Advanced Low Energy Enzyme Catalyzed Solvent for CO_2 Capture

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Akermin: an advanced biocatalyst company

AKERMIN

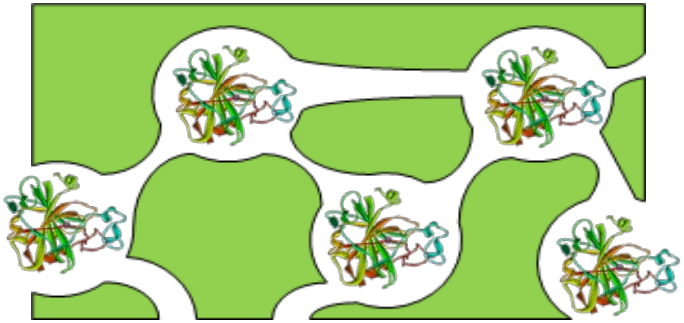
- Founded in 2004 to commercialize patented enzyme immobilization and stabilization technology
  - Technology based on use of novel micellar polymers to immobilize and stabilize enzymes
  - Originally developed at St. Louis University, Akermin has exclusive, world-wide rights
- Technology initially validated in biofuel cells
  - Enzyme catalyst life extended from hours or days to over three years in fuel cell electrodes
- Akermin's technology can be applied to a variety of enzymes for applications requiring long enzyme life under harsh conditions
  - Focused on carbon capture opportunity

Project Overview

- Project participants
  - Akermin
  - Battelle Memorial Institute
  - Pacific Northwest National Laboratory (PNNL)
- Project duration: 24 months
- Funding:
  - Total award: $3,256,759
  - DOE funding: $2,605,407 (includes $350,000 to PNNL)
  - Cost share: $651,352

Technology Background

- Akermin's enzyme stabilization and immobilization technology is based on the use of micellar polymers to encapsulate the enzyme
  - Encapsulates enzyme within micellar "pocket" to provide exceptional stabilization without loss of enzyme activity
  - Provides stabilization against denaturation without restricting degrees of freedom of movement for enzyme
  - Porous nature of film allows for diffusion of reactants and products to and from enzyme active site



Key driver: energy cost

- Solvent-based systems show promise for post-combustion CO_2 capture but current technologies impose an unacceptable energy demand on power plant due to energy required for solvent regeneration.
- Carbonate systems offer potential for lower regeneration energy, but exhibit slow kinetics, requiring operation at high temperatures and pressures.

Absorbent	Heat of Reaction GJ/ton CO_2 (kJ/kg CO_2)
Monoethanolamine - H_2O (MEA)	1.92 (1919)
Diethanolamine - H_2O (DEA)	1.93 (1930)
Methyldiethanolamine - H_2O (MDEA)	1.34 (1340)
Potassium carbonate - H_2O	0.64 (640)

Enzymatic catalysis for CO_2 capture

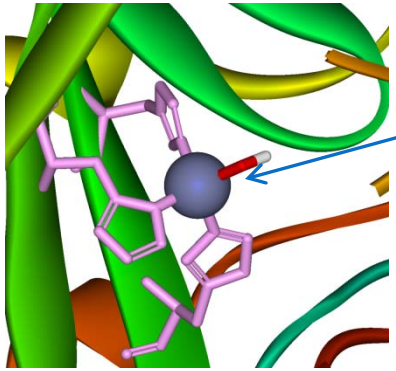
- Carbonic anhydrase catalyzes the hydration of CO_2 to bicarbonate, the rate-limiting step for bicarbonate formation.

$$CO_2 + H_2O = H^+ + HCO_3^-$$

- Carbonic anhydrase is among fastest known enzymes, with $k_{cat} = 10^6\ sec^{-1}$.

- Carbonic anhydrase activity is expressed ubiquitously among all living organisms, providing broad genomic diversity.

- Stabilization of CA enzyme is required to achieve adequate enzyme activity retention under operating conditions of pH and temperature for effective carbon capture.



