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Putting enzymes to work™

NOVEL FLOW SHEET FOR LOW ENERGY CO_2 CAPTURE ENABLED BY BIOCATALYST DELIVERY SYSTEM

Kick off Meeting
Project: DE-FE0012862
DOE-NETL; Pittsburgh, PA.

November 22, 2013

OUTLINE

- Project Overview
- Observations
- Approach and Analysis
- Objectives
- Preliminary Data
- Tasks & Milestones
- Project Structure/Organization
- Schedule
- Budget Summary
- Decision points/ Success Criteria

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PROJECT OVERVIEW

Participants, Duration, Funding

- **Project awardee and subcontract TEA:**

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WorleyParsons
resources & energy

- **Enzyme Supply:**

novozymes®
Rethink Tomorrow

- **Fabrication and Instrumentation:**

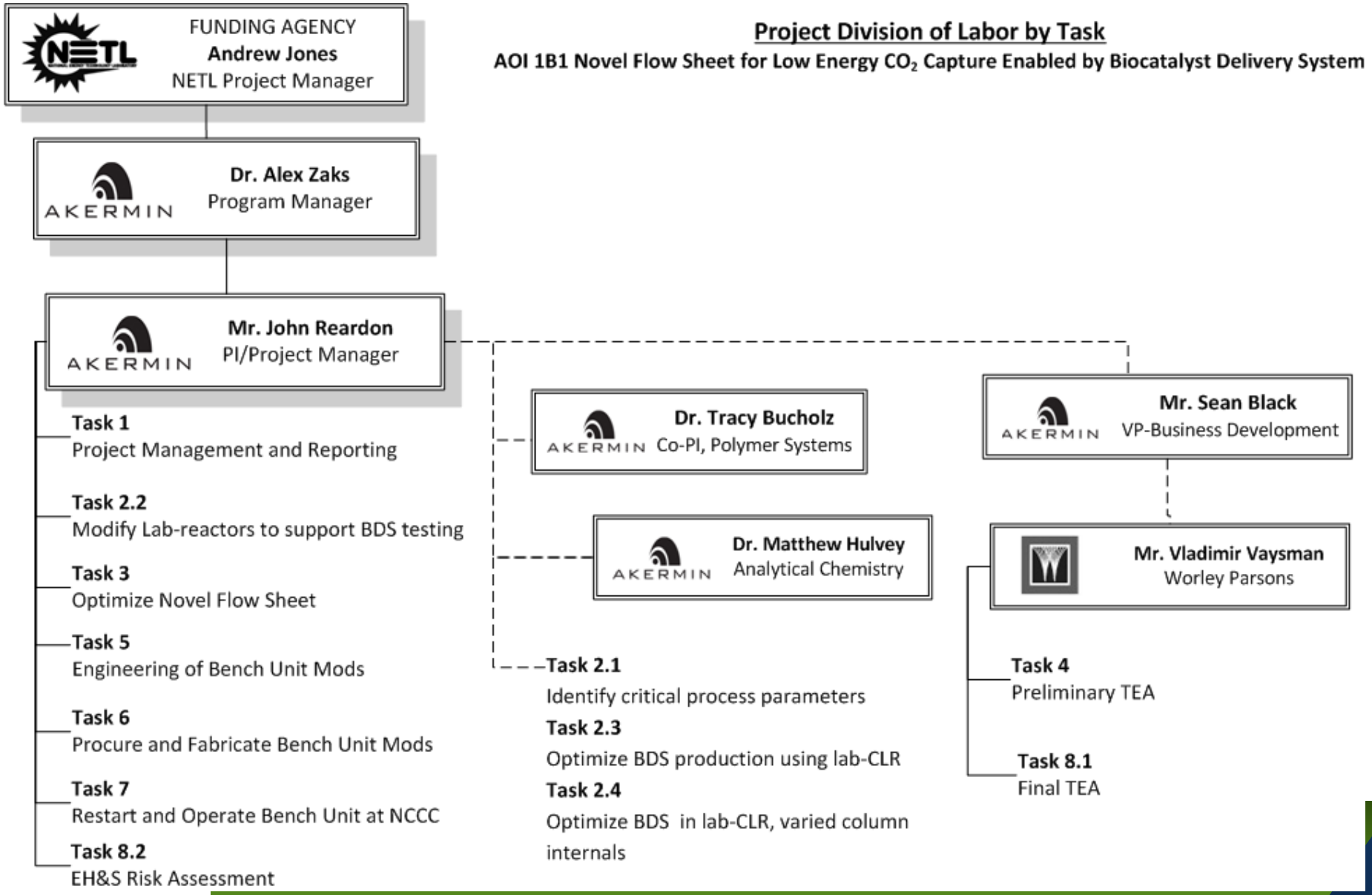
EPIC
MOVING AMERICAN MANUFACTURING FORWARD

EMERSON

- **Duration: 36 months** (Oct 2013 to Sept 2016)
- **Funding:**

DOE Funding:	$ 2,999,560
Akermin Cost share:	$ 2,066,889 (40.8%)
Total Project:	$ 5,066,449

