



NETL 2014 TRANSFORMATIONAL CARBON CAPTURE TECHNOLOGY WORKSHOP

Solvent-Enabling Enzymes

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DOMINANT APPROACH FOR CO₂ CAPTURE TODAY: CHEMICAL ABSORPTION WITH AMINES

Where does it fall short?

- High operating costs & poor environmental profile
 - Increases energy requirements
 - Relies on volatile solvents
 - Generates hazardous by-products
 - Accompanied by solvent degradation
- Inadequate for large-scale CO₂ capture from flue gas streams

ALTERNATIVE SOLVENTS



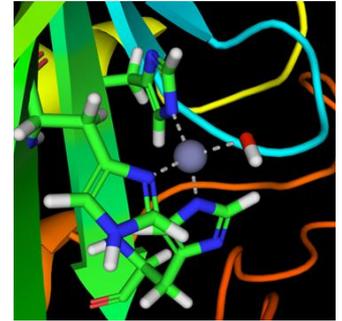
Solvent Characteristics	Baseline (Amines)	K_2CO_3
No amine aerosol emissions		X
Non-volatile (No VOC or HAPs)		X
Non toxic		X
High Capture Rate	X	
Oxidative stability		X
Low viscosity		X
Low corrosion		X
Limited flue gas polishing needed		X

K_2CO_3 is kinetically slow but otherwise highly attractive solvent

The use of K_2CO_3 requires a **catalyst**

CARBONIC ANHYDRASE: NATURE'S PERFECT CATALYST

- Interconverts CO_2 and HCO_3^- to maintain acid-base balance and transport CO_2 out of tissues.
- A family of ubiquitous enzymes
 - Mammals, aquatic organisms, insects, plants, fungi, bacteria and archaea
- Active site contains metal (Zn^{2+})
- MW ~ 30,000
- Desirable characteristics:
 - Thermostable
 - Resistant to high pH (9.5-10.5)
 - Expressed at high levels with few impurities



$$k_{\text{cat}}/K_{\text{M}} = 10^8 \text{ M}^{-1}\text{s}^{-1}$$
$$k_{\text{cat}} = 10^6 \text{ s}^{-1}$$

CHALLENGE



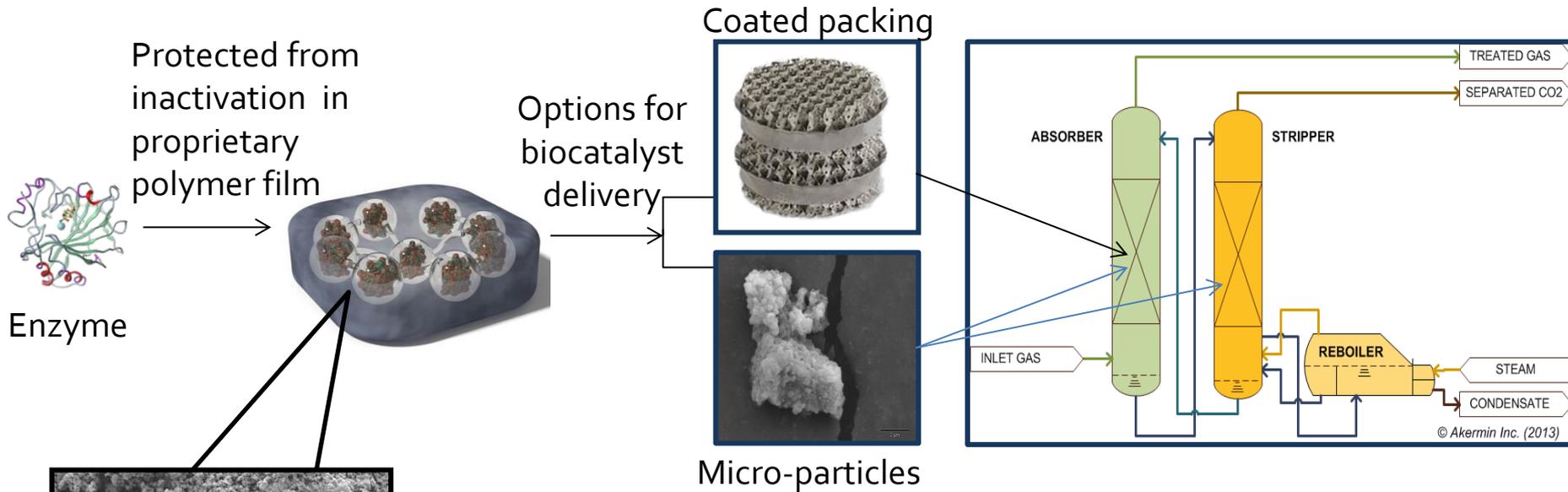
- How to make a biocatalyst evolved in nature work under industrial conditions with following stressors:



- Temperature (40- 105 °C)
- Extreme pH (9.8-10.2)
- Impurities (SO_x, NO_x, etc.)
- Shear Forces
- Multiphasic systems

