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ADVANCED LOW ENERGY ENZYME-CATALYZED SOLVENT FOR CO_2 CAPTURE

John Reardon; Director, Engineering
Project: DE-FE0004228
NETL National CO_2 Capture Technology Meeting; Pittsburgh, PA

July 9, 2013

OUTLINE

- Company profile and project overview
- Technical background & fundamentals
- Progress and current status
- Summary of results
- Future work

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AKERMIN INC.

Company profile

- **St. Louis-based biotechnology company**
- Developing lower cost, environmentally friendly solutions for CO_2 capture for variety of applications
- Integrating proprietary biocatalyst delivery with various solvent systems

BIO RESEARCH & DEVELOPMENT GROWTH
BRDGPark
AT THE DANFORTH PLANT SCIENCE CENTER

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

- **Test Site: (NCCC)** NATIONAL CARBON CAPTURE CENTER

Fabrication: EPIC Systems,

Instrumentation: EMERSON

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

DOE Funding:	$ 3,275,043
Akermin Cost share:	$ 2,881,695
Total Project:	$ 6,156,738

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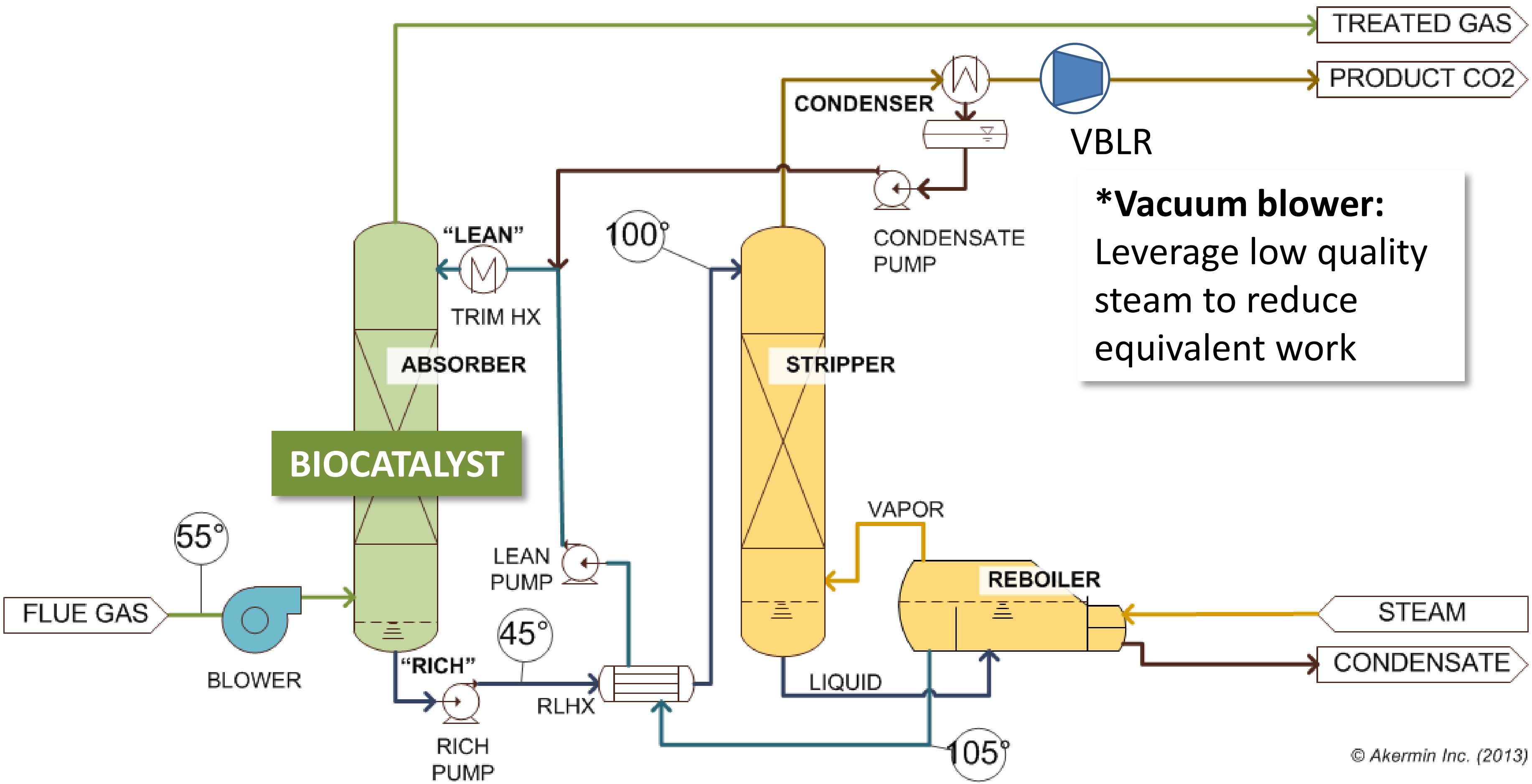
TECHNICAL BACKGROUND AND FUNDAMENTALS

SCHEMATIC BASIC OPERATION

Indicative temperatures and pressures "simple solvent system"



***Vacuum blower:**
Leverage low quality steam to reduce equivalent work

*Temperatures shown here are indicative of ~ adiabatic scenario using potassium carbonate regenerated at near ambient pressure.

