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ADVANCED LOW ENERGY ENZYME-CATALYZED SOLVENT FOR CO_2 CAPTURE

Close Out Meeting
Project: DE-FE0004228
DOE-NETL; Pittsburgh, PA.

November 22, 2013

OUTLINE

- Project overview
- Results and lessons learned
  - Biocatalyst Coating Development (Tasks 2 & 3)
  - Lab-scale reactor studies (Tasks 4 & 5)
  - Model development data (Task 6.1)
  - Scaled-Up Demonstration (Tasks 7, 8, 9)
  - Techno-economic analysis (Tasks 6.2-6.5)
- Budget summary
- Success criteria

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PROJECT OVERVIEW

Participants, Duration, Funding

- **Project awardee, FFRDC, and Subcontract:**

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Pacific Northwest NATIONAL LABORATORY

Battelle The Business of Innovation

- **Enzyme Supply:**

novozymes® Rethink Tomorrow

- **Fabrication & Instrumentation; and Test Site:**

EPIC MOVING AMERICAN MANUFACTURING FORWARD

EMERSON

NATIONAL CARBON CAPTURE CENTER

- **Project: 36 months** **(Oct 2010 to Sept 2013)**
- **Funding:**

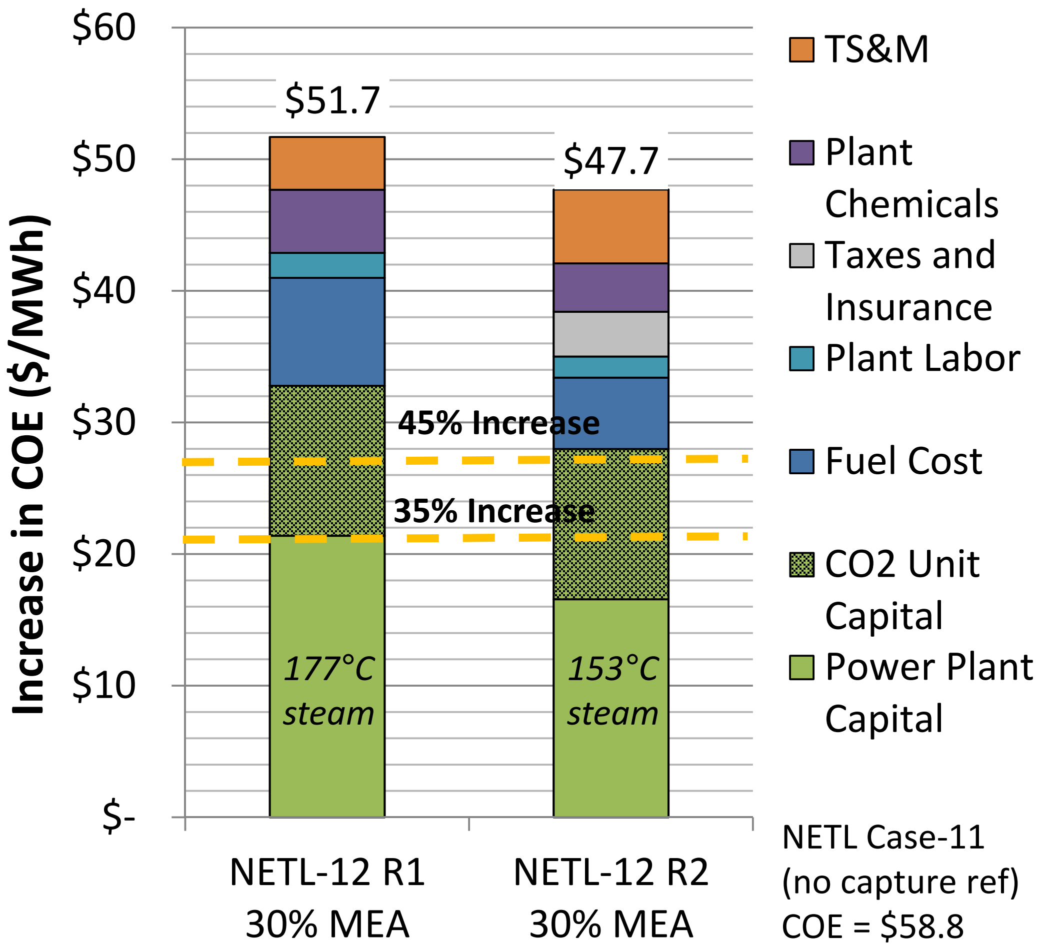
Total NETL Award (incl. FFRDC)	***$3,791,464***
Akermin cost share:	***3,047,194*** *(44.56%)*
Total:	***$6,838,658***

THE PROBLEM: REDUCE COST OF CAPTURE

DOE Goal: 90% capture, less than 35% increase in COE (20.6 $/MWh ICOE)

Key issues/opportunities:

- Incremental Power Plant Capital
  - Equivalent Work of Steam (re-boiler duty and temp.)
  - Parasitic Power (compression, fans, pumps)
- CO_2 Capture Unit Capital
  - Absorber
  - Stripper
  - OH Wash
  - DCC (flue gas cooler)
  - Cross-Exchanger
- Increased Fuel & Chemicals
  - Parasitic Power driven



Improving energy efficiency is key, impacts many areas; reducing extraction steam temperature improves efficiency/cost;

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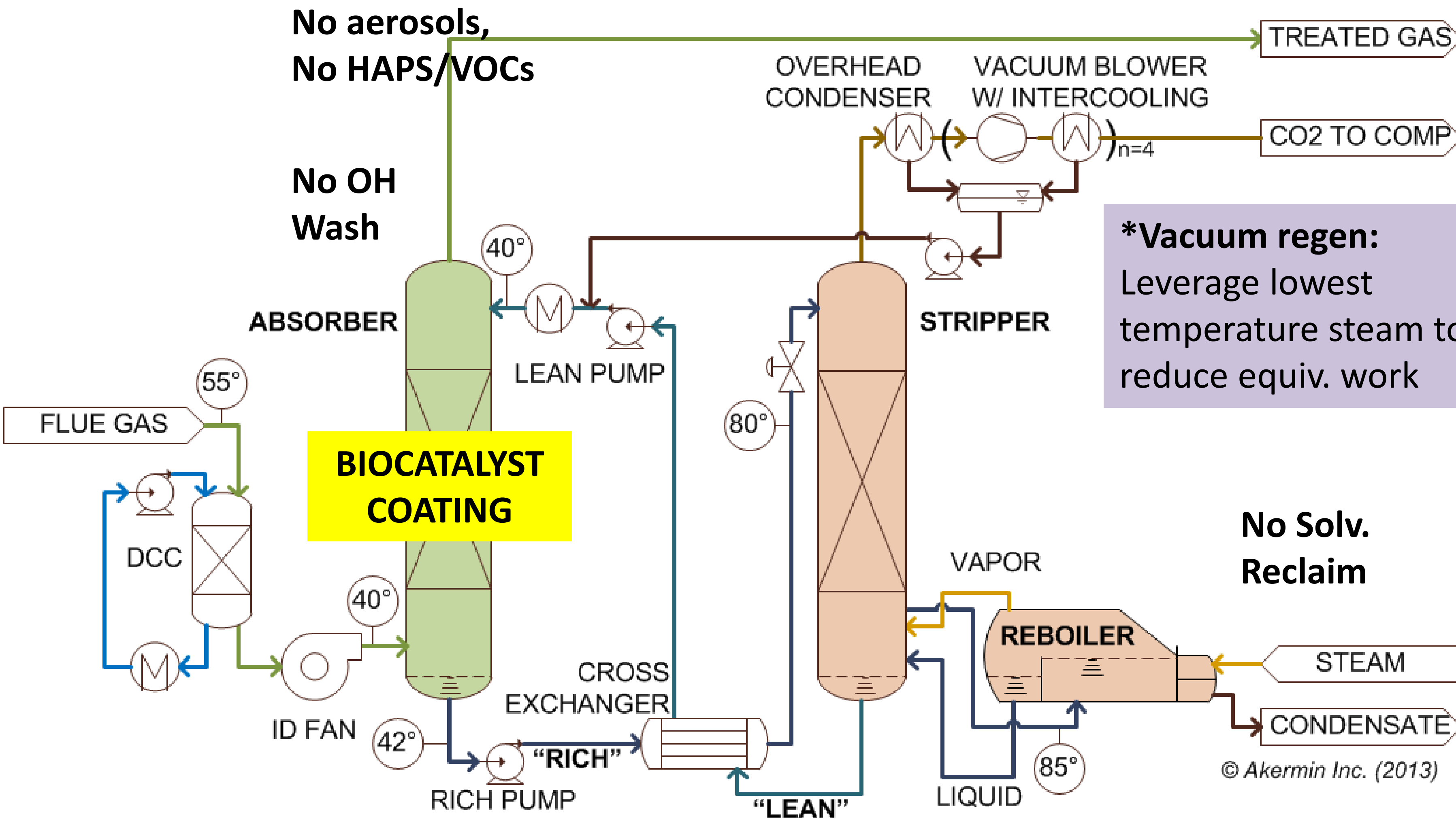
APPROACH: BIOCATALYST ENABLED SOLVENTS

This project: Biocatalyst coated packing, low temp regeneration of K2CO3



***Vacuum regen:**
Leverage lowest temperature steam to reduce equiv. work

Biocatalyst fixed in the absorber prevents denaturing in the stripper /reboiler

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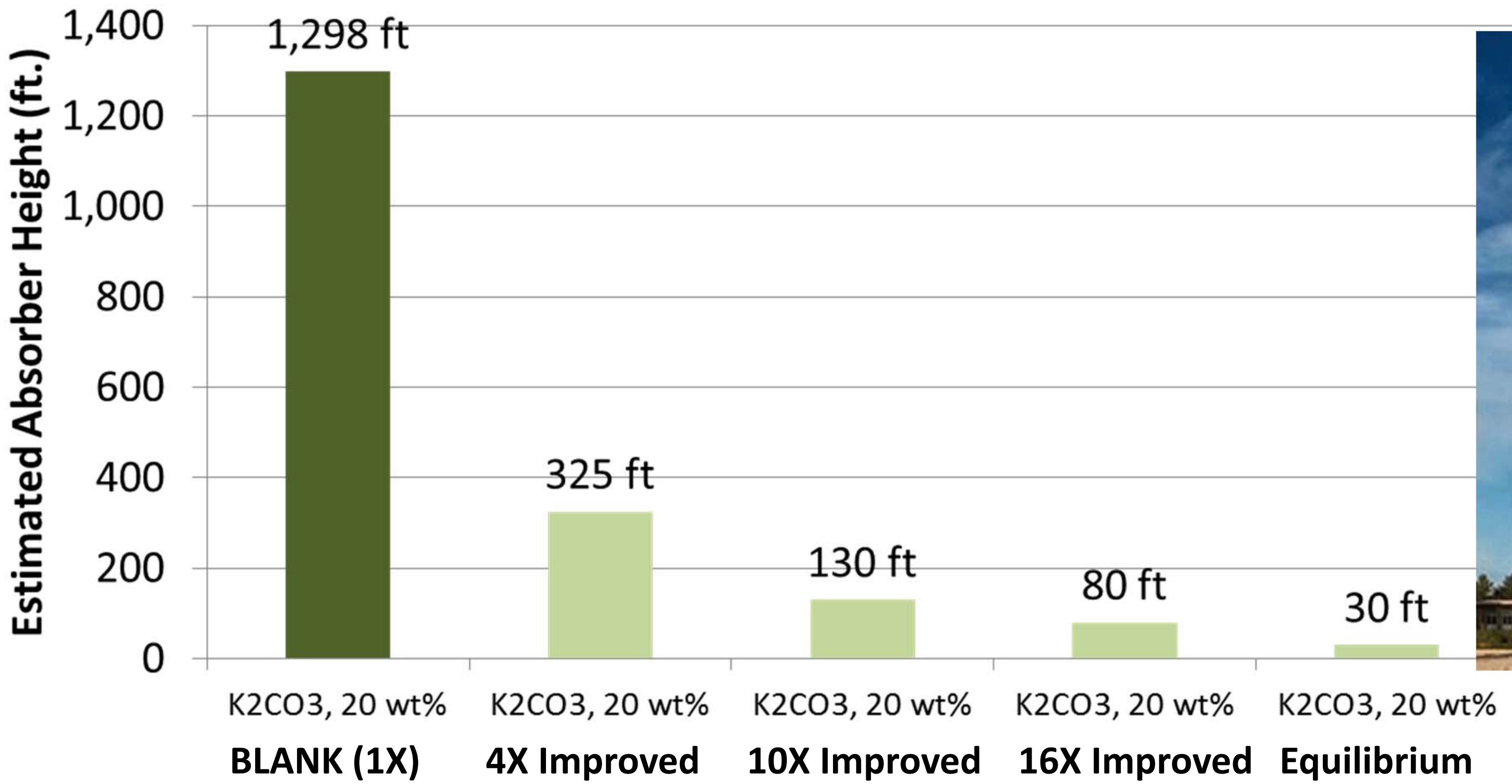
BIOCATALYST ENABLED

Reducing column height enables certain solvent systems to become feasible



Akermin catalyst technology reduces column heights to feasible range

BENEFITS TO PROGRAM: ENABLE SLOW, BENEFICIAL SOLVENTS

The most effective and scalable method of CO_2 capture from flue gas is via chemical reaction

Desired Characteristic	Baseline (Amines)	(one example) K_2CO_3
No amine aerosol emissions		X
No VOC emissions		X
No toxic air or liquid emissions		X
High Rate	X	
High/Low ΔH_{Rxn}	HIGH	LOW
Low regeneration energy potential		X
Oxidative stability		X
Low viscosity		X
Low corrosion		X
Low or No flue gas polishing needed		X

Catalyst broadens the choice of solvents to be used in CO_2 capture; Low temperature regeneration is complimentary to DOE portfolio

TECHNICAL CHALLENGES

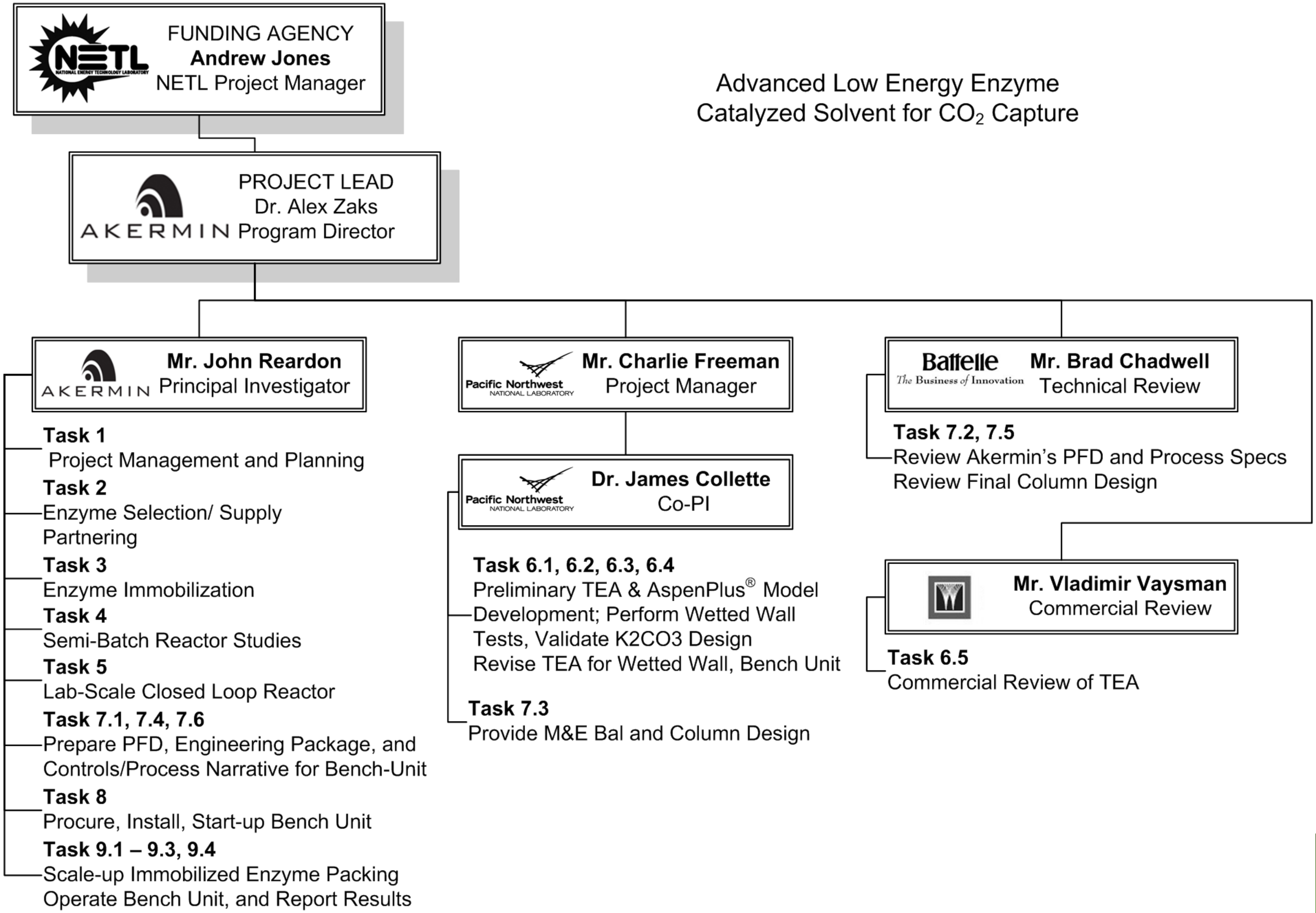
- Achieve long-term enzyme stability, minimize replacement costs
- Minimize inhibition by flue gas impurities
- Maximize enzyme retention, minimize leaching
- Maximize activity (minimize diffusion resistance)

PROJECT OBJECTIVES

- Achieve >10X improvement in overall mass transfer coefficient
- Demonstrate 90% CO_2 capture in the bench scale unit
- Operate bench unit for six months, characterize the endurance performance of the biocatalyst delivery system
- Generate data to validate and refine simulation models to confirm key advantages
- Perform modeling and cost estimation to demonstrate how such a system would scale and cost-effectively integrate into an existing coal-fired power plant.