Enzyme optimization and advanced delivery is critical

AKERMIN'S BIOCATALYST DELIVERY SYSTEM



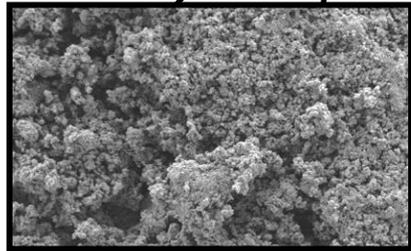
Protected from inactivation in proprietary polymer film

Enzyme

Options for biocatalyst delivery

Coated packing

Micro-particles



High surface area polymer films enable higher mass transfer rate

Successful biocatalyst approach enables:

- Non-toxic, non-volatile solvent(s)
- Novel process schemes

FIELD PILOT UNIT DEMONSTRATION

Installed at NCCC December 2012



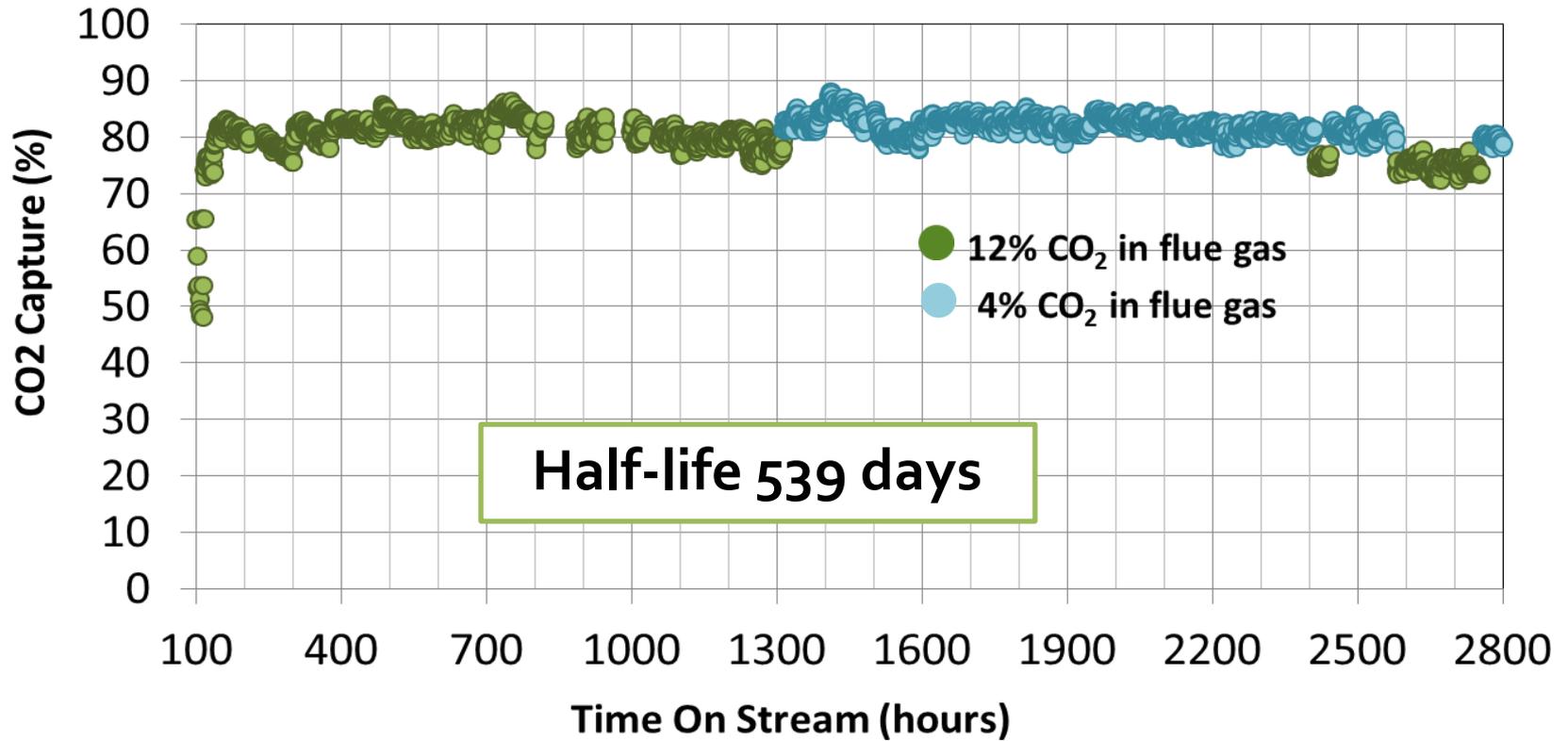
- 8.33" ID x 26 ft packing
- Gas: 30 Nm³/hr
- Liquid: 275 LPH