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CORE TECHNOLOGY FOR THIS PROJECT

Coated packing: Akermin's first generation biocatalyst delivery system

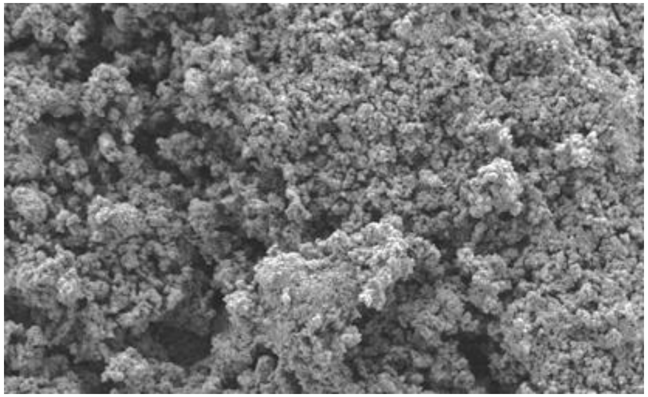
ENZYME

SOLUTION OF MONOMERS AND ADDITIVES

ENZYME SUSPENSION

COATING

ASSEMBLY



SEM IMAGE OF COATING

Proprietary formulation achieves high activity and stability

CHEMISTRY: CA-CATALYZED CO_2 ABSORPTION

- CA accelerates hydration of CO_2 to bicarbonate:

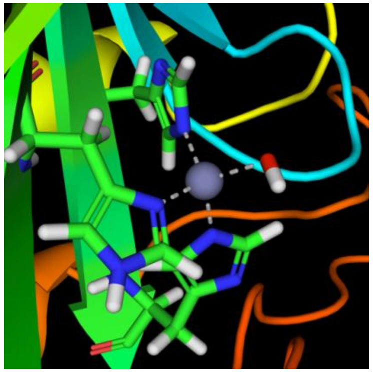
$$H_2O + CO_2 \overset{\textbf{CA}}{\rightleftharpoons} H^+ + HCO_3^-$$

- Base captures proton to complete reaction

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

- Akermin explored numerous CAs
- CA developed by Novozymes is top candidate
  - Highly active
  - Resistant to major impurities in flue gas
  - Thermostable
  - Resistant to high pH (9-10.5)
  - High expression level, few impurities

Active site of CA



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

CA: Carbonic Anhydrase

Key point: CA mechanism is potentially applicable in many basic solvent systems

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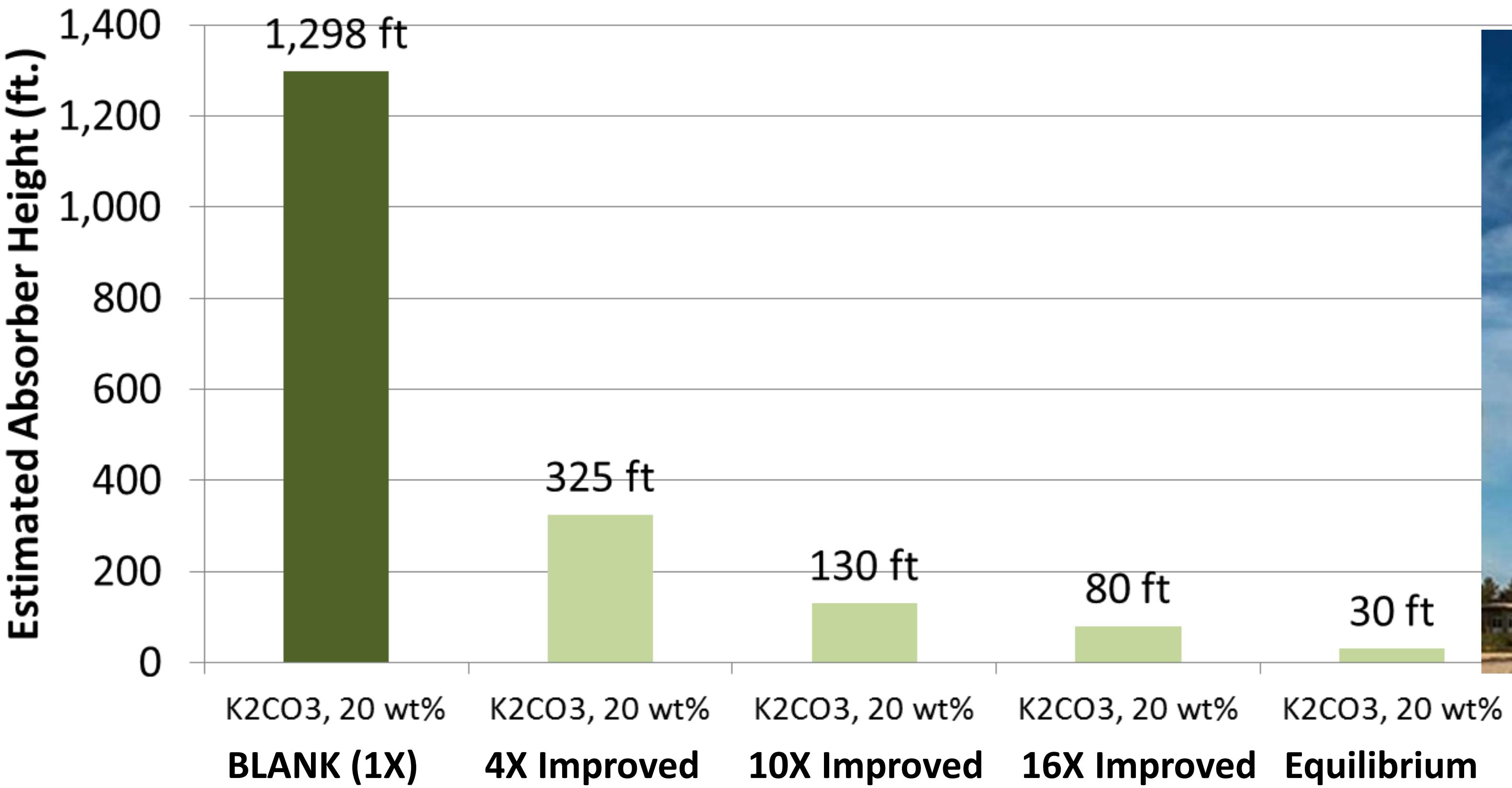
CATALYST REDUCES COLUMN PACKED HEIGHT