PROJECT ORGANIZATION, TASKS

Advanced Low Energy Enzyme Catalyzed Solvent for CO_2 Capture



RESULTS, DISCUSSION, LESSONS LEARNED

Biocatalyst Coating Development (Tasks 2 & 3)

BACKGROUND: CARBONIC ANHYDRASE

- A family of ubiquitous enzymes
- In nature interconvert carbon dioxide and bicarbonate to maintain acid-base balance and to help transport carbon dioxide out of tissues.
- MW ~ 30,000
- Active site contains Zn^{2+}
- CA accelerates hydration of CO_2 to bicarbonate

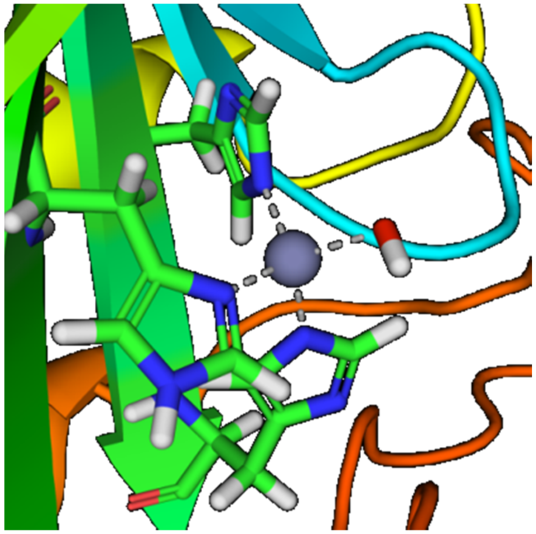
$$H_2O + CO_2 \overset{\textbf{CA}}{\rightleftharpoons} H^+ + HCO_3^-$$

- Base captures proton to complete reaction

$$B + H^+ \rightleftharpoons BH^+$$

- Tested CA from a variety of sources

Active site of CA



$k_{cat} = 10^6$/sec

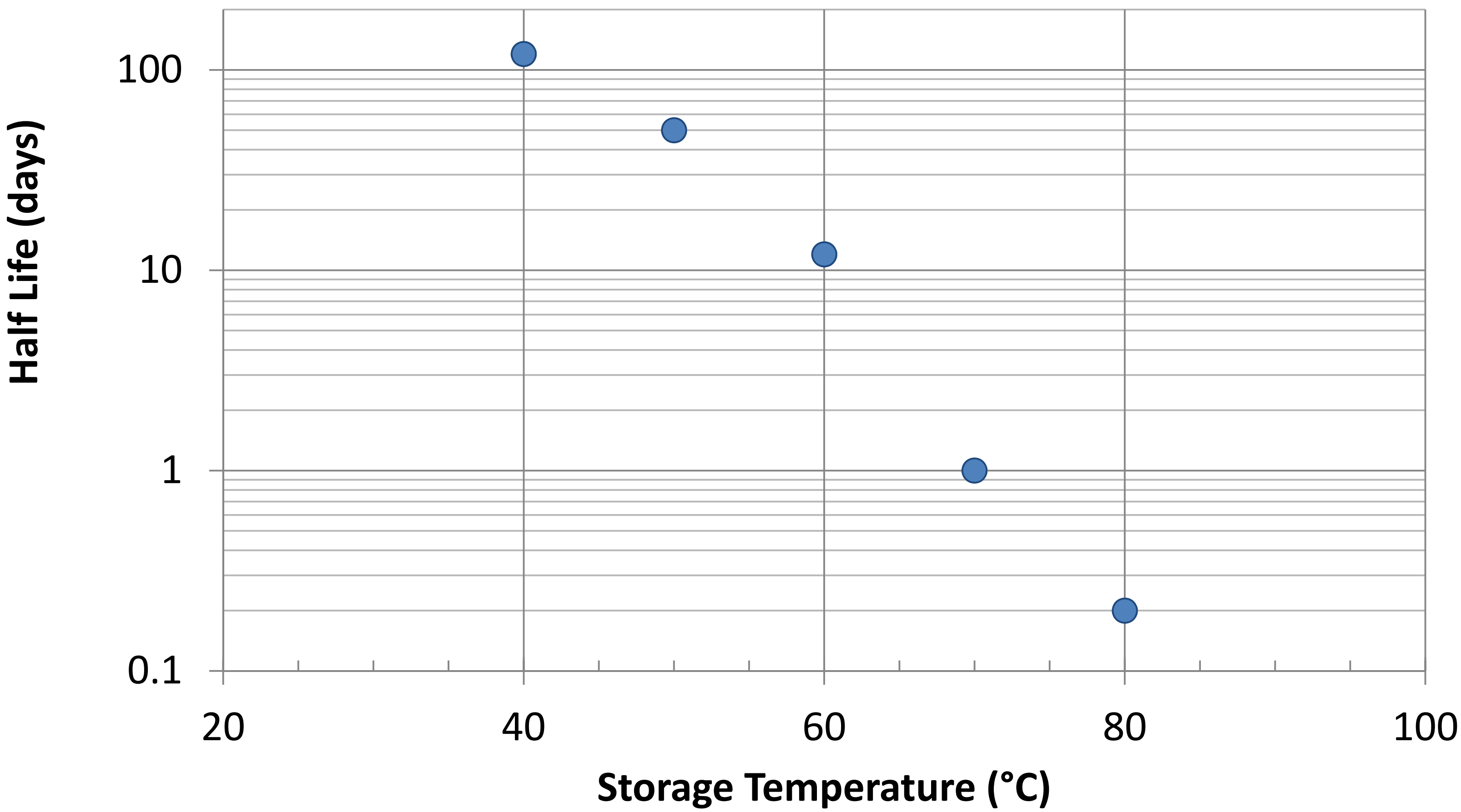
The approach is applicable to many basic solvent systems

COLLABORATION WITH NOVOZYMES

- CA from Novozymes was selected as top candidate
  - Highly active
  - Resistant to major impurities in flue gas
  - Thermostable
  - Resistant to high pH (9-10.5)
  - Few impurities
- Established a supply arrangement with Novozymes
- Ensured supply of sufficient quantity of enzyme to support development and demonstration studies

ENZYME HALF-LIFE WITH TEMPERATURE

Soluble enzyme half-life data at various temperature (interpolated from activity with time data)



Soluble enzyme half-life at 40°C: ~120 days; immobilization may extend lifetime; Further stabilization possible by genetic engineering of enzyme

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CA TOLERANT TO MOST FLUE GAS CONTAMINANTS

Inhibition Studies with Novozyme CA

Contaminant	Anticipated in flue gas (DOE FOA 000785)	Soluble Product	IC50 (mM)
NO_X	53 ppmv	Nitrate (NO_3^-)	~ 1000
		Nitrite (NO_2^-)	> 2000
SO_X	46 ppmv	Sulfate (SO_4^{-2})	> 500
		Sulfite (SO_3^{-2})	>100
Chloride	< 1ppm*	Chloride (Cl^-)	> 2000
Heavy Metals	1.3 ppbw	Mercury Hg^{+2}	0.14

*Expected to be negligible after caustic scrubber, not reported in DOE FOA 0785

Sulfate, sulfite, nitrate, nitrite, chloride : little or no inhibitory potency

DESIRED CHARACTERISTICS OF BIOCATALYST DELIVERY SYSTEM FOR CO_2 CAPTURE

- Provides protective environment against inactivation by temperature, solvents, and shear forces
  - Encapsulation/entrapment-based
- Compatible with commercial mass transfer devices
- Minimizes internal diffusional limitations
  - CO_2 permeable and highly porous support
- Low cost, scalable
  - Commercially available starting materials
  - Simple one/two-step protocol

Two approaches identified: micellar polymer and sol-gel based

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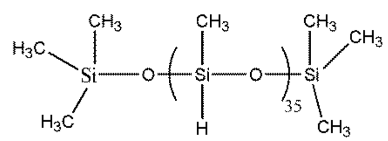
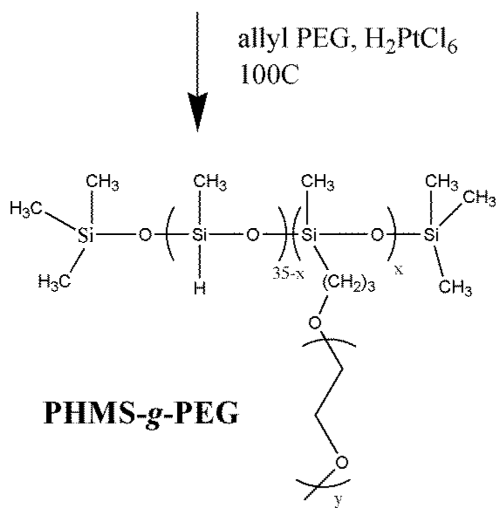
FIRST GENERATION IMMOBILIZATION APPROACH: MICELLAR POLYMERS WITH TAILORED PORE STRUCTURES

Micellar polymer formation:

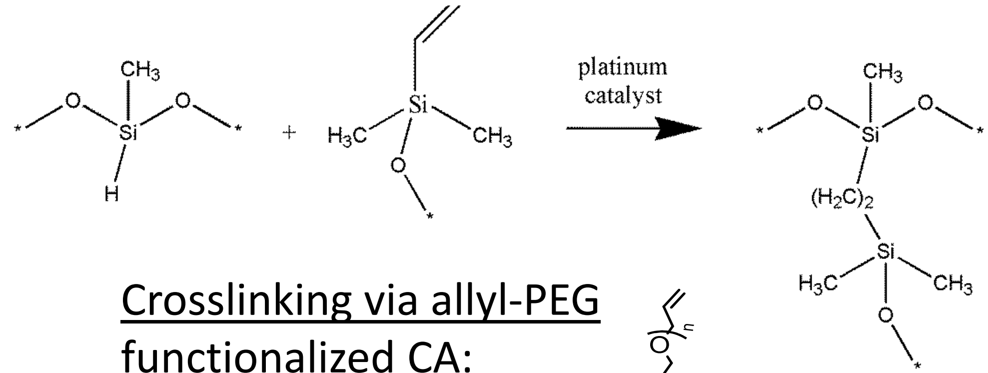


Poly(hydrogenmethylsiloxane), PHMS

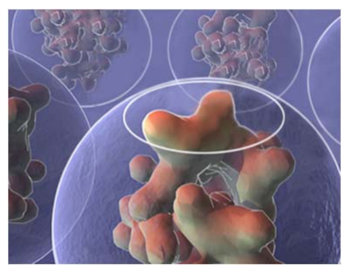


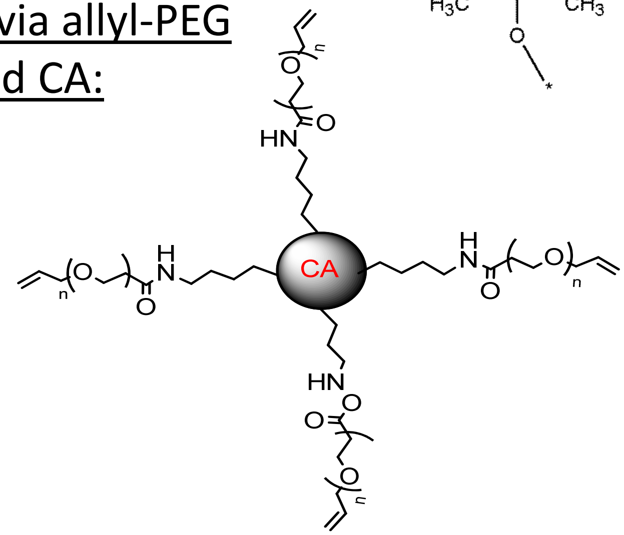
PHMS-*g*-PEG

Cross-linking via hydrosilylation:



Crosslinking via allyl-PEG functionalized CA:





High degree of enzyme retention was demonstrated with micellar polymer approach (~90%)

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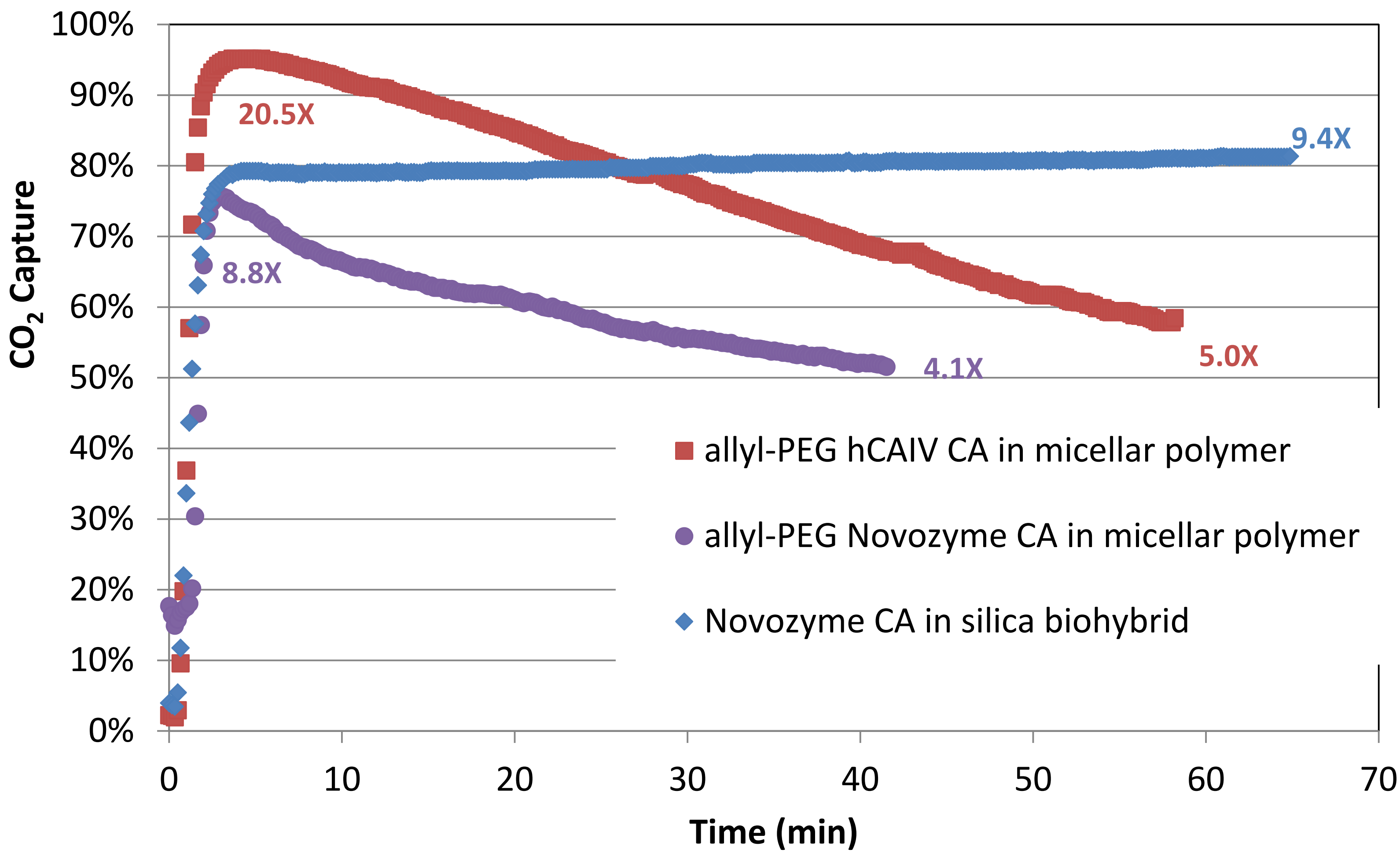
KINETICS OF CO_2 CAPTURE BY CA IMMOBILIZED IN MICELLAR POLYMERS AND SOL-GEL



CO_2 capture with CA in micellar polymer declines rapidly
Sol-gel immobilization appears to be a more promising approach

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IMMOBILIZATION, COATING AND DELIVERY OF ENZYME TO THE ABSORBER

Enzyme

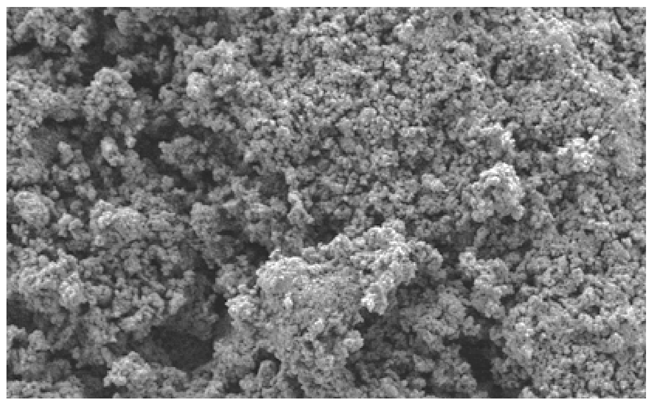
Solution of Silicon alkoxide and additives

Suspension (Sol)