PROJECT TEAM



Project Division of Labor by Task

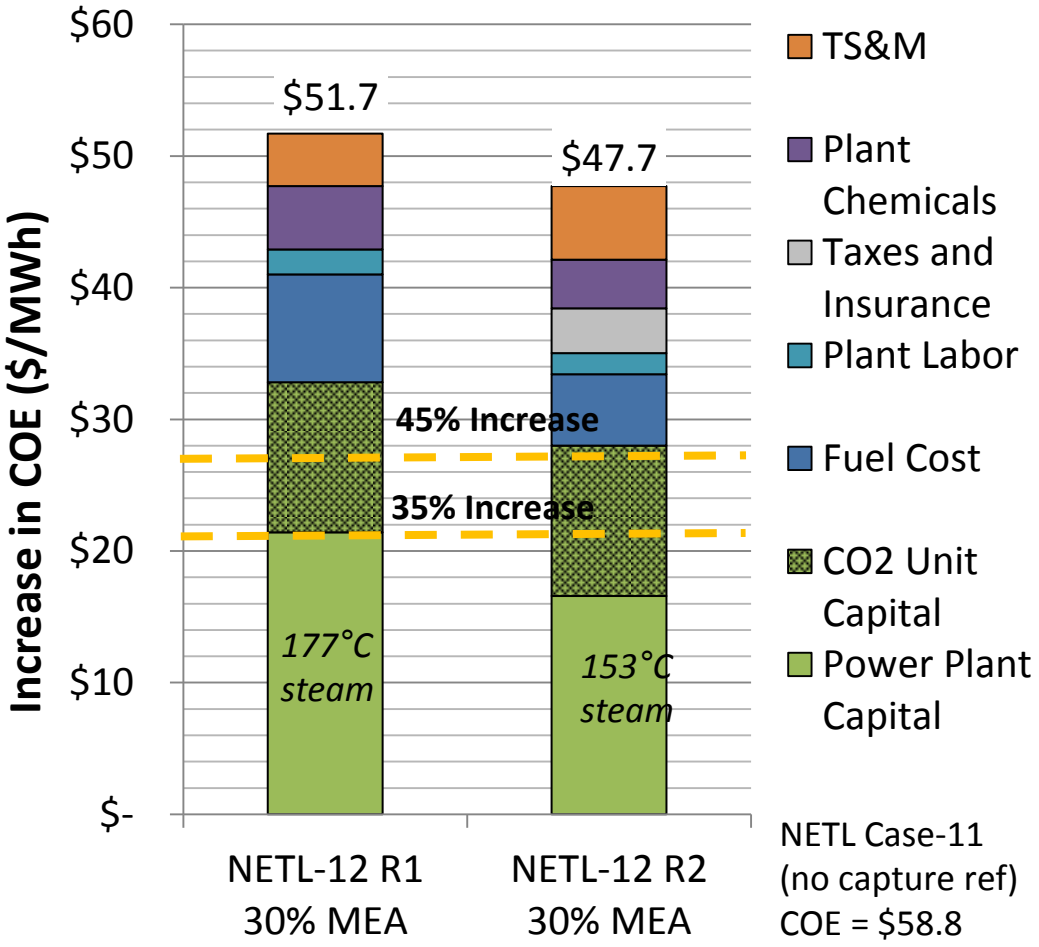
AOI 1B1 Novel Flow Sheet for Low Energy CO_2 Capture Enabled by Biocatalyst Delivery System

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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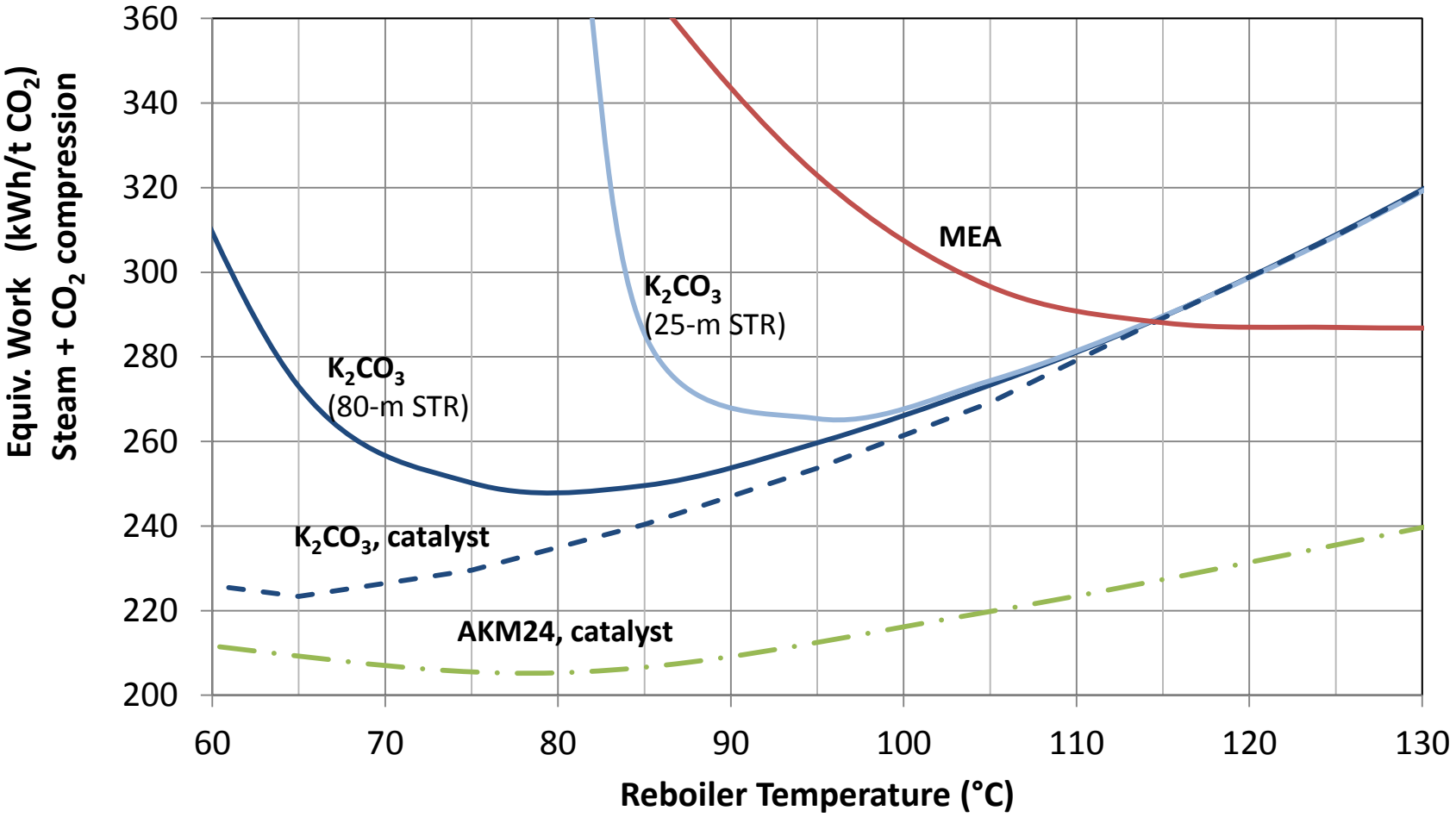
EQUIVALENT WORK OF STEAM + COMPRESSION