❖ Sulzer M500X

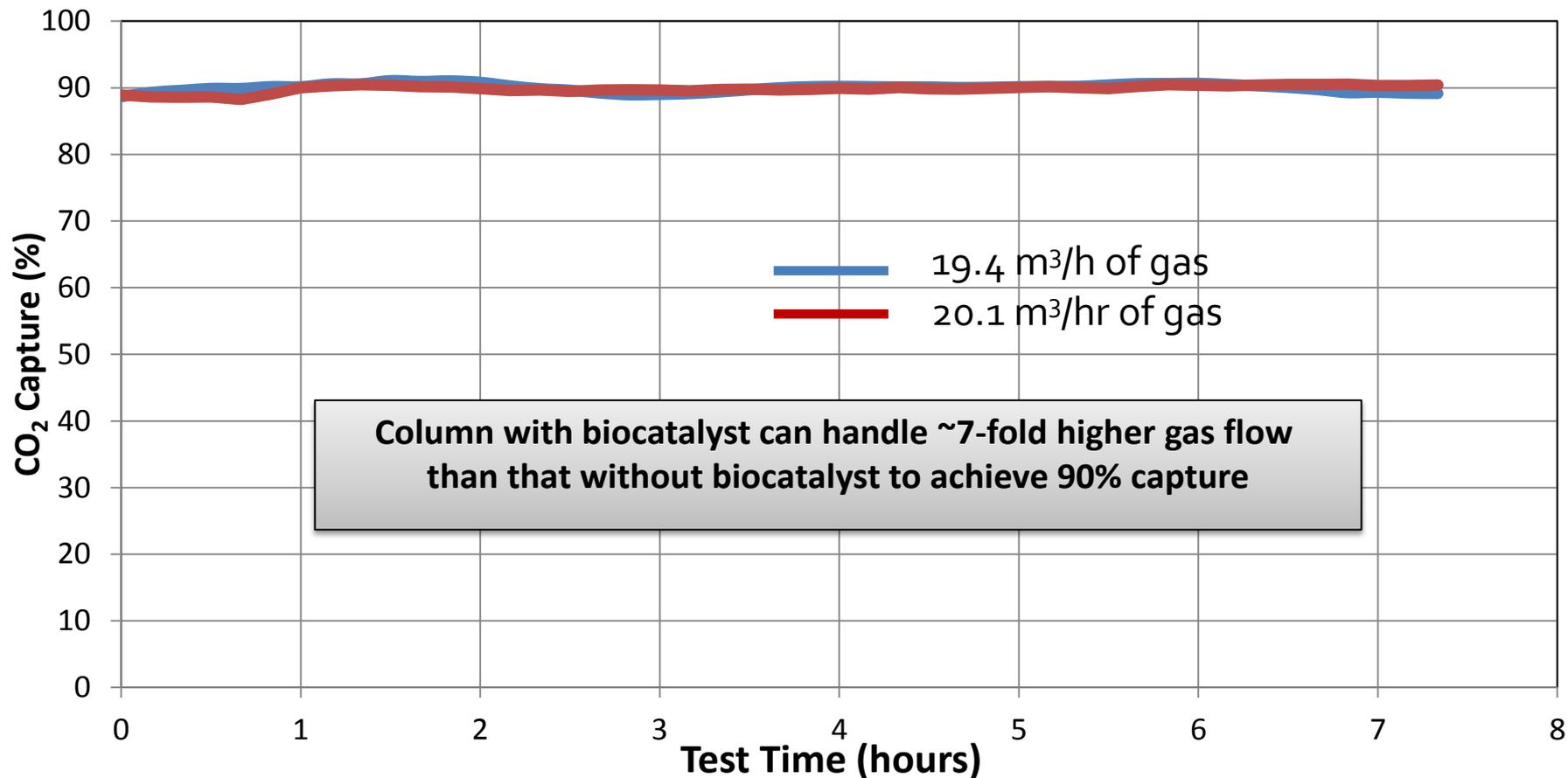
- Unit with immobilized enzyme operated May – Oct 2013

FIELD TRIAL: LONG-TERM PERFORMANCE



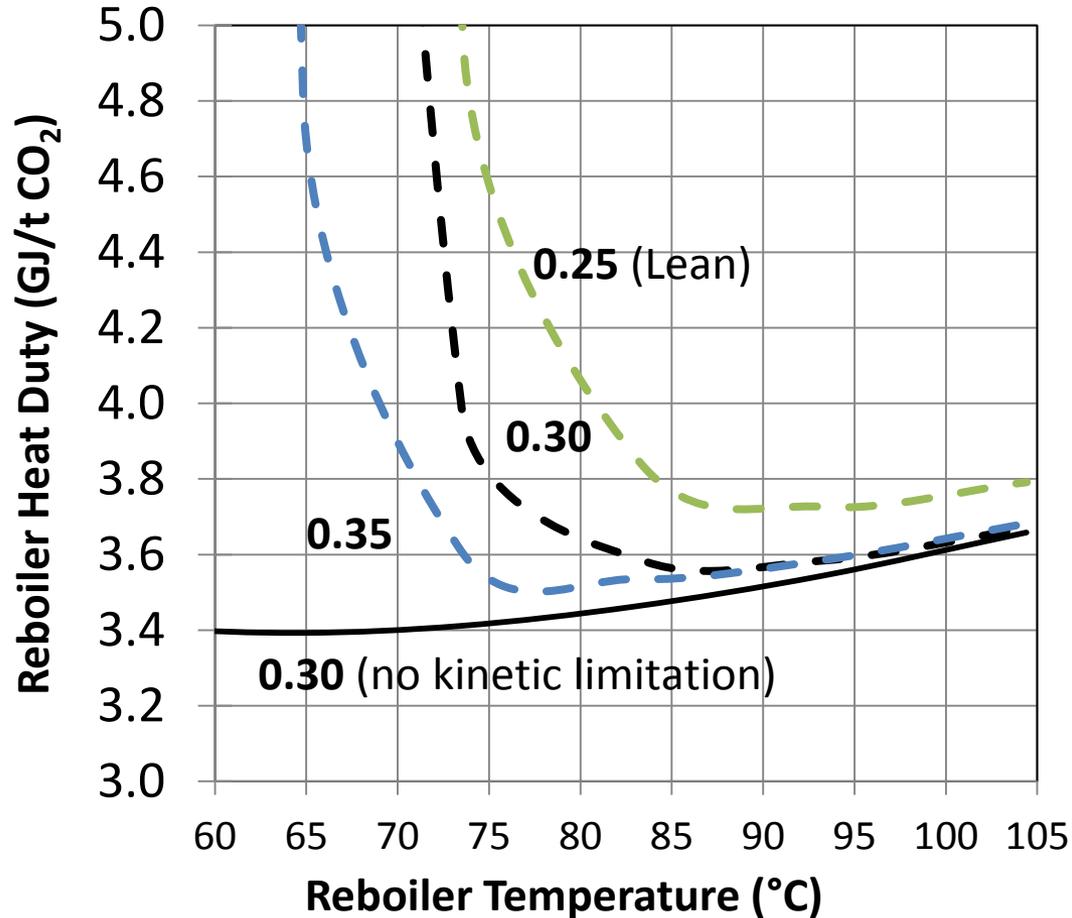
2,800 hours on CO₂ steam with 99% availability