Coating

Curing

Sulzer unit with immobilized CA

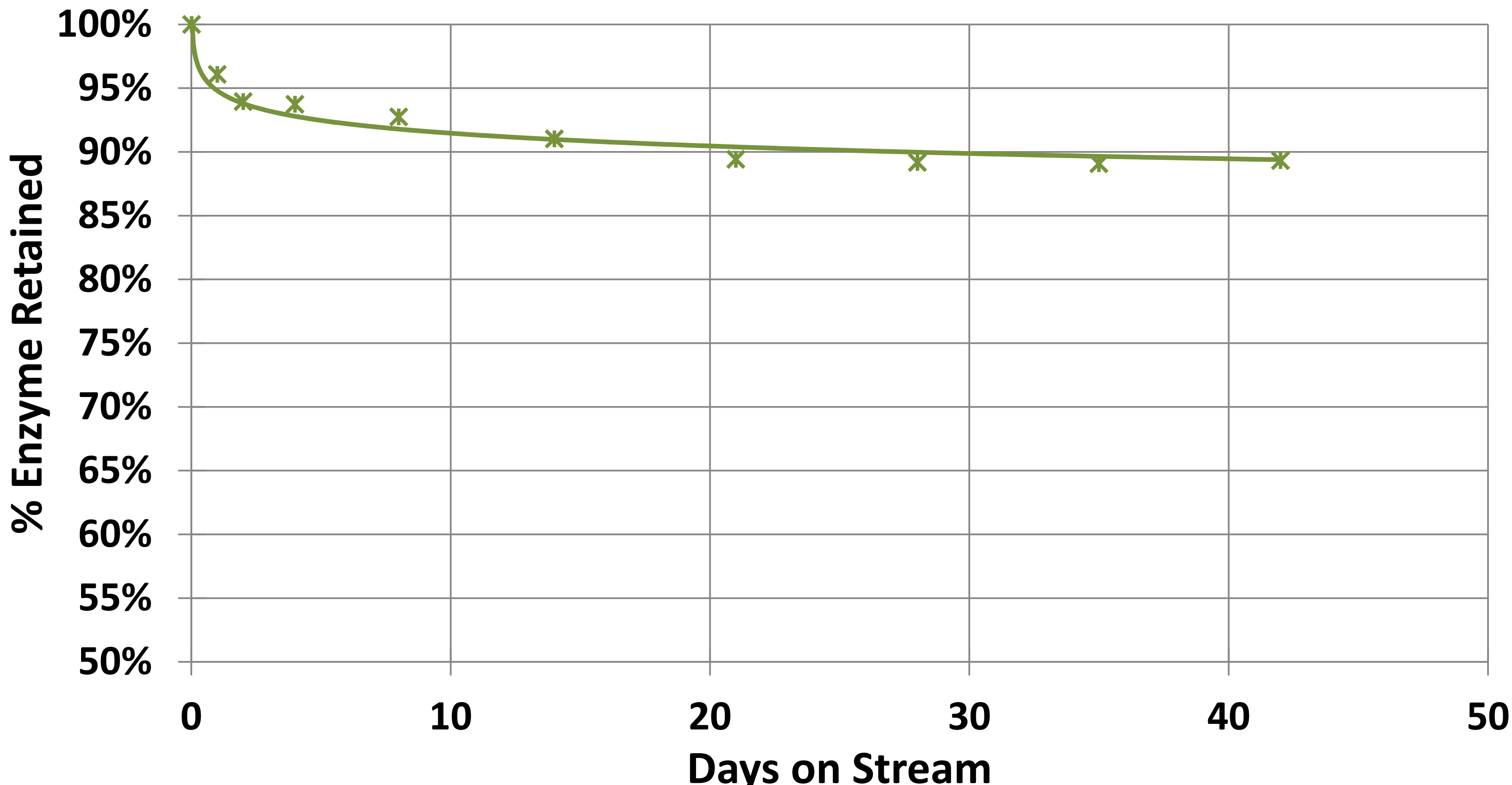


SEM IMAGE OF COATING

approach deposits CA at gas/liquid interface of commercial columns

MILESTONE (A1): >80% ENZYME RETENTION, AFTER 400 HRS IN CONTINUOUS LIQUID FLOW

Sol-gel encapsulated enzyme, continuous liquid flow test with leached enzyme quantified by HPLC



Milestone achieved in budget period one. Recent data review suggests leaching is complete after about 30 days and ~90% retained

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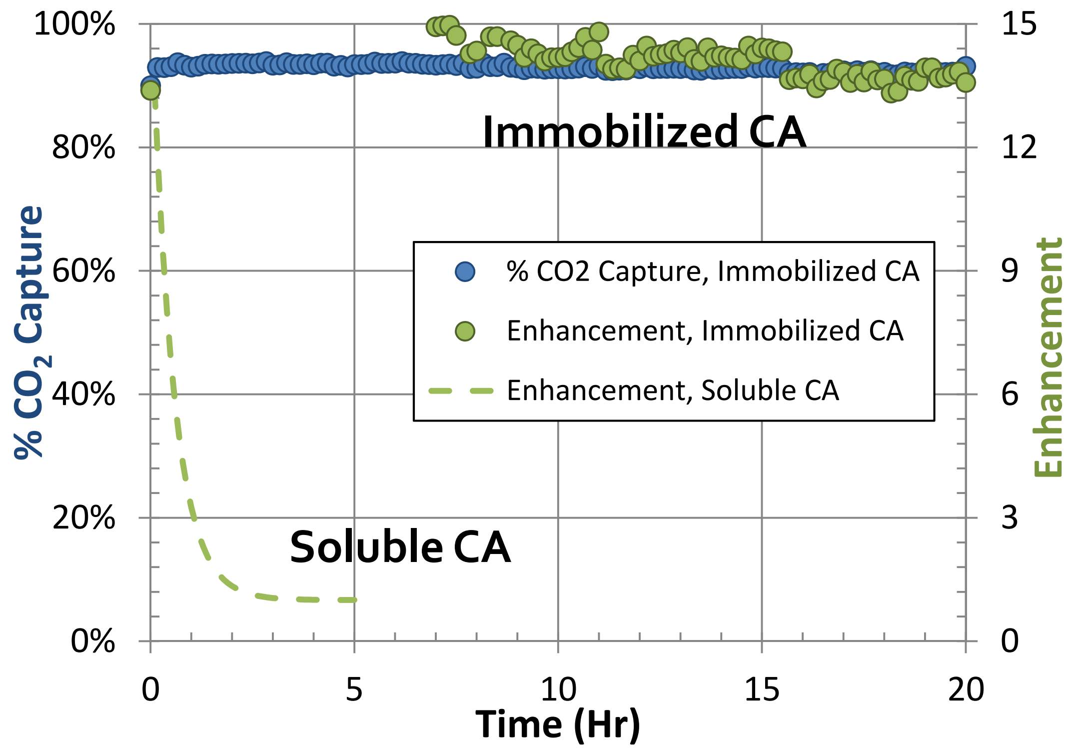
PERFORMANCE OF SOLUBLE AND SOL-GEL IMMOBILIZED ENZYMES

Closed-loop reactor

Performance of biocatalyst coated packing and soluble CA in closed-loop reactor with steam regeneration



15% CO_2; 20% carbonate (w/w) pH 10.1; p = 1 psig

10-15 fold acceleration with immobilized CA demonstrated

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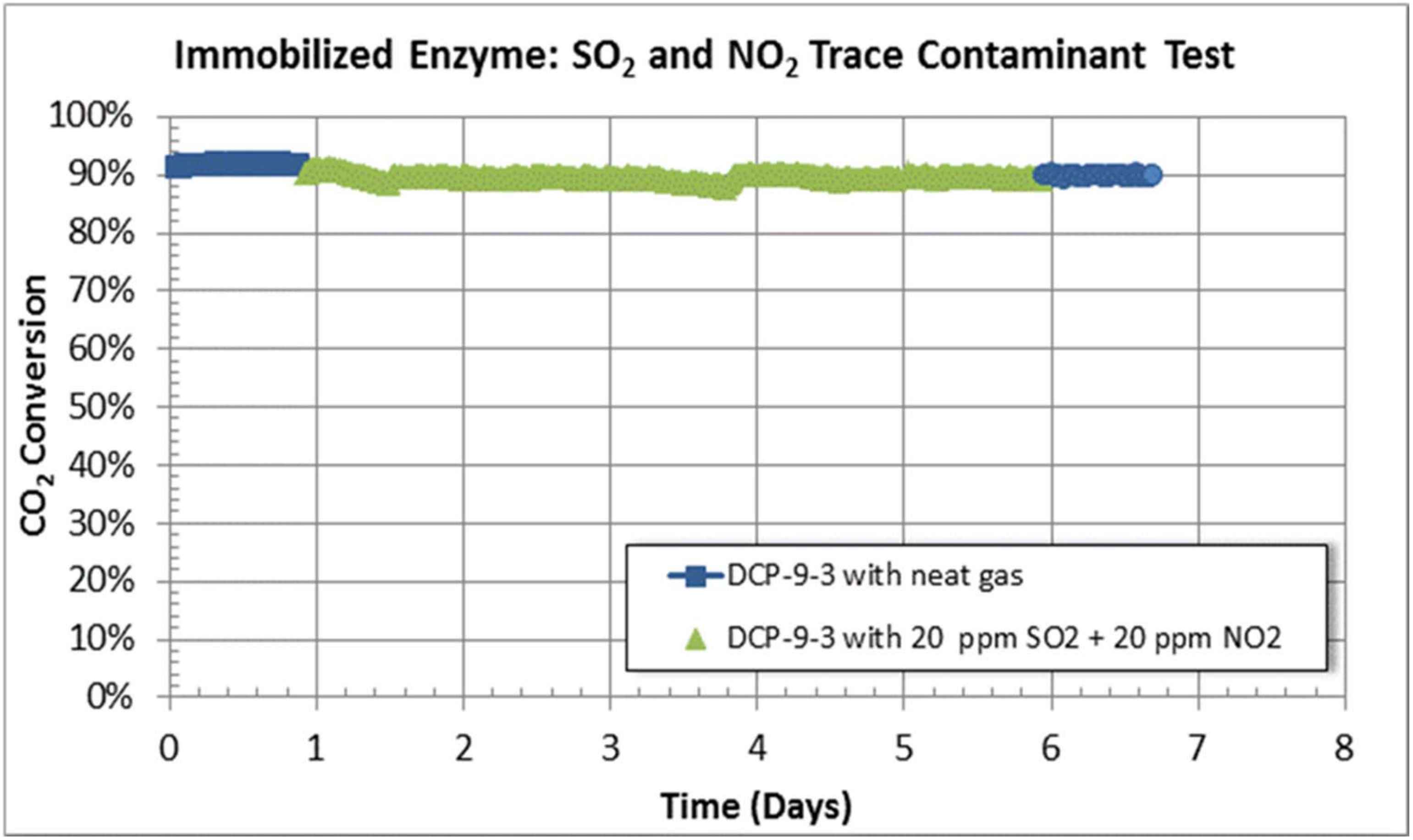
MILESTONE (A5): GAS-PHASE CONTAMINANTS

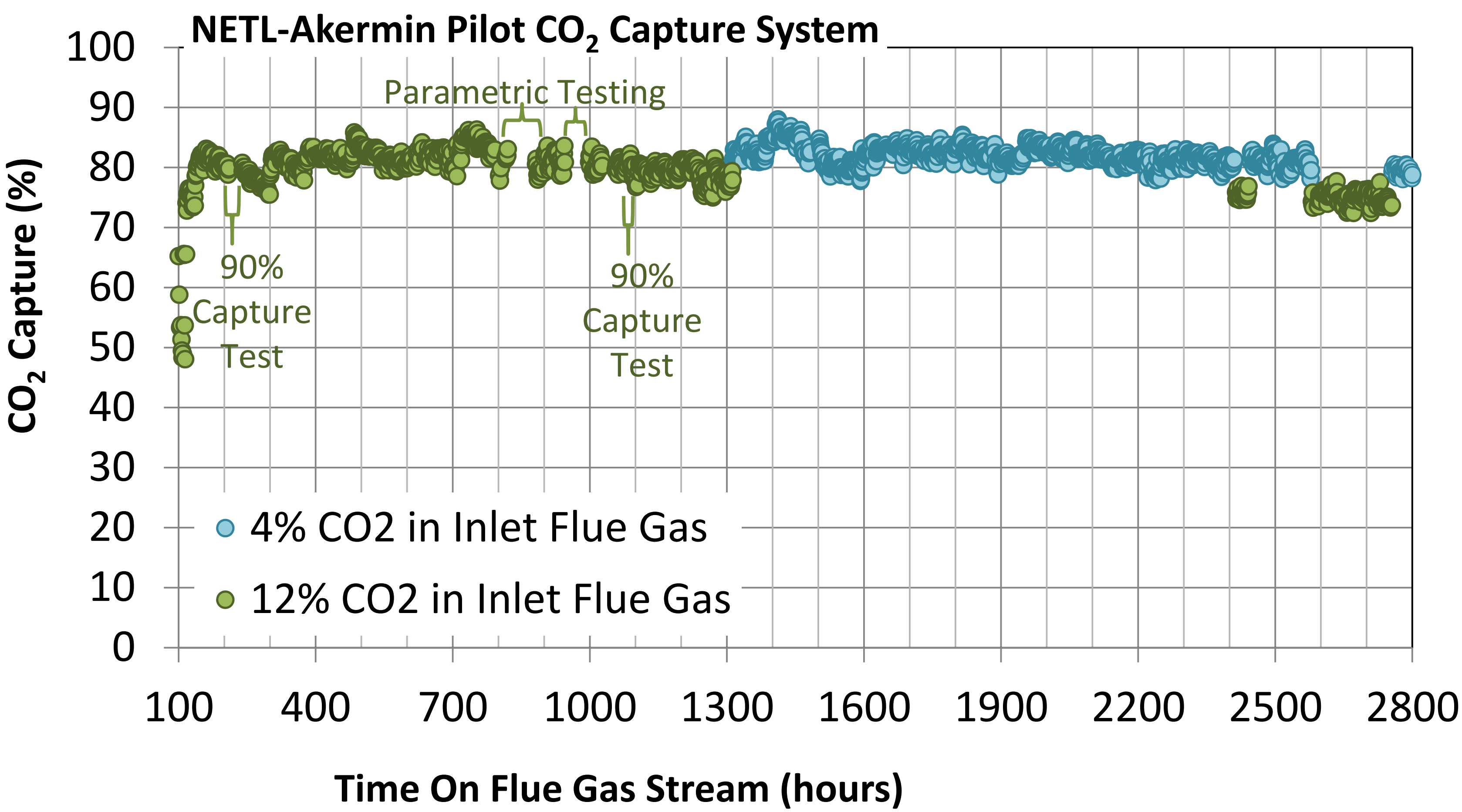
Trace contaminant testing with SO_x and NO_x mixtures (20 ppm each)
200 SCCM gas feed, 15% CO2 at 1.07 bara, 20 ml/min of 20% K2CO3 at 25% XCL.



sample had no loss in activity when exposed to a feed gas containing NO_2 and SO_2 and maintained 90% CO_2 capture for the duration

BENCH UNIT (K_2CO_3 W/ BIOCATALYST), THROUGH 10/3/13

Data at design flow (31.5 Nm^3/hr, 275 LPH, X_{CL} ~ 25%)



2800 Hrs On Stream @ 10/03/2013

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RESULTS, DISCUSSION, LESSONS LEARNED

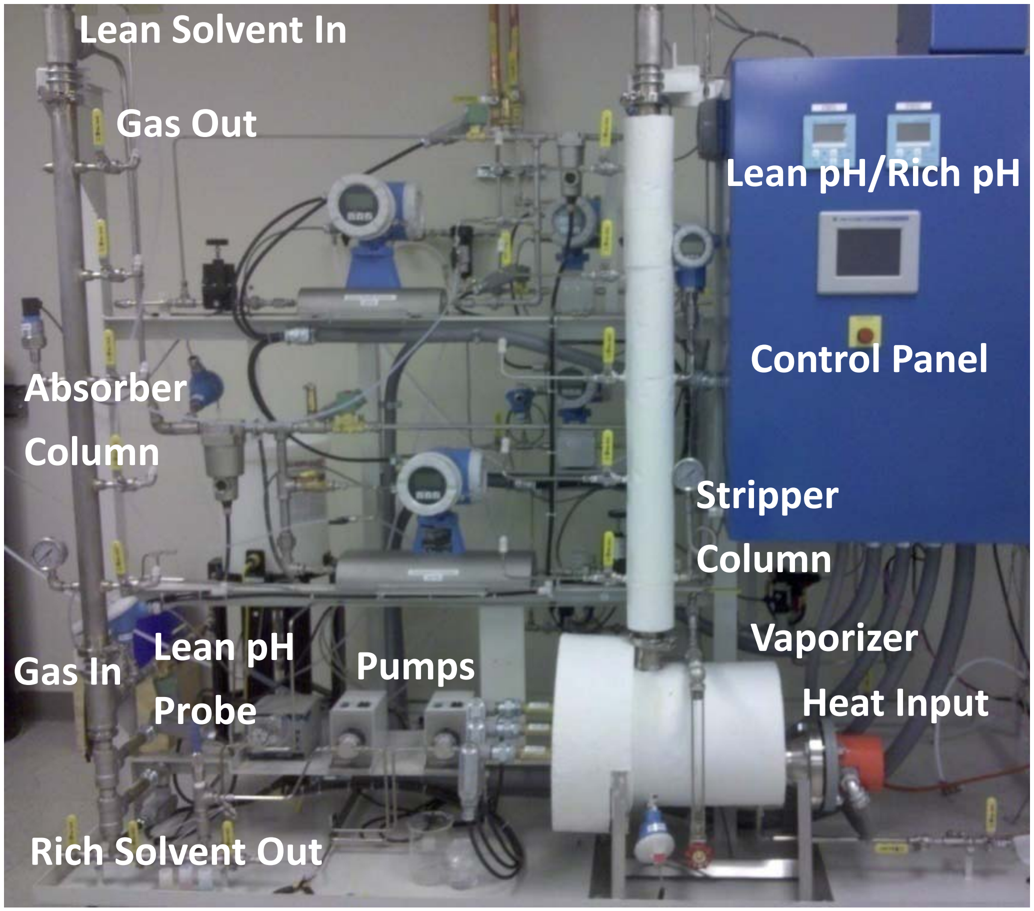
Lab-scale reactor studies (Tasks 4, 5)