30% MEA (~83 kJ/mol), 20% K2CO3 (~28 kJ/mol) and AKM24 compared



Minimum equivalent work benefits from solvent and catalyst

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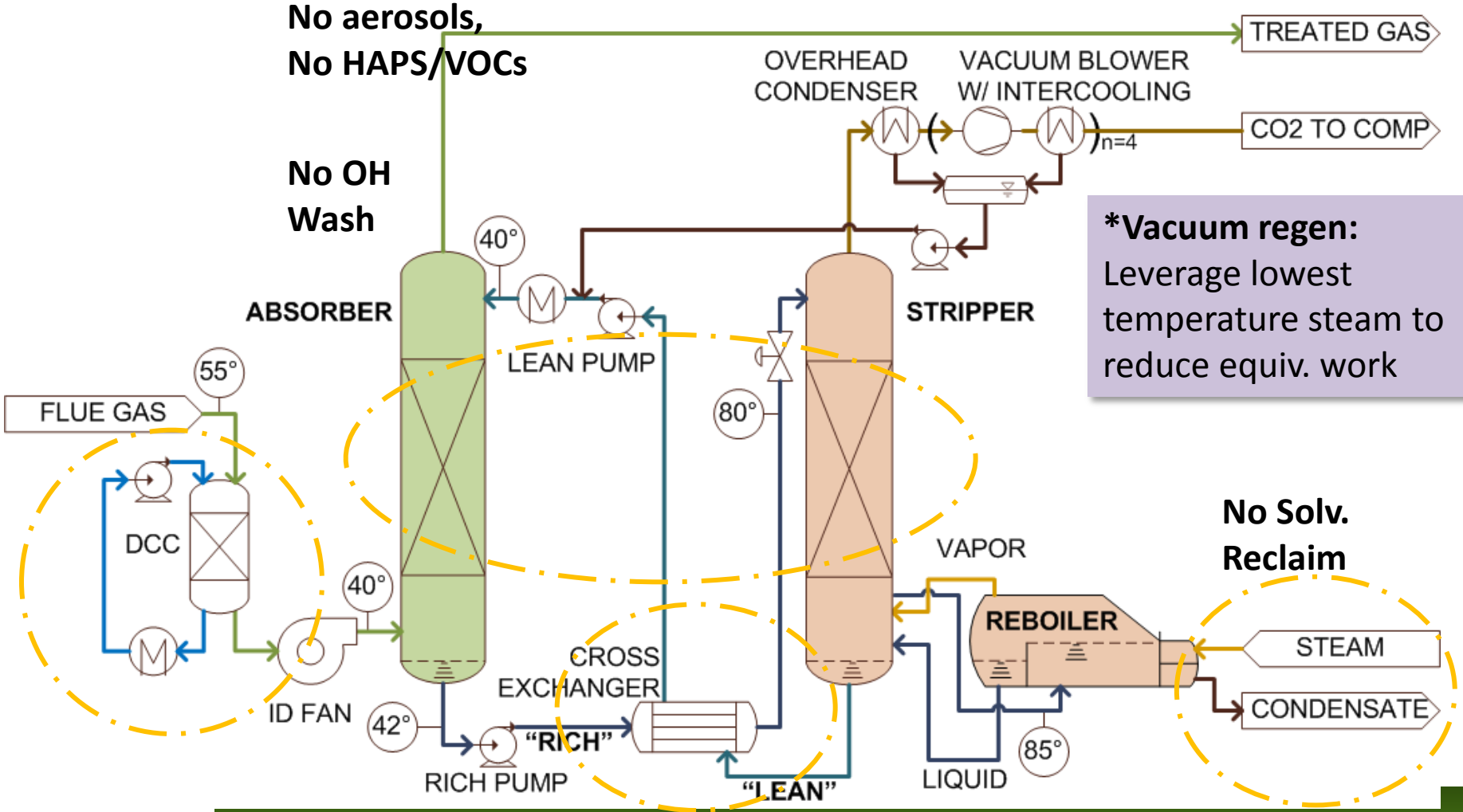
APPROACH: BIOCATALYST ENABLED SOLVENTS