FIELD TRIAL: DEMONSTRATION OF 90% CAPTURE



90% capture with immobilized enzyme is achievable

IMPACT OF KINETIC LIMITATIONS ON REBOILER DUTY OPERATED WITH KHCO_3



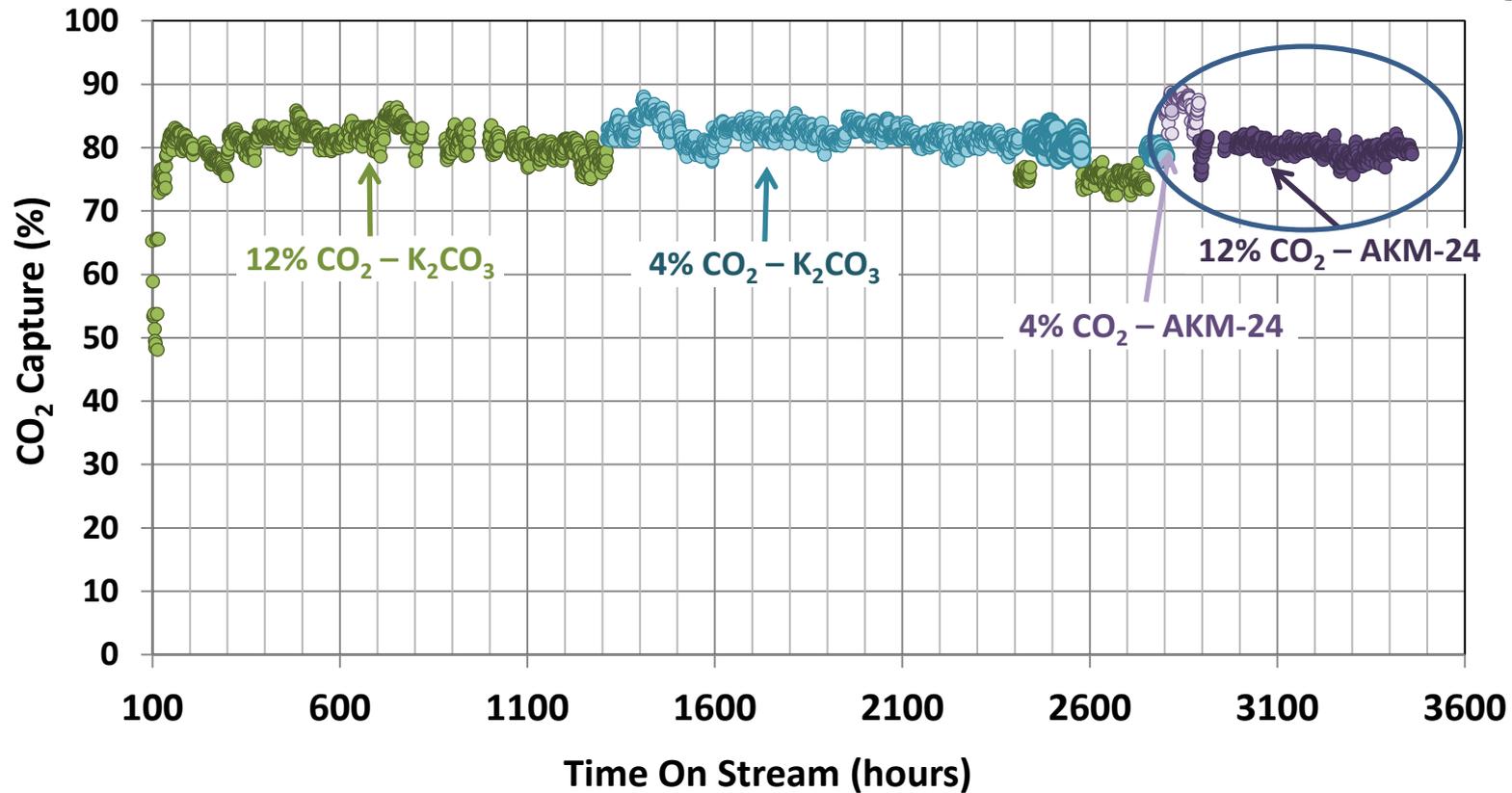
~3.4 GJ/t_{CO₂} with K_2CO_3 , basic flow sheet