Reducing column height enables certain solvent systems to become feasible



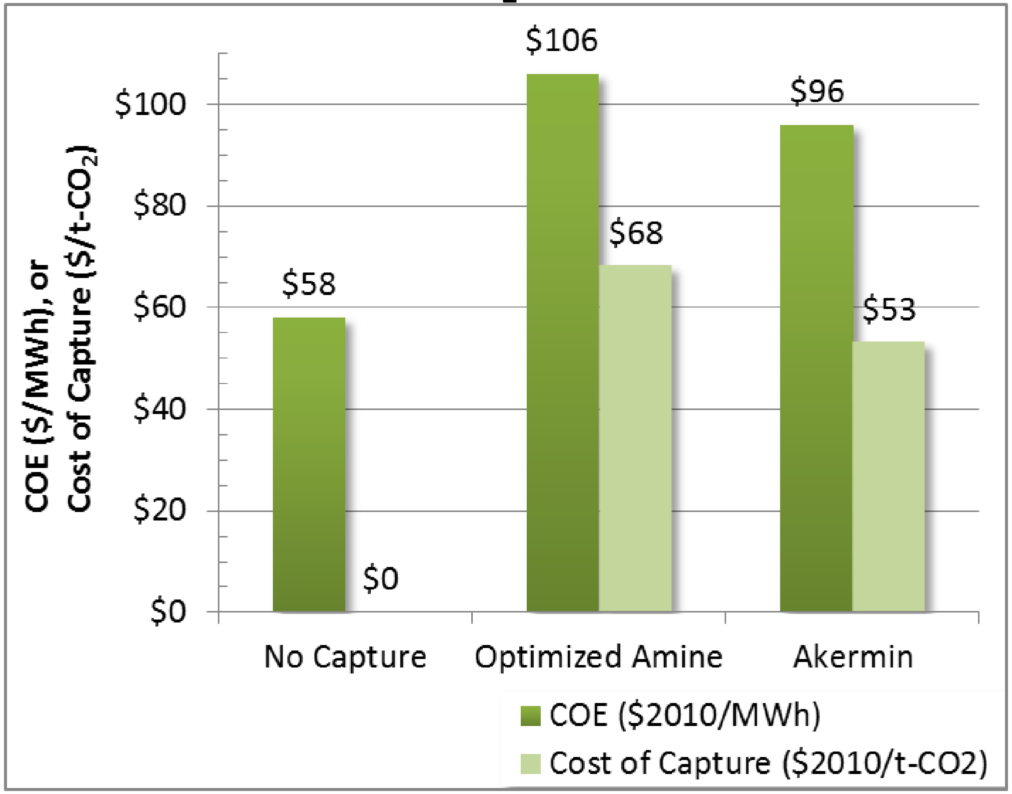
Goal: > 10X overall improvement in packing height

BENEFITS OF TECHNOLOGY TO THE PROGRAM

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

Desired Characteristic	Baseline (Amines)	K_2CO_3
No amine aerosol emissions		x
No VOC emissions		x
No toxic air or liquid emissions		x
High Rate	x	
High/low ht rxn	high	low
Low regeneration energy potential		x
Oxidative stability		x
Low viscosity		x
Lower corrosivity		x
Low or No flue gas polishing needed		x

Estimated Costs of Greenfield Super Critical PC Power Plant with CO_2 Capture



Both CCS cases include a $5.7 /MWh charge for CO_2 Transport, Storage and Monitoring

Technology broadens the choice of solvents to be used in CO_2 capture

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TECHNICAL CHALLENGES

- Achieve long-term stability
- Minimize inhibition by flue gas impurities
- Maximize enzyme retention, minimize leaching
- Maximize activity (minimize diffusion resistance)
- Replenishment of enzyme with minimal interruption