Akermin technical approach

- Enable the use of low energy carbonate solvents through enzymatic catalysis of bicarbonate formation

  $K_2CO_3 + CO_2 + H_2O = 2\ KHCO_3$ $\Delta H_r = 640$ kJ/kg CO_2

  – Goal is to achieve low solvent regeneration energy with kinetics comparable to benchmark amine systems.

- Stabilize and immobilize carbonic anhydrase to achieve activity retention over extended time period under industrial conditions

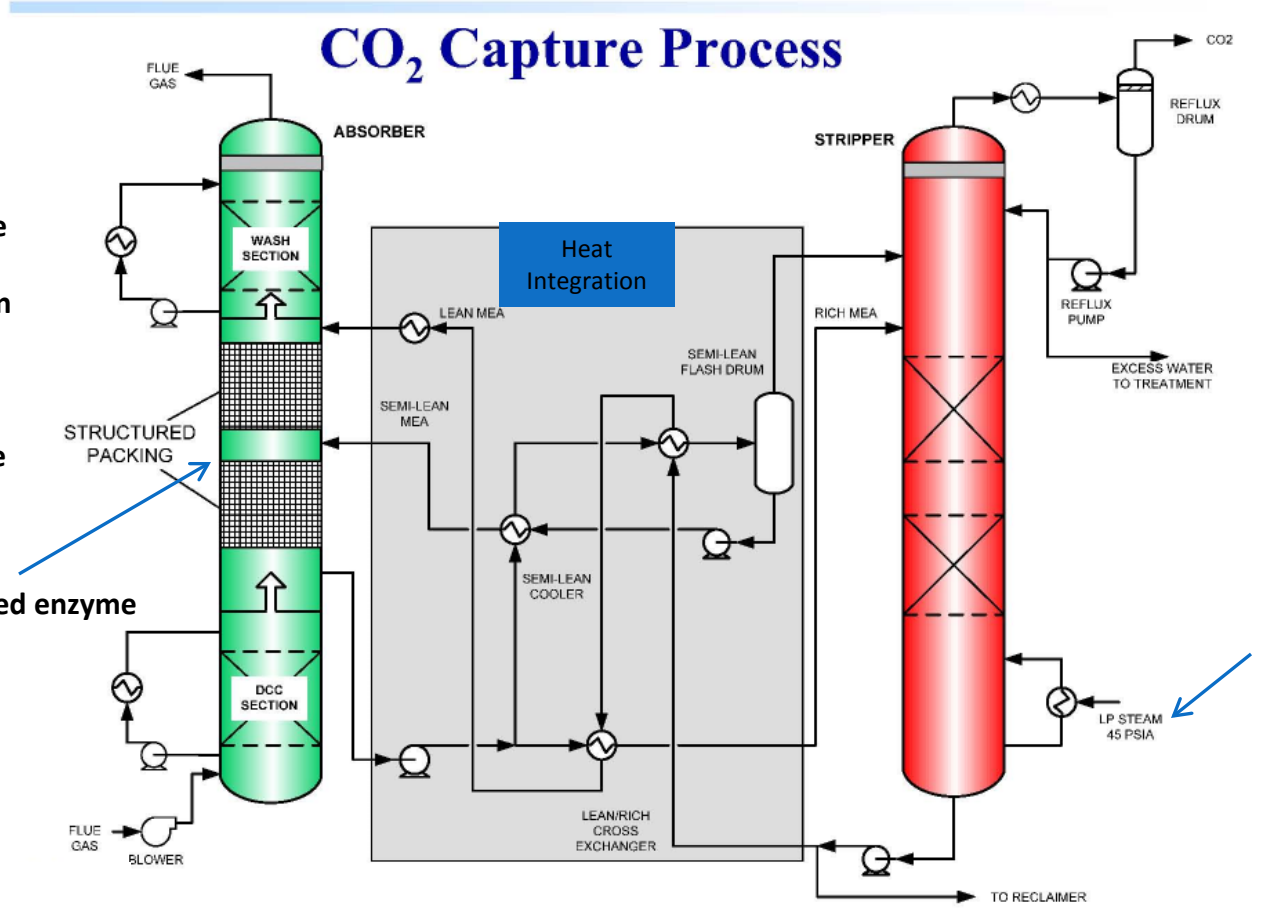
  – Initial system operational lifetime goal of 6 months