CHALLENGE: HOW TO FURTHER MINIMIZE ENERGY

Second generation solvent, AKM-24

- ✓ **High CO₂ loading**
- ✓ **Low regeneration energy**
- ✓ Non-volatile
- ✓ Low EH&S risks
- ✓ Low molecular weight
- ✓ Thermally stable
- ✓ Highly water-soluble
- ✓ Manufacturing route established
- ✓ Used in the past for gas treating

LONG-TERM PERFORMANCE OF THE PILOT WITH K_2CO_3 AND AKM24



Long-term stability with both solvents demonstrated

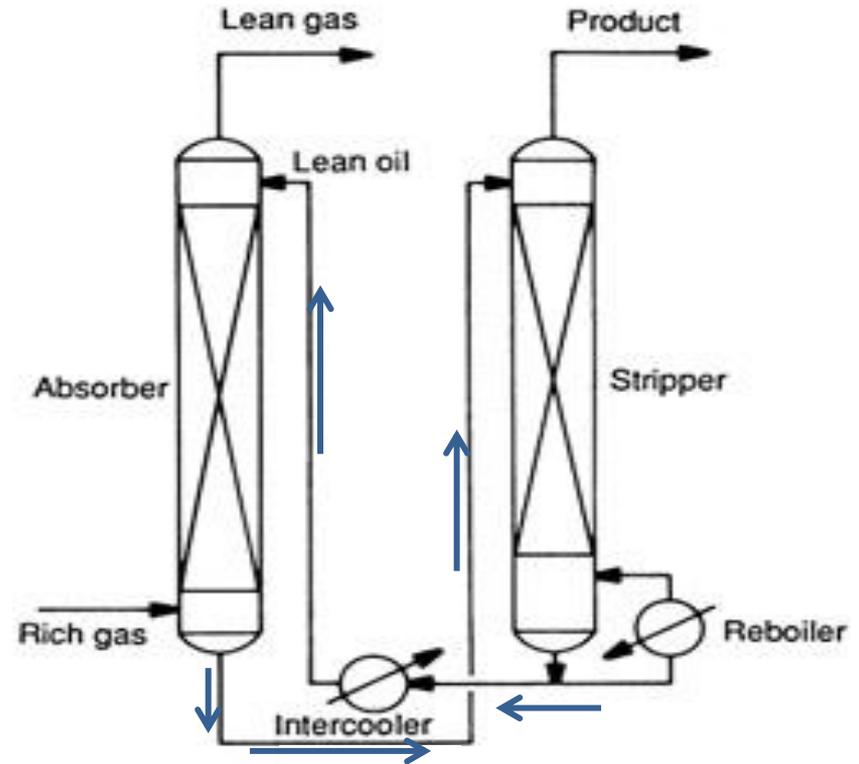