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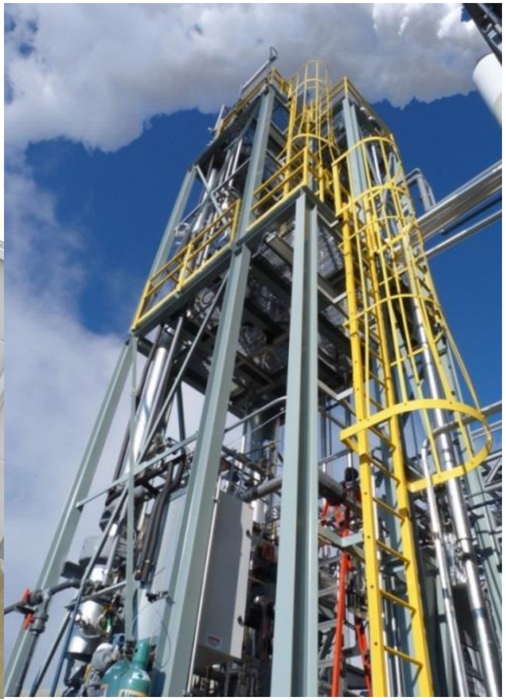
PROGRESS AND CURRENT STATUS

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:

EPIC

EPIC Systems,

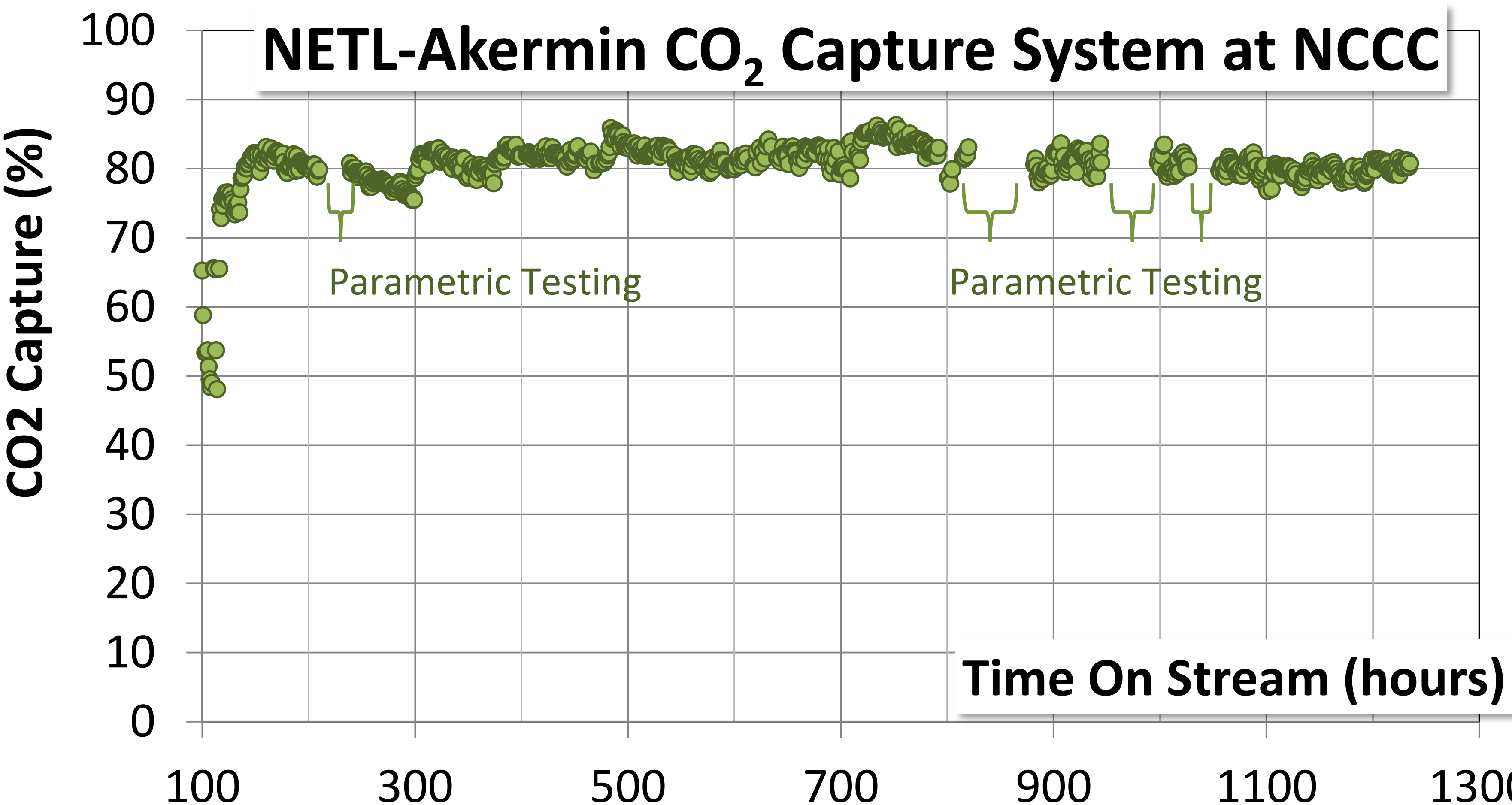
Instrumentation and controls:

EMERSON

- Blank testing complete
- Immobilized enzyme installed and has been operating since May 2013
- Planning to operate through end of September 2013.