Model development data (Task 6.1)

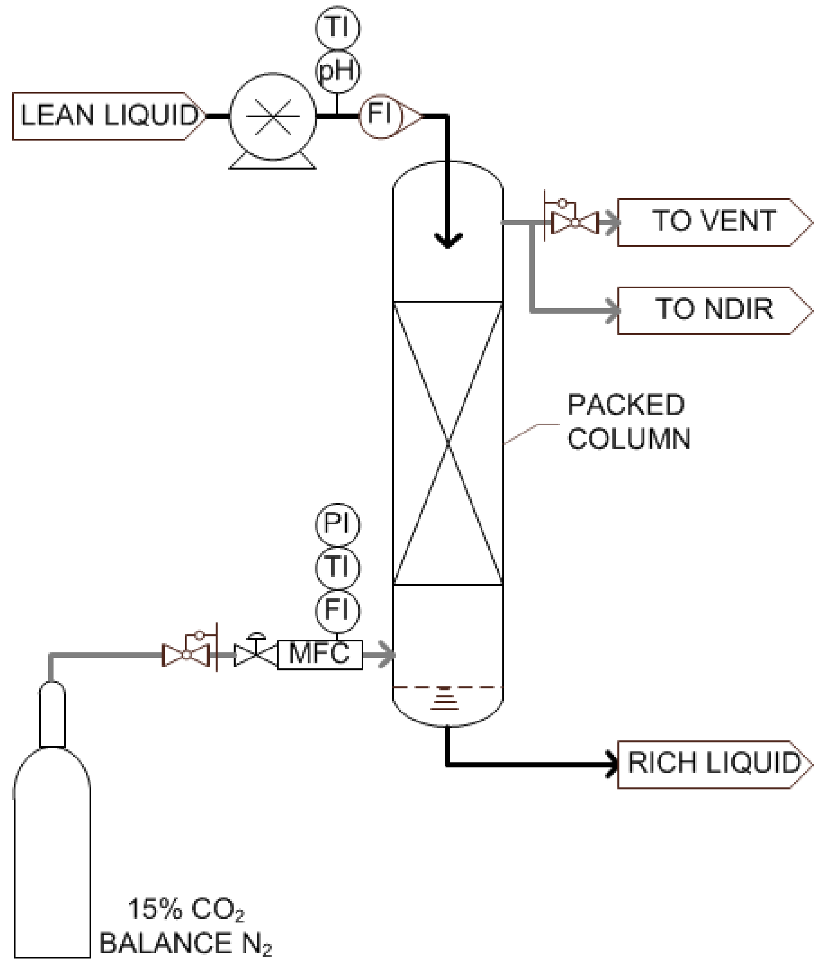
LAB-SCALE TEST REACTORS

Closed Loop Reactor (Structured Packing), and Single Pass Reactor (random packing)

CLOSED LOOP REACTOR



SINGLE PASS REACTOR



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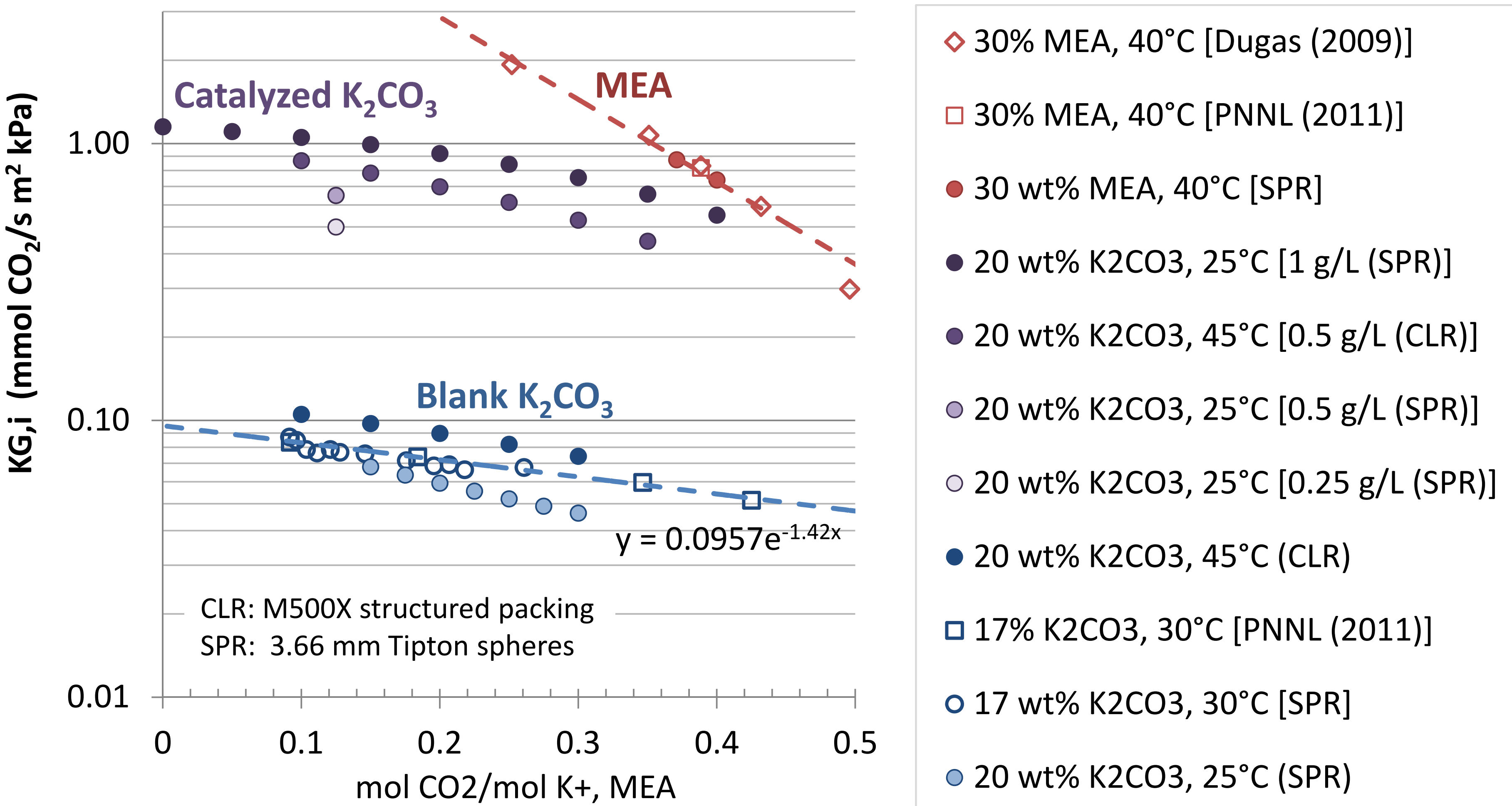
COMPARISON OF MASS TRANSFER COEFFICIENTS BLANK K_2CO_3, ENZYME ENHANCED K_2CO_3 AND MEA



Significant enhancements possible with 0.5 and 1 g CA/ L solution.

Trends with CO_2 loading similar in lab-reactor and WWC

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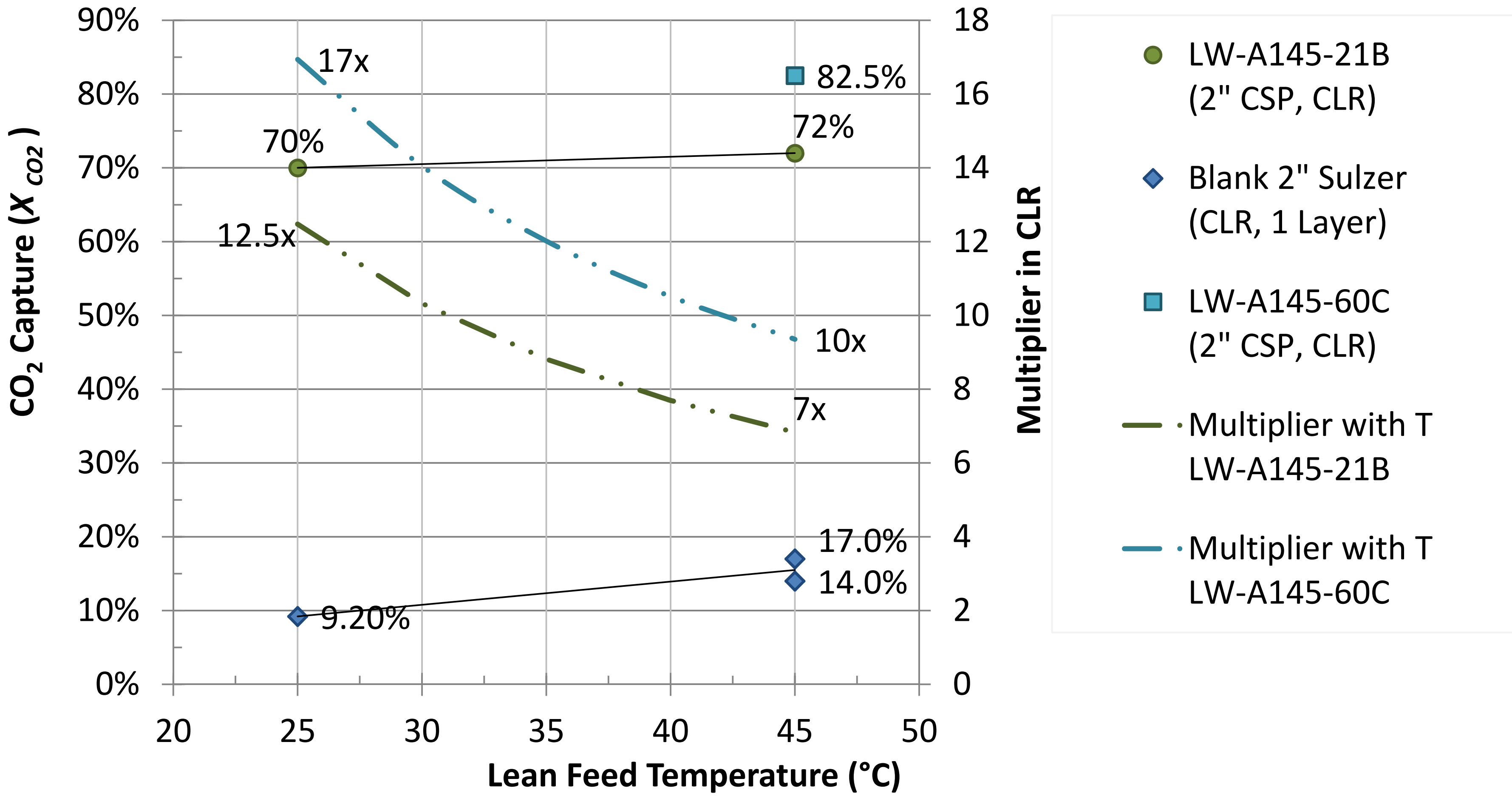
IMMOBILIZED ENZYME DATA, VARIOUS TEMPERATURES

When lean feed temperature is varied, blank is more thermally activated



Milestone (A3) met: >10x enhancement. Biocatalyst enhancement of 12.5 to 17x at 25°C, and 7 to 10x at 45°C

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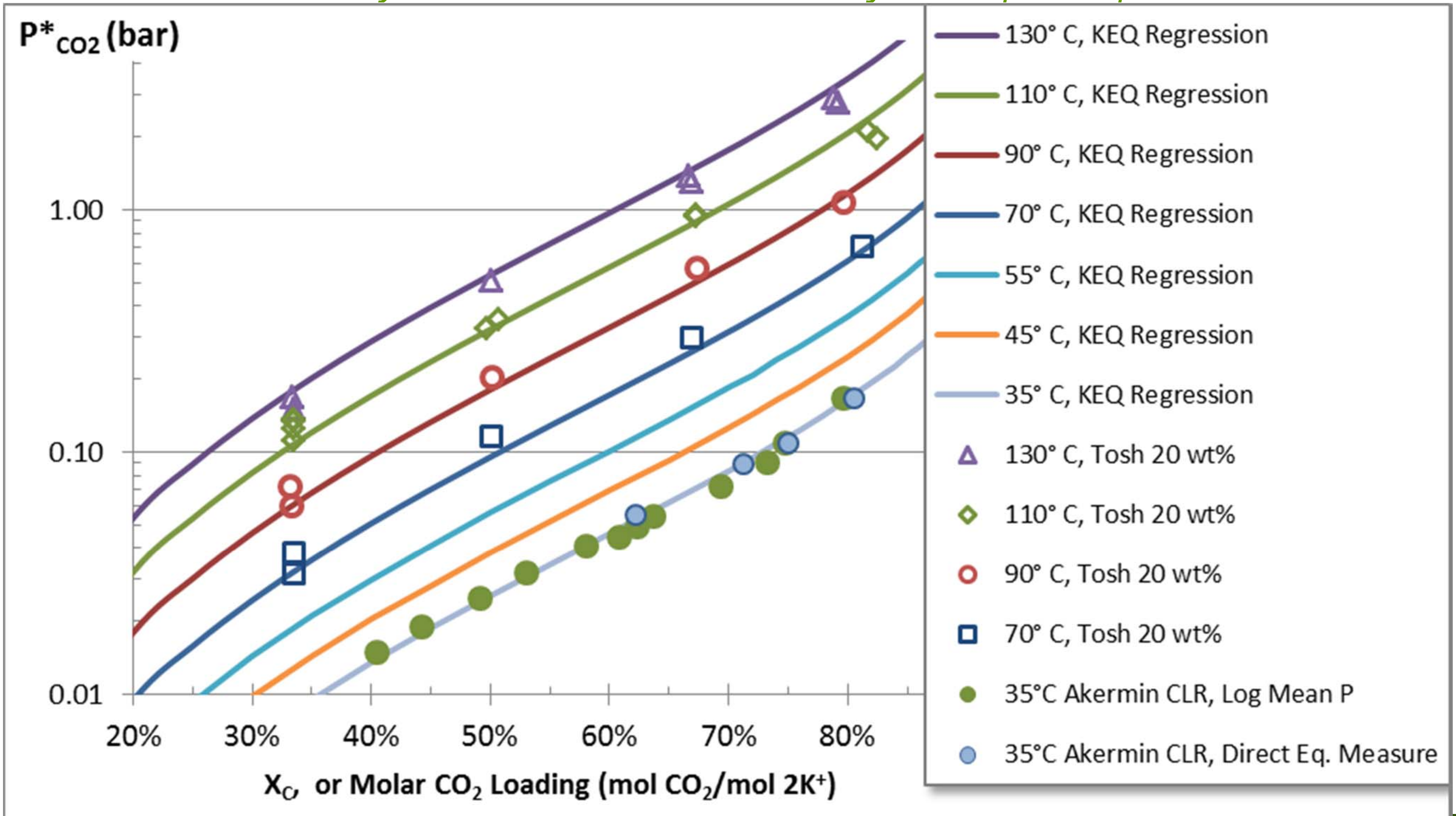
EQUILIBRIUM P_{CO2} DATA AND PREDICTIONS OVER K_2CO_3 SOLUTIONS

Literature and laboratory data show consistent model for CO2 partial pressure calculation



