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Advanced Enzyme-Catalyzed CO_2 Capture in Low-Energy Solvents

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Pittsburgh, PA
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- **St. Louis-based biotechnology company**
- **Developing next generation cost and energy efficient, environmentally benign systems for CO_2 capture**
- **Technology based on integrating an enzyme within a proprietary biocatalyst delivery system which permits:**
  - Use of low energy solutions of carbonates
  - Incorporation into a traditional chemical absorption process

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

PROJECT OVERVIEW

- **Project participants**

- **Project duration: 33 months (initiated in October 2010)**
- **Funding**

Total Project:	$ 4,749,469
DOE Funding:	$ 2,909,678
Akermin Cost share:	$ 1,839,791

PROJECT OBJECTIVES

- **Engineer Bench-Scale Carbon Capture System**
  - ~5 kWe (500 SLPM flue gas)
- **Demonstrate 90% CO_2 capture from flue gas in a bench-scale unit in the presence of biocatalyst and potassium carbonate**
- **Characterize rate enhancement of biocatalyst**
- **Demonstrate tolerance to flue gas impurities**
- **Evaluate impact of external conditions on process performance**
- **Demonstrate CO_2 capture on flue gas for duration of 6 months**
- **Generate process data to further refine simulation models**
- **Model and evaluate the capital and operational costs for full-scale coal-fired power plant**

CARBONIC ANHYDRASE

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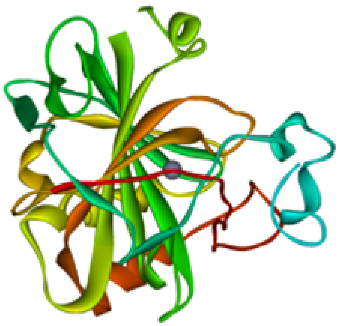
- **CA accelerates hydration of CO_2 to bicarbonate:**



