Center for Applied Energy Research

A Process with Decoupled Absorber Kinetics and Solvent Regeneration through Membrane Dewatering and In-Column Heat Transfer

(DE-FE0031604)

May 18, 2018

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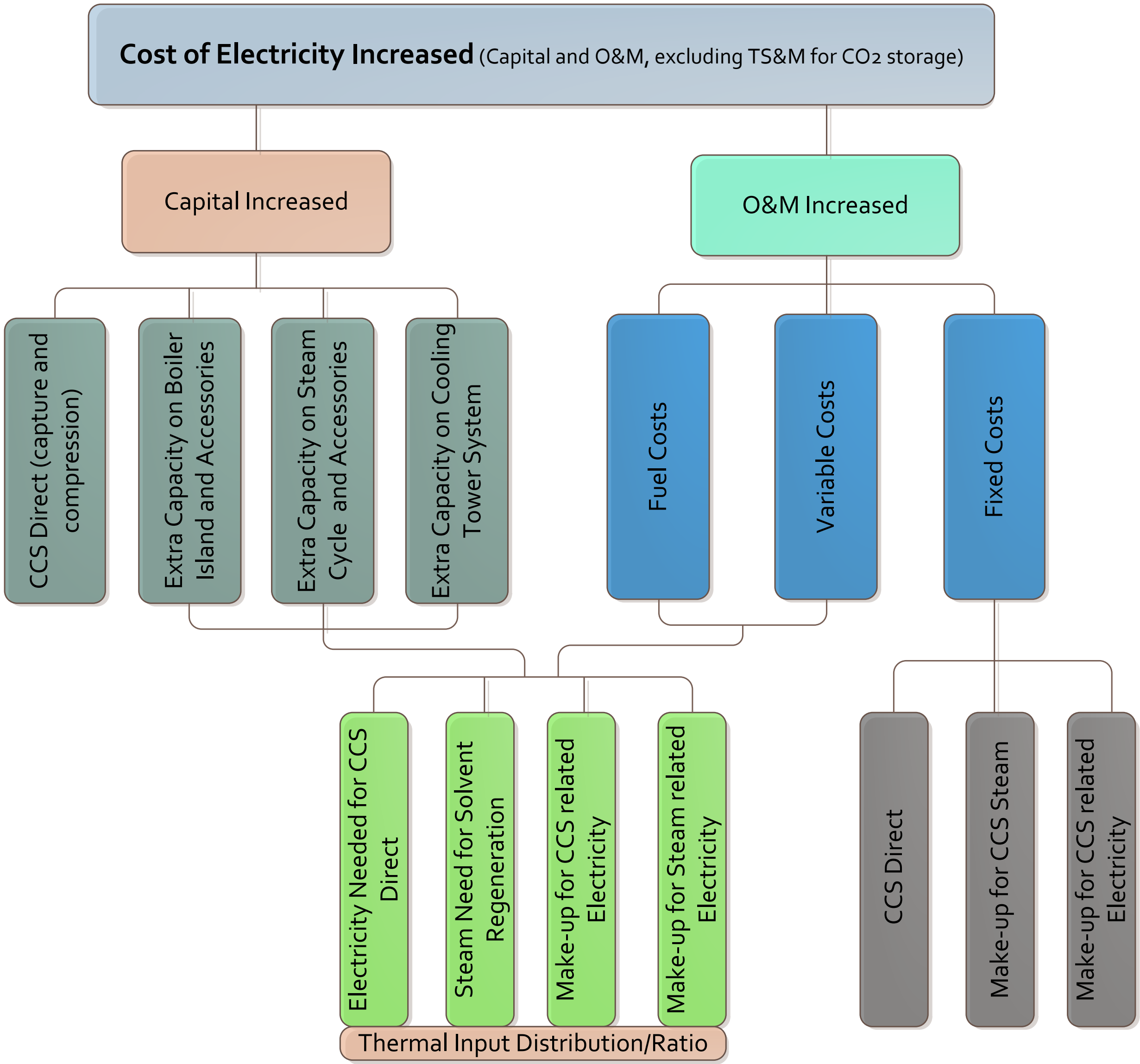
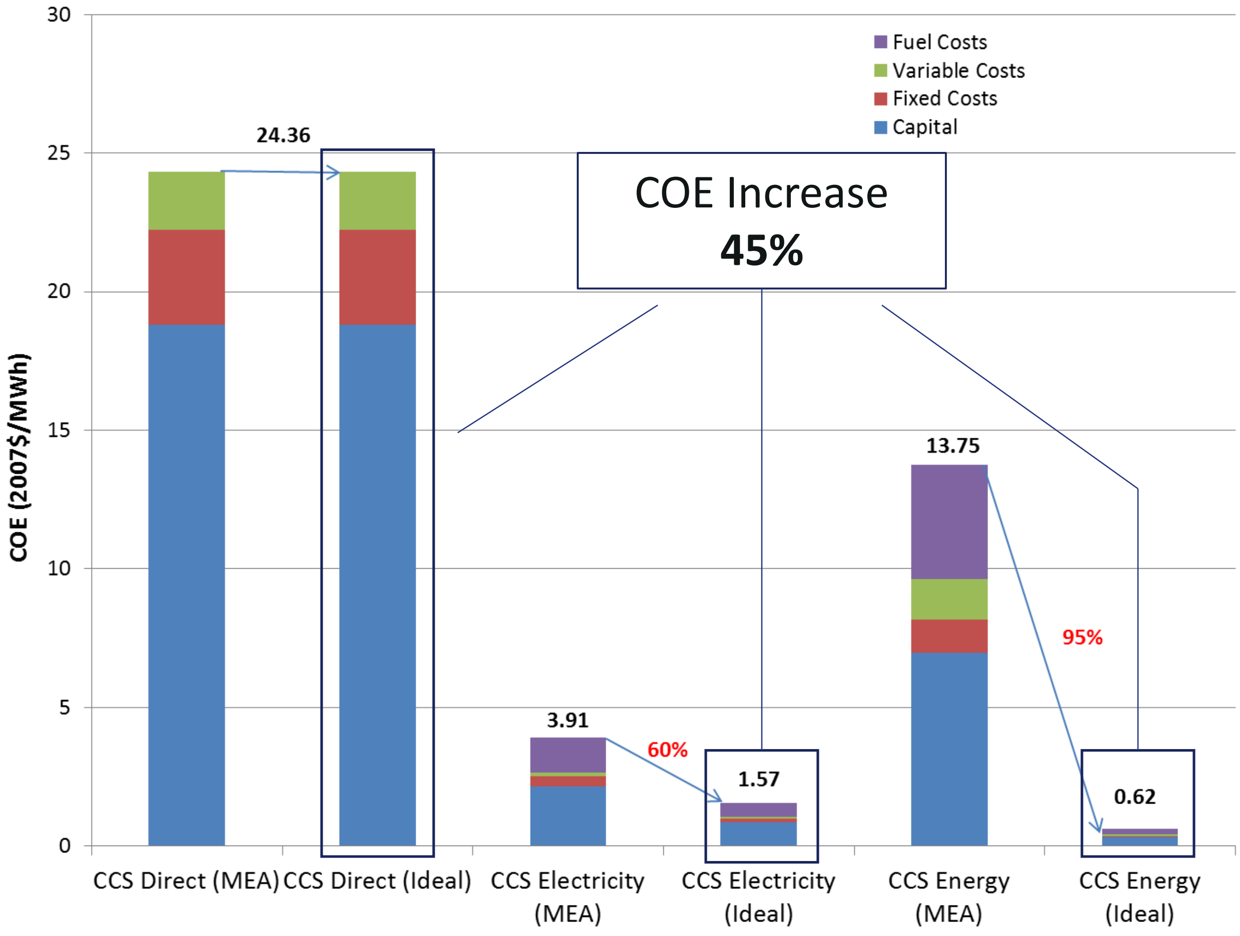
Outline