Aspen model was tuned and verified based on equilibrium data

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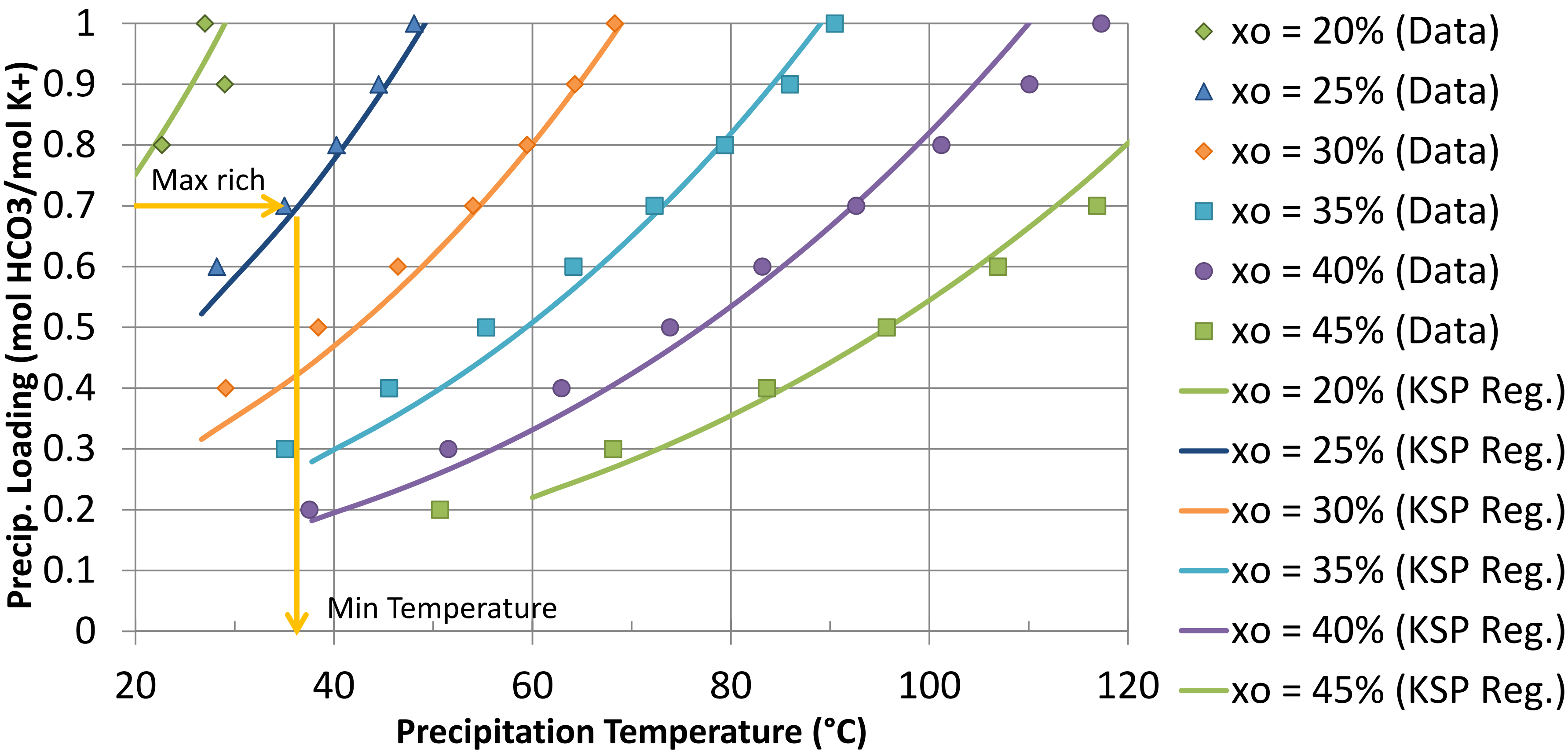
PRECIPITATION DATA

Literature (Akermin, Kohl and Nielsen) data for $KHCO_3$ precipitation used to develop K_{SP} equation



$$K_{SP} = 7.2923 + \frac{-2580.7}{T} + 0.6685\ \ln(T), \qquad T\ in\ K$$

Precipitation data entered in to Aspen model using K_{SP} regression

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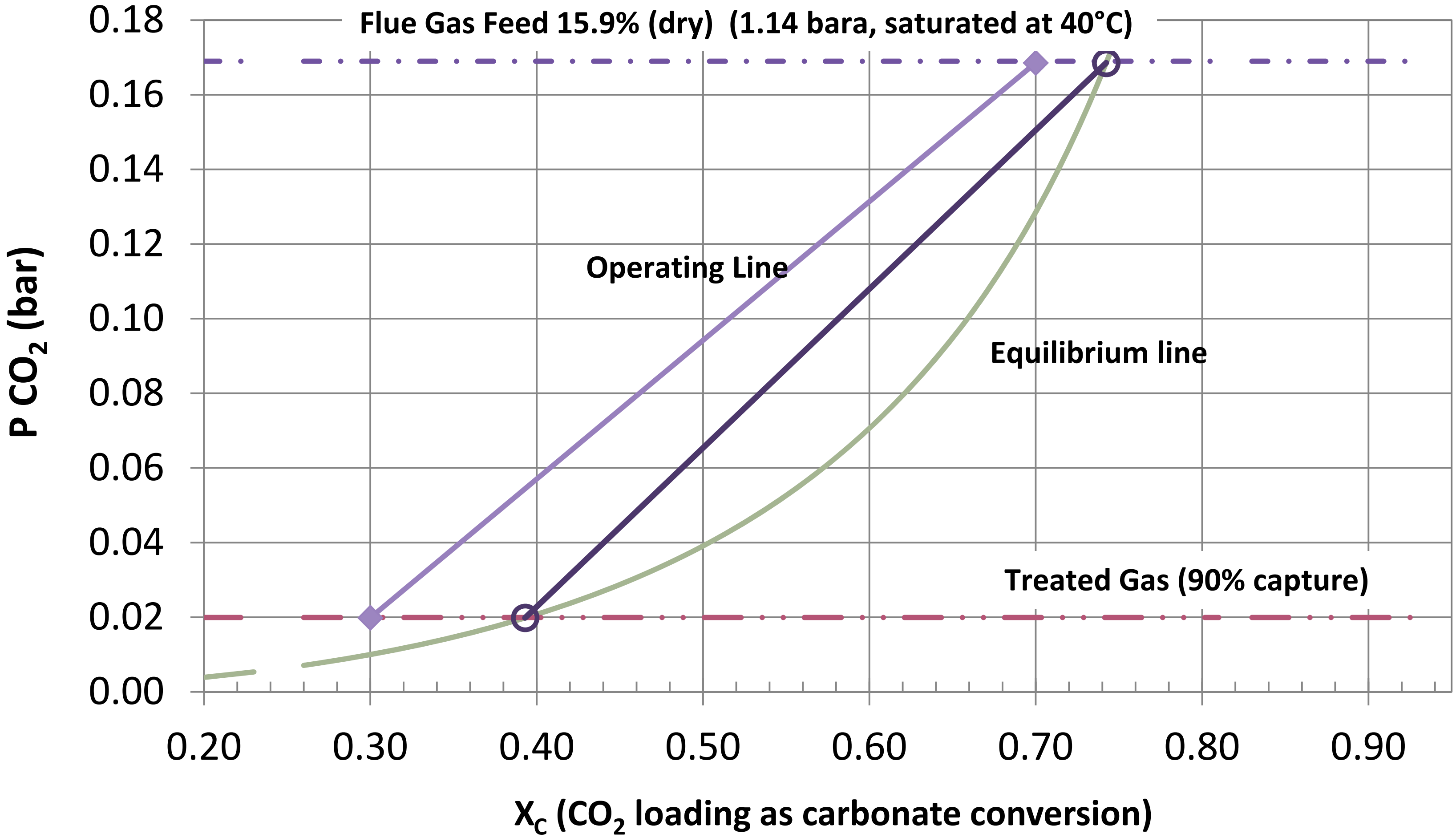
ABSORBER DESIGN OPERATING LINE

Equilibrium curve is intersected by DOE Case 12 flue gas feed PCO2 and 90% capture line



Preferred operating conditions: ~ 0.35 to 0.70 mol/mol K_2CO_3
20% K2CO3 (w/w), 40° Liquid feed, 90% Capture

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RESULTS, DISCUSSION, LESSONS LEARNED

Scaled-Up Demonstration (Tasks 7, 8, 9)

BENCH UNIT CURRENTLY OPERATING AT NCCC

Installed at NCCC December 2012

- Sulzer M500X
- 8.33" ID x 26 ft packing
- Gas: 30 Nm^3/hr
- Liquid: 275 LPH

Module Design and Fabrication:

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Instrumentation and controls: EMERSON

- Testing at NCCC is complete
- Immobilized enzyme installed operated from early May 2013 to end Sept 2013

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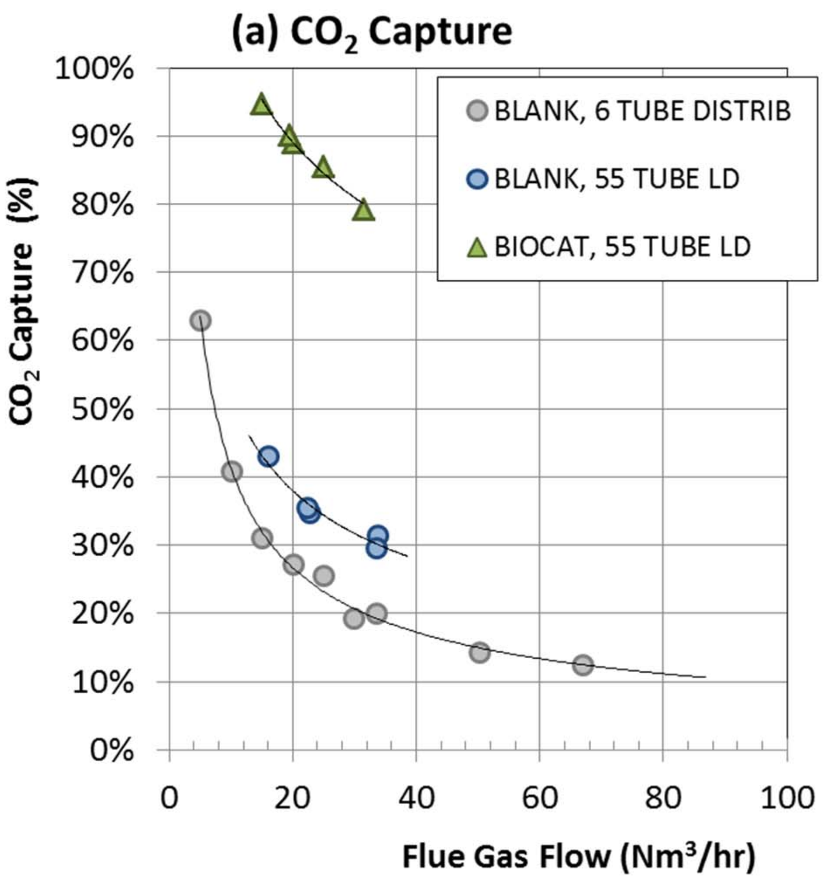
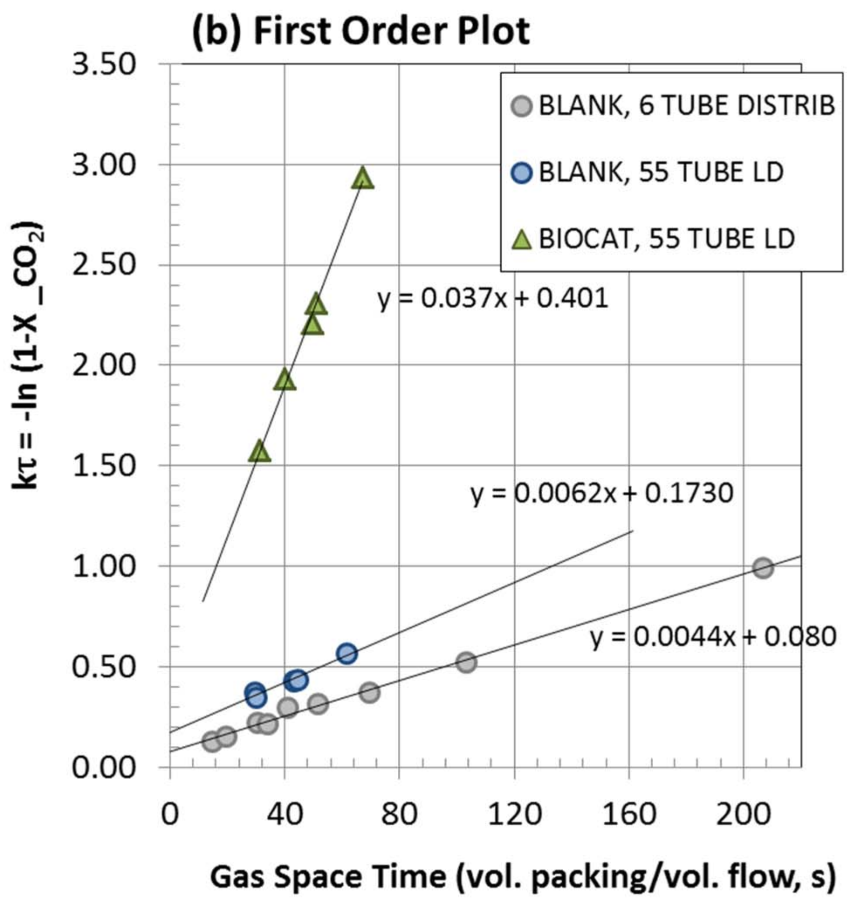
CLEAR ENHANCEMENT OBSERVED

Immobilized enzyme data compared to blank, same liquid distributor: ~ 6X improvement in slope on first order rate plot (indicative of column height reduction)





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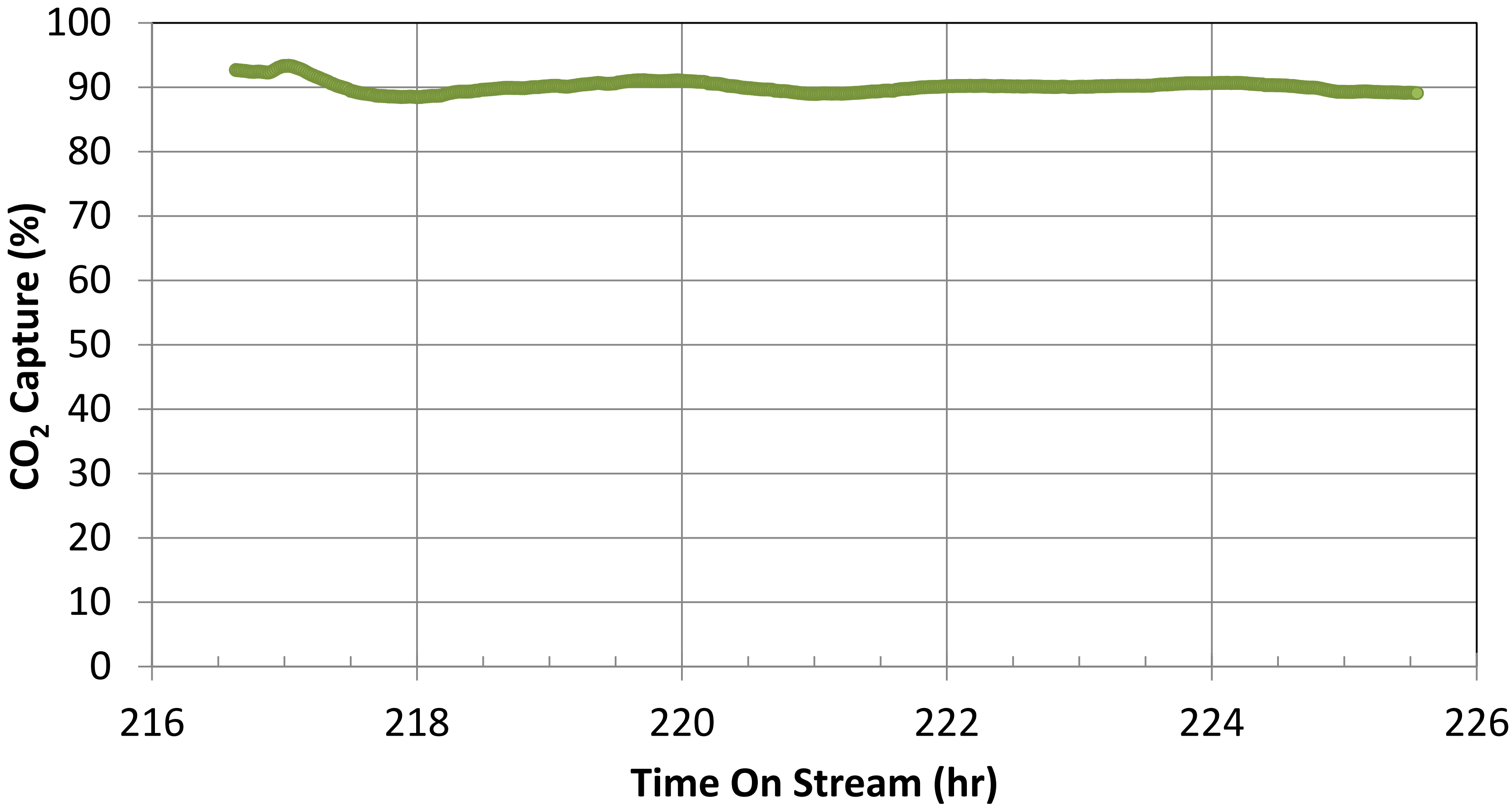
90% CO_2 CAPTURE TEST (~20 SCMH)

Biocatalyst achieved (average) 90.1% CO_2 capture with ~20 Nm^3/hr flue gas flow compared to blank estimated ~2.8 Nm^3/hr flue gas flow at 90% capture.