BENCH UNIT DATA WITH BIOCATALYST

Data at design flow (31.5 Nm^3/hr, 275 LPH, XCL ~ 25%)



More than 1250 Hrs On Steam as of 7/09/2013, and continues.

Average CO2 inlet ~ 12% (dry basis)

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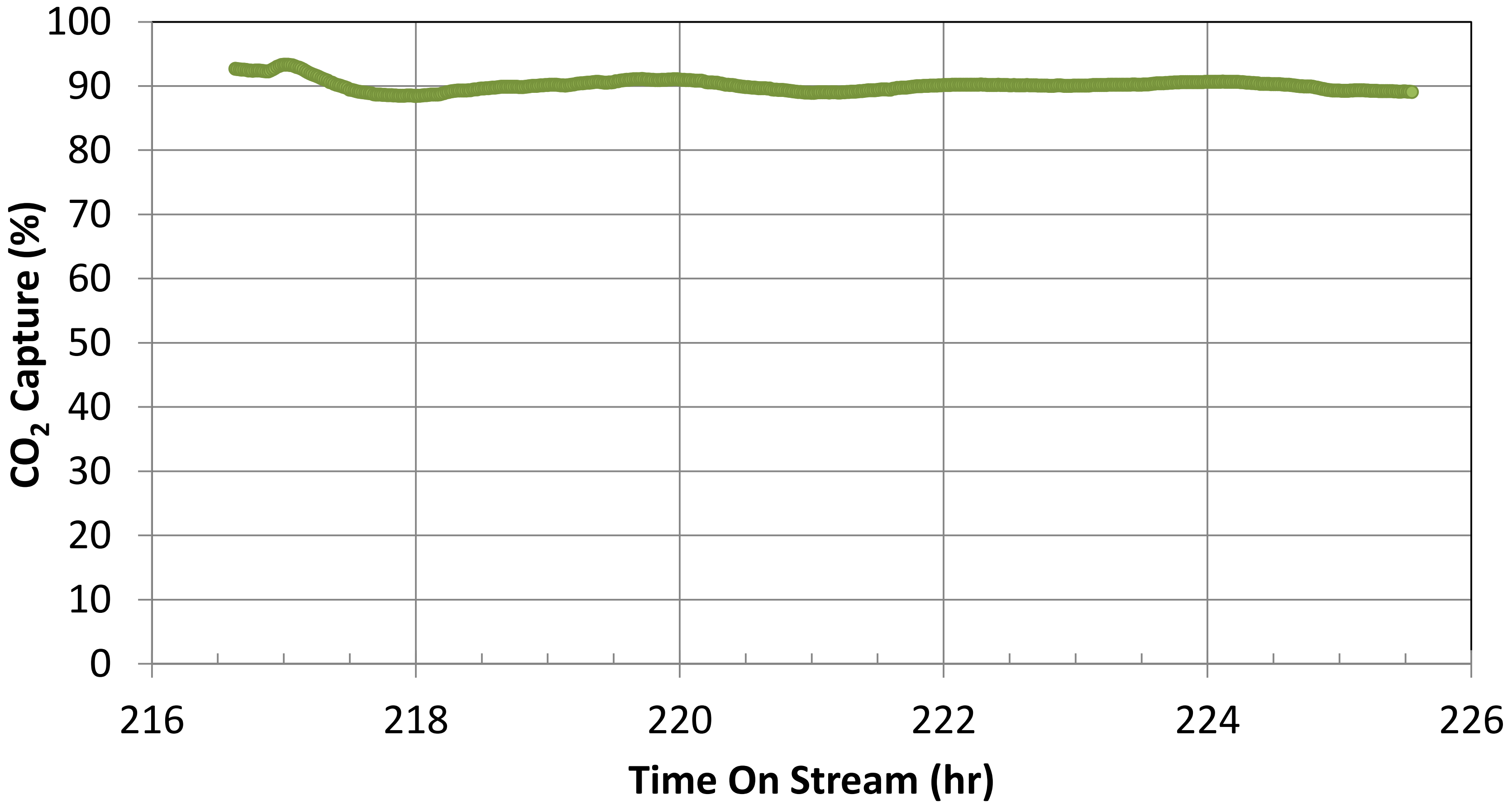
90% CO_2 CAPTURE TEST (~20 SCMH)

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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QUANTIFIED HEAT STABLE SALT ACCUMULATION

PRELIMINARY (1 week of data), additional results pending

Component	HSS (mg/L)	Rate moles/L /year	Loss of Solv. Capacity (%/year)
Nitrite (NO_2^{2-})	25.1	0.0283	0.83%
Nitrate (NO_3^{-})	6.41	0.0054	0.16%
Sulfate (SO_4^{2-})	36.1	0.0195	1.14%
Total	**67.6**	**0.0532**	**1.55%**

Preliminary estimate < 2%/year loss in capacity by HSS.
Additional data and analytical results are pending.