Biocatalyst enabled AKM24 solvent; improvement is proposed in circled areas



Low energy, low volatility solvent AKM24 enabled by biocatalyst system

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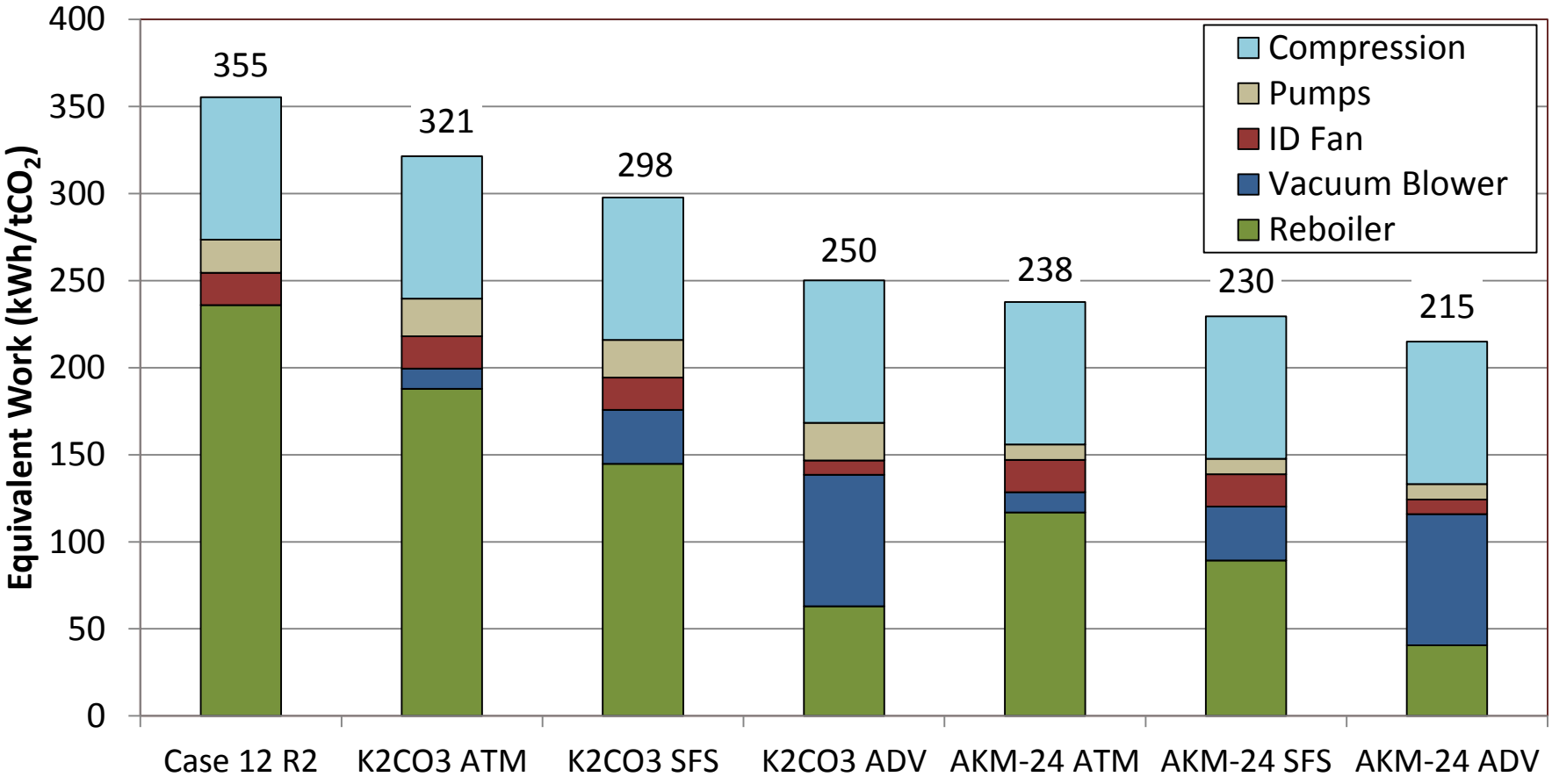
LOWER EQUIVALENT WORK

Net parasitic power depends on steam temperature (efficiency) and reboiler heat duty



AKM-24 with advanced flow sheet ~ 37% reduction in equivalent work and potentially ~30% reduction in capital relative to Case 12 (30% MEA)