$$\boxed{CO_2 + H_2O \xrightarrow{CA} HCO_3^- + H^+}$$

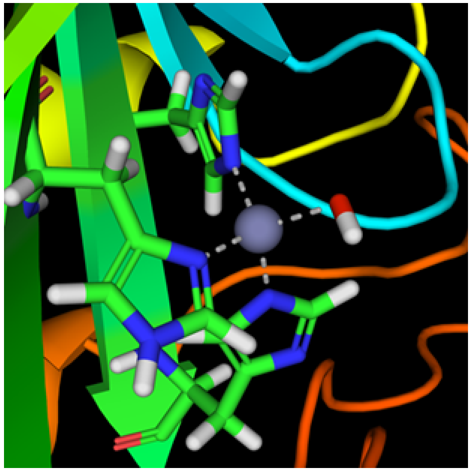
MDEAH$^+$

MDEA

CO_3^{--}

HCO_3^-

Active site of CA

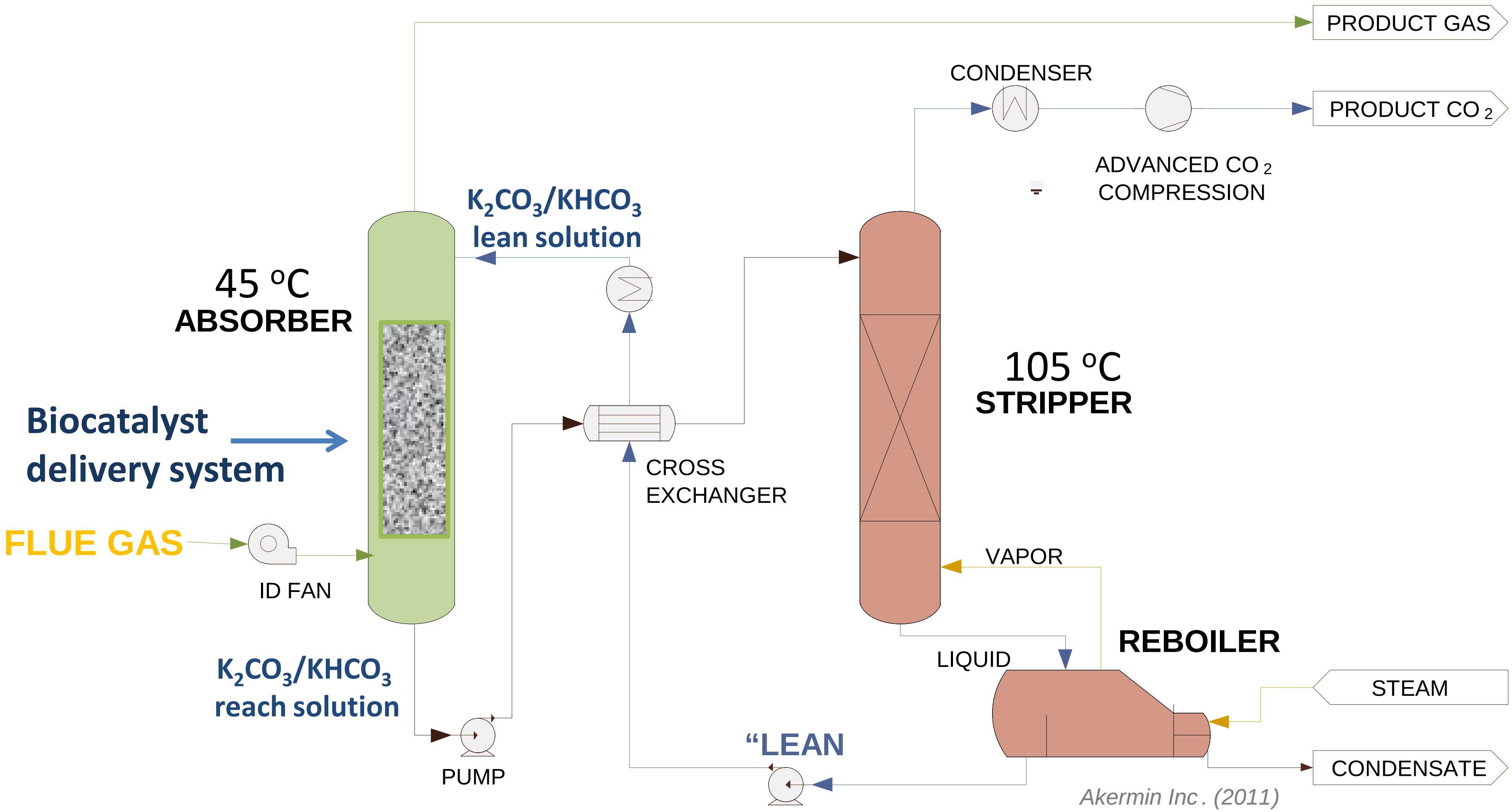


$k_{cat} = 10^6$/sec

- **Akermin explored numerous CAs for CO_2 capture**
- **CA developed by Novozymes is top candidate**
  - Highly active
  - Resistant to major impurities in flue gas
  - Thermostable
  - Resistant to high pH (9.5-10.5)
  - High expression level, few impurities

