An Advanced Catalytic Solvent for Lower Cost Post-combustion CO_2 Capture in a Coal-fired Power Plant

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http://www.caer.uky.edu/powergen/home.shtml

Project Overview

Project Details

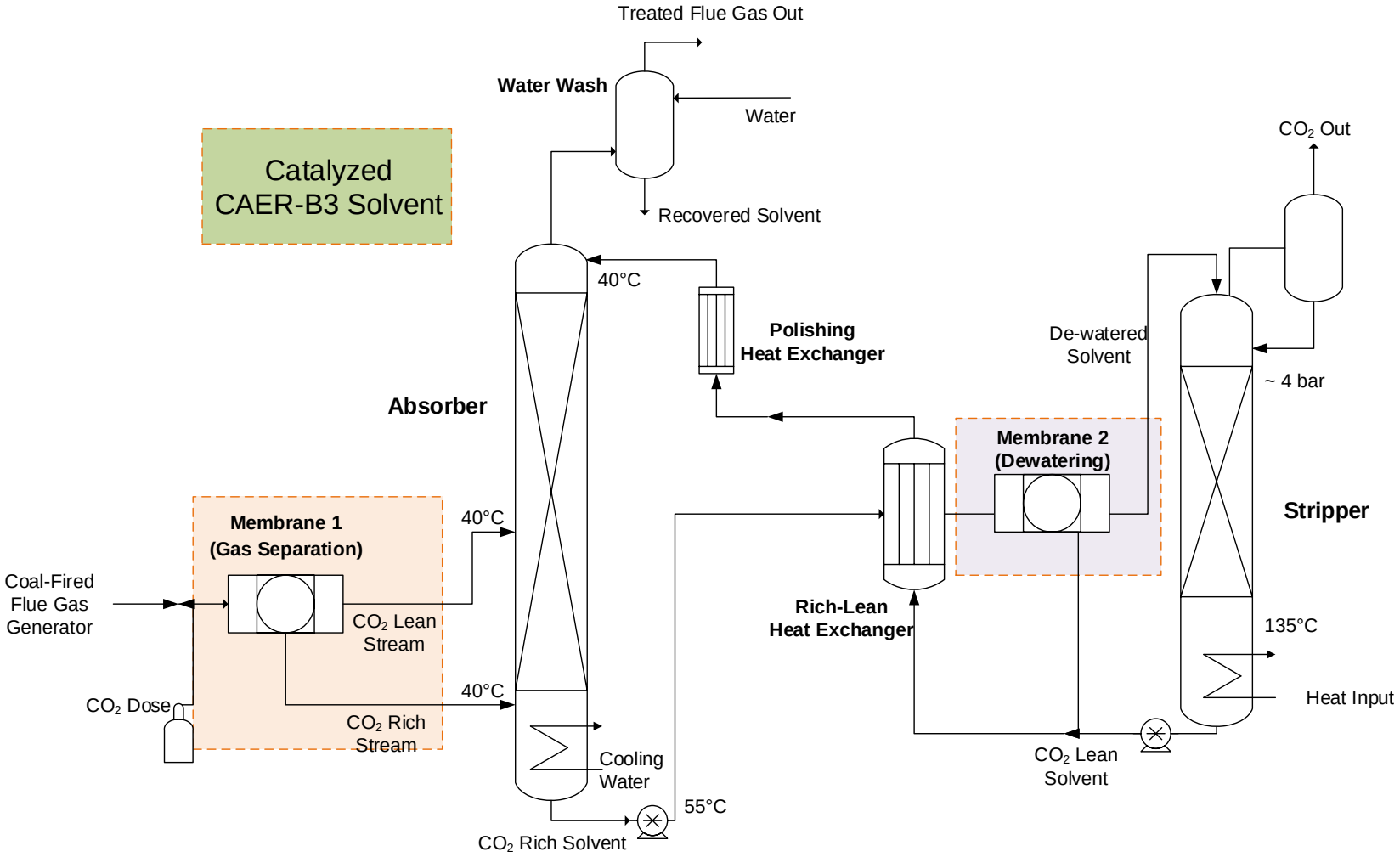
- **Benefit from Multiple CAER Technologies: Solvent, Catalyst, Membrane, Process**
- **Project Cost:**
  - **DOE share:$2.97M**
  - **Cost share:$742K ($500K from CMRG)**
- **Period Performance:** 10/1/2013 – 12/30/2016