Akermin's micellar polymer technology provides the enabling technology for achieving required enzyme stabilization

Key capital and operating cost drivers

Carbonic anhydrase impacts absorption kinetics enabling use of carbonate

Immobilized enzyme



Low heat of regeneration of bicarbonate results in energy savings (less steam) and lower parasitic load on power plant

Technology Development Challenges

AKERMIN

- Enzyme immobilization
  - Greater than 80% physical retention in flow liquid
- Enzyme stabilization
  - Long life under anticipated absorber conditions (40 – 60°C, pH 9-10, high ionic strengths)
- Flexible immobilization technology needed
  - Easily adapt to improved enzymes, enzyme independent
  - Adaptable to varied carbonate chemistries (K_2CO_3/$KHCO_3$, ammonium carbonate, MDEA, etc.)
- Process design and scale-up information needed
  - Improved understanding of costs, optimized energy, column performance
- Unique Absorber Design Challenge
  - Heterogeneous catalysis in (3) phase system, complex mass transfer problem
  - Detailed model development and bench-unit validation is needed
- Demonstrate tolerance to trace contaminants in flow system
  - Tolerance to sulfur and nitrogen oxides in bench-scale flow system

Our Project with NETL addresses these development needs

Key Program Objectives

- Evaluate potential enzyme isoforms for stability to anticipated operating conditions and down-select to preferred option
- Optimize micellar polymer to achieve high enzyme immobilization and stabilization
- Develop detailed Aspen model of enzyme-catalyzed carbonate system and extrapolate to a power plant equivalent to 550 MWe
  - Includes mass and energy balances, electric power requirements and projected chemical and maintenance costs.
  - Will allow direct comparison of operating costs for baseline approach and CA-catalyzed approach
- Build and test a closed loop bio-reactor capable of processing up to 500 standard liters per minute of gas, the approximate equivalent of a 5 kWe power plant
  - Demonstrate continuous operation over a 6 month period

Akermin Development Plan

Phase-1 Proof of Concept

1. Project Management, Planning, Reporting
2. Enzyme Selection, Partnering for Scaled Expression
3. Enzyme Immobilization, Characterization, Lifetime Studies
4. Detailed lab-scale semi-batch stirred reactor studies