NEW FIELD PILOT PROJECT

Initiated in Oct'13 in collaboration with the U.S. Department of Energy

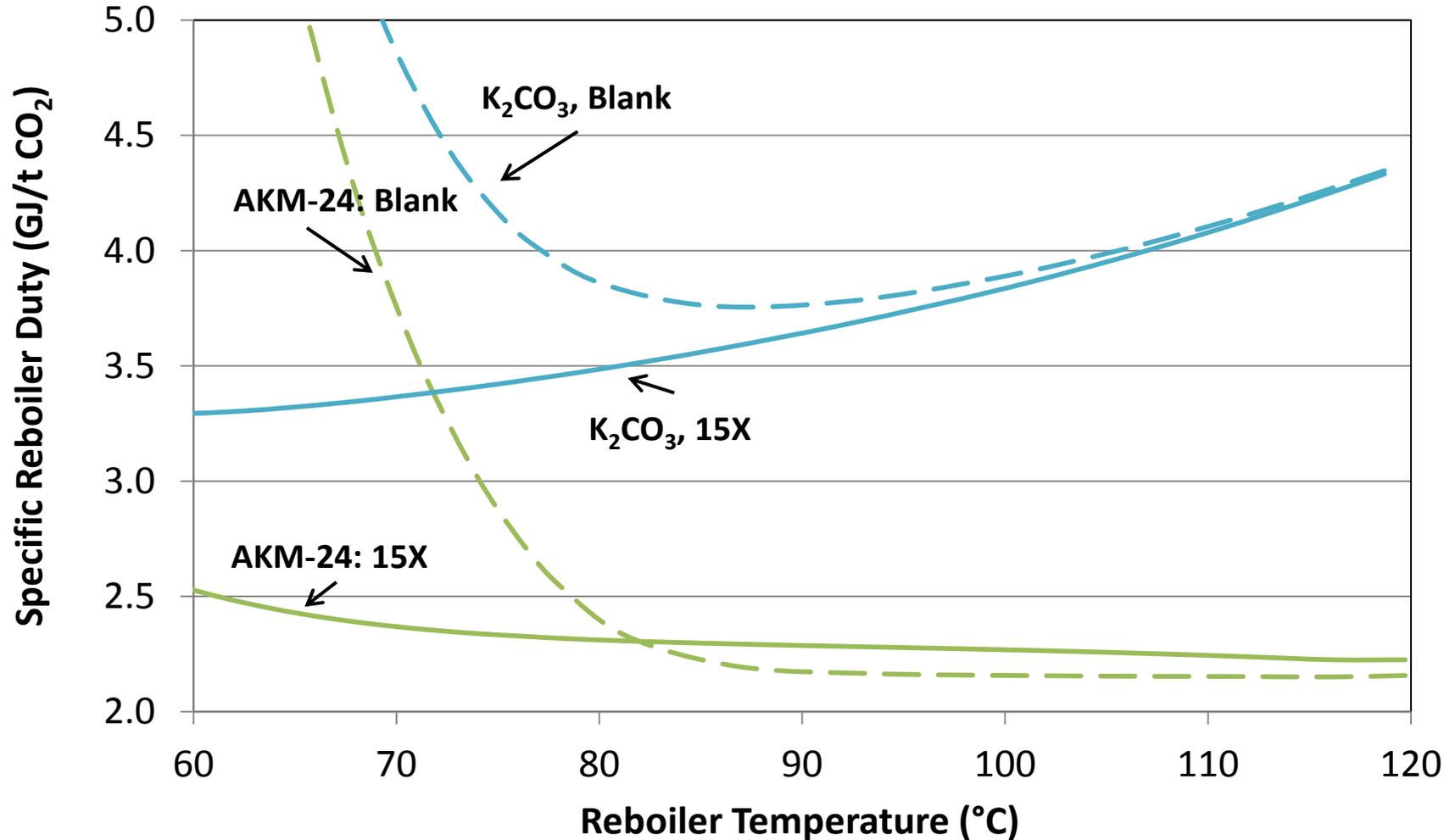
- focus on micro-particle enzyme delivery system and AKM24

■ Goals

- Demonstrate *in situ* catalyst replacement
- Performance of new solvents
- Advanced process design
- Further reduction of energy and capital costs



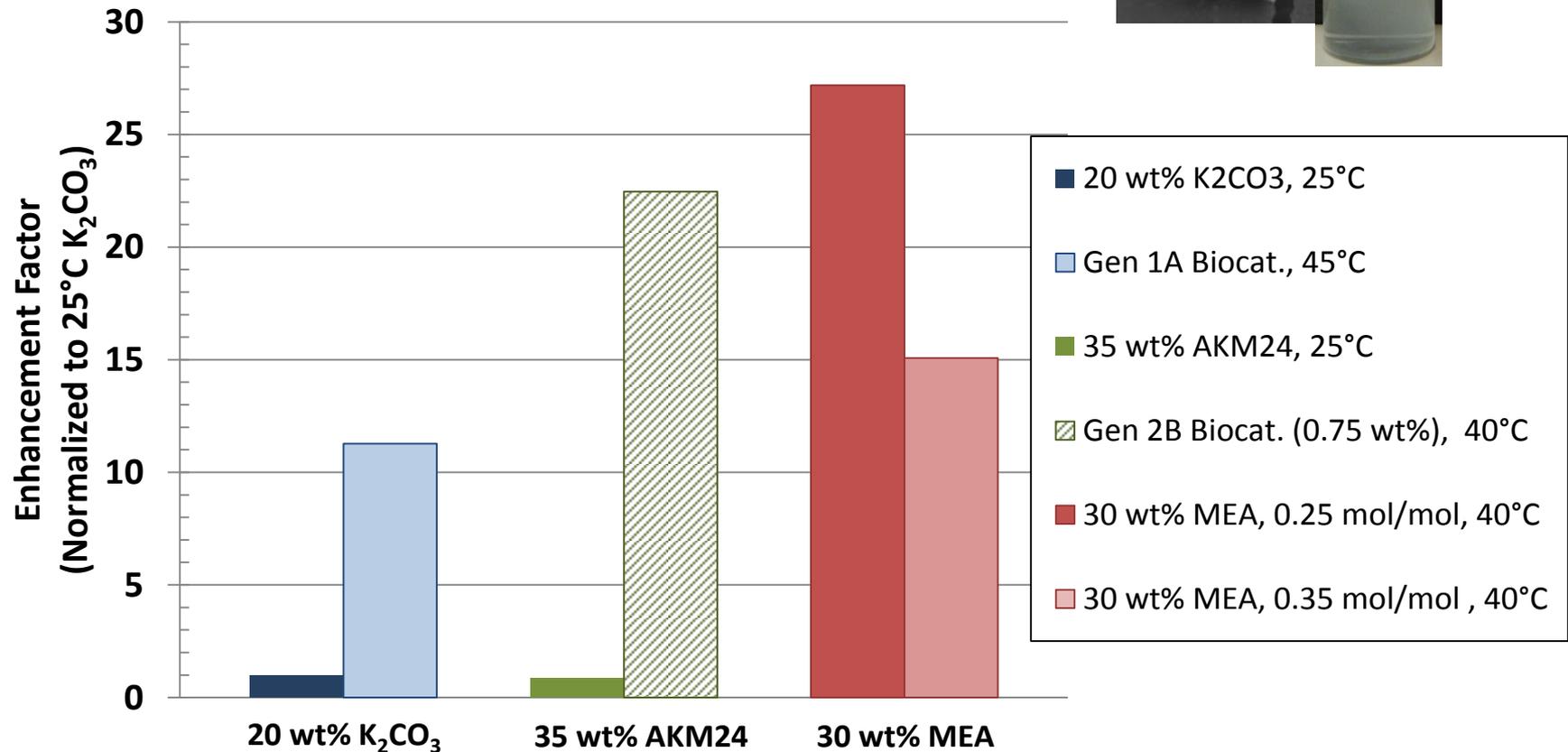
SPECIFIC REBOILER DUTY FOR K_2CO_3 AND AKM-24