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QUANTIFIED CO_2 PURITY: ~99.98%

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%**

High selectivity is clearly demonstrated with a high purity product

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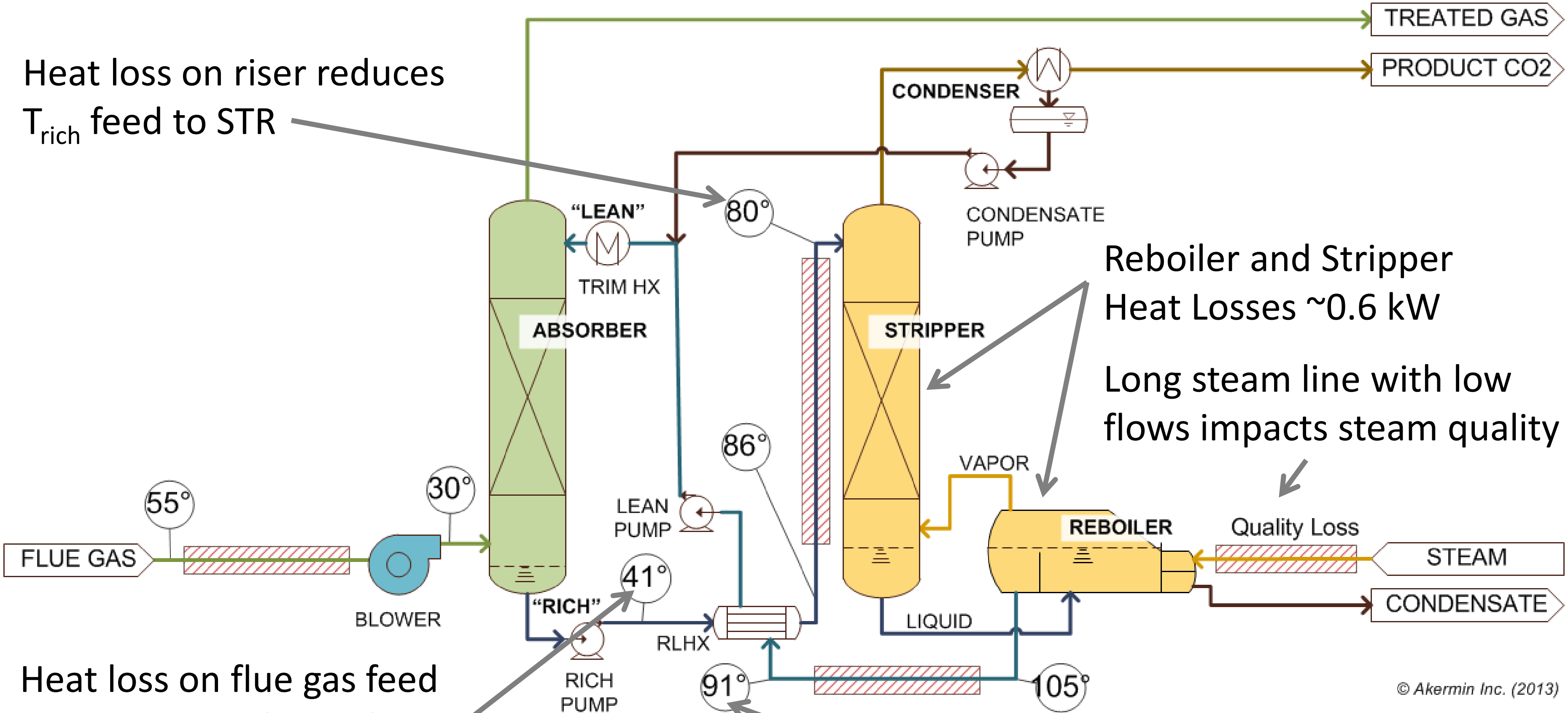
HEAT LOSSES ON BENCH-SCALE PLANT