Phase-2 Lab-scale process development

5. Lab-Scale Closed Loop Reactor Testing

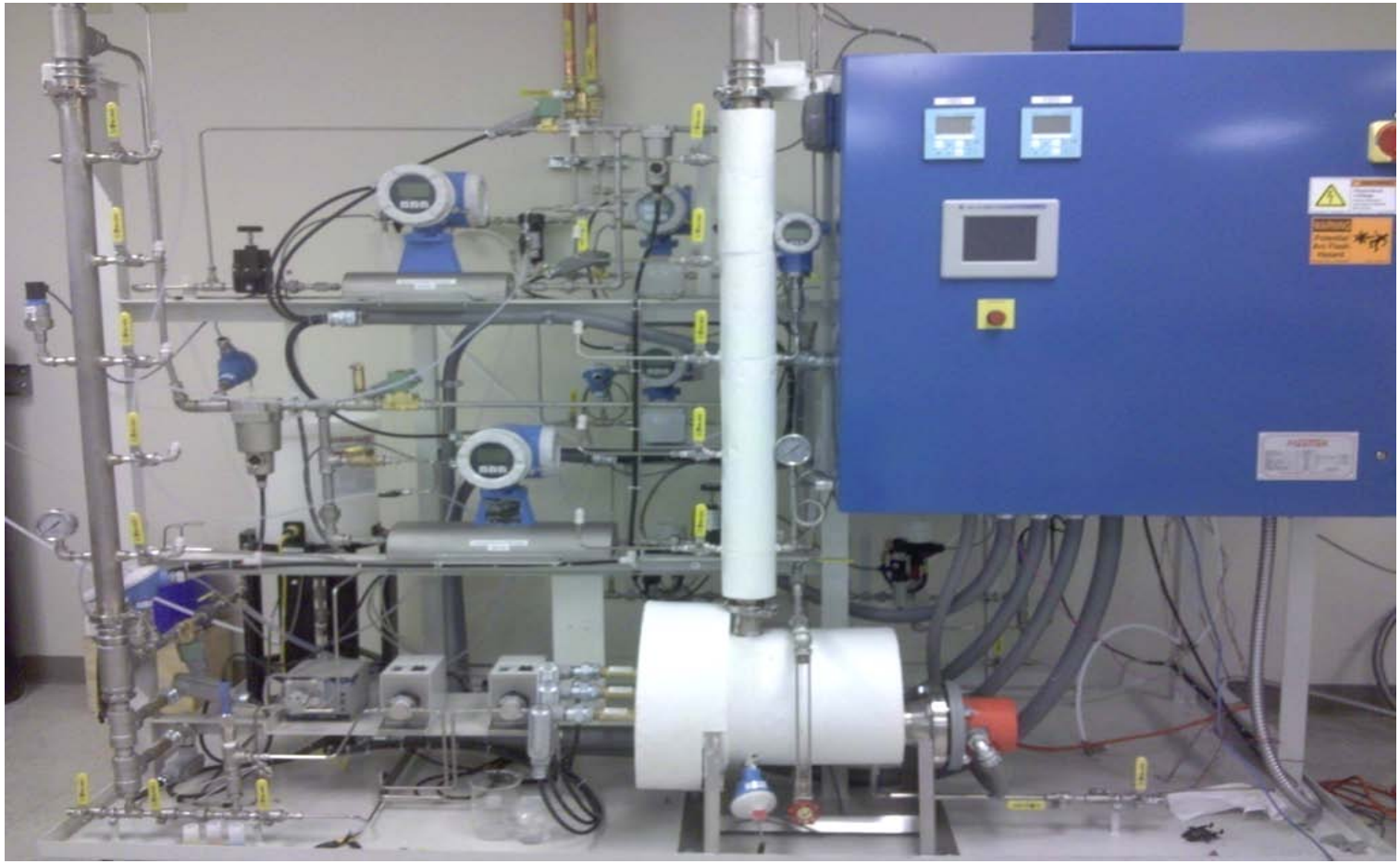
Phase-3 Process scale-up and Demonstration

6. Aspen Plus® Model Development, Cost Estimation
7. Engineering of Bench-Scale Carbon Capture System
8. Procure, Install and Start Up Bench Unit
9. Demonstrate CO_2 Capture in Enzyme Catalyzed Bench-Unit

Project Methodology

- Using established activity assays for CA, measure CA activity for various isoforms under accelerated stress conditions, both free enzyme and immobilized enzyme
- Optimize micellar polymer by evaluating polymer composition, grafting density, cross-link density
- Employ lab scale reactor to obtain preliminary kinetic data and evaluate operating conditions for CA-catalyzed CO_2 capture
- Using wetted-wall testing, measure gas-liquid mass transfer rates and reaction kinetics, with and without enzyme
- Operate lab closed loop reactor to gain experience benefiting scale up and obtain preliminary enzyme life data under continuous operation
- Based on Aspen modeling results, design and commission a bench-scale closed loop carbon capture system
  - Operate for 6 months to establish robust data set for system operating costs

Akermin Closed Loop Reactor for Carbon Capture



Future activities

- Bench-scale reactor will be designed to facilitate on-site testing at multiple locations, as requested by DOE
- Development for other applications
- Establish appropriate partnerships to accelerate commercialization

Key team members

- John Reardon Akermin
  - Principal investigator, Director, Engineering
- Dr. Wayne Gellett Akermin
  - Director, Chemical Systems
- Dr. Tracy Bucholz Akermin
  - Senior Scientist, Polymer Chemistry
- Dr. Tizah Anjeh Akermin
  - Senior Scientist, Organic Chemistry
- Josh Schumacher Akermin
  - Senior Chemical Engineer
- Dr. Bruce Sass Battelle
  - Principal investigator, Battelle
- Dr. James Collett PNNL
  - Principal investigator, PNNL
- Andrew Jones U.S. DOE-NETL
  - Project Manager