y
60°	4X	3.5X	3X	2.5X	2X	250X	1.6X	1.4X/350X	1X	500X	700X

2. **Short sections of packing (less than 15ft each) and gas/liquid distribution between sections**
3. **Discretized packing selection based on flooding and T profile**

- Diameter based on flooding management
  - Determined by temperature and packing
  - Traditionally Under-utilization of some sections of the column

EH&S Evaluation

- Evaluation based on UKy-CAER small pilot research, literature review and solvent suppliers.
- Recommended appropriate storage measures for chemicals
- Recommended proper PPE and handling methods
- Toxicity is minor for solvents:
  - Irritation only after direct contact (no ecotoxicity).
- Continue monitoring for nitrosamines as those compounds pose significant human risk even at low concentrations
- **No significant EH&S risks identified to affect implementation of the proposed project.**

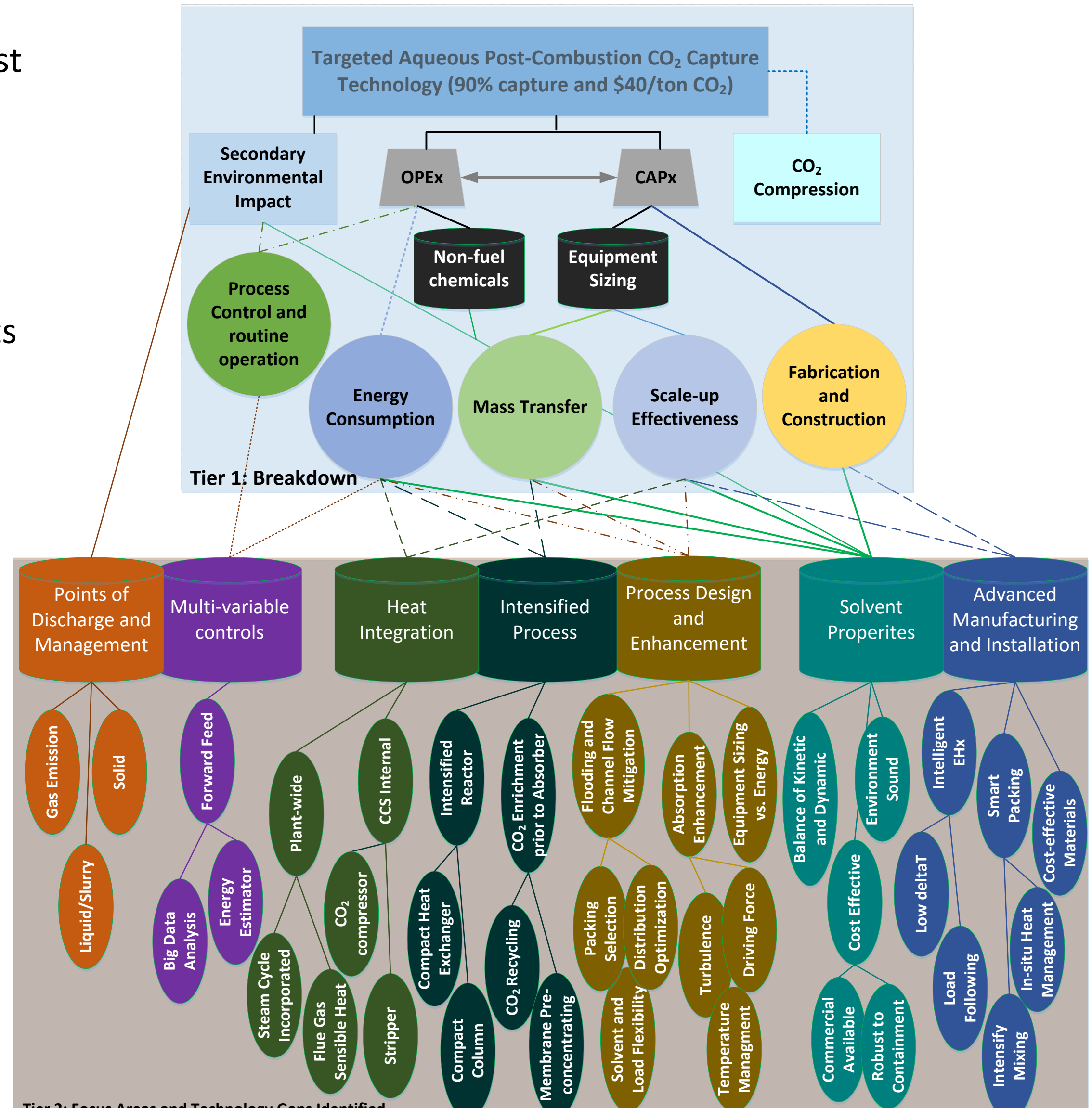
Technology Gap Analysis

Near-term technical gaps:

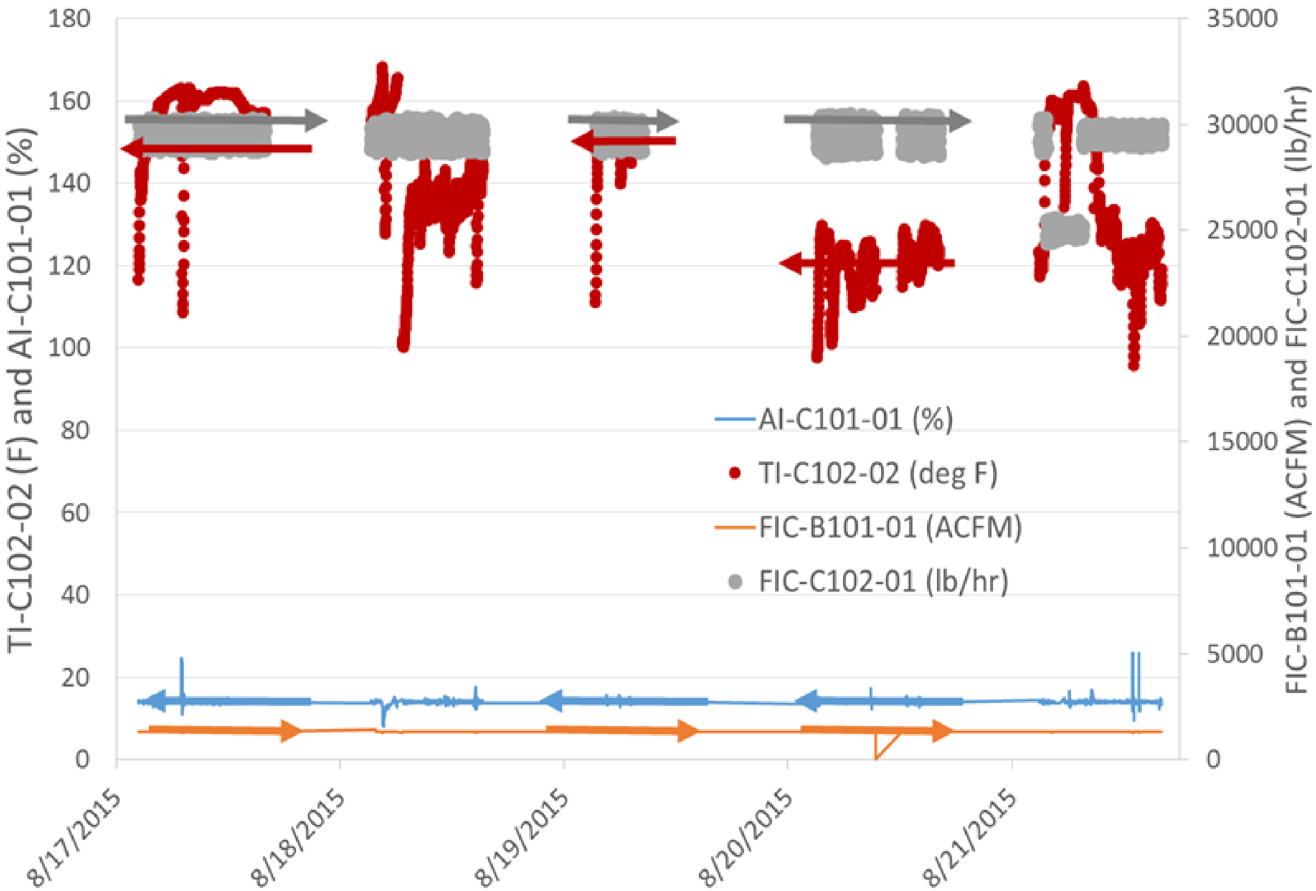
1. Cost effective solvent with high stability, high cyclic capacity and fast kinetics
2. Gas/liquid distribution to prevent channel flow
3. Waste management and point of discharge (gas and liquid)
4. Equipment sizing vs. operating costs
5. Material and methods of construction
6. Process intensification
7. Unit operation to maintain the performance
8. Heat integration

Long-term technical gaps:

9. Smart packing
10. Appropriate absorber temperature profile
11. Heat exchange
12. Smart operations

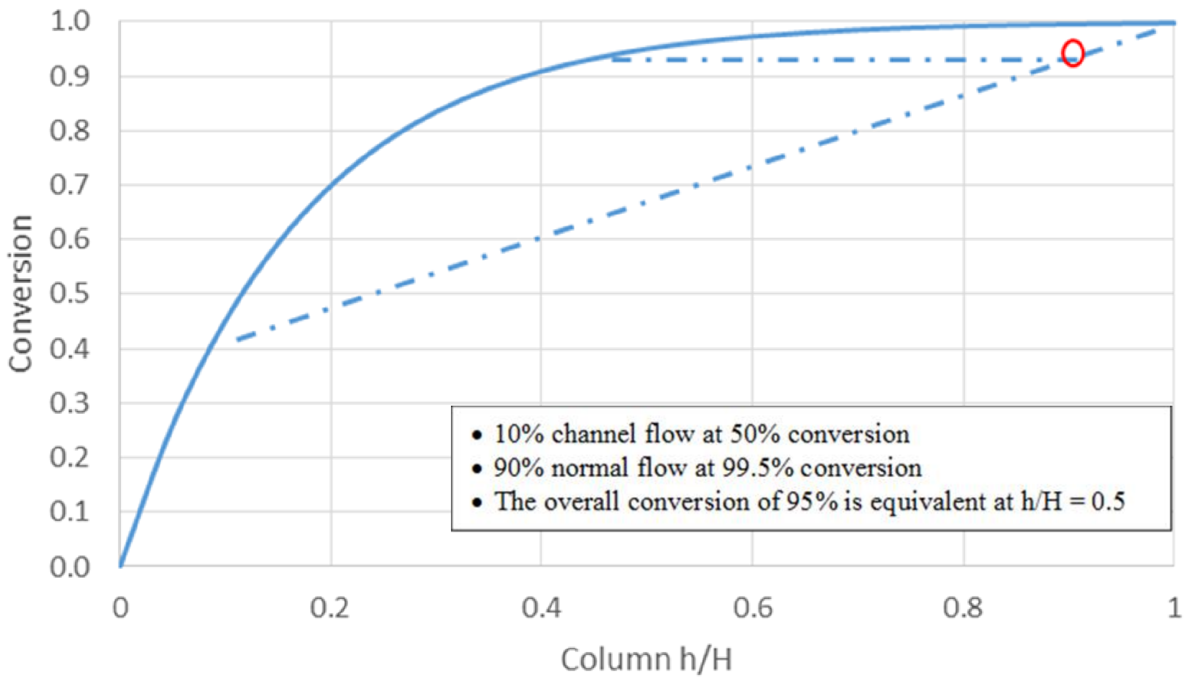


Presence of Channel Flow



- The variation of local L/G and channel flow will lead to variation in temperature readings
- 160 °F corresponds to normal operation
- The changing temperature values were caused by uneven flow or channel flow