- Background
- Team/organization
- Objectives
- Technical Approach
- Scope of Work
- Project Schedule/Milestones
- Budget
- Decision Points and Success Criteria
- Project Risks and Mitigation

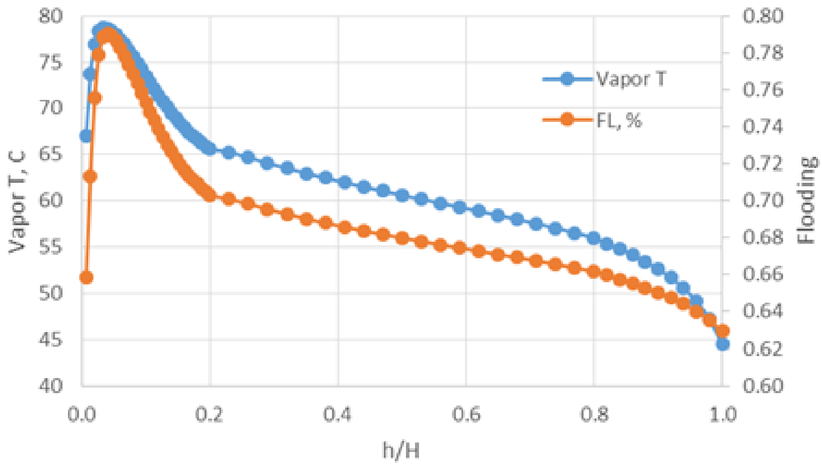
Background: Analysis Approach and Methodology



What will Happen for Case with Theoretical Energy Consumption?