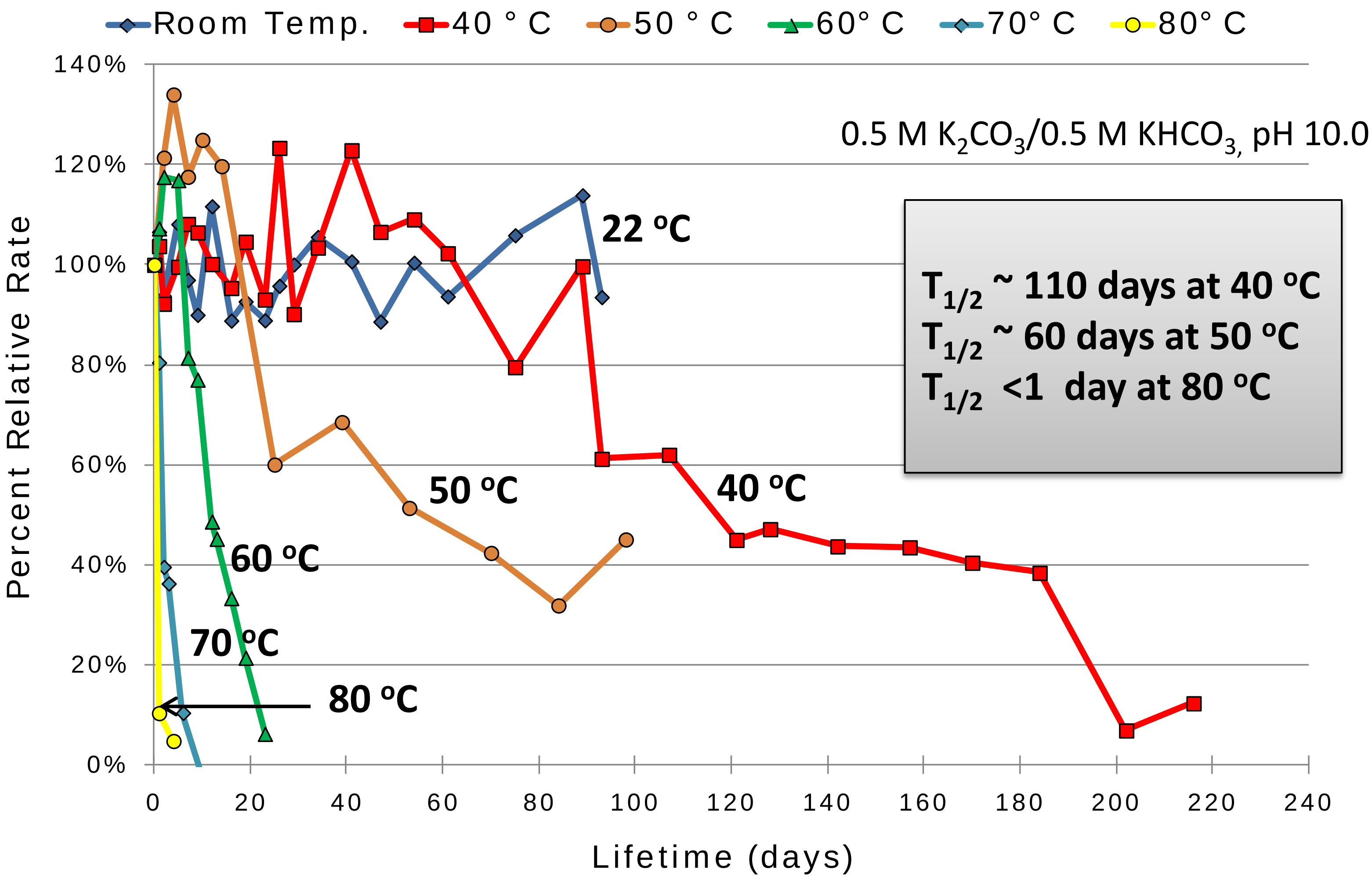
TECHNOLOGY FUNDAMENTALS

Basic unit design for CO_2 capture incorporating biocatalyst



Akermin Inc . (2011)

THERMOSTABILITY OF FREE CARBONIC ANHYDRASE



CHARACTERISTICS OF BIOCATALYST DELIVERY SYSTEM

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

BASIC PROCESS FLOWCHART

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ENZYME

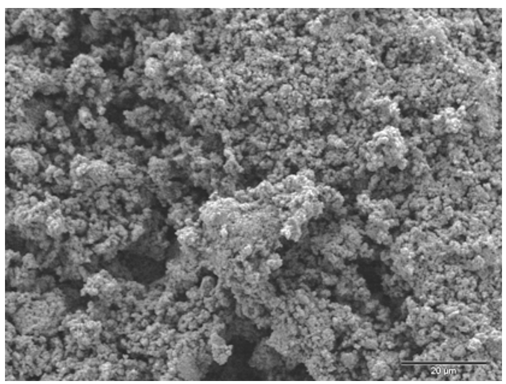
SOLUTION OF MONOMERS, ADDITIVES, ETC.