Impact on Absorber Performance



Capture Efficiency vs. Height

- Solid line – typical reactor curve

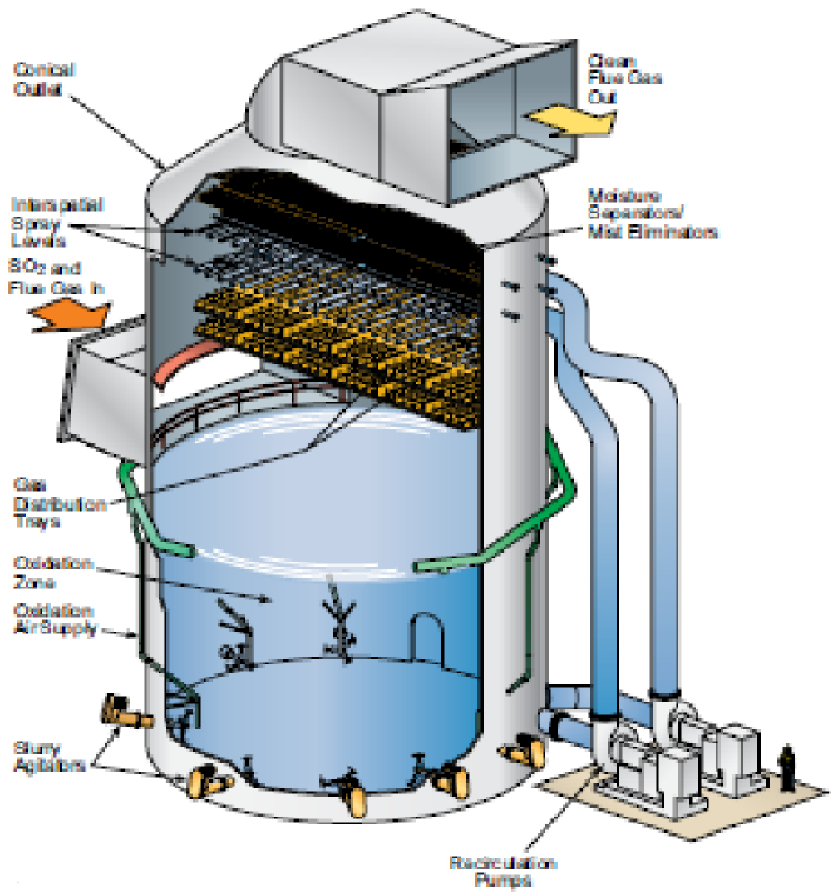
Effect of Channel Flow

- Small amount of channel flow (10% of the area) only yields 50% conversion in that area
- Rest of column (90% of the area) yields standard conversion of 99.5%
- Average for the column is 95% (red dot)
- Equivalent to 50% reduction in height/stages

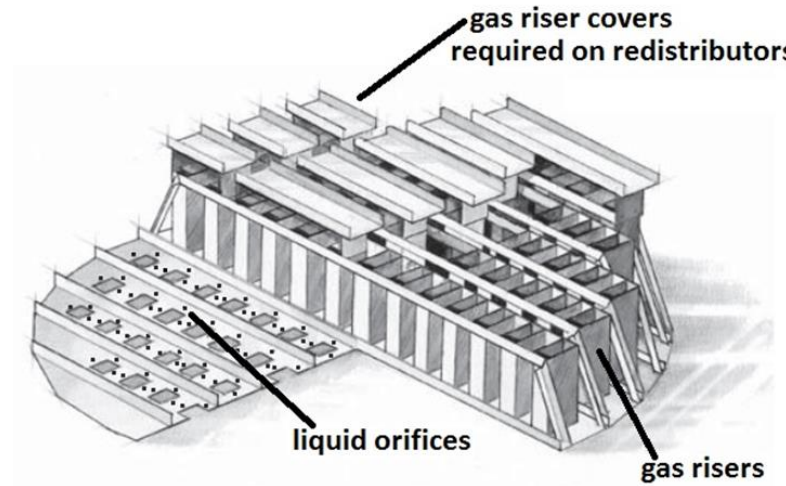
Advanced Absorber – Liquid Distribution

http://www.babcock.com/library/Documents/e1013167.pdf and 2.)Packed Tower Internals. Bulletin KGMTIG-1. Rev. 3-2010. 2003-2010. Koch-Glitch, LP.

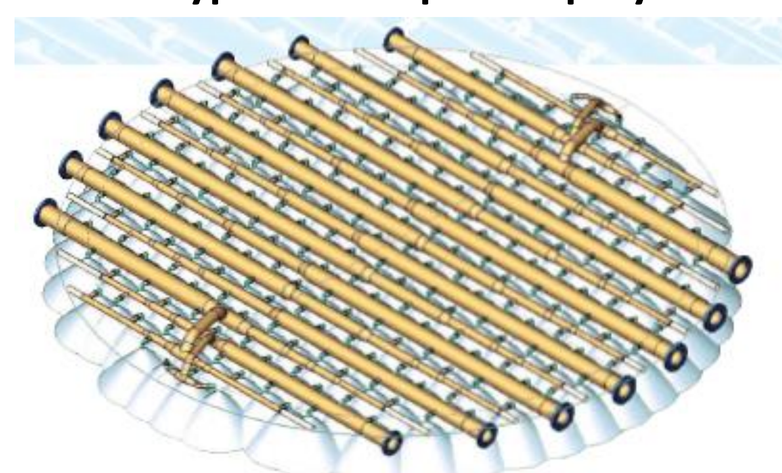
1. New advanced liquid distribution – Modeled on FGD