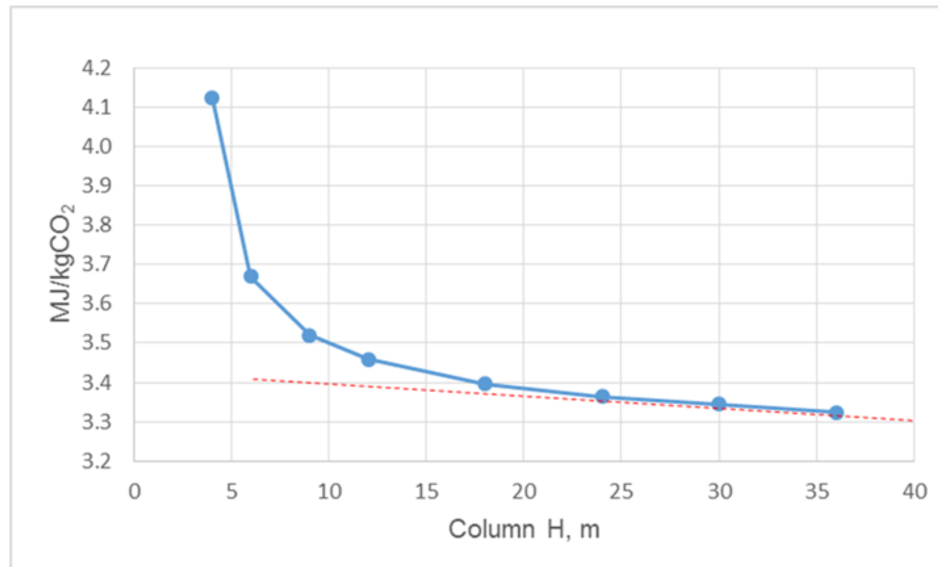


Two Main Root Causes



Too focused on energy savings

Provide safe zone for packing ineffective -- gas/liquid channel flow

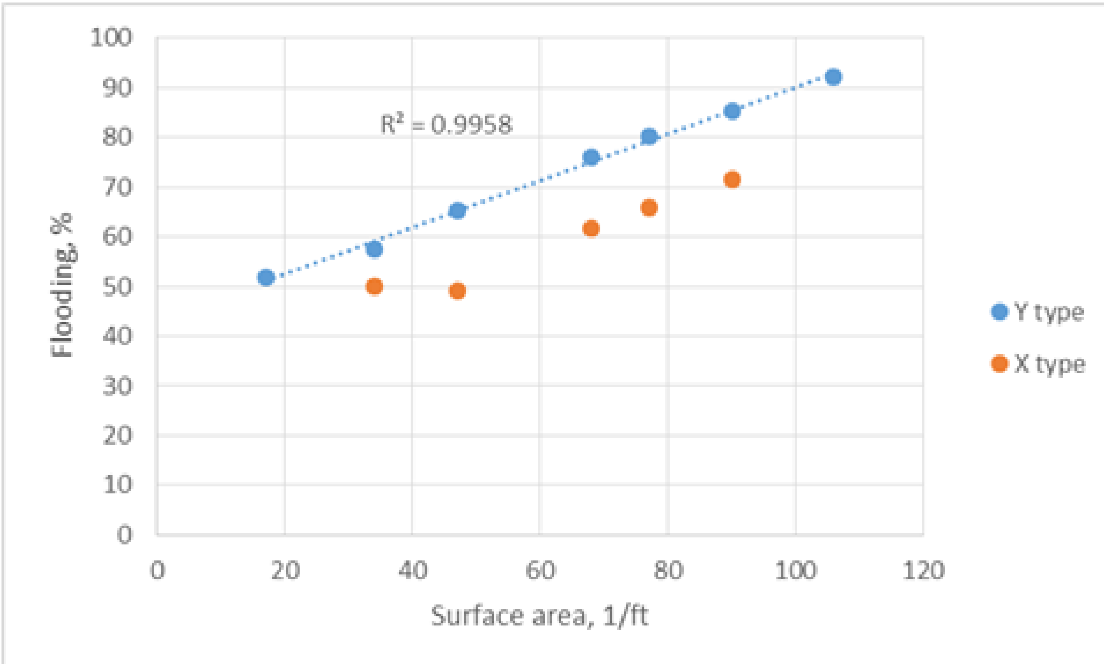


Flooding Point to Determine ID

-- No notable difference when L/G = 3-4

Varying height to match kinetic and physical properties

Thought 1: Taking Advantage of Packing

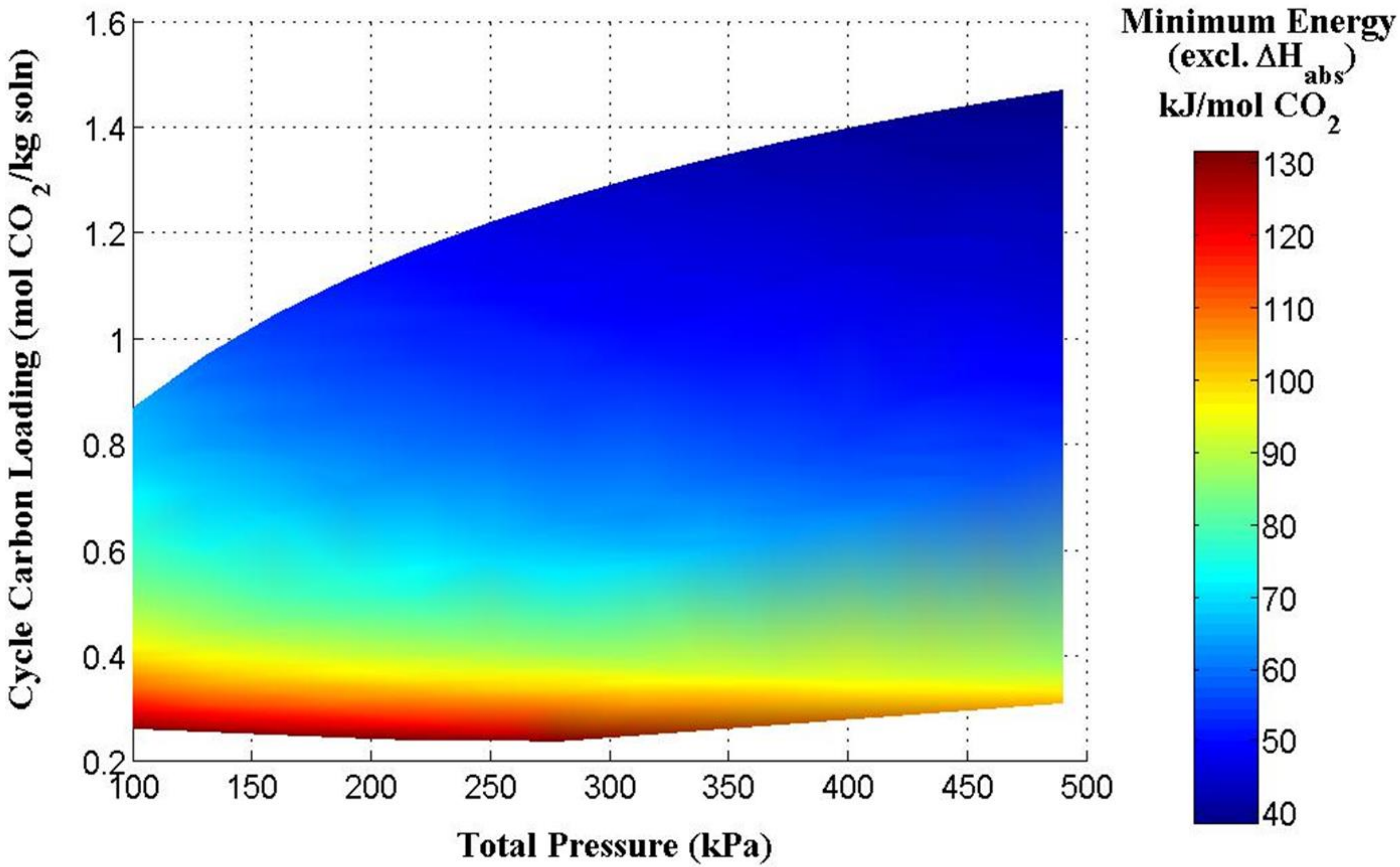


Inclination Angle:
Y – 45º
X – 60º

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

Thought 2: Can We Manage the Operational Cost?