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

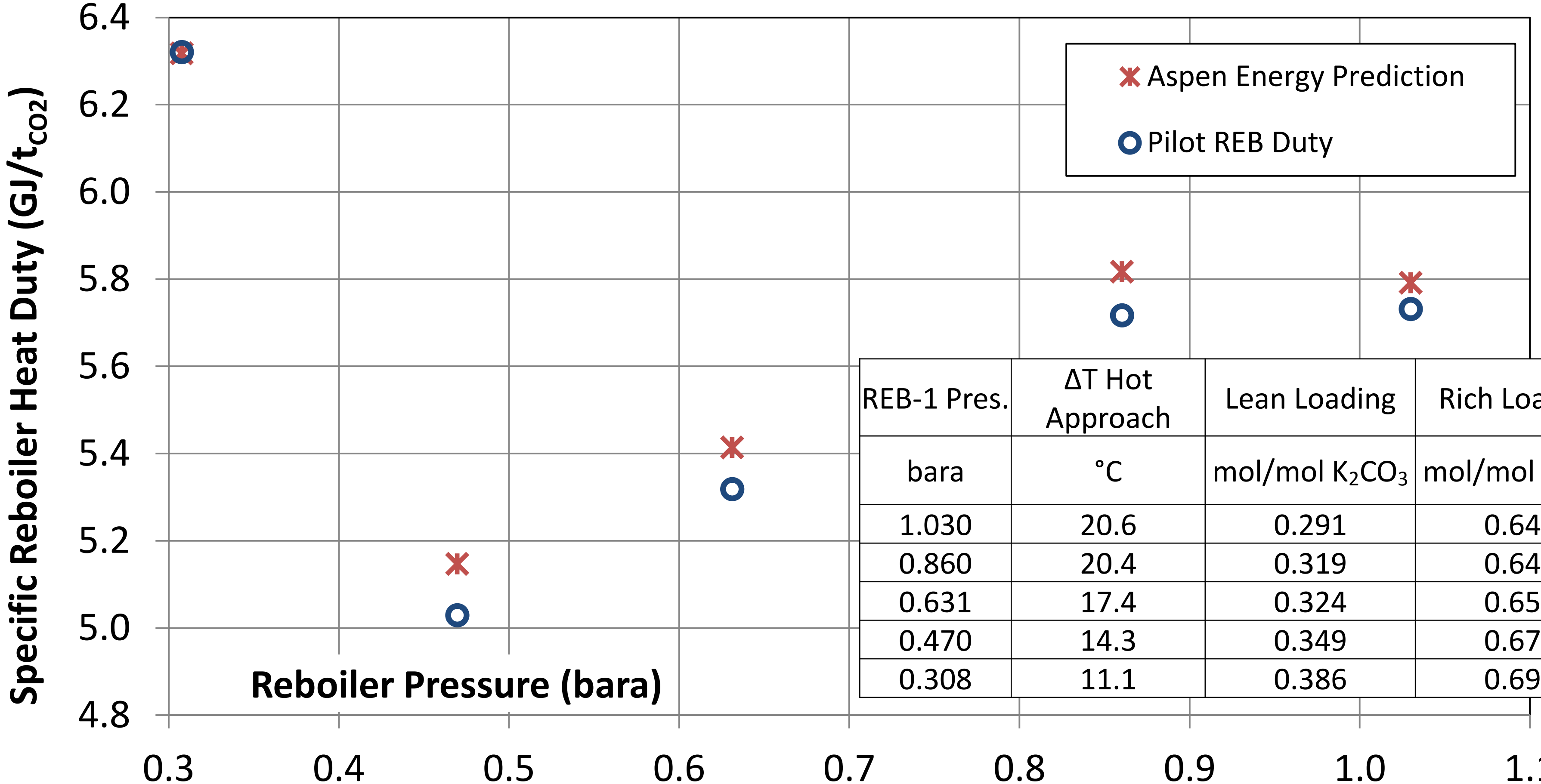
Heat loss on flue gas feed impacts T_{rich} solution here

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)