Project Objectives

Develop a pathway to low-cost CO_2 capture via Integration of multiple CAER technologies to verify an advanced catalytic solvent with integrated membrane dewatering for solvent enrichment in our 0.1MWth pilot plant (Proof of concept)

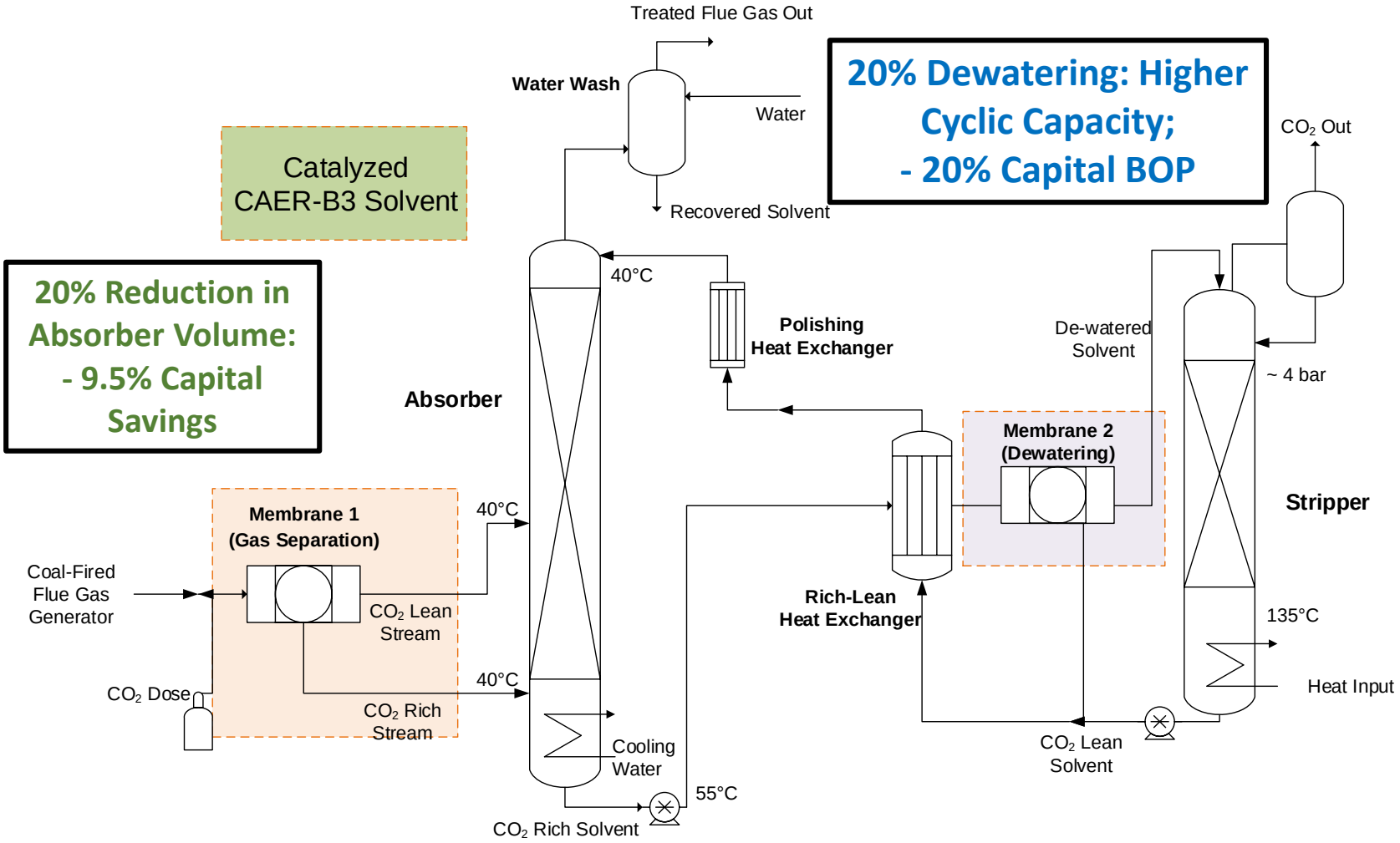
CAER	CMRG	SMG	WorleyParsons resources & energy
• Project Management • Catalytic Solvent Testing • ASPEN Modeling • Membrane Synthesis	• Cost-Share • Technical Support	• PPE Recommendation • EH&S analysis	• Front-End Engineering • Techno-Economic Analysis

CAER ad-CCS Process



Pre-absorber CO_2 enrichment, catalyst enhanced solvent, and dewatered CAER-B3 used to lower the capital and energy cost of CO_2 capture.