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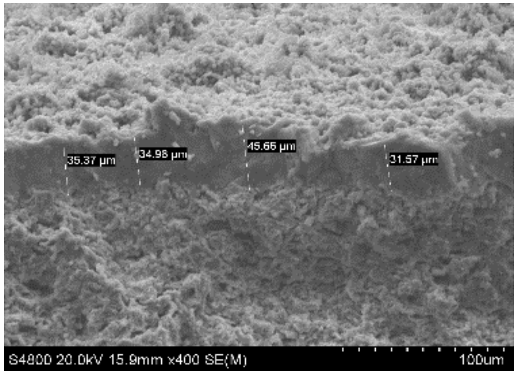
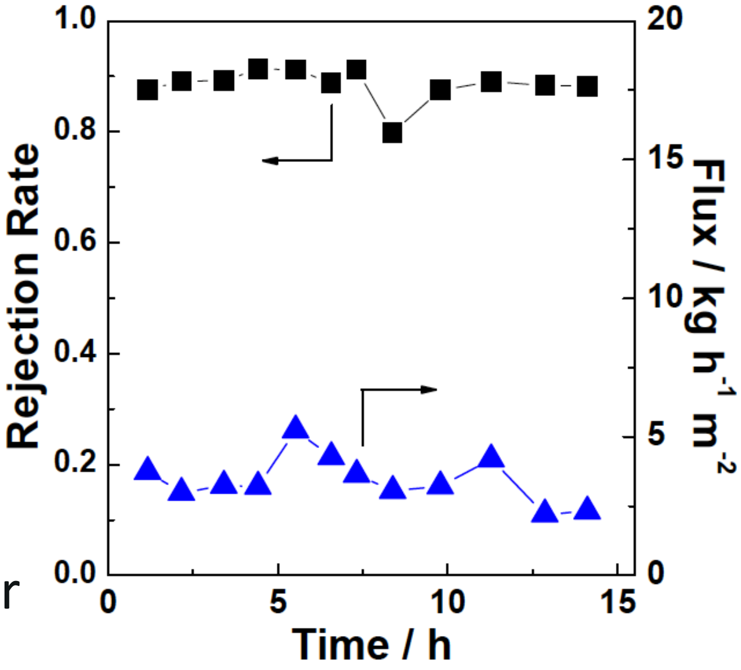
CAER's Research on Zeolite Membrane Module

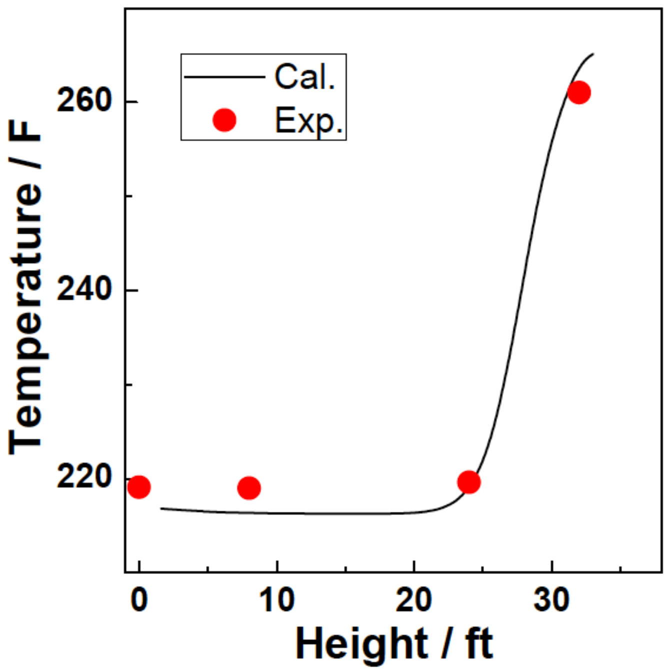
- Started in 2010
- Funded by State of KY, ARPA-E, and DOE/NETL
- Have been working on catalytic zeolite (T) and water reduction (Y)
- Focus on membrane synthesis and small modular configuration

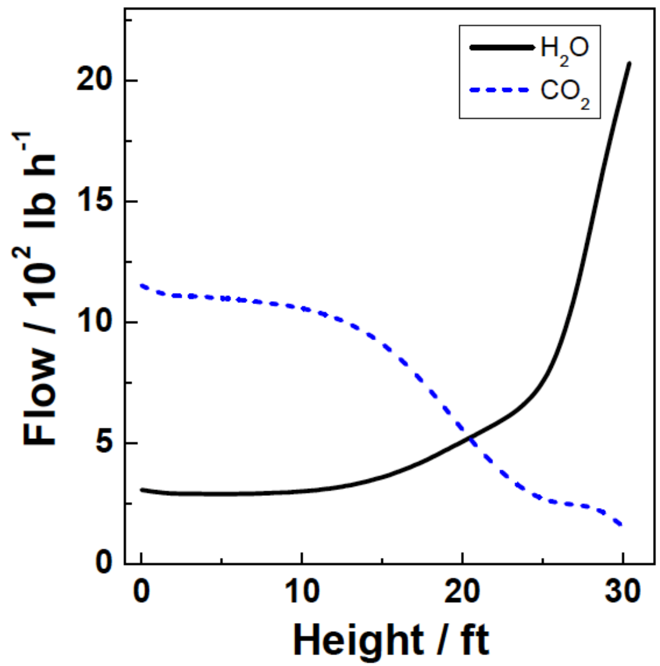


Commercially used in other organic/water separations.