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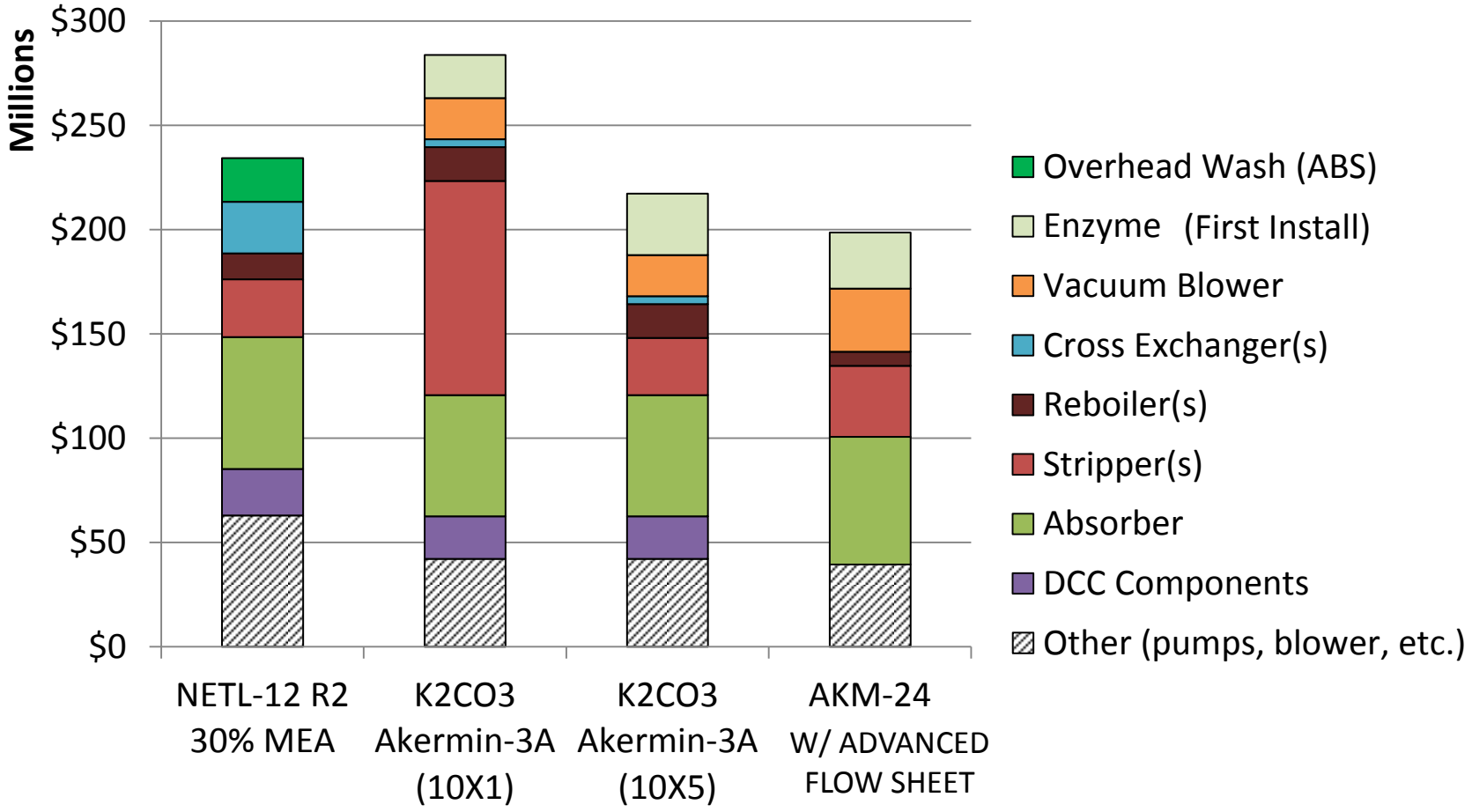
PRELIMINARY CAPITAL COST ESTIMATES

Data from previous project used for advanced flow sheet cost estimation
For 3A Case: ("Absorber Reduction Factor" X "Stripper Reduction Factor")