AKM-24 is estimated to achieve 30% reduction in reboiler heat duty

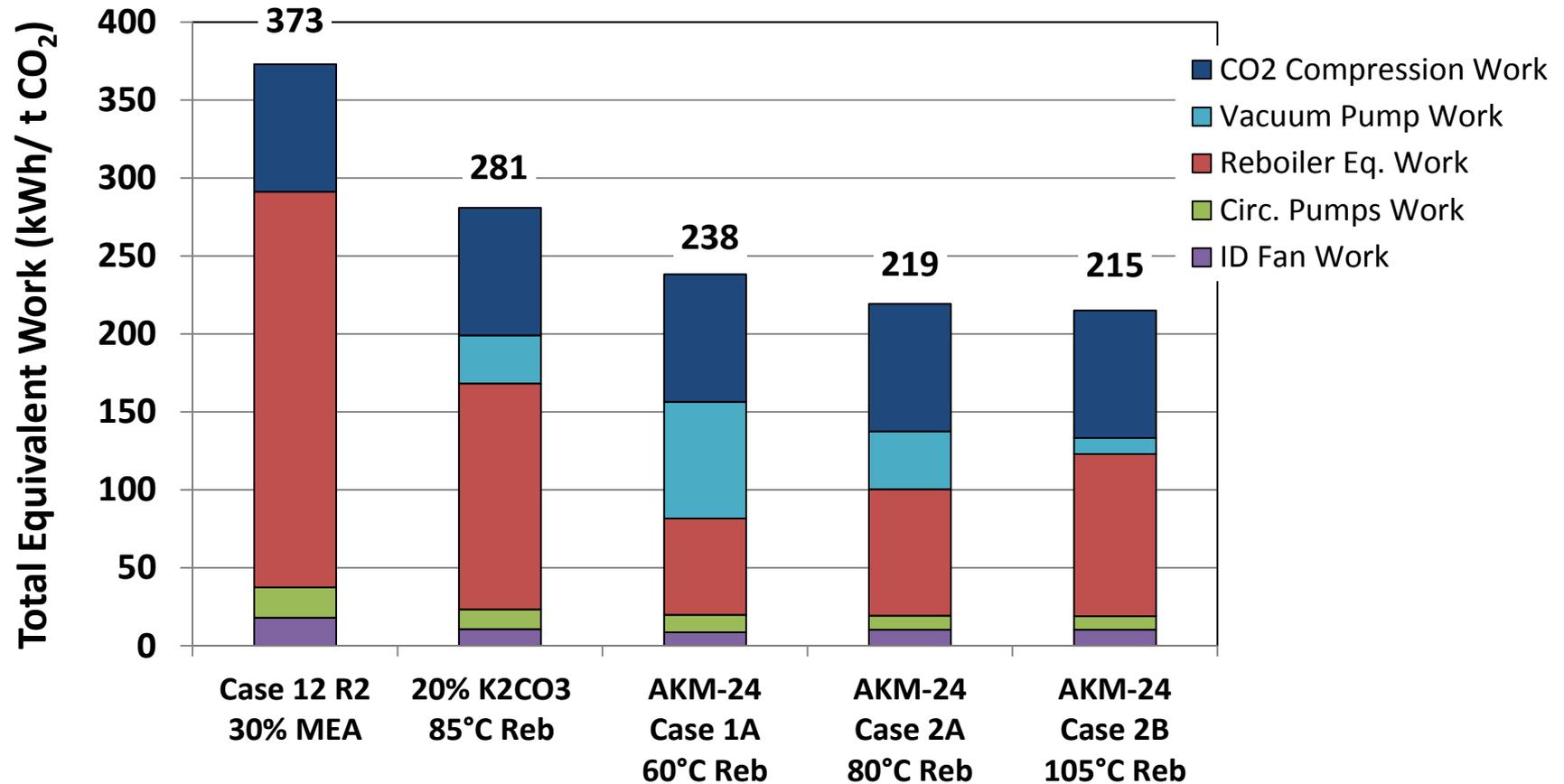
ENHANCEMENT FACTOR FOR GEN-1 (PACKING) AND GEN-2 (MICRO-PARTICLES)