Advanced Stripping -- Secondary Vapor Generation Point





Temperature (left) and flow (right) conditions inside a stripping column. Towards the top of the column, the temperature will rise and significant energy will be expended to vaporize water (lower CO_2/H_2O ratio).

Unique Facility -- 30 L/min Small Bench Unit

Coal-Derived Flue Gas-based 0.1 MWth CO_2 Capture Unit

Project Team

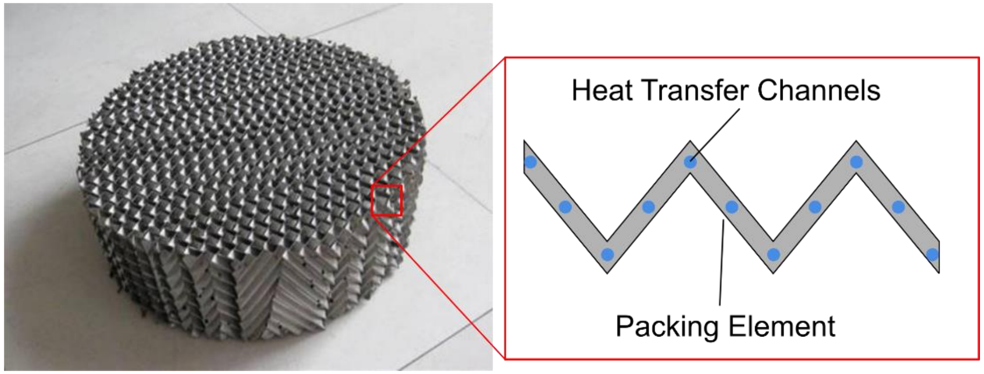
Activity Leaders	Tasks
James Landon (UKy-CAER)	• Task 1, 3, 4, 5, 6, 7, 8 – Project Management and Reporting, Zeolite Membrane, Long-Term Testing Validation
Kunlei Liu (UKy-CAER)	• Task 1, 4, 5, 6 – Project Coordination, budgeting, Engineering Support
Fan Zhen (UKy-CAER)	• Task 5, 6, 9 – Stripper Modification, Process Simulation
Du Nguyen (LLNL)	• Task 2, 6 – Fabrication of Smart Packing Material
Richard Ciora (MPT)	• Task 3, 4, 6, 7 – Membrane Fabrication and Scale-up
Andrew Sexton (Trimeric)	• Task 9 – Techno-Eco Analysis and Cost Methodology
Clay Whitney (SMG)	• Task 10 – EH&S and Risk Assessment

Project Objective

Developing transformative post-combustion CO_2 capture through:

1. 3-D printed two-channel structured packing material to control the absorber temperature profile
2. Zeolite membrane dewatering unit capable of >15% dewatering of the carbon-rich solvent prior to the stripper
3. Two-phase flow heat transfer prior to the stripper providing a secondary point of vapor generation

Tasks – Heat Transfer Packing



- Heat transfer packing material will be designed and printed by LLNL
- A vendor will be identified for scale-up
- Testing will take place in the small and large bench units

<u>Associated Tasks</u>:

<u>Task 2</u>: 3-D Printed Packing Material for Absorber

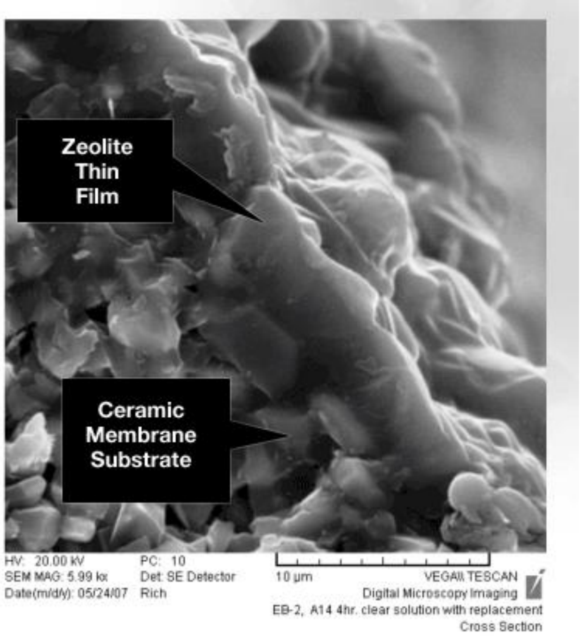
<u>Task 4</u>: 30 L/min CO_2 Capture Bench Unit Evaluation

<u>Task 6</u>: 0.1 MWth Post-Combustion CO_2 Capture Facility Evaluation

Tasks – Zeolite Membrane Module

Zeolite Y membrane can stably dewater amine process streams for extended time periods without fouling

The packing density will be increased through alternative zeolite supports and packing arrangement.