Biocatalyst enhancement benefits absorber and stripper costs

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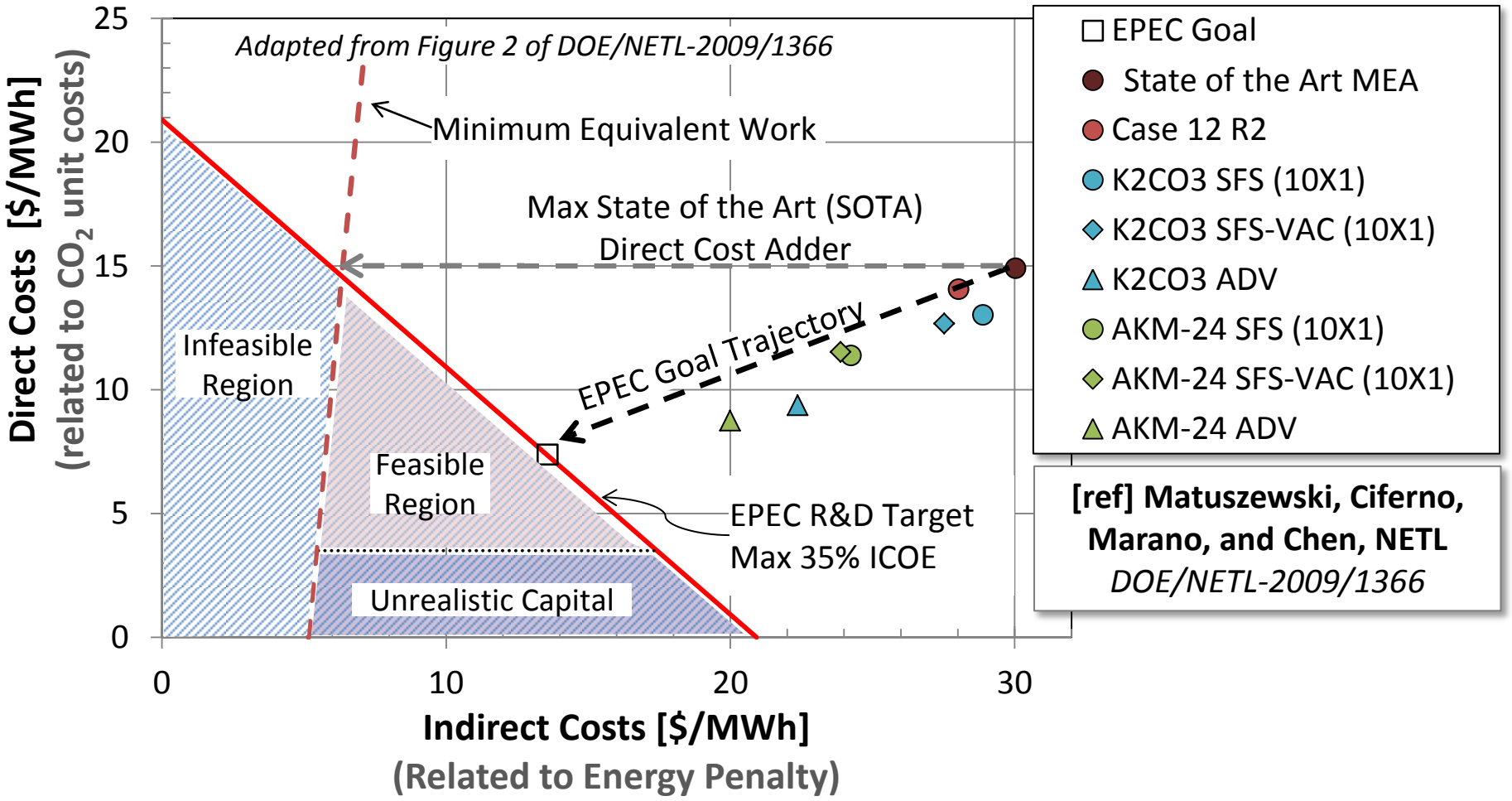
PROGRESS TOWARDS DOE GOAL

Two Paths: Reduction of Direct (CO_2 Unit) Costs and Indirect (Energy Penalty) Costs



Combination of AKM-24 with isothermal flow-sheet enabled by catalyst starts to approach DOE EPEC cost goal for CO2 capture

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PROJECT OBJECTIVES

- Reduce cost of capture by >30%
- Achieve parasitic power: 200 to 220-kWh/t CO_2
  - lowest grade steam for solution regeneration
- Reduce capital costs >20%
  - Catalyst deployed throughout system, reduce and eliminate equipment
- Demonstrate *on-stream* catalyst replacement
- Deploy non-volatile, environmentally benign solvent with significantly higher CO_2 absorption capacity than 20% K2CO3
- Complete six-month demonstration at the National Carbon Capture Center (NCCC) using coal combustion flue gas
- Complete techno-economic and engineering merit study w/WP
- Demonstrate progress toward DOE long-term goals

90% CO2 capture is assumed for all DOE goals

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SECOND GENERATION SOLVENT: AKM 24

AKM-24, high performing solvent:

- ✓ Non-volatile
- ✓ Thermally stable
- ✓ Highly water-soluble
- ✓ Low molecular weight
- ✓ High CO_2 loading
- ✓ Low regeneration energy
- ✓ Low EH&S risks

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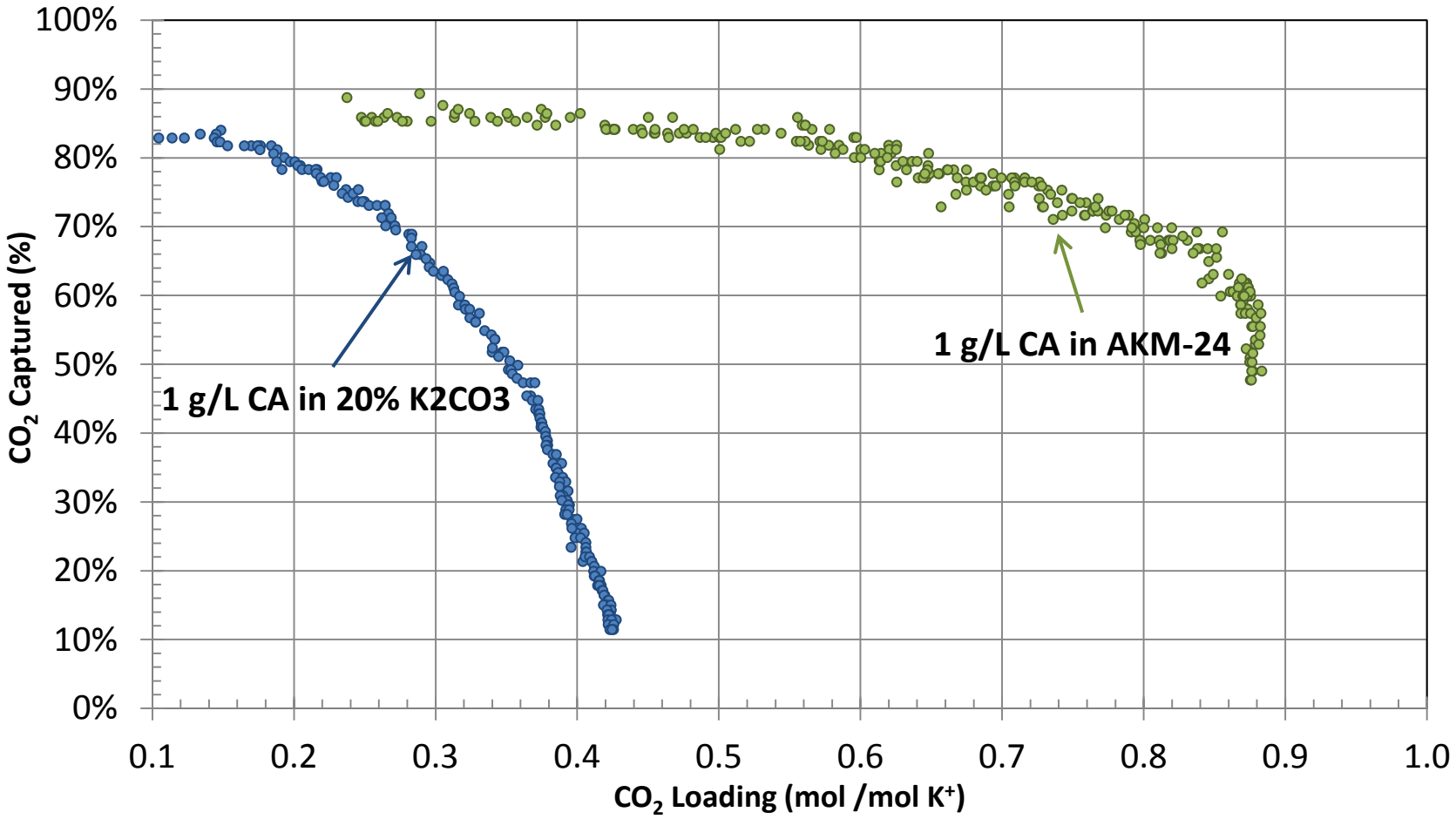
CA PERFORMANCE IN 20% K_2CO_3 & AKM-24