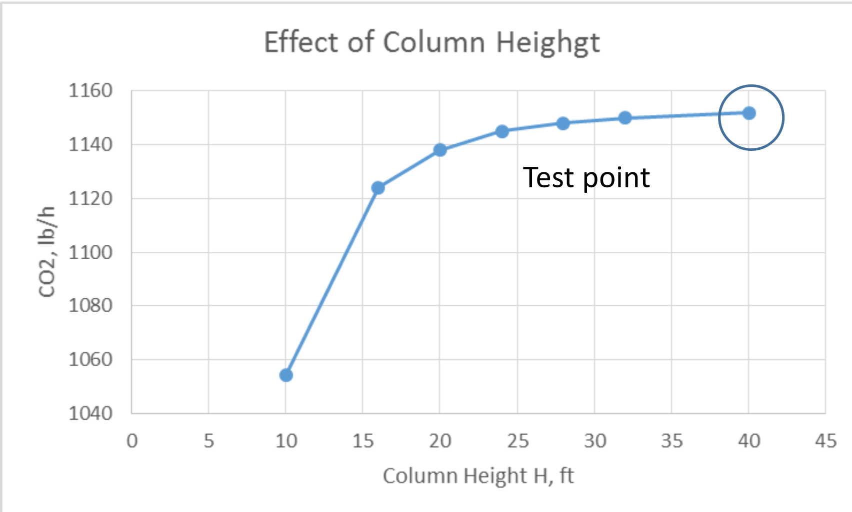
Traditional Amine Liquid Distribution

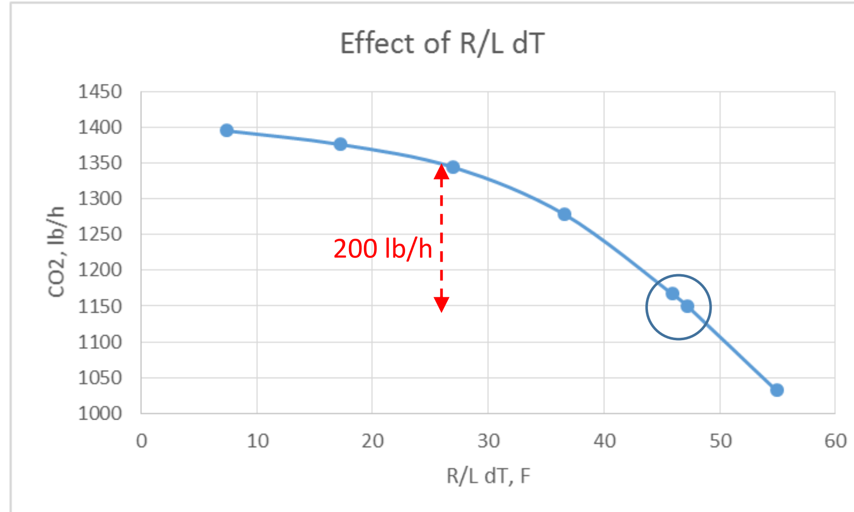


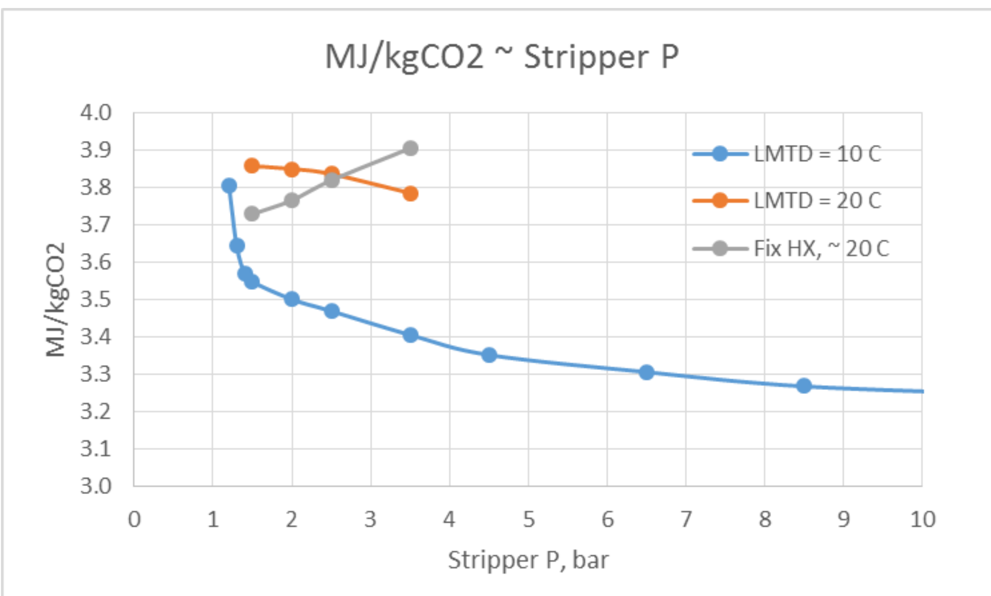
FGD Type – Interspatial Spray Header