~7-fold higher gas flow achieves 90% capture with biocatalyst compared to without biocatalyst in the current column

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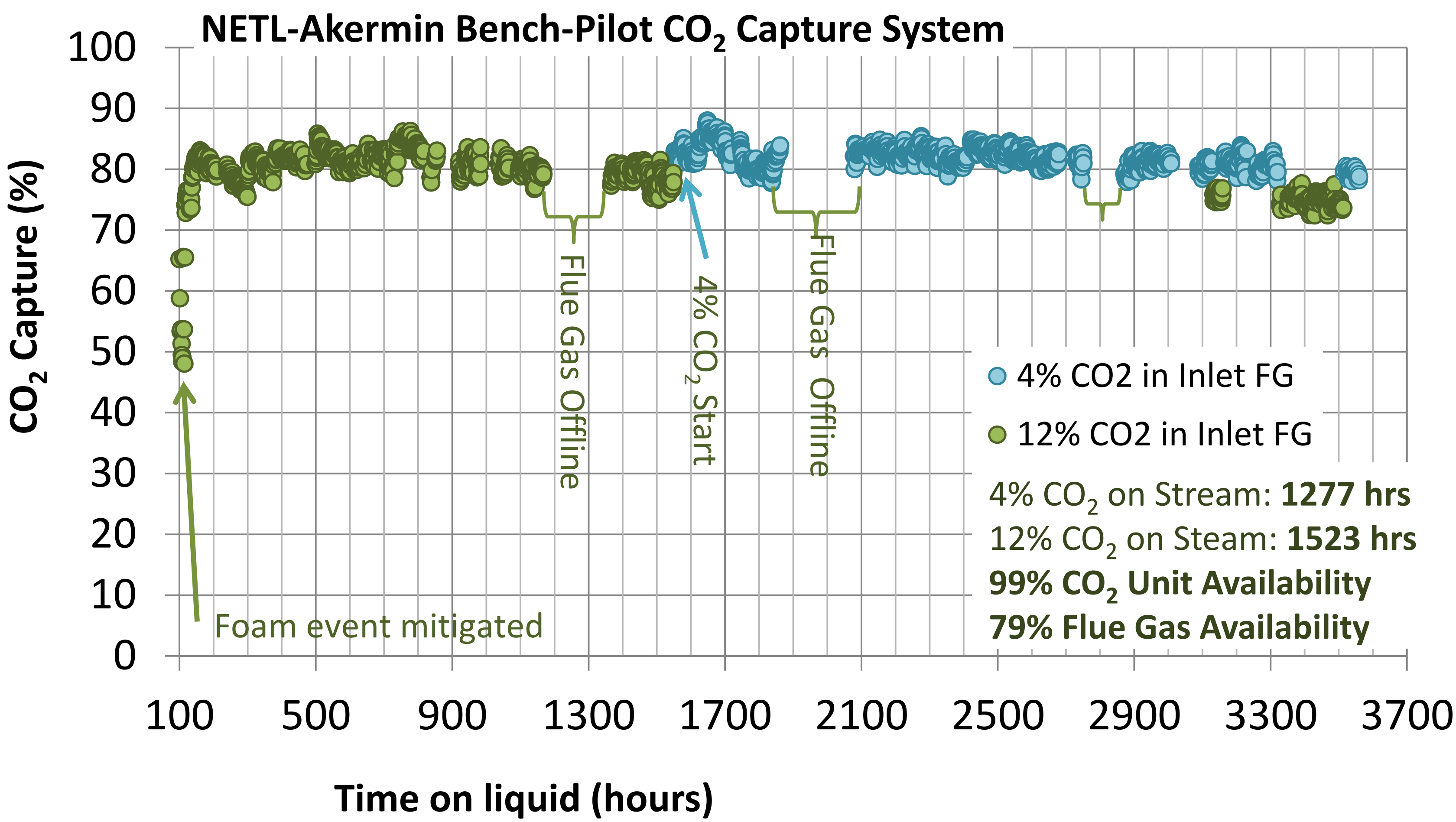
BENCH UNIT (K_2CO_3 W/ BIOCATALYST), THROUGH 10/3/13

Time since startup, data at design flows (31.5 Nm^3/hr, 275 LPH, XCL ~ 25%)



3560 Hrs Since Start-Up @ 10/03/2013

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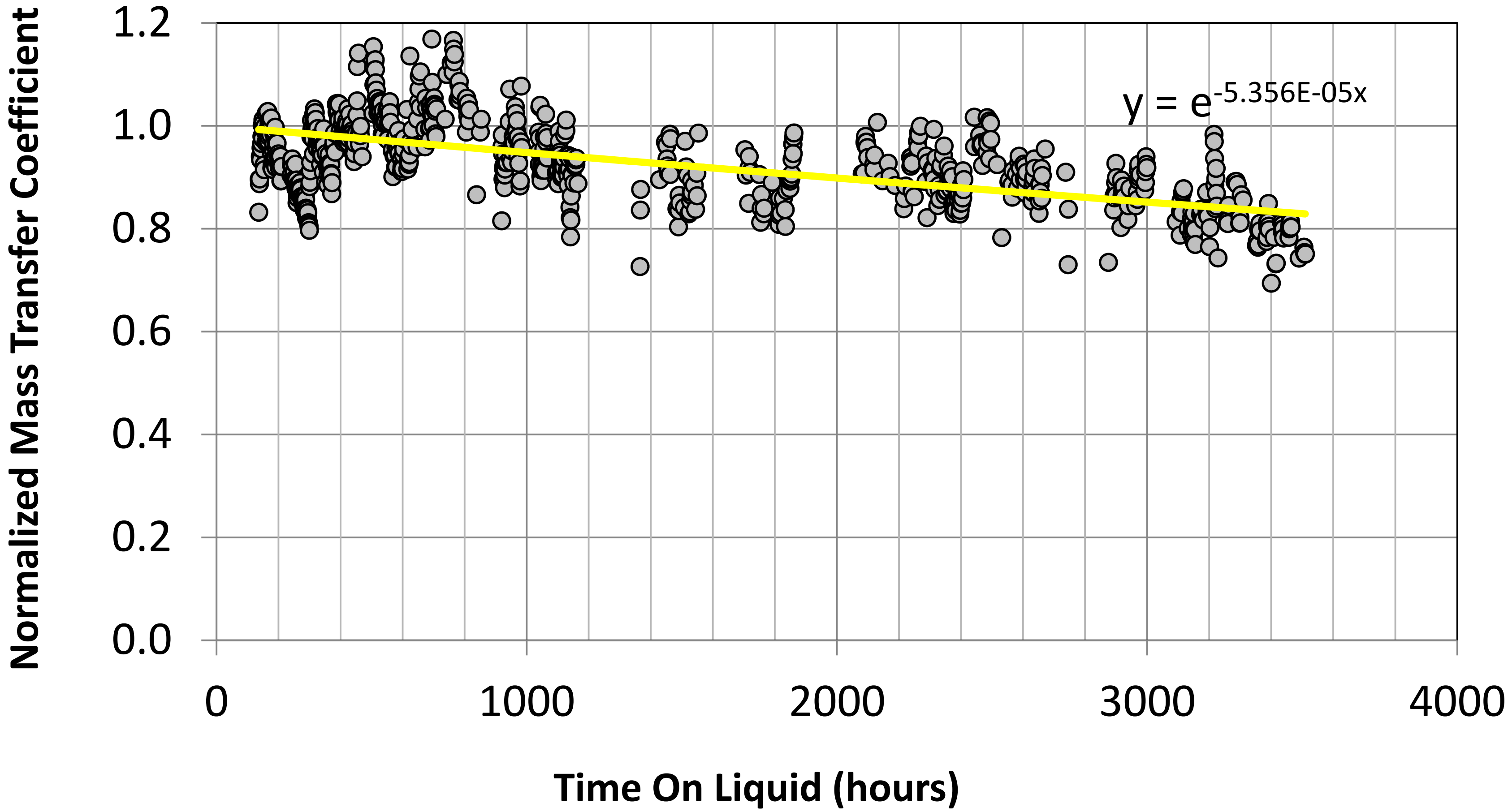
ALL MASS TRANSFER COEFFICIENT DATA, NORMALIZED

Biocatalyst enhanced, Flue gas: 31.5 Nm³/hr; liquid: 275 LPH, Lean loading ~ 25%



All data normalized to respective initial mass transfer coefficient shows

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SUMMARY OF CATALYZED MASS TRANSFER LIFE-TIME DATA

Analysis of mass transfer coefficient with time on liquid

Data Segments	Exponent (hrs^{-1})	Time constant (days)	Half Life (Days)
All Data:	5.356 E-05	778	539

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HEAT STABLE SALT (HSS) ACCUMULATION

Liquid samples fro first 12% CO2 flue gas

Coal Flue Gas Feed [12% CO_2 Feed, 5/7/2013 to 7/8/2013, 1260-hrs on flue gas]	HSS (mg/L) after 1260 hrs	Annual Loss of Solvent Capacity	Corrected Annual Loss of Solvent Capacity
Nitrite (NO_2^-)	191	0.80%	0.95%
Nitrate (NO_3^-)	96	0.15%	0.16%
Sulfate (SO_4^{2-})	40	0.39%	0.42%
Total	327	1.34%	1.54%

HSS amounts to less than < 1.6 %/year loss in capacity by HSS.
For flue gas with similar composition as the NCCC

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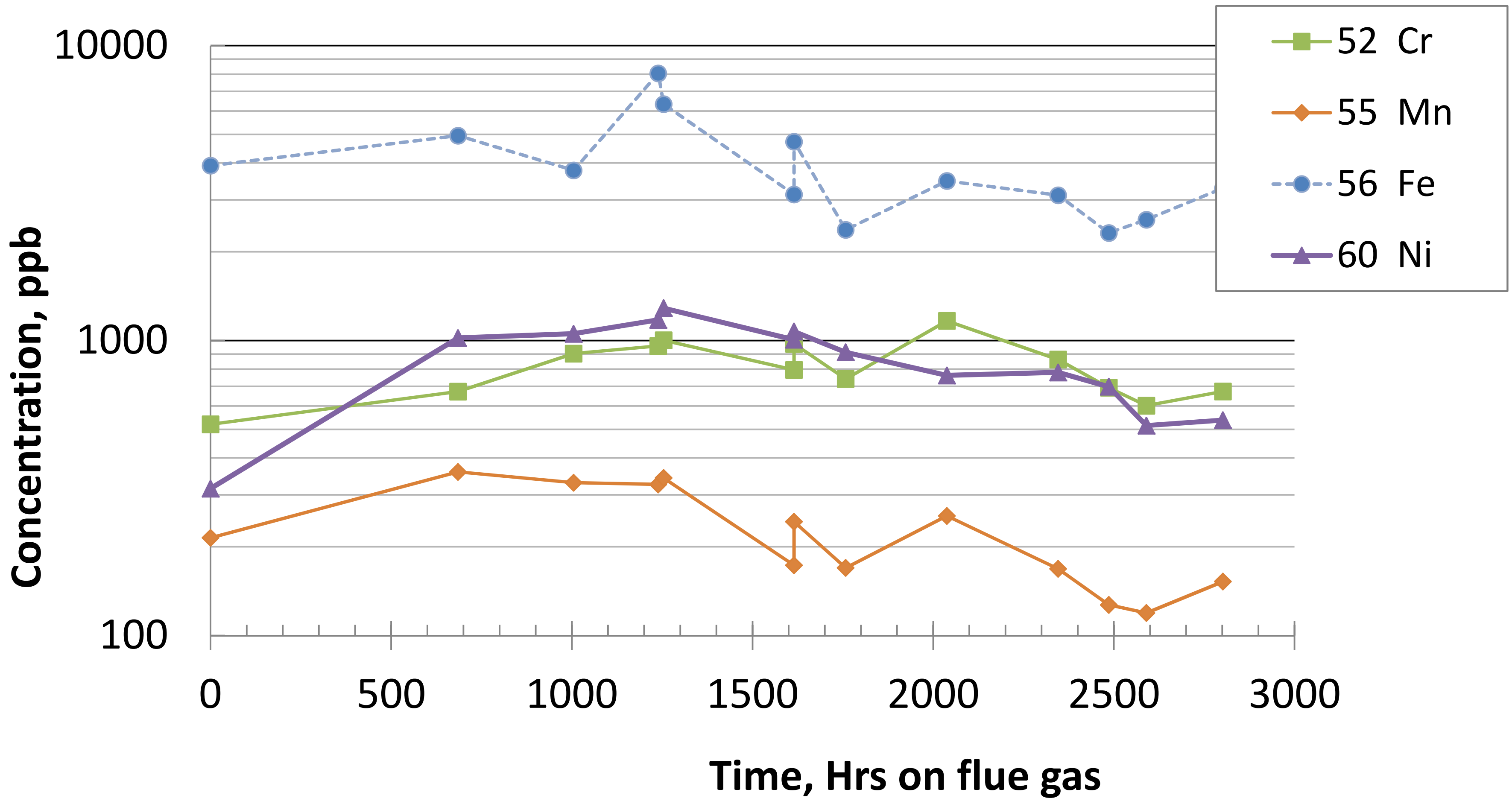
CORROSION PRODUCT ANALYSIS BY ICP/MS

304 Stainless Steel: Fe 71%, Cr 18%, 8% Ni, 2% Mn, Others <1%.



Based on Ni. or Cr. accumulation, corrosion is < 0.1 microns/year; assuming 32 m² internal surface area (excl. packing)

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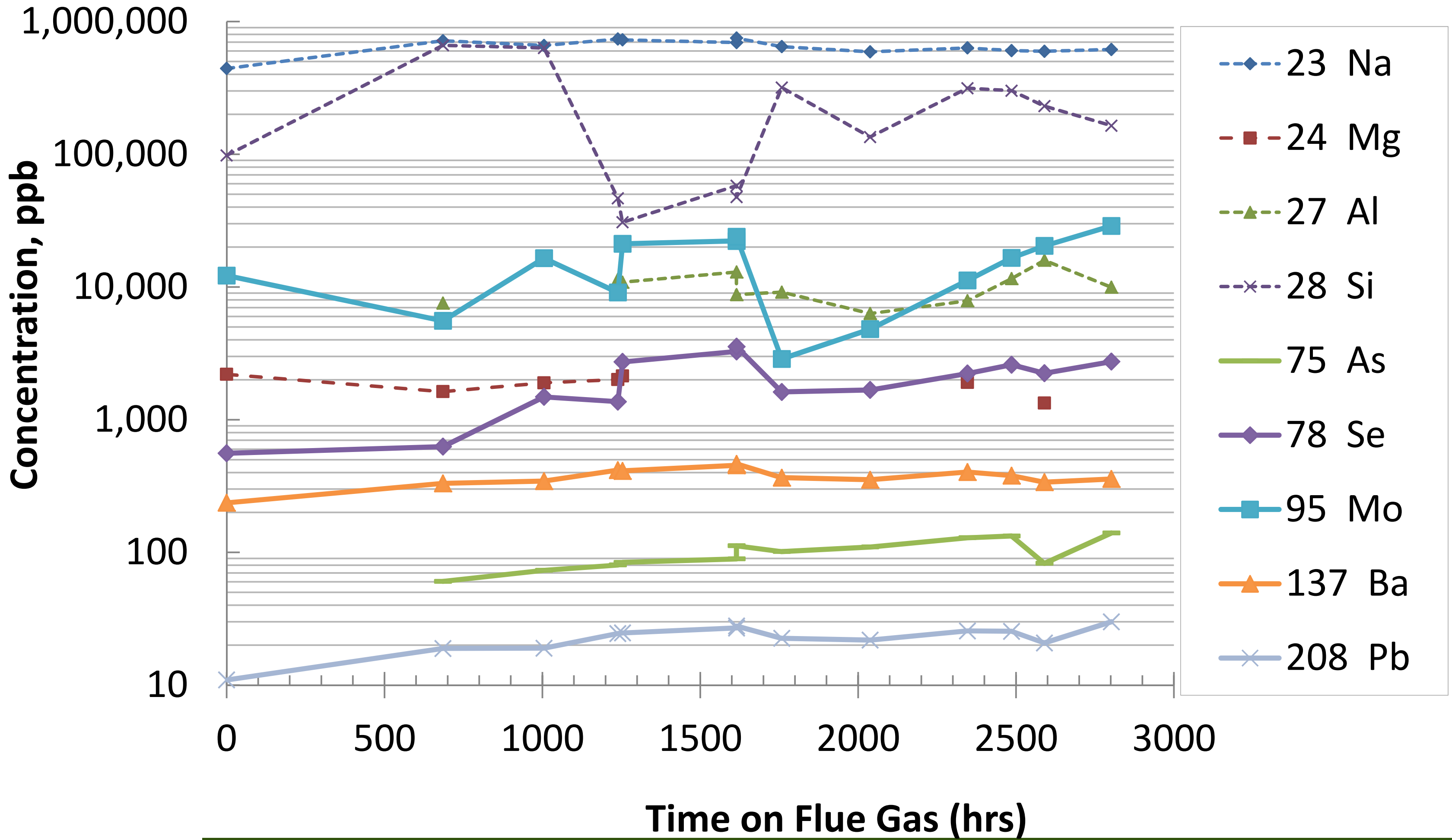
HEAVY METALS ACCUMULATION

Build up of heavy metals below estimated inhibitory thresholds



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QUANTIFIED CO_2 PURITY: ~99.98% (DRY BASIS)

NCCC sampled CO_2 product and analyzed purity with Gas Chromatography

Component	Sample #1	Sample #2
O_2	ND	ND
Ar+ O_2	0.01%	0.01%
N_2	0.01%	0.01%
Net CO_2	**99.98%**	**99.98%**

Aerosol emissions from absorber less than 0.8 ppm (limit of detection)