SPR – 400 SCCM gas flow w/ 15% CO2, 25 mL/min solvent, 25 ℃, 1 psig, 65 g packing



Rate enhancement is extended over a greater range of CO_2 loading for AKM-24 compared to K_2CO_3

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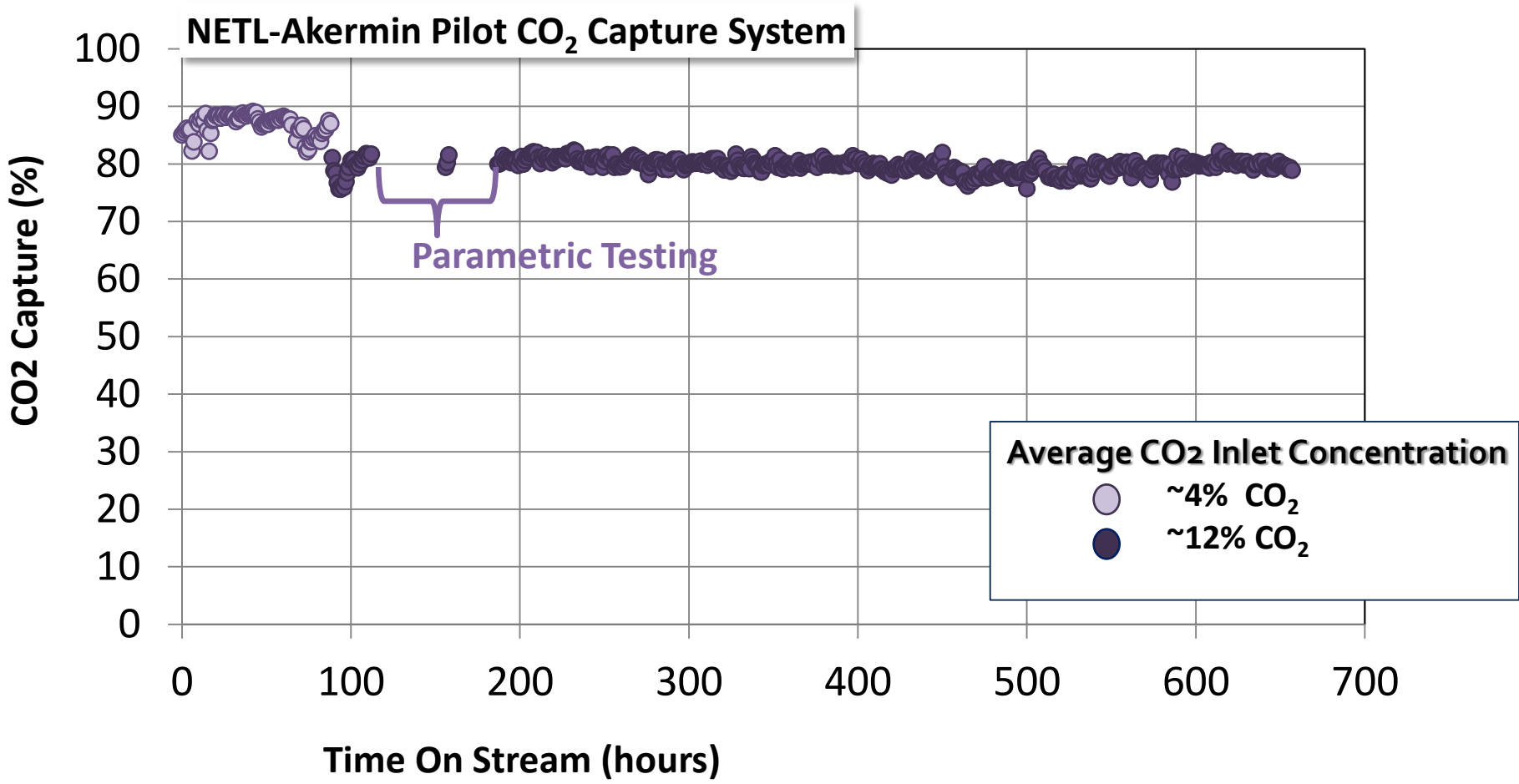
AKM-24 PILOT PLANT DATA W/ BIOCATALYST (10/31/13)