The Trade-off between Packing, Pressure, L/R EHx on Specific Energy





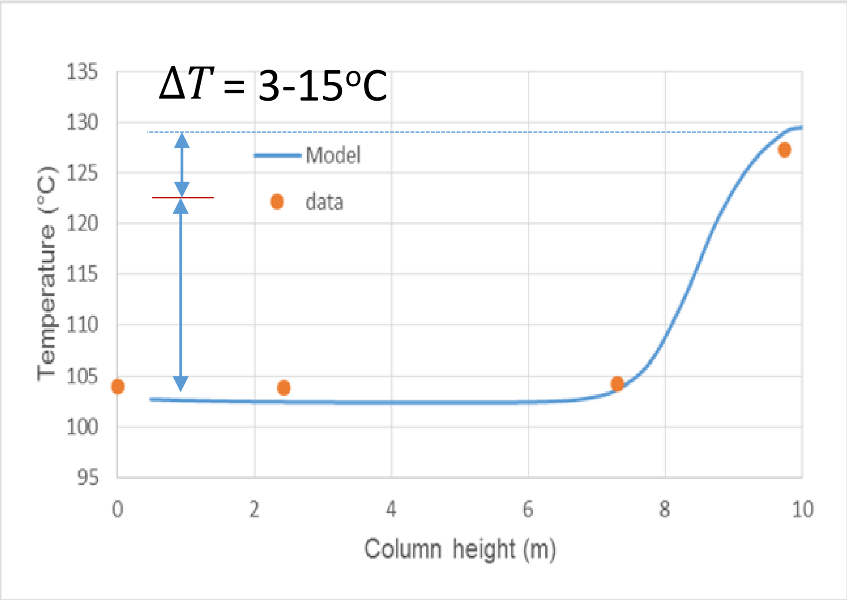


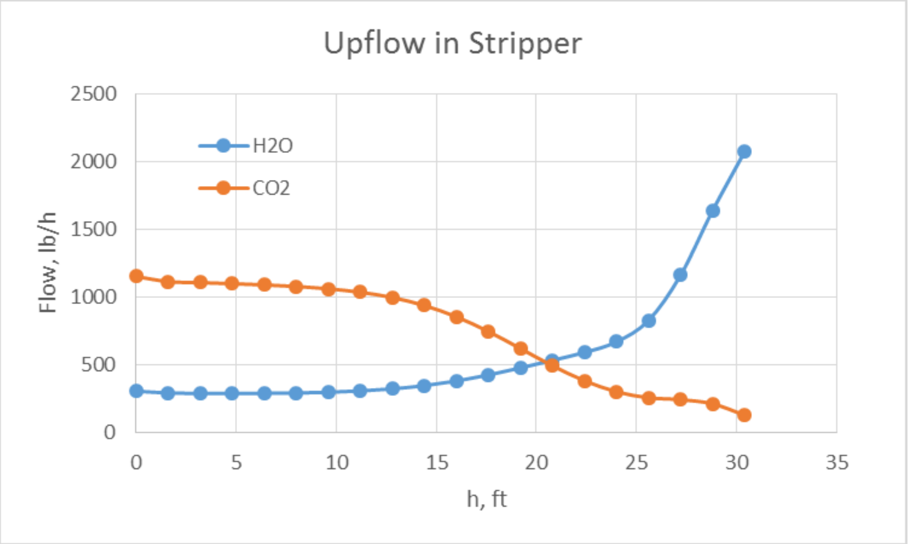
Proposed solutions:

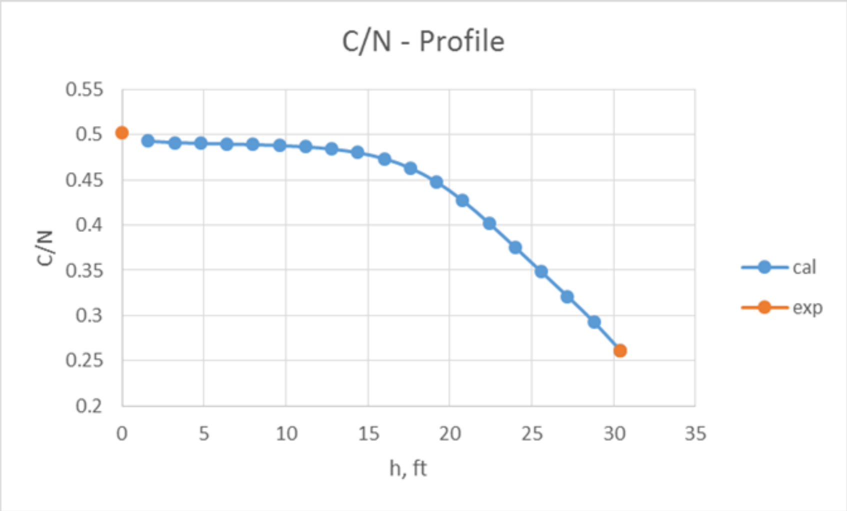
1. Split trains
2. No excess capacity

$$\mathbf{Nu = C \cdot Re^{0.8} \cdot Pr^{0.3} \cdot (\mu/\mu_w)^{0.14}}$$

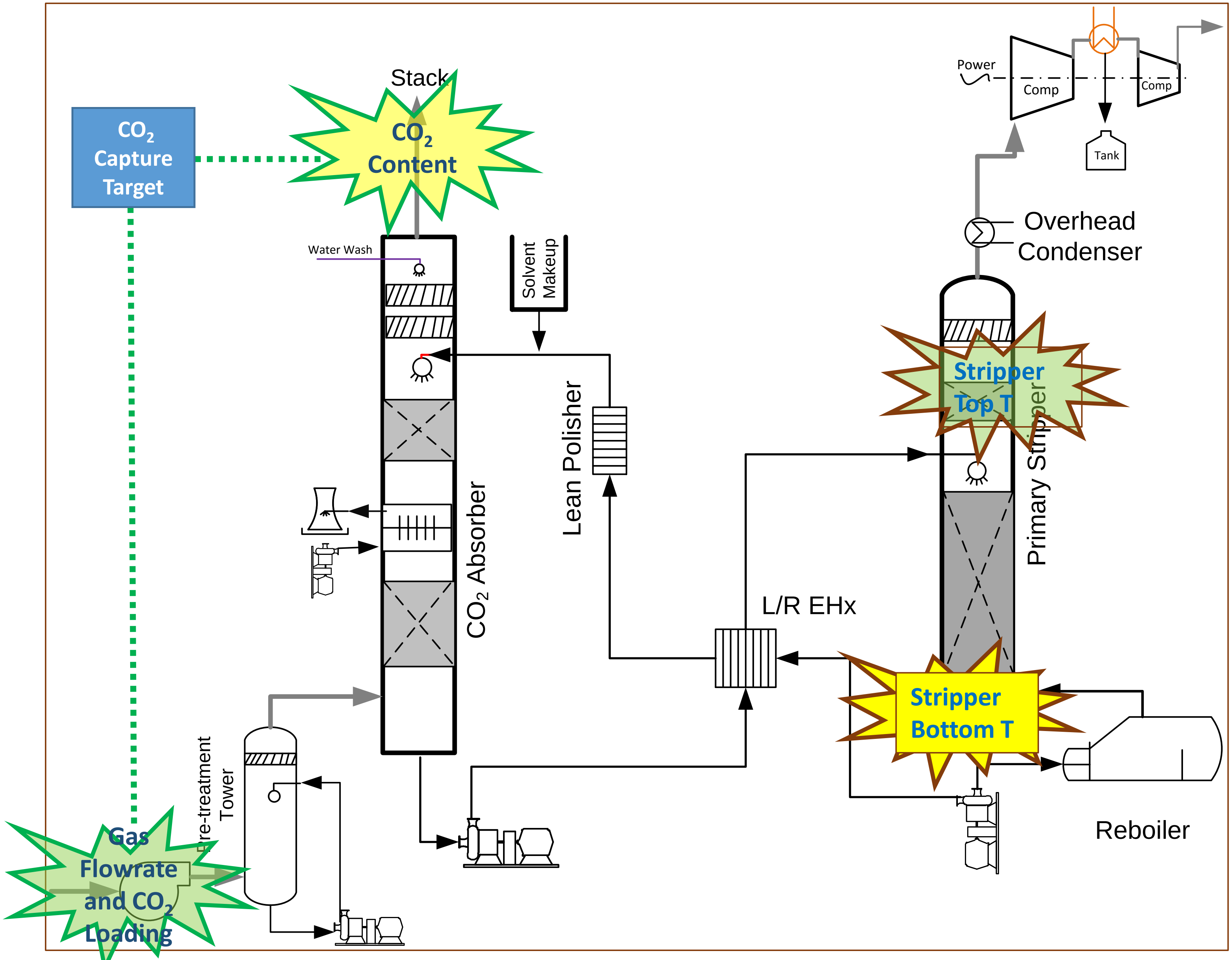
The Equilibrium Controlled and Mismatched Rich Fed Stripper