Associated Tasks:

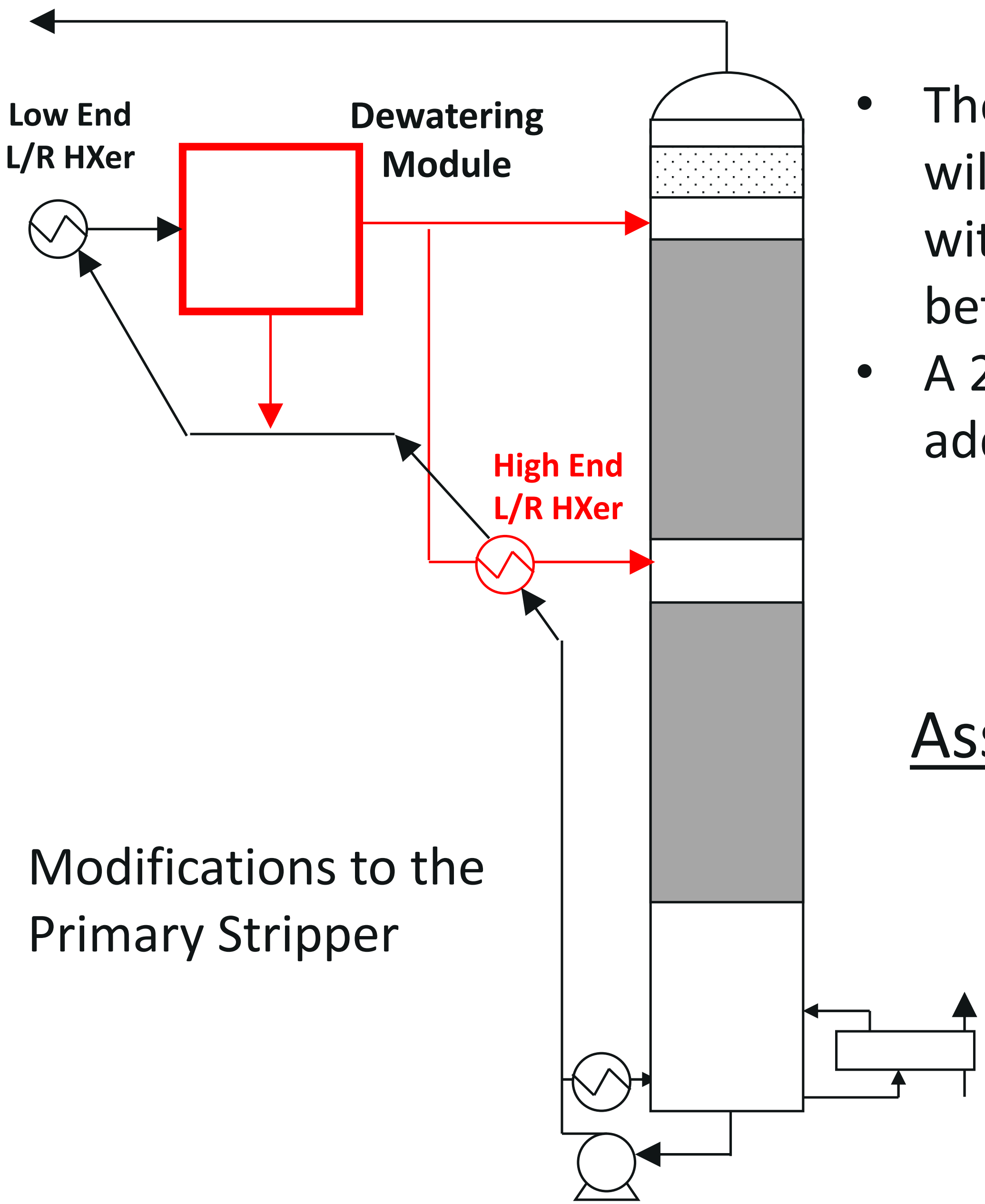
Task 3: Zeolite Dewatering Module Development and Fabrication

Tasks 4 & 6: Bench Unit Evaluations

Task 7: High Packing Density and Performance Zeolite Y Membranes

Task 8: Composite Zeolite and Alternative Dewatering Membranes

Tasks – Stripper Modification



- The existing L/R heat exchanger will be split into two sections with a dewatering membrane in between
- A 2-ft section of packing will added to stripper

Modifications to the Primary Stripper

Associated Tasks:

Task 6: 0.1 MWth Post-Combustion CO_2 Capture Facility Evaluation

Task 9: Techno-Economic Analysis

Project Budget – Resource Load

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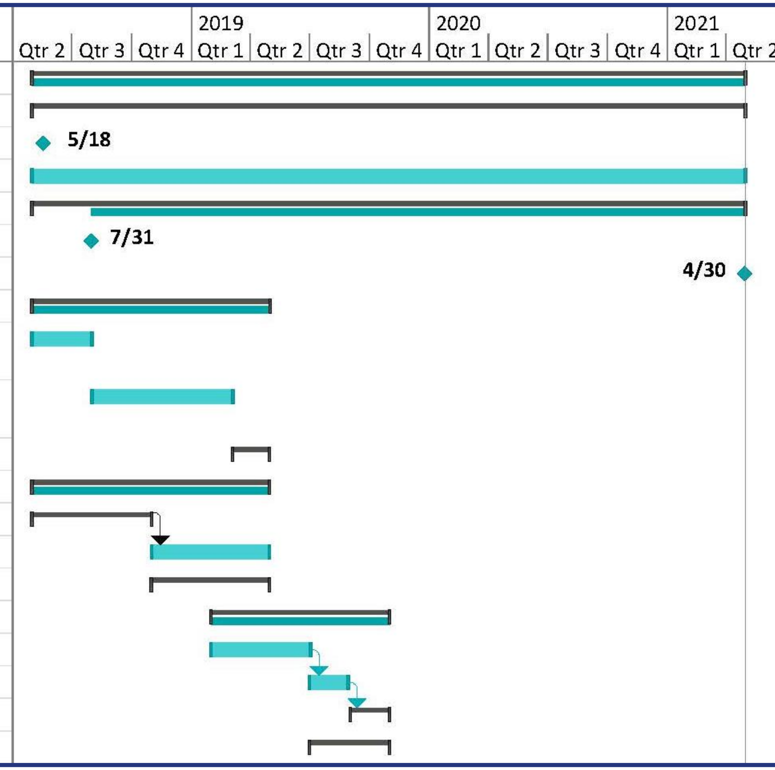
Resource Loaded Schedule				
Task	Task Name	Start	Finish	Task Cost
1	Project Management and Planning	5/1/2018	4/30/2021	$411,574
2	3-D Printed Packing Material for Absorber	5/1/2018	5/1/2019	$322,605
3	Zeolite Dewatering Module Development and Fabrication	5/1/2018	4/30/2019	$584,592
4	30 L/min CO_2 Capture Bench Unit Evaluation	1/31/2019	10/31/2019	$615,320
5	Test Plan Development	7/1/2019	10/31/2019	$63,839
6	Evaluation of Proposed Technique at 0.1 MWth Post-Combustion CO_2 Capture Facility	11/1/2019	4/30/2021	$968,190
7	High Packing Density and Performance Zeolite Y Membranes	10/31/2019	7/31/2020	$274,417
8	Composite Zeolite and Alternative Dewatering Membranes	7/31/2020	1/31/2021	$137,209
9	Techno-Economic Analysis	4/30/2020	4/30/2021	$189,026
10	Topical Report Preparation and Submission	11/2/2020	4/30/2021	$167,477