ENZYME SUSPENSION

1. COATING

2. CURING

ASSEMBLY

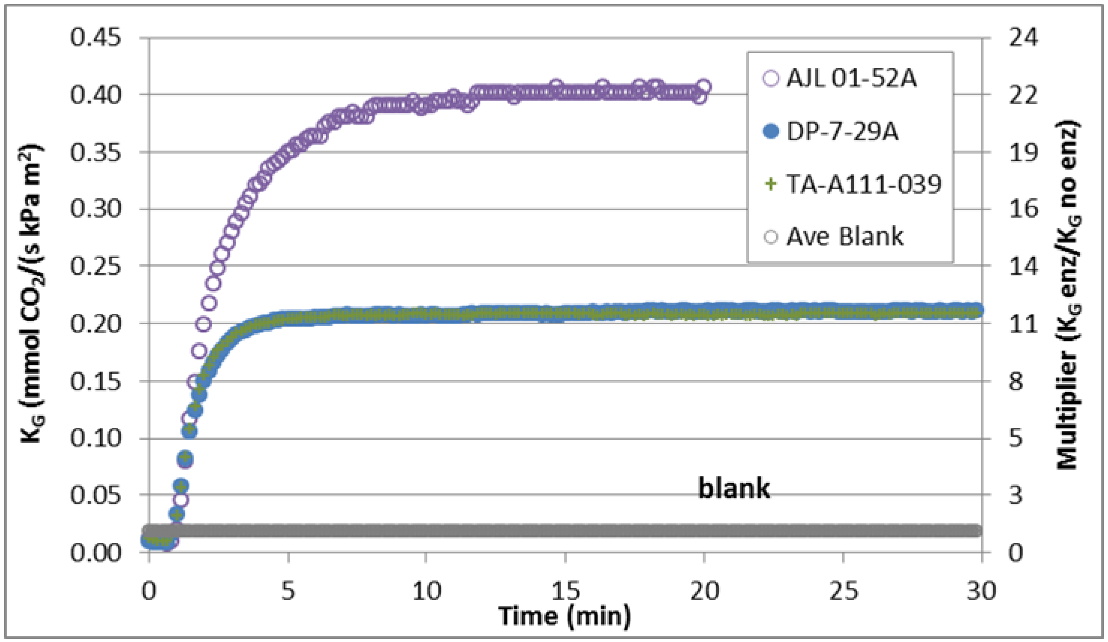


SEM IMAGE OF COATING

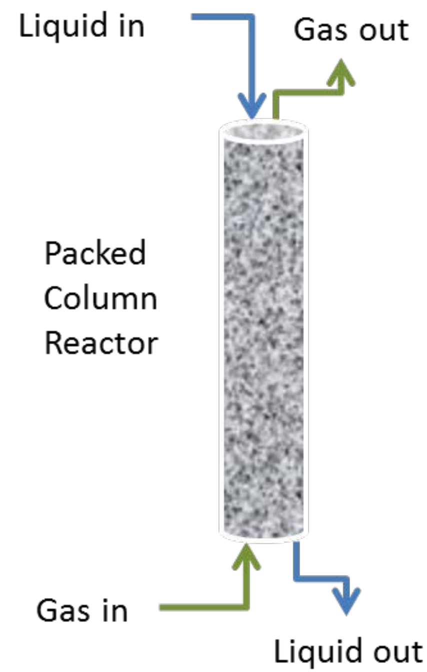
Akermin developed several proprietary approaches to exhibit CA at gas/liquid interface of absorber column

PERFORMANCE OF BIOCATALYST IN A COUNTER-CURRENT FLOW COLUMN

20% carbonate (w/w) pH 10.1; p = 1 psig; CO_2 absorption at 45^{o}C;



K_G per packing area, lab-scale test reactor interfacial area ~ 30%



Up to 22-fold increase of K_G was demonstrated

BIOCATALYST MAXIMIZES MASS TRANSFER AND REDUCES COLUMN HEIGHT

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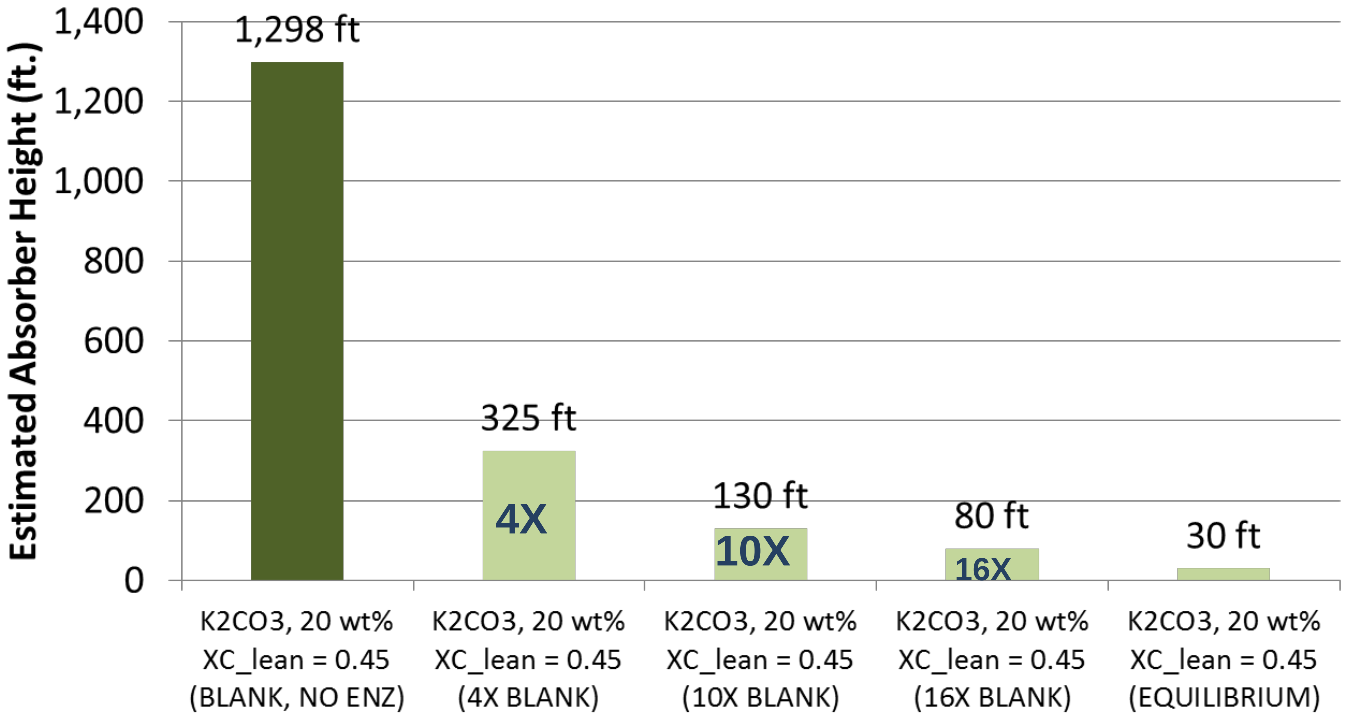


Enhancement over 10X reduces the absorber height to less than 130 feet for a 550 mWe coal-fired power plant*