The Conventional Control Scheme



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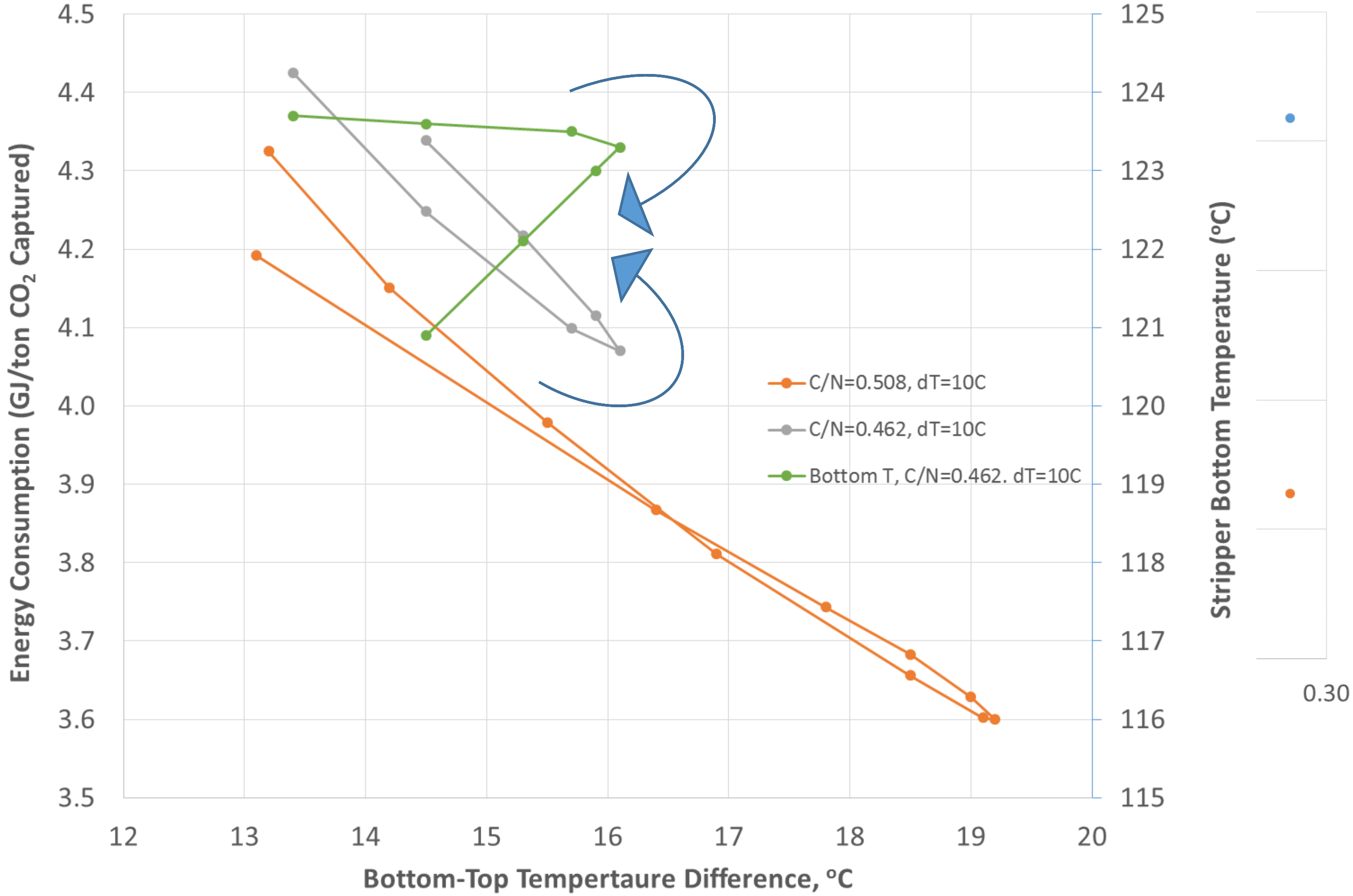
The Uncontrollable Stripper



DE-FE0026497 Close-out Meeting, Pittsburgh, PA, October 27, 2017

Summary

- Phase 1 Completed
  - Briefs and Reports (submitted before 3/31/16)
    - TEA
    - Technology Gap Assessment
    - EH&S Report and Environmental Questionnaires
    - Topical Report on Pilot Plant and Proposal for Phase 2
    - Design Package Topical Report
    - Solvent and Absorber Column Internals Sensitivity Analysis
    - Quarterly Reports
  - Project Cost Share agreements and Host Site agreement (submitted on 6/30/2016)

Acknowledgements

- DOE NETL: Bruce Lani, David Lang, Elaine Everitt and Lynn Brickett
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- LG&E and KU: David Link, Michael Manahan, Mayhar Ghorbanian, Jeff Joyce, and Jim Dimas
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- Smith Management Group: Clayton Whitney, Daniel Hardin, Stewart McCollam and Sarah Carty
- Koch Modular Process Systems: John Rec, Lindsay Turner, Stan Lam and Elizabeth Manning
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- CMTA Engineers: Kevin Mussler