VACUUM REGENERATION: ASPEN VS. DATA

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

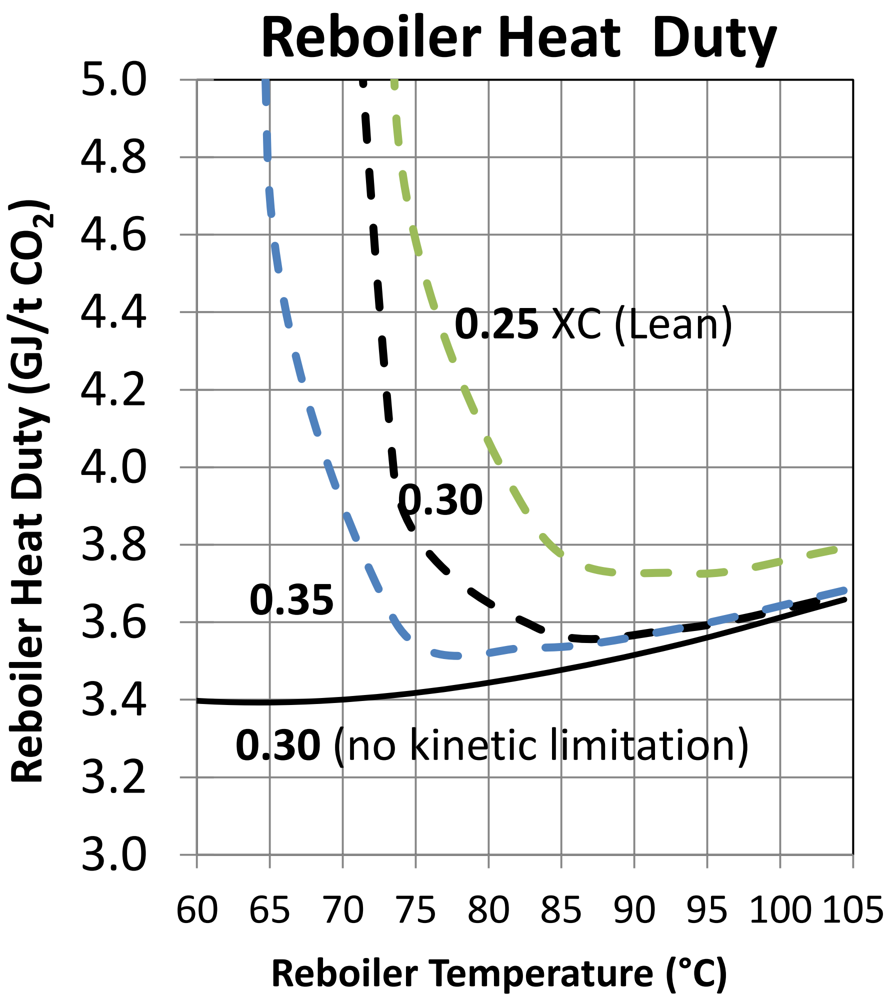


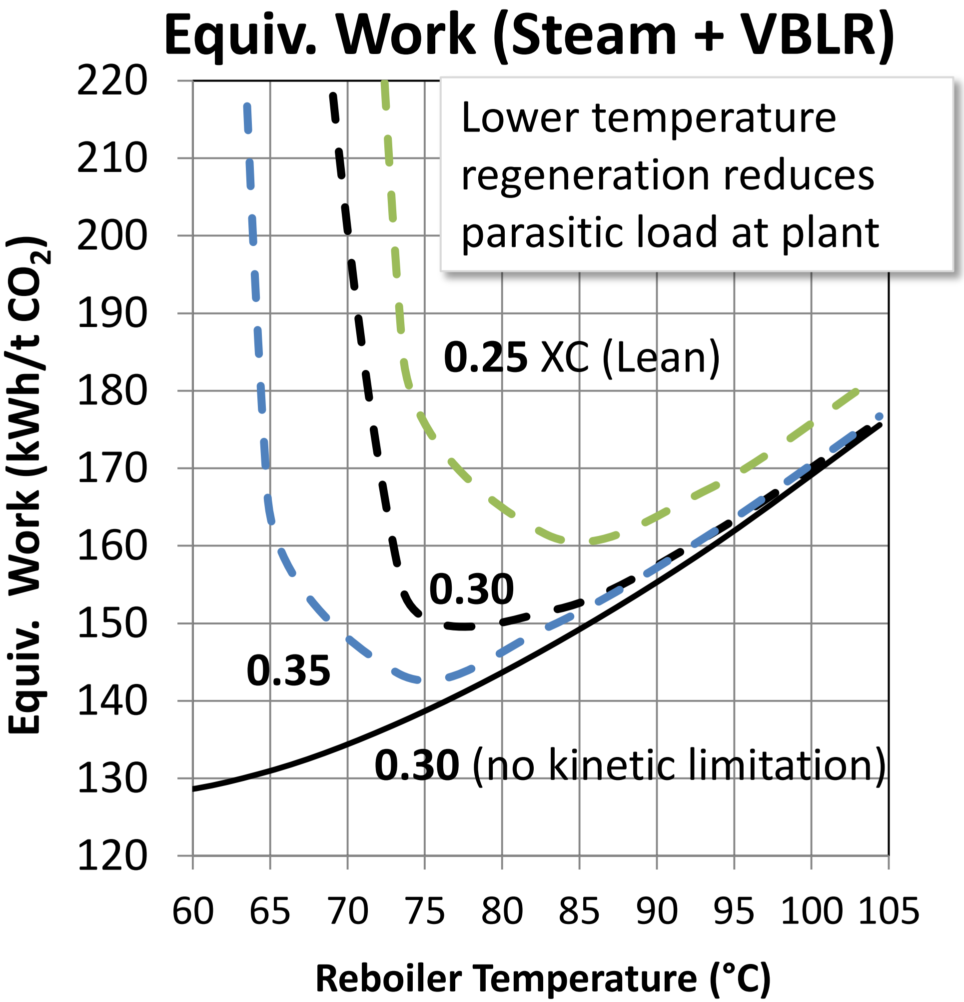
REB-1 Pres.	ΔT Hot Approach	Lean Loading	Rich Loading
bara	°C	mol/mol K_2CO_3	mol/mol K_2CO
1.030	20.6	0.291	0.645
0.860	20.4	0.319	0.645
0.631	17.4	0.324	0.650
0.470	14.3	0.349	0.673
0.308	11.1	0.386	0.697

Aspen model agrees within ~ 2.5% of measured values.

ENERGY & EQUIVALENT WORK VS. REBOILER TEMP.

Using lower grade steam reduces the loss of power-generating capacity for the plant!





- ~3.5 GJ/t_{CO_2} with K_2CO_3, basic flow sheet
- Equivalent work < 150 kWh/ t CO_2 for Steam + VBLR to 1.6 bar

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SUMMARY OF RESULTS

- Demonstrated that significant acceleration of CO_2 capture is achieved with immobilized CA in the absorber
- Demonstrated 90% capture using K2CO3 salt solution
- Demonstrated > 1200 hours online with no detectible decline in performance
- Negligible heat stable salts accumulation
- >99.9% purity of CO2 product
- Near zero aerosol formation
- 30% - 50% reduction in equivalent work of steam regeneration, including vacuum blower

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FUTURE WORK

Outside of this project

- Complete TEA with PNNL (this project)

Beyond this project:

- Scale-up, automate, and optimize manufacture of immobilized enzyme
- Develop and demonstrate second generation replaceable enzyme delivery system
- Demonstrate alternative solvents to further reduce regeneration energy and to lower equivalent work
- Explore alternative biocatalyst-enabled flow sheets

Wrapping up current project with final TEA and report.

ACKNOWLEDGMENTS

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- Battelle
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- EPIC Systems Inc:
  - Module design, fabrication, controls programming
- Emerson:
  - Instrumentation and controls

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