- Micro-particles specifically designed to partition to gas-liquid interphase



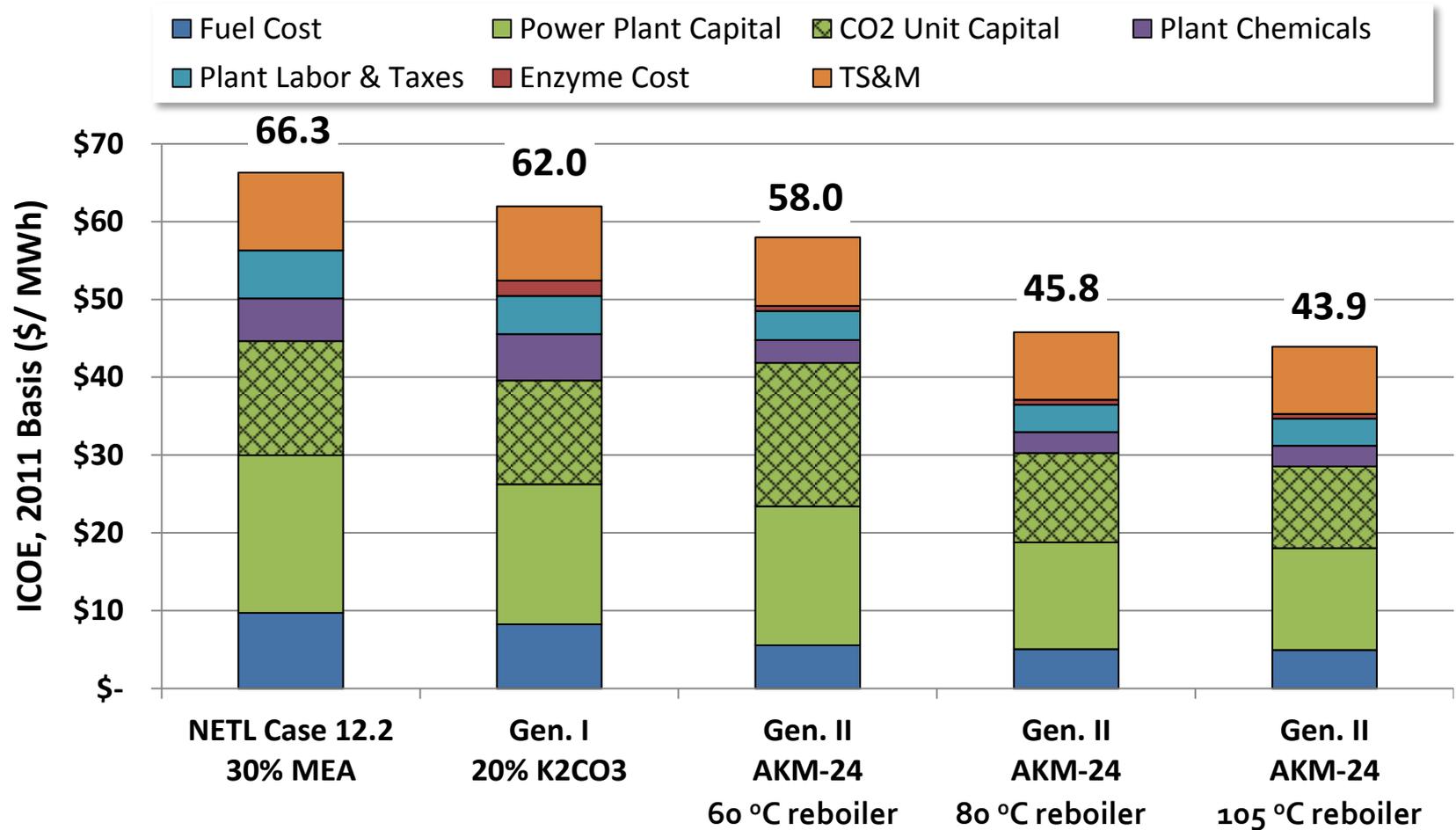
Micro-particles demonstrate a significantly higher acceleration potential than coatings

COMPARISON OF TOTAL EQUIVALENT WORK FOR VARIOUS CAPTURE SYSTEMS



Potential of reducing total equivalent work by 42% compared to Case 12

INCREMENTAL COST OF ELECTRICITY (ICOE) FOR VARIOUS CAPTURE SYSTEMS RELATIVE TO NETL CASE-11



~ 33% reduction in ICOE appears to be achievable

FUTURE WORK AND NEXT SCALE ACTIVITIES

Commercial scale Biogas treating unit

- Size: 500 Nm³/hr. biogas
 - (50% of avg. commercial unit)
- \$7 MM, three year project
- 50% funding through EUDP (Danish Energy Agency)
- Schedule:
 - Project Kickoff – Jan 2014
 - Commissioning – May 2015
 - Operations – July 2015
- 24 months operation and testing



Upgrading biogas to pipeline specification at industrial scale using biocatalyst

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