**Aspen Plus modeling by PNNL*

STUDY OF CA INHIBITION BY PRODUCTS OF HYDRATION OF FLUE GAS IMPURITIES

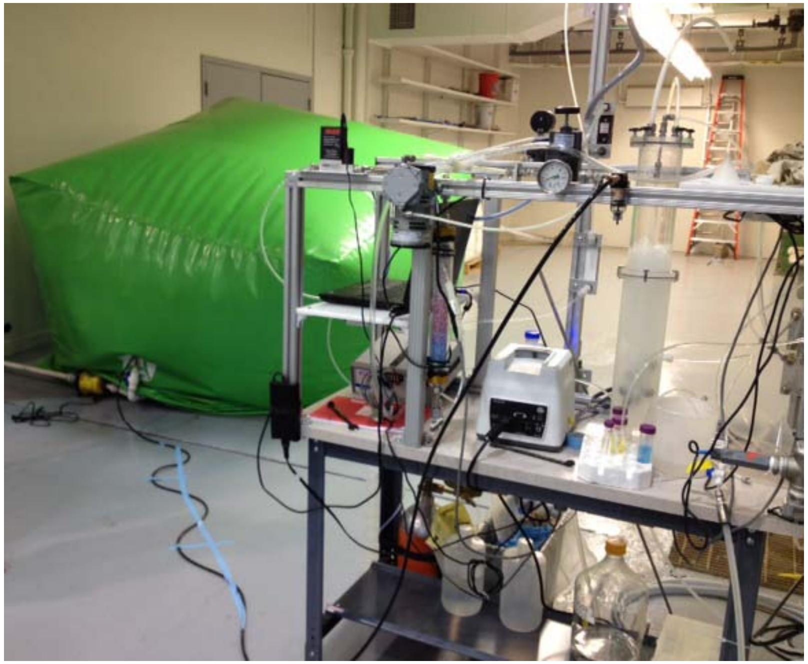
Solution study

Contaminant	Anticipated Concentration	Soluble Product	IC50 (mM)
NO_X	~80 ppm	Nitrate (NO_3^-)	~ 1000
		Nitrite (NO_2^-)	> 2000
SO_X	~45 ppm	Sulfate (SO_4^{-2})	> 500
		Sulfite (SO_3^{-2})	>> 10
Chloride	< 1ppm	Chloride (Cl^-)	> 2000

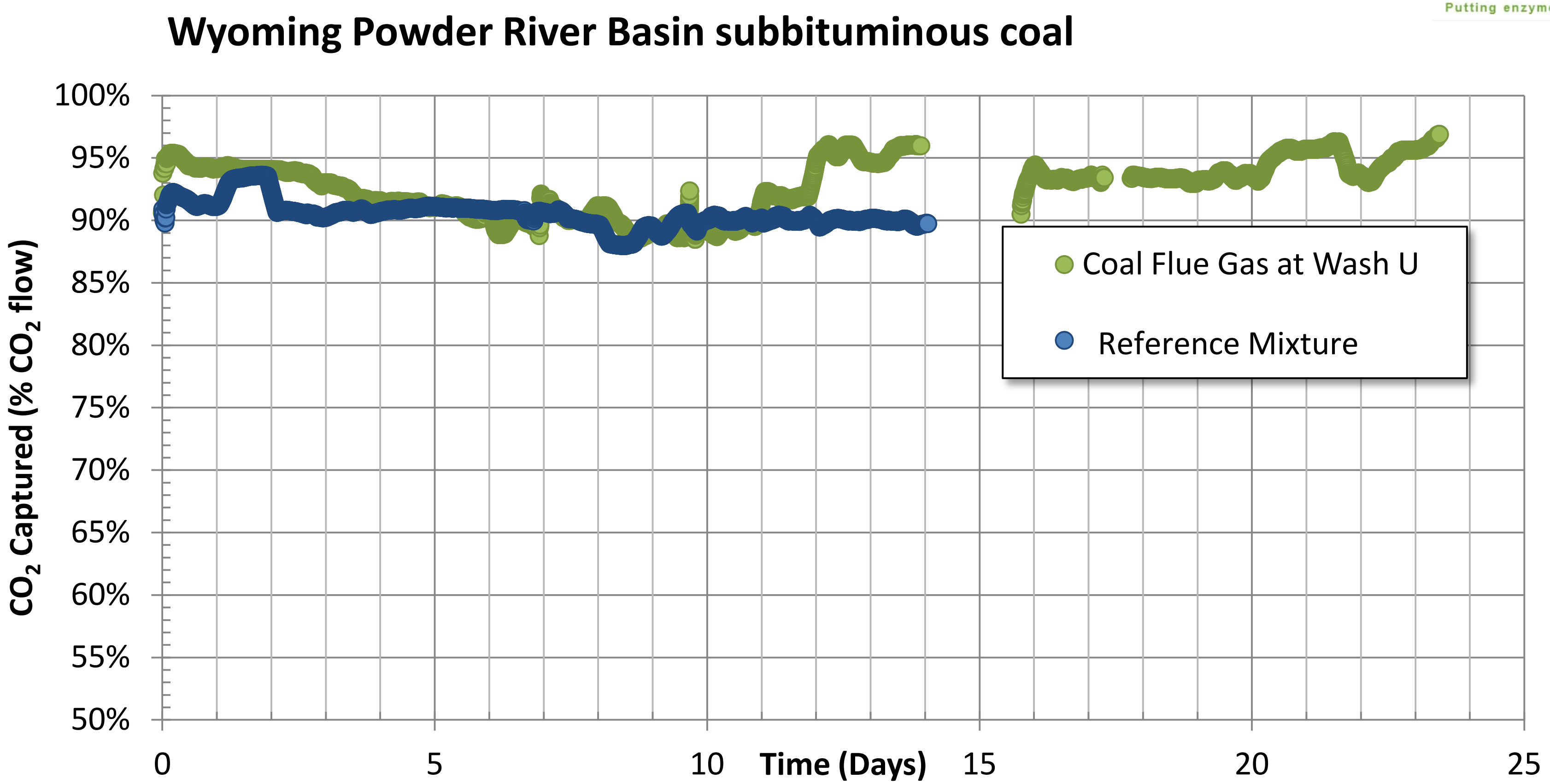
Sulfate, sulfite, nitrate, nitrite and chloride have little or no inhibitory potency