High selectivity is clearly demonstrated with a high purity product

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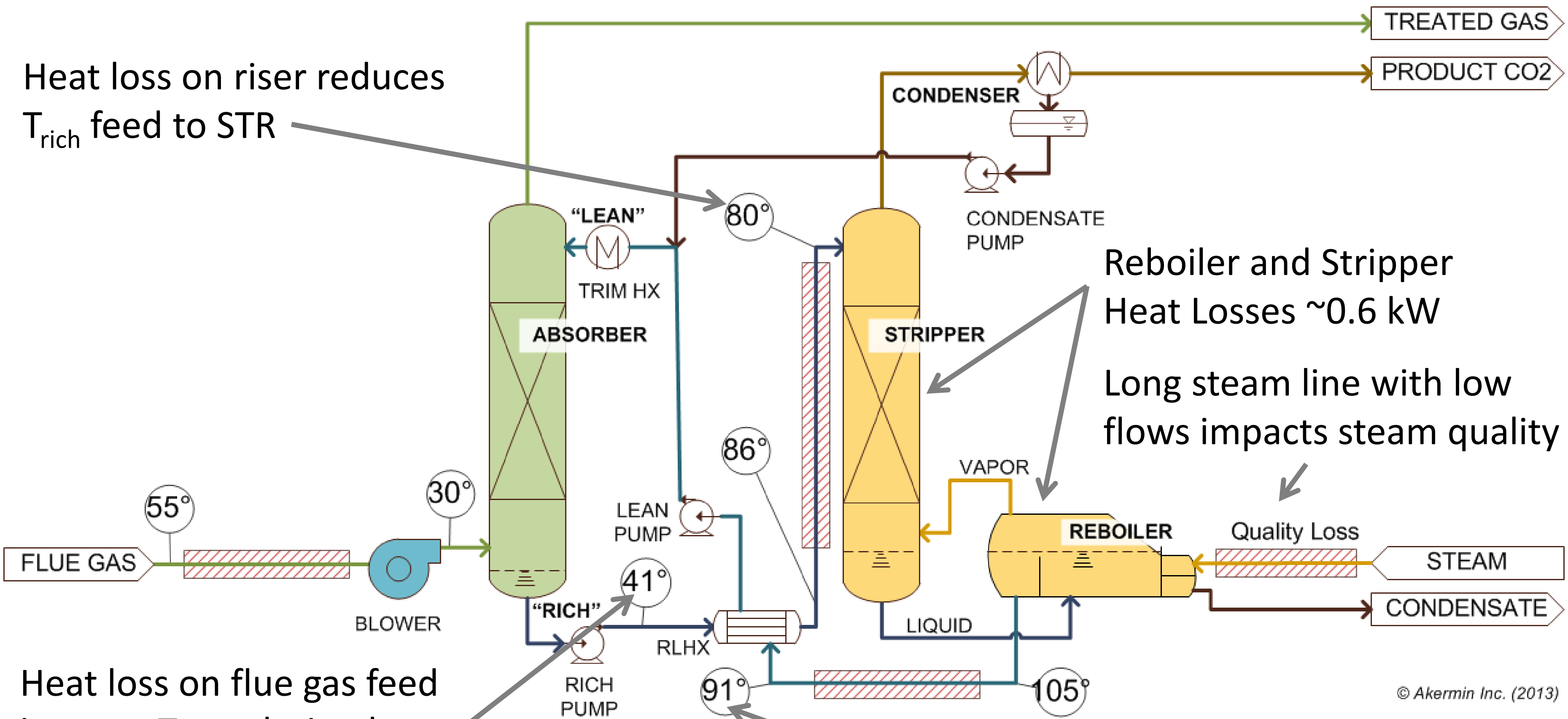
HEAT LOSSES ON BENCH-SCALE PLANT

Five Key Areas of Heat Loss Affecting Reboiler Duty (Temperatures displayed in ℃)



Heat loss on riser reduces T_{rich} feed to STR

Reboiler and Stripper Heat Losses ~0.6 kW

Long steam line with low flows impacts steam quality

Heat loss on flue gas feed impacts T_{rich} solution here

Heat loss from reboiler line results in lower maximum approach temperature

Combined effects of heat loss result in higher reboiler duties than could be achieved under adiabatic conditions (e.g., larger scale)

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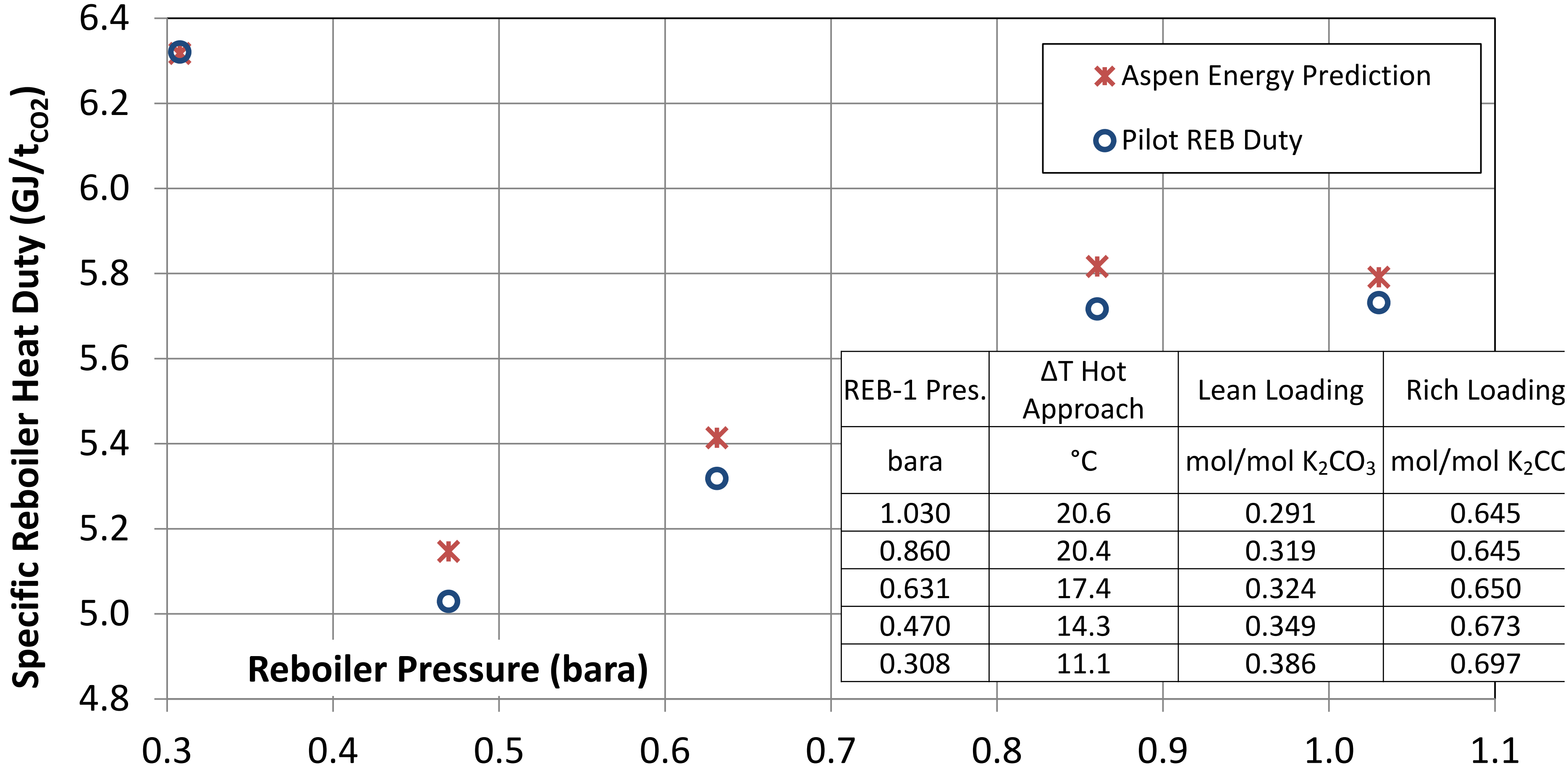
VACUUM REGENERATION: ASPEN VS. DATA

This plot used for comparing Aspen prediction and regeneration energy data at test condition



REB-1 Pres.	ΔT Hot Approach	Lean Loading	Rich Loading
bara	°C	mol/mol K_2CO_3	mol/mol K_2CC
1.030	20.6	0.291	0.645
0.860	20.4	0.319	0.645
0.631	17.4	0.324	0.650
0.470	14.3	0.349	0.673
0.308	11.1	0.386	0.697

Aspen model agrees within ~ 2.5% of measured values.

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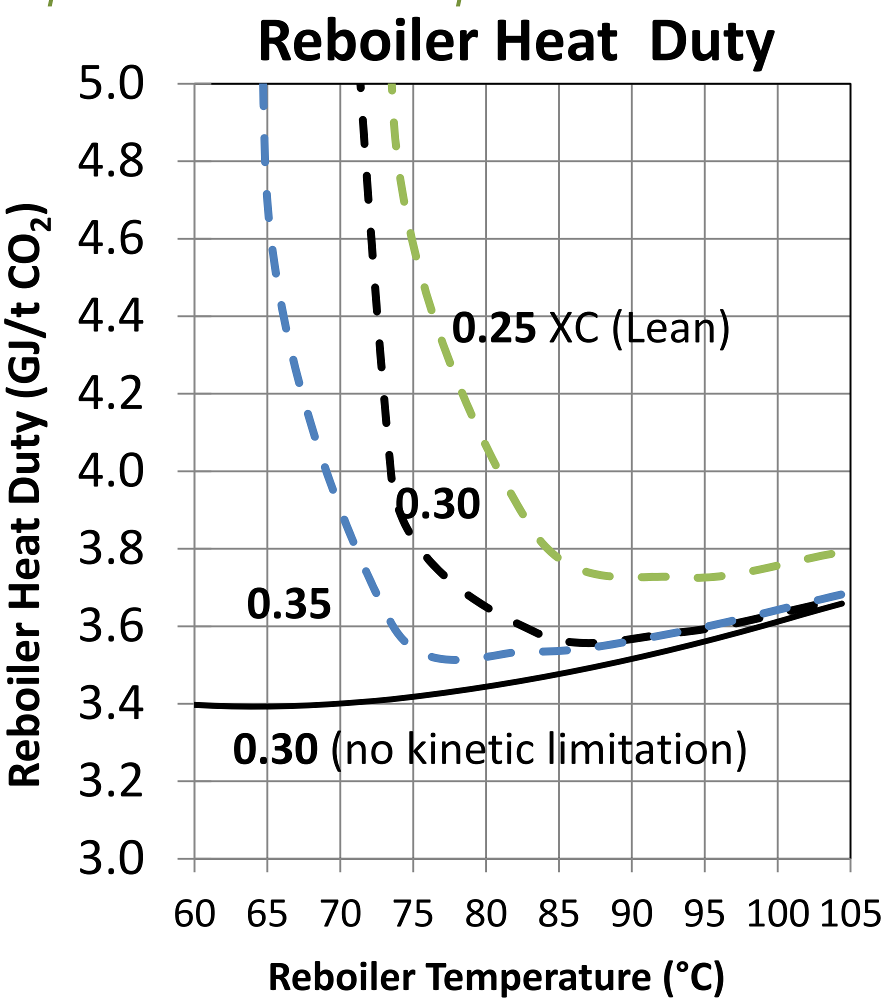
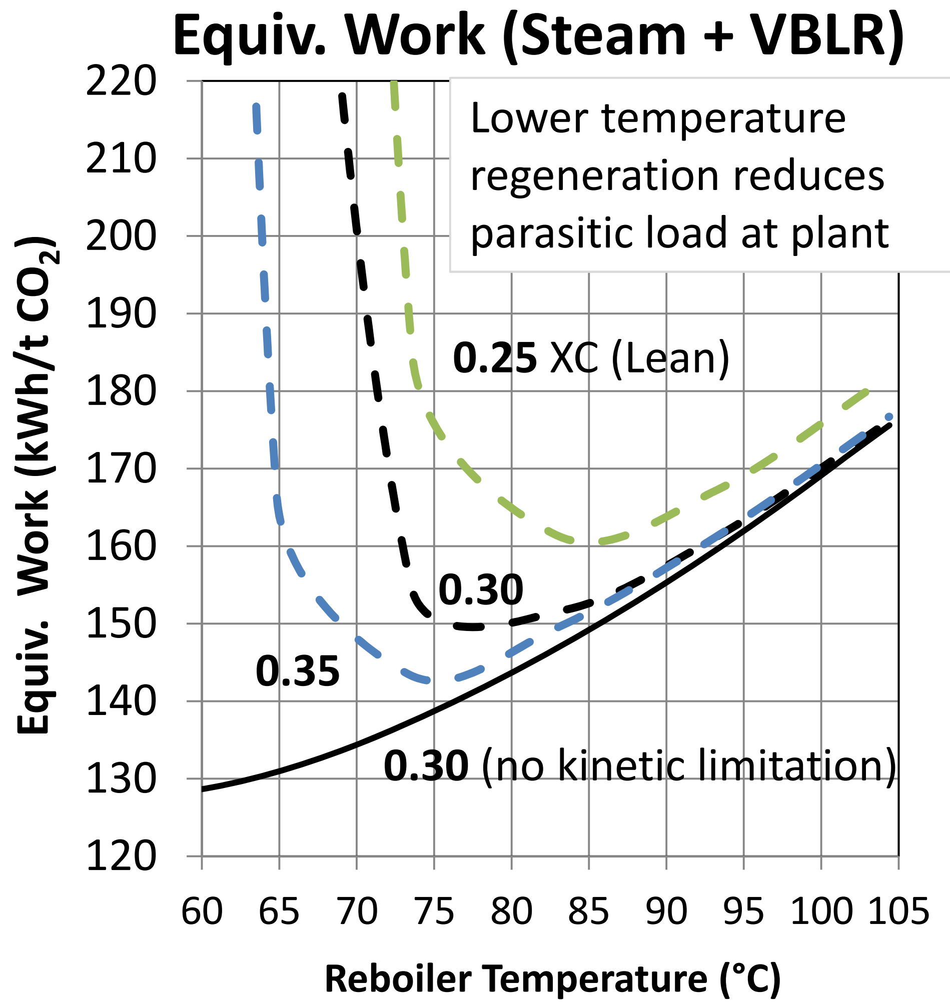
KINETICS OF BICARBONATE DEHYDRATION IMPACTS ENERGY PERFORMANCE IN STRIPPER BELOW ~80 TO 85°C

Equivalent work is impacted





- ~3.5 GJ/t_{CO_2} with K2CO3, basic flow sheet
- Equivalent work < 150 kWh/ t CO2 for Steam + VBLR to 1.6 bar

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RESULTS, DISCUSSION, LESSONS LEARNED

Techno-Economic Modeling (Task 6.2-6.5)

TEA CASES

Column Height Reduction Assumptions for final TEA study and other key assumptions

Case	Comment	Absorber Flux Relative to Blank	Stripper Flux Relative to Blank
Akermin-3A (6X1)	Current Bench Unit Performance	6	1
Akermin-3A (10X1)	More recent formulations	10	1
Akermin-3A (10X5)		10	5

- 20% K_2CO_3, 0.3-0.7 mol/mol, NETL-12 spec. flue gas w/ 90% capture
- ~40°C absorption temp., 87°C reboiler temp. , 10°C steam-reboiler ΔT
- ~70% Flooding in ABS-1, M500X packing, 70% area efficiency
- 55.7 m^3/m^2-h liquid load in STR-1, M500X packing, 70% area efficiency
- 5°C cold-side ΔT in rich-lean cross exchanger
- 2-stage vacuum blower (83% eff.), 6-stage compressor (86% eff.)

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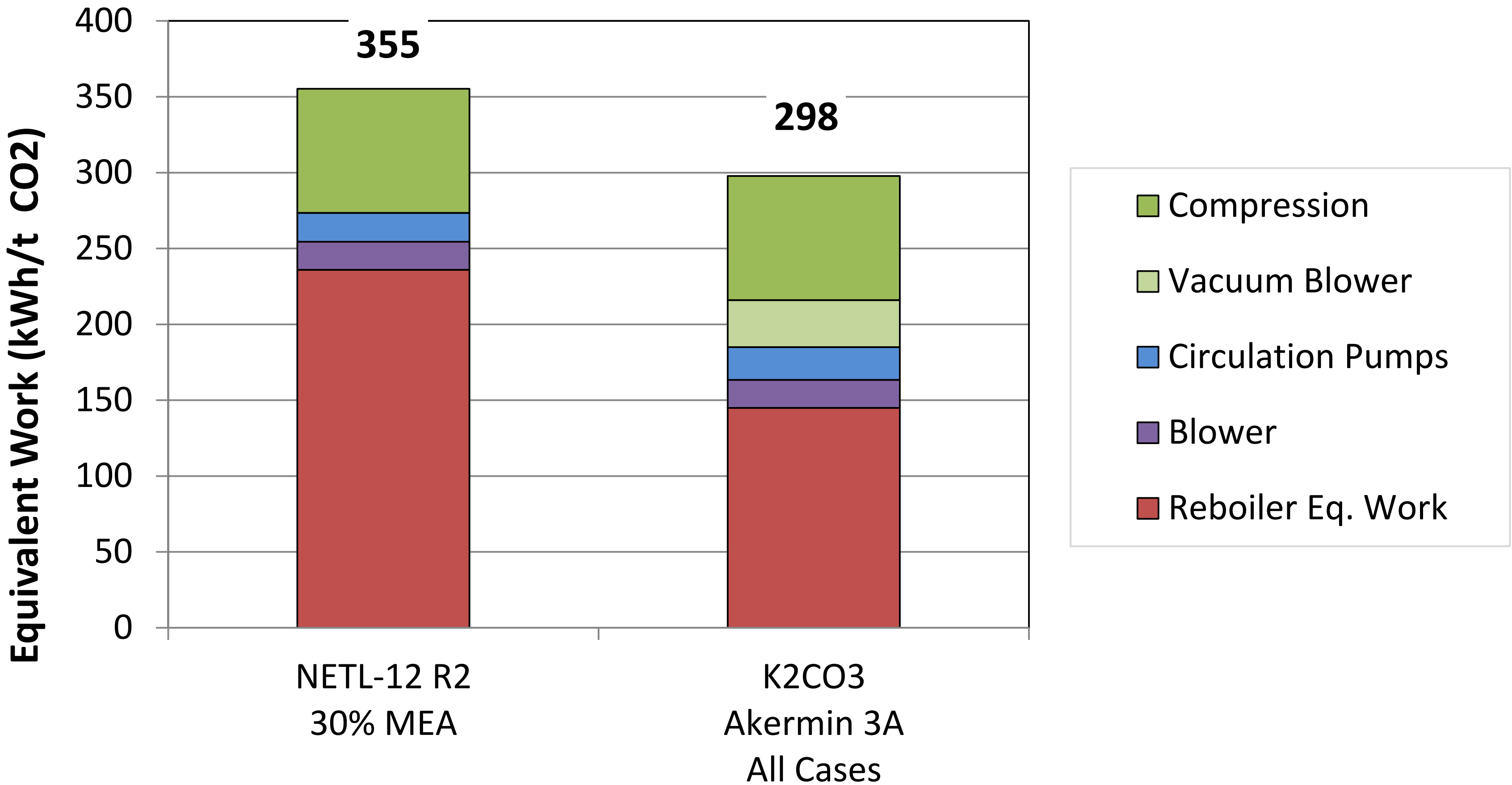
EQUIVALENT WORK FOR TEA CASES