Time on-stream, data at design flow (31.5 Nm^3/hr, 275 LPH), $X_{C,Lean}$ ~ 0.28



~650 hours on stream demonstrates stability, performance in AKM24

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SCOPE OF WORK

- Optimize production of the novel Biocatalyst Delivery System.
- Demonstrate consistent long-term performance in lab-prototype closed loop reactors.
- Optimize the isothermal process flow sheet to achieve lowest equivalent work.
- Provide independent techno-economic analysis and EH&S evaluation with third party firms.
- Demonstrate the energy performance and sustained activity over-time using commercially-generated flue gas at a scale of 500 to 1000 standard liters per minute of flue gas feed.

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RESOURCE LOADED SCHEDULE—PERIOD (1)

SOPO BREAKOUT SCHEDULE		BP-1						Cost by Task
WBS	DESCRIPTION OF TASK OR SUBTASK	Oct-13	Jan-14	Apr-14	Jul-14	Oct-14	Jan-15	
1.0	**Project Management & Planning**	a b				j		$ 334,189
2.0	**Optimize production of immobilized biocatalyst**							$ 1,748,955
2.1	Identification of critical BDS process parameters	c						
2.2	Modify lab-scale CLR to support BDS testing	d						
2.3	Optimize BDS production using lab CLR feedback		e			g h		
2.4	Optimize BDS in CLR with varied column internals							
3.0	**Optimize Flow Sheet, Minimize Eq. Work, Cost**							$ 142,359
3.1	Thermodynamic, kinetic, precip data into Aspen							
3.2	Optimize novel flow sheet with AKM24			f				
4.0	**Preliminary Techno-Economic Analysis**							$ 260,623
4.1	Consulting engineering to support TEA							
4.2	Preliminary TEA					i		
5.0	**Engineering of Bench Unit Modifications**							$ 312,407
5.1	Engineering and costing of bench unit mod						k	
5.2	Bench Unit PHA						l	
						BP1 Total		**$ 2,798,533**

RESOURCE LOADED SCHEDULE—PERIOD (2)

SOPO BREAKOUT SCHEDULE		BP-2						Cost by Task
WBS	DESCRIPTION OF TASK OR SUBTASK	Apr-15	Jul-15	Oct-15	Jan-16	Apr-16	Jul-16	
1.0	**Project Management & Planning**							$ 374,133
6.0	**Procurement and Fabrication of Bench Unit Mods**							$ 1,069,251
6.1	Procure bench unit modifications	m						
6.2	Modify Bench Unit			n				
7.0	**Comission and Operate Bench Unit at Test Site**							$ 552,151
7.1	Commission and establish baseline				o			
7.2	Parametric and endurance testing with biocat				p		q,r	
7.3	Bench unit decomissioning							
8.0	**Final Technology Assessment**							$ 272,381
8.1	Final TEA						s	
8.2	EH&S risk assessment						t	
							BP2	**$ 2,267,916**
							Total	**$ 5,066,449**

BUDGET SUMMARY: AWARD #DE-FE0012862

Final negotiated budget

NETL AWARD DE-FE0012862					
	Budget Period 1 10/1/2013 - 3/31/2015		Budget Period 2 4/1/2015 - 9/30/2015		TOTAL
	Gov't Share	Cost Share	Gov't Share	Cost Share	
Akermin	$ 1,516,664	$ 1,141,801	$ 1,230,592	$ 925,088	$ 4,814,145
Worley Parsons	140,067		112,237		252,304
Total	**$ 1,656,731**	**$ 1,141,801**	**$ 1,342,829**	**$ 925,088**	**$ 5,066,449**
Cost Share	59.2%	40.8%	59.2%	40.8%	

Akermin is providing >40% cost share

DECISION POINTS/SUCCESS CRITERIA

Budget Period 1

- Successful completion of all BP-1 proposed work
- Preliminary modeling shows < 220 kWh/tCO2
- Demonstrate 500 hrs @ > 90% retention of activity w/ one catalyst makeup cycle
- Deploy a non-volatile, environmentally benign solution that doubles CO_2 absorption capacity relative to 20% K2CO3
- Submit preliminary Techno Economic Analysis
- Submit fixed cost proposal for bench unit modifications
- Submit and have approved a continuation application for BP-2

DECISION POINTS/SUCCESS CRITERIA

Budget Period 2

- Successful completion of all BP-2 proposed work
- Modified bench unit demonstrates > 2000 hrs on stream
- Final TEA demonstrates > 30% reduction in cost of capture relative to NETL-12
- Final TEA demonstrates potential to achieve DOE target of 90% capture with <$40/t CO_2
- Submit final Techno Economic Analysis
- Submit EH&S risk assessment
- Submit final report

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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
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