Project Schedule – Budget Period 1

Task Name	Start	Finish
1 Project Management and Planning	5/1/18	4/30/21
1.1 Task Management and Execution	5/1/18	4/30/21
1.1.1 Project Kickoff Meeting Held	*5/18/18*	*5/18/18*
1.2 Update PMP	5/1/18	4/30/21
1.3 Briefings and Reports	5/1/18	4/30/21
1.3.1 Technology Maturation Plan	*7/31/18*	*7/31/18*
1.3.2 Project Final Report Complete	*4/30/21*	*4/30/21*
2 3-D Printed Packing Material for Absorber	5/1/18	5/1/19
2.1 Identification of Additive Manufacturing Compatible Heat Transfer Materials	5/1/18	7/31/18
2.2 Design and Fabrication of Packing Material using Additive Manufacturing	8/1/18	3/5/19
2.3 Manufacturer Identification and Technology Transfer	3/5/19	4/30/19
3 Zeolite Dewatering Module Development and Fabrication	5/1/18	4/30/19
3.1 Membrane Synthesis Optimization	5/1/18	10/31/18
3.2 Large-batch Synthesis of Zeolite Y Membranes	11/1/18	4/30/19
3.3 Design of Membrane Module	10/31/18	4/30/19
4 30 L/min CO2 Capture Bench Unit Evaluation	1/31/19	10/31/19
4.1 Advanced Structured Packing Study	1/31/19	7/2/19
4.2 Integration and Testing of Zeolite Y Module	7/1/19	8/29/19
4.3 Possible Modification/Improvement Identification	9/2/19	10/31/19
5 Test Plan Development	7/1/19	10/31/19

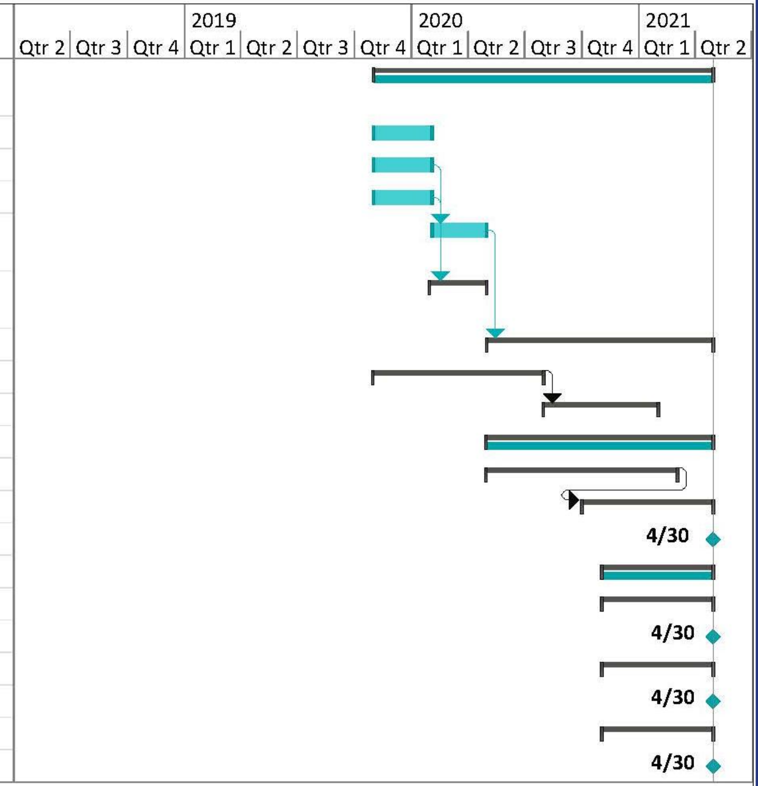


Budget Period 1 Summary:

1. Printed packing material and zeolite membrane development
2. Construction and verification testing of 3-D heat-transfer packing material in the absorber and zeolite dewatering module prior to the stripper in UKy-CAER's 30 L/min small bench CO_2 capture unit
3. Test Plan Development for 0.1 MWth large bench CO_2 capture unit