TESTING ON FLUE GAS

- **Evaluate resistance of the biocatalyst delivery system to Hg, SO_x and NO_x**
- **Demonstrate endurance performance using actual flue gas**
  - Flue gas was generated at the *Advanced Coal and Energy Research Facility* at Washington University in St. Louis
  - Flue gas was gathered into a 10 m^3 bag from a short duration combustion test



TESTING ON FLUE GAS

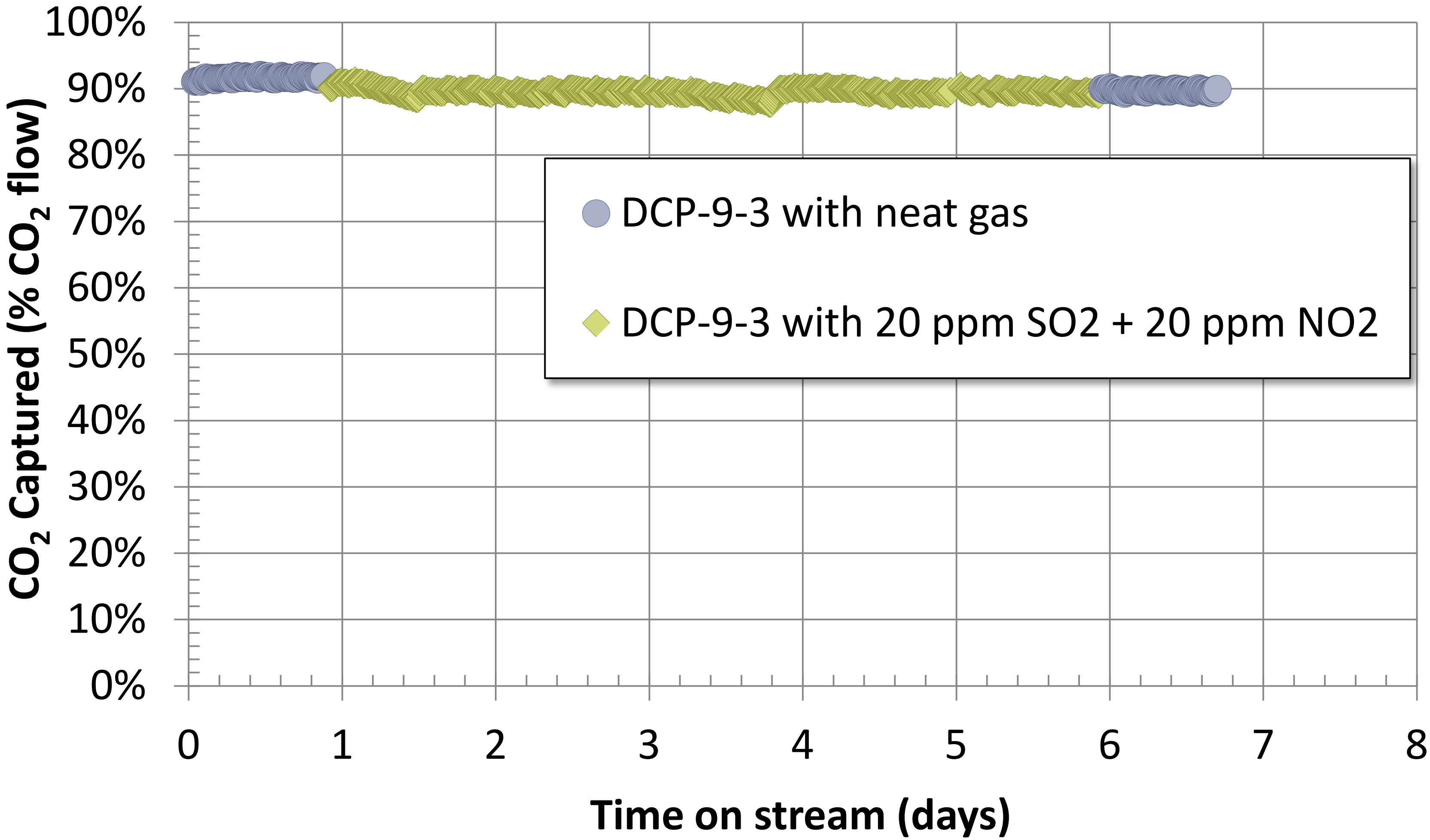