NETL-12 R2: 153 ℃ steam, 23.9% steam-power eff., 3.56 GJ/tCO_2 reb. duty

K_2CO_3: 97 ℃ steam, 13.9% steam-power eff., 3.76 GJ/tCO_2 reb. duty



16% reduction in equivalent work

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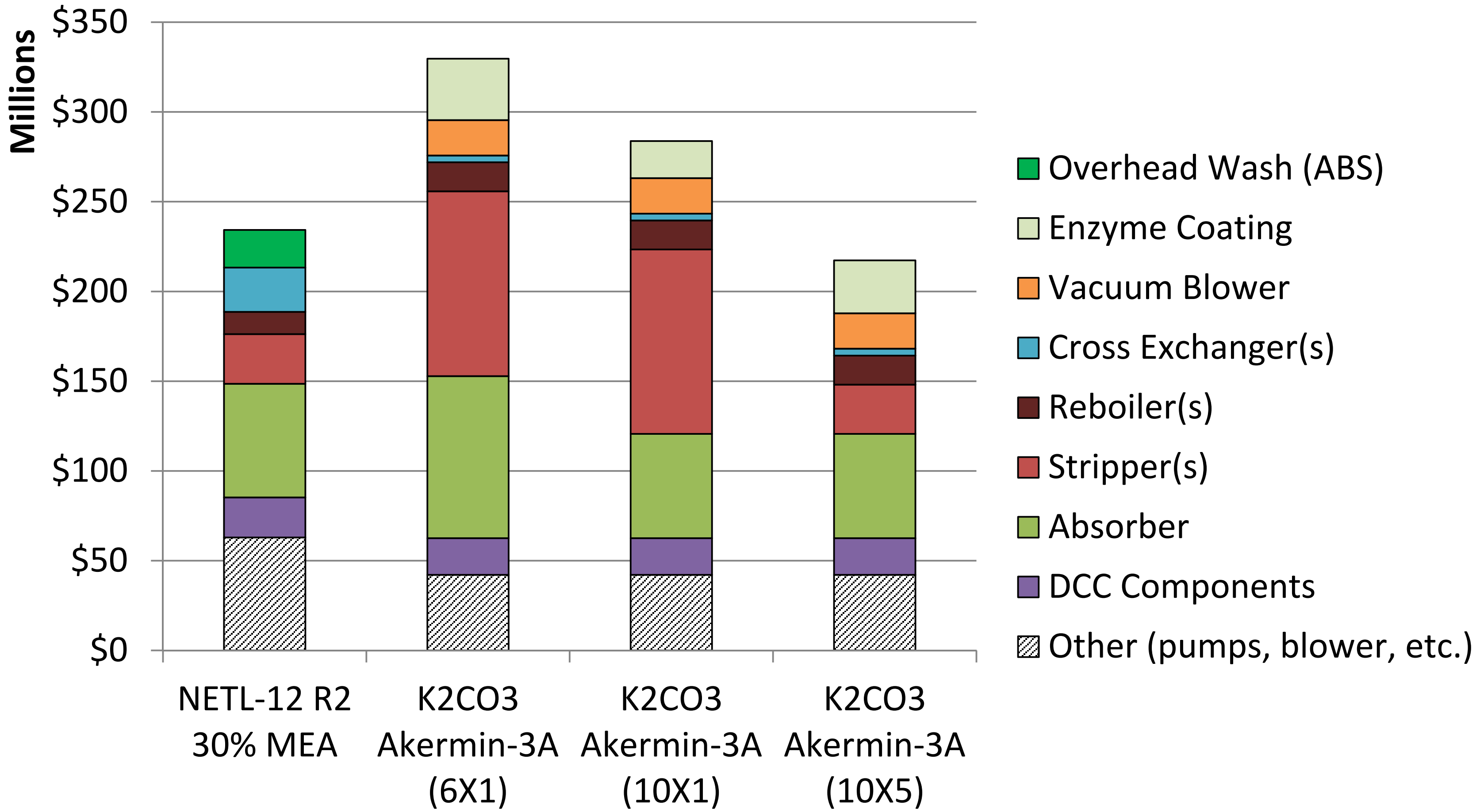
CAPITAL COSTS OF CO_2 CAPTURE UNIT

Opportunities to reduce capital cost



Improving biocatalyst performance and adding to stripper improves CO2 unit capital costs

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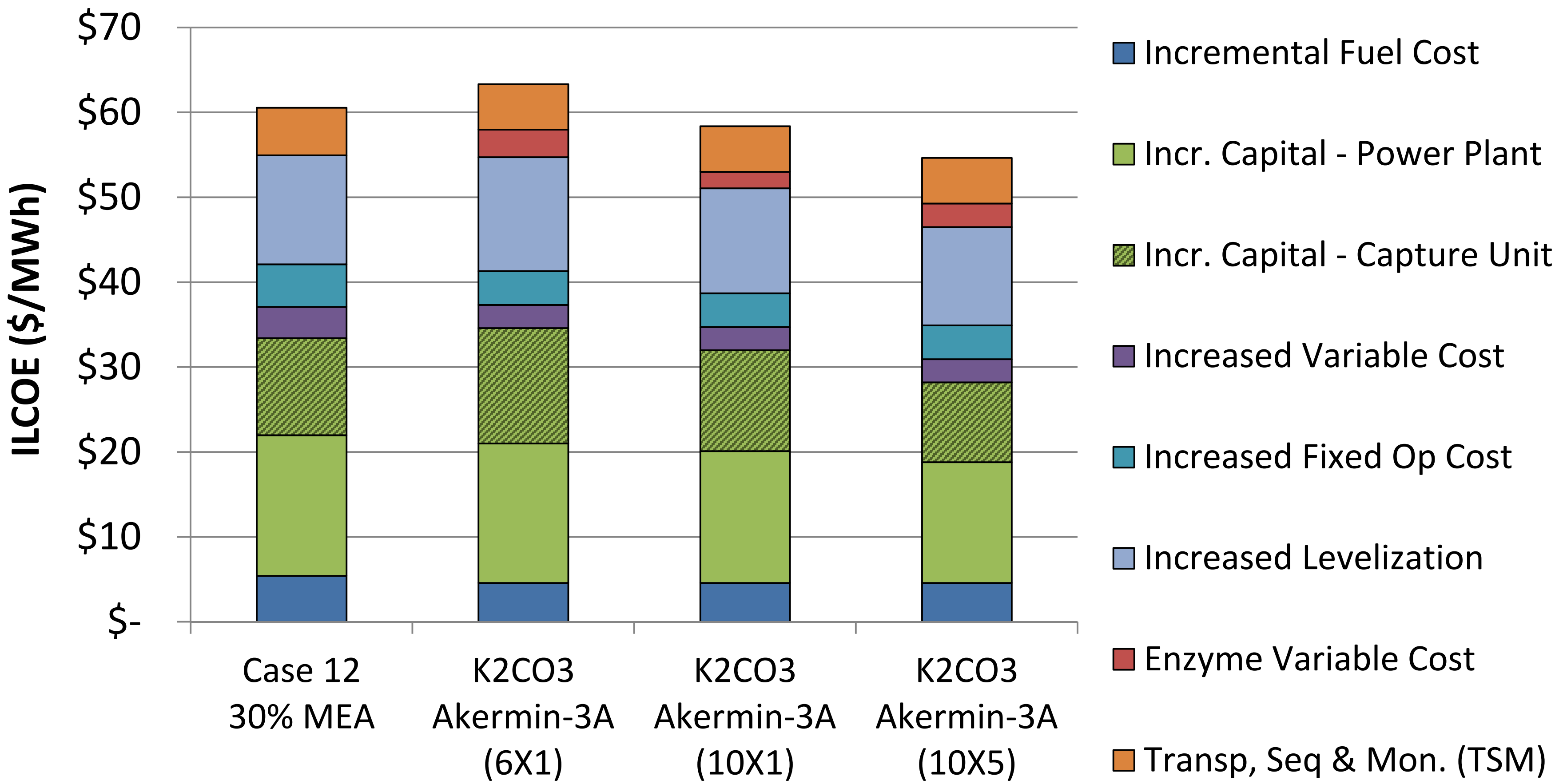
INCREASE IN LCOE



Reducing stripper height helps improve economics

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COST OF ELECTRICITY (PNNL TEA STUDY)

	No Capture (NETL-11) Supercritical PC Boiler	30% MEA (NETL- 12)	K_2CO_3 Akermin-3A (6X1)	K_2CO_3 Akermin-3A (10X1)	K_2CO_3 Akermin-3A (10X5)
Fuel Cost	14.2	19.6	18.8	18.8	18.8
Capital Cost	31.7	59.6	61.6	59.0	55.2
Variable Cost	5.0	8.7	7.8	7.8	7.8
Enzyme Variable Cost	0.0	0.0	3.2	1.9	2.8
Fixed Operating Cost	8.0	13.0	11.9	11.9	11.9
Transport, Seq. & Monitor (TSM)	--	5.6	5.4	5.4	5.4
COE ($/MWh)	**58.9**	**106.5**	**108.7**	**104.8**	**101.9**
Levelization Factor†	1.269	1.269	1.269	1.269	1.269
LCOE ($/MWh) (customer price)	**74.7**	**135.1**	**137.9**	**133.0**	**129.3**
% Increase in LCOE versus No Capture	**--**	***80.9%***	***84.7%***	***78.1%***	***73.1%***
% Increase in LCOE relative to NETL-12	**--**	**--**	***2.0%***	***-2.1%***	***-4.4%***

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COST OF AVOIDED CO_2 (WORLEYPARSONS)

	Akermin-3A 6x1		Akermin-3A 10x1		Akermin-3A 10x5	
Total Plant Costs ($/kW)	2,997		2,869		2,685	
Total Overnight Cost (2007$/kw)	3,690		3,534		3,308	
Total Overnight Cost (2007$x1,000)	2,028,542		1,942,782		1,818,541	
Total As Spent Capital (2007$)	4207		4029		3771	
Annual Fixed Operating Costs ($/yr)	48,944,654		48,944,654		48,944,654	
Variable Operating Costs ($/MWh)	11.01		9.70		10.53	
COE($/MWh, 2007$)	PNNL	W-P	PNNL	W-P	PNNL	W-P
CO2 TS&M Costs	5.4	5.4	5.4	5.4	5.4	5.4
Fuel Costs	18.8	18.8	18.8	18.8	18.8	18.8
Variable Costs	11.0	11.0	9.7	9.7	10.6	10.5
Fixed Costs	11.9	12.0	11.9	12.0	11.9	12.0
Capital Costs	61.6	61.6	59.0	59.0	55.2	55.2
COE($/MWh, 2007$)	**108.7**	**108.7**	**104.8**	**104.8**	**101.9**	**101.9**
Avoided Cost ($/t CO_2 avoided)	71.64		66.03		61.80	
Cost of Capture ($/t CO_2 captured)	52.25		48.16		45.08	

Cost of avoided CO2 for NETL Case 12 : $68.95/tCO2 avoided

Cost of CO2 capture for NETL Case 12: $47.84/ t CO2 captured

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PROJECT CONCLUSIONS

- Demonstrated >12-fold enhancement at 45°C compared to blank
- Reduce total equivalent work by ~16% with ~85°C reboiler
- Demonstrated 90% capture; ~ 7-fold increase in flow relative to blank.
- Demonstrated ~2800 hours on coal flue gas at the NCCC with steady performance of ~ 80% CO_2 capture
- Reliable operation was demonstrated (99% availability/ flue gas supply).
- Low heat stable salts accumulation (< 1.6% of solvent capacity per year).
- Greater than 99.9% purity of CO_2 product measured by NCCC.
- K_2CO_3 aerosol emissions less than 0.8 ppm (limit of detection)
- Negligible detectible corrosion rates using 304-stainless steel.
- Cost of capture similar to NETL Case-12

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SUCCESS CRITERIA (BUDGET PERIOD ONE)

- ✓ Completion of all tasks in BP1
- ✓ Demonstrated >80% retention of enzyme in flowing system
- ✓ Demonstrated >10-fold rate enhancement over blank K_2CO_3
- ✓ Provide Aspen data for 550 MWe power plant
- ✓ Submission of a preliminary TEA
- ✓ Submission of engineering, design package for bench unit
- ✓ Submission/approval of continuation application for BP1 to BP2

All success criteria for budget period one were met at the conclusion of BP-1.

SUCCESS CRITERIA (BUDGET PERIOD TWO)

- ✓ Completion of all work in BP2
- ✓ Demonstrate 50% retention of activity after 200 days on-line in lab-scale CLR at target pH, temperature, concentration.
- ✓ Demonstrate that enzyme tolerates SO_2 and NO_2 for at least 100 hrs
- ❑ Demonstrate a reboiler heat duty of 2.1 GJ/t CO_2 (900 Btu/lb)
- ✓ Submission of the final TEA, final report, and Aspen model data

Success criteria for budget period two were met except for the reboiler heat duty. Adiabatic reboiler heat duty ~3.5 GJ/t CO_2 (equivalent) in bench unit.

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FUTURE WORK

Successful proof of concept of immobilized biocatalyst was demonstrated

Approach to further reduce cost of capture:

- Higher capacity and lower regeneration energy solvents enabled by biocatalyst
- Alternative flow sheets that can provide lower energy, lower equivalent work, and further capital cost reduction

Biocatalysts can be deployed to enable a variety of novel solvents and flow sheet configurations to reduce the cost of capture

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FINAL BUDGET VS ACTUAL – BP1

(Against original approved budget)

COMBINED	BUDGET PERIOD 1 10/1/2010 - 9/30/2010				No -cost extension 10/1/2011 - 12/31/2011	BP1 TOTAL	
	Q1	Q2	Q3	Q4	Q5		
Baseline Cost Plan							
Federal Share	460,344	438,074	310,614	169,462	-	1,378,494	
Non-Federal Share	109,156	111,604	75,157	48,708	-	344,625	**20.0% cost share**
Total Planned	569,500	549,678	385,771	218,170	-	1,723,119	
Cumulative Baseline Cost	569,500	1,119,178	1,504,949	1,723,119	1,723,119		
Actual Incurred Cost							
Federal Share	246,302	400,365	556,739	141,085	26,416	1,370,907	
Non-Federal Share	56,059	72,874	115,164	283,599	506,523	1,034,219	**43.0% cost share**
Total Planned	302,361	473,239	671,903	424,684	532,939	2,405,126	
Cumulative Baseline Cost	302,361	775,600	1,447,503	1,872,187	2,405,126		
Variance							
Federal Share	214,042	37,709	(246,125)	28,377	(26,416)	7,587	**
Non-Federal Share	53,097	38,730	(40,007)	(234,891)	(506,523)	(689,594)	
Total Planned	267,139	76,439	(286,132)	(206,514)	(532,939)	(682,007)	
Cumulative Baseline Cost	267,139	343,578	57,446	(149,068)	(682,007)		

*** $7,587 remained unused in BP1 from the PNNL budget. This was used in BP2.**

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FINAL BUDGET VS ACTUAL – BP2

(Compared against final NETL budget for BP2. Estimates for wrap up charges through December 2013)

	BUDGET PERIOD 2 1/1/2012 - 9/30/2013								
	ACTUALS								
COMBINED	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**BP#2**	
Baseline Cost Plan									
Federal Share	399,034	405,371	323,455	187,972	612,132	318,585	166,421	2,412,970	
Non-Federal Share	208,879	212,195	173,288	98,397	325,559	191,060	165,499	1,374,877	
Total Planned	607,913	617,566	496,743	286,369	937,691	509,645	331,920	3,787,847	**36.30% cost share**
Cumulative Baseline Cost	607,913	1,225,479	1,722,222	2,008,591	2,946,282	3,455,927	3,787,847		
Actual/Estimated Incurred Cost									
Federal Share	141,520	524,093	411,358	420,134	379,337	336,027	208,088	2,420,557	
Non-Federal Share	370,132	245,560	435,605	392,373	240,355	163,451	165,499	2,012,975	
Total Planned	511,652	769,653	846,963	812,507	619,691	499,478	373,587	4,433,532	**45.40% cost share**
Cumulative Baseline Cost	511,652	1,281,305	2,128,268	2,940,775	3,560,466	4,059,945	4,433,532		
Variance									
Federal Share	257,514	(118,722)	(87,903)	(232,162)	232,795	(17,442)	(41,667)	(7,587)	**
Non-Federal Share	(161,253)	(33,365)	(262,317)	(293,976)	85,204	27,609	-	(638,098)	
Total Planned	96,261	(152,087)	(350,220)	(526,138)	318,000	10,167	(41,667)	(645,685)	
Cumulative Baseline Cost	96,261	(55,826)	(406,046)	(932,184)	(614,184)	(604,018)	(645,685)		

*** $7,587 remained unused in BP1 from the PNNL budget. This was used in BP2.**

Total NETL Award (incl. FFRDC)	***$3,791,464***
Akermin cost share:	***3,047,194*** *(44.56%)*
Total:	***$6,838,658***

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  - Instrumentation and controls

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