Project Schedule – Budget Period 2

Task Name	Start	Finish
6 Evaluation of Proposed Technique at 0.1 MWth Post-Combustion CO2 Capture Facility	11/1/19	4/30/21
6.1 Stripper and Auxiliary Facility Modification and Retrofit	11/1/19	2/2/20
6.2 Packing Design Update and Acquisition of Packing	11/1/19	2/2/20
6.3 Fabrication of Zeolite Y Membrane Module	11/1/19	2/2/20
6.4 Installation and Verification Studies of Advanced Packing Material	2/3/20	4/30/20
6.5 Installation and Verification Studies of Zeolite Y Membrane Module	1/30/20	4/30/20
6.6 1000-hour Long-term Operation	5/1/20	4/30/21
7 High Packing Density and Performance Zeolite Y Membranes	10/31/19	7/31/20
8 Composite Zeolite and Alternative Dewatering Membranes	7/31/20	1/31/21
9 Techno-Economic Analysis	4/30/20	4/30/21
9.1 Modeling	4/30/20	3/3/21
9.2 Techno-economic Analysis	10/1/20	4/30/21
9.2.1 TEA complete	*4/30/21*	*4/30/21*
10 Topical Report Preparation and Submission	11/2/20	4/30/21
10.1 State Point Data Table	11/2/20	4/30/21
10.1.1 State Point Data Table complete	*4/30/21*	*4/30/21*
10.2 Technology Gap Analysis	11/2/20	4/30/21
10.2.1 TGA complete	*4/30/21*	*4/30/21*
10.3 Environmental, Health, and Safety (EH&S) Assessment	11/2/20	4/30/21
10.3.1 EH&S complete	*4/30/21*	*4/30/21*



<u>Budget Period 2 Summary</u>:

1. Retrofit of UKy-CAER's 0.1 MWth CO_2 capture large bench unit
2. Integration and long-term testing of packing material, zeolite module, and modified stripper operation in 0.1 MWth unit
3. Higher performance zeolite membrane module

Project Management Plan – Success Criteria

Decision Point	Date	Success Criteria
Completion of Budget Period 1	10/31/2019	1. Peak Absorber Temperature Reduced by >10 °C Confirmed 2. Zeolite Y Membranes with Fluxes >10 kg/m^2/h Confirmed at Rejection Rates of >90% 3. Dewatering Zeolite Y Module Design Complete with >200 m^2/m^3 4. Test Plan Complete for 0.1 MWth Capture Unit
Project Completion	4/30/2021	1. Stripper Heat Integration Provides >10% Energy Savings on 0.1 MWth Capture Unit 2. Long-Term Energy Savings of >15% from 1000-hour Process Study 3. Dewatering Membrane Packing Density Increase to >400 m^2/m^3 4. Aspen Model for Entire Integrated System 5. TEA Complete for Integrated Process 6. EH&S Assessment Complete for Integrated Process 7. Updated State Point Data Table for Membrane 8. Technology Gap Analysis Complete

Project Risk Management

Risk Assessment, Management Mitigation and Response Strategies.				
Description of Risk	TRL	Probability	Impact	Risk Management Mitigation and Response Strategies
Management Risks				
Subcontract Agreement Delay		L	M	Dedicated UK staff will be identified
Communication problems among parties involved		L	M	Careful coordination, routine meeting with entire project team
Resource Risks				
Project Cost Overrun		L	H	Project team assistance with additional cost share provided by UKRF and CMRG
Project Schedule Overrun		L	M	Proactive planning, no cost extension

Project Risk Management

Risk Assessment, Management Mitigation and Response Strategies.				
Description of Risk	TRL	Probability	Impact	Risk Management Mitigation and Response Strategies
Technical Risks				
Dewatering Membrane Flux too Low	3	M	M	• Relocate the membrane to high-temperature site • Increase the rejected pressure • Alternative zeolite-type such as T-zeolite
Liquid/Gas Contact Impeded by Packing Heat Transfer Structure	3	L	M	• Modify the geometry • Surface treatment
3-D Printed Packing Material not Compatible for Application (poor heat transfer efficiency)	3	L	H	• Redesign internal surface with turbulence generator • Change metal material
Current Large CCS Strippers Configuration not Adequate for Split Feed	4	L	M	Modifications will be made to current vessel, or new vessel will be obtained

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Predicted Plant Efficiency, COE, and CO_2 Capture Cost

TOTAL (STEAM TURBINE) POWER, kWe	740,717
AUXILIARY LOAD SUMMARY, kWe	
Coal Handling & Conveying	510
Pulverizers	3,850
Sorbent Handling & Reagent Preparation	1,260
Ash Handling	740
Primary Air Fans	1,810
Forced Draft Fans	2,770
Induced Draft Fans	10,700
SCR	70
Baghouse	100
Wet FGD	4,150
CO_2 Capture System Auxiliaries	13,681
CO_2 Compression	33,469
Miscellaneous Balance of Plant[2,3]	2,000
Steam Turbine Auxiliaries	400
Condensate Pumps	832
Circulating Water Pump	7,894
Ground Water Pumps	707
Cooling Tower Fans	4,087
Transformer Losses	2,569
TOTAL AUXILIARIES, kWe	91,599
NET POWER, kWe	649,118
Net Plant Efficiency (HHV)	33.55%
Net Plant Heat Rate (Btu/kWhr HHV)	10,169
Consumables	
As-Received Coal Feed (lb/hr)	565,820
Limestone Sorbent Feed (lb/hr)	57,835

	Case B12A	Case B12B	This Proposal
		90%	90%
COE ($/MWh, 2011$)	82.3	142.8	115.4
CO_2 TS&M Costs	0	9.6	8.2
Fuel Costs	24.6	30.9	29.6
Variable Costs	9.1	14.9	11.3
Fixed Costs	9.6	15.2	12.1
Capital Costs	39	72.2	54.1
COE (2011$/MWh) (excluding T&S)		133.2	107.2
CO_2 Captured, lb/MWh		1927	1632
Cost of CO_2 Captured ($/tonne CO_2)		66.6	44.8
Cost of CO_2 Captured ($/tonne CO_2) (excluding T&S)		58.2	33.6
Incremental COE		73.5%	40.3%
Reduction of Incremental COE from Case 12			45.2%
Reduction of COE from Case 12			19.2%

>19% COE reduction when compared to Case 12

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Acknowledgements

- DOE-NETL: David Lang, Lynn Brickett, José Figueroa
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- Duke Energy, LG&E-KU, EPRI, CMRG Members

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