~ 90-95% CO_2 capture sustained for over 23 days on flue gas (~14% feed)

~ 90-92% CO_2 capture on Reference Mixture (~15% CO_2 in air) for 14 days

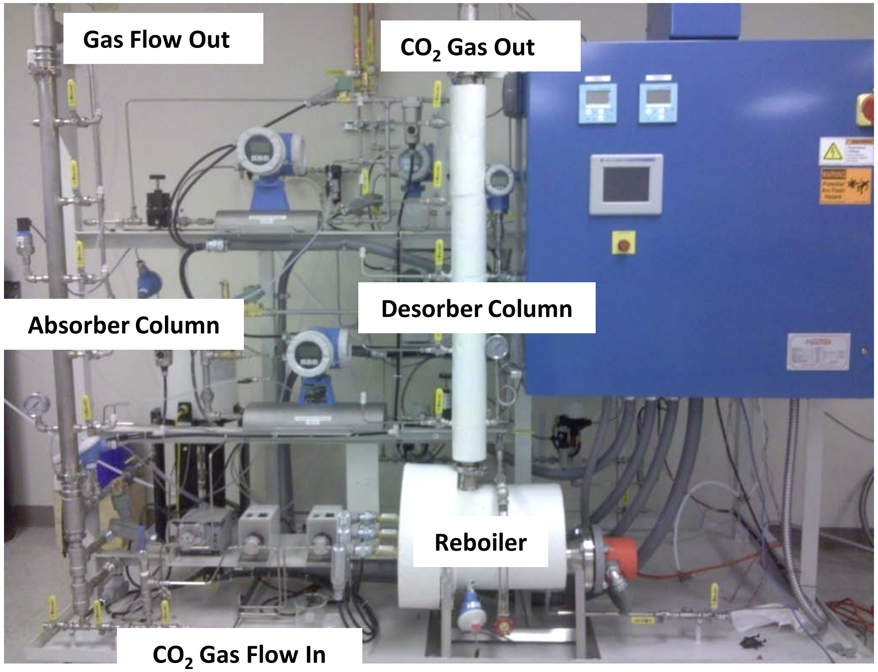
Overall performance is stable in both cases

STUDY OF TRACE CONTAMINANTS: 20 PPM SO_2 AND 20 PPM NO_2



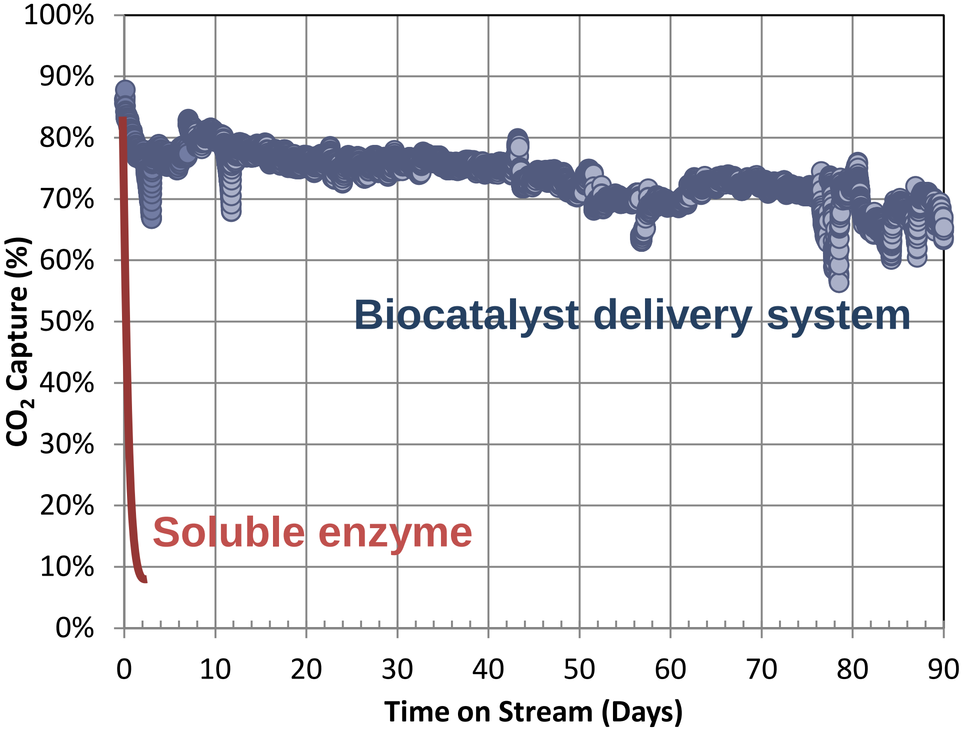
~90% capture maintained over the duration of the experiment

LONG-TERM PERFORMANCE OF CLOSED LOOP REACTOR



Akermin's Closed Loop Reactor

400 mL/min 15% CO_2; 20% carbonate (w/w)
pH 10.1; p = 1 psig; CO_2 absorption at 45°C;
thermal swing desorption at 105°C



>20 million CO_2 molecules hydrated by one CA molecule over 75 days
Initial performance >400 kg CO_2 captured per day per kg of CA

ADVANTAGES OF BIOCATALYST DELIVERY SYSTEM WITH CARBONATE CHEMISTRY

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- **Significant Rate Enhancement**
  - Lower absorber column heights resulting in lower capital expenditures
- **Energy-efficient process: Low Parasitic Load**
  - Flexibility to regenerate at wide range of pressures/temperatures
- **Carbonate solution has negligible vapor pressure**
  - Lower solution losses and no need for wash columns resulting in lower capital and operating expenses
- **Operation at lower temperatures (40°C) and pH values**
  - Low corrosion rates relative to conventional amine & carbonate processes
- **Carbonate solution does not degrade in presence of oxygen and impurities, which reduces both capital and operating expenses**
  - No need for reforming
  - No expected polishing FGD
- **Carbonate solution is low cost commodity chemical**
  - Combined with lower solution losses, equates to lower replacement costs
- **Environmentally-friendly process**
  - No solvent or nitrosamine emissions to the atmosphere
  - Benign (potentially reusable) by-products with lower disposal costs

A simple process chemistry and design that yields a low-cost solution for CO_2 capture

PROGRESS AND CURRENT STATUS

PROJECT STATUS

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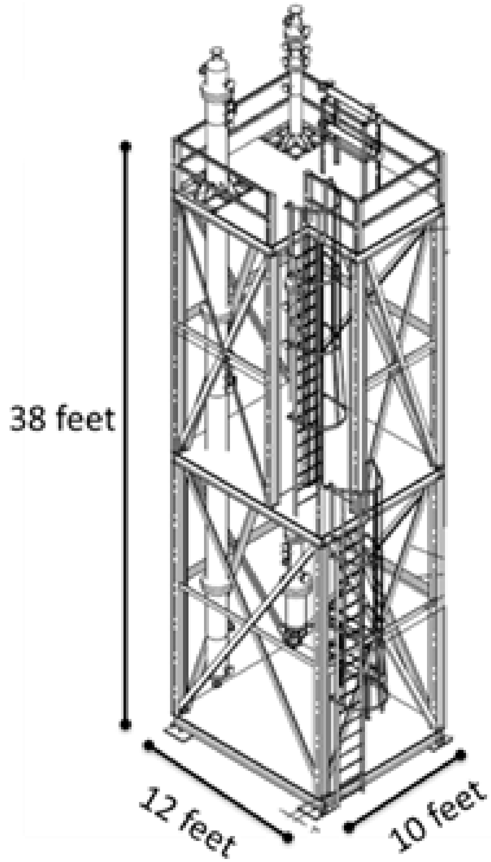
- **Key Milestones Completed to Date**
  - Demonstrated >80% physical protein retention
  - Completed Wetted Wall kinetic testing for K_2CO_3
  - Defined preferred conditions for low energy operation
  - Demonstrated 10+ fold acceleration of CO_2 capture
  - Completed baseline techno-economic analysis
  - Finalized Bench unit column design, M&E balance
  - Executed Site Agreement with NCCC
  - Performed testing of flue gas contaminants

BENCH UNIT SPECIFICATIONS

- **Absorber Design Case**
  - 500 SLPM flue gas (nominal)
  - 90% Capture, nominal 0.175 tpd CO_2
  - Sulzer 500 m^2/m^3 packing
  - Nominal Liquid: 300 kg/hr (nominal)
  - 20 wt% K_2CO_3, lean pH ~10
- **Heat recuperative cross exchanger and trim coolers**
- **Emerson Delta-V Control System**



Akermin Pilot Unit

UPCOMING ACTIVITIES

Fabrication of Bench Unit	June – October 2012
Scale-up coating process and coat ~100 m^2 of contactor	November 2012
Install/Commission	November 2012
Initial Testing (blank)	December 2012
Initial Testing (biocatalyst)	January 2013
Operate unit for six months	January – June 2013
Model and evaluate the capital operational costs for full-scale coal-fired power plant	June 2013

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