CAER ad-CCS Process



Pre-absorber CO_2 enrichment, catalyst enhanced solvent, and dewatered CAER-B3 used to lower the capital and energy cost of CO_2 capture.

Overall Schedule and Milestones

	Previous work	Current Project				Future Development	
Yr	2011-2013	2013	2014	2015	2016	2017-2020	>2020
BP	-	1	1/2	2/3	3	-	-

Fundamental Development of concept by CAER

Slipstream ~2MWth

10 MWe

Laboratory Validation and Scale-up

Solvent Optimization
Milestone: VLE and model regression

Membrane Enrichment
Milestone: 5% enrichment over 5hr

Catalyst Scale-up
Milestone: Develop method to produce 50g/batch

Milestone: PPE recommendation & front-end engineering analysis

Parametric Testing on 0.1 MWth Unit

Catalyst Production
Milestone: 500g produced

Parametric Testing
Milestone: 100hr runs with and without catalyst completed

Membrane Enrichment
Milestone: 10% enrichment over 100hr and module design

Verification Testing on 0.1 MWth Unit

Verification Run
Milestone: 500hr verification run

Membrane Enrichment
Milestone: Unit integrated and 20% dewatering observed

Techno-Economic Analysis
Milestone: Favorable TEA

EH&S
Milestone: Favorable EHS assessment

Parametric Testing Results

Parameter	Range
L/G (wt/wt)	3 – 5.3
Lean Inlet Temp. (°C)	30, 40, 45
Stripper Pressure (bar)	2.5, 3.1, 3.8

- Stripper Pressure

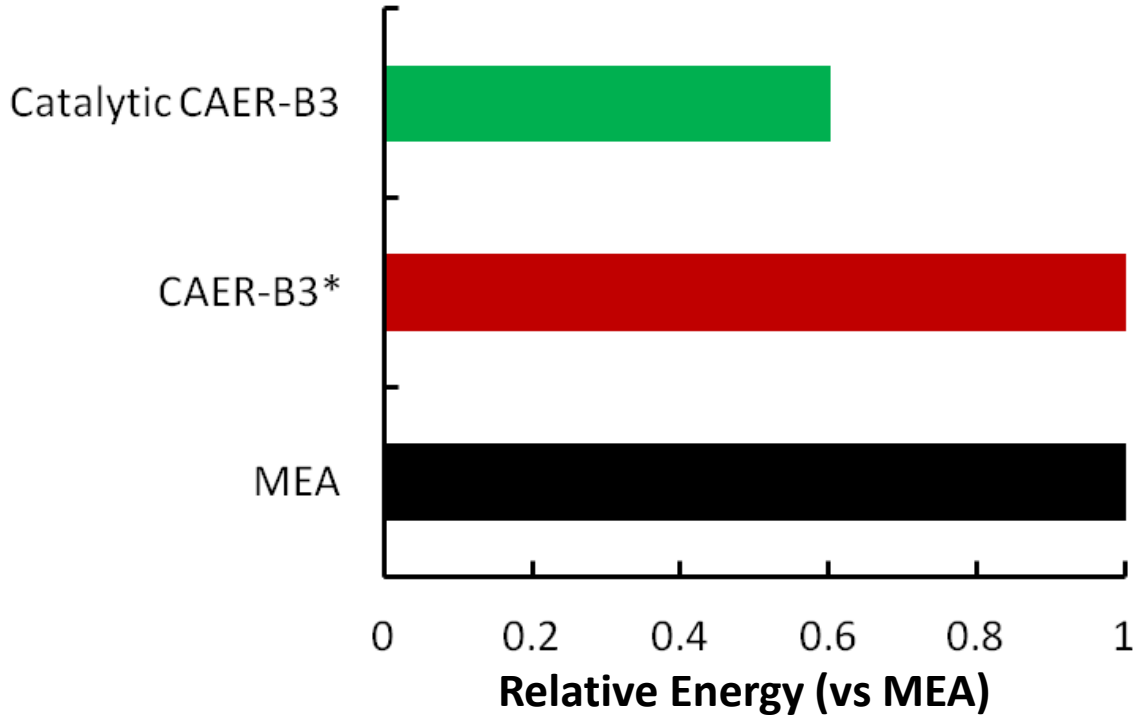
3.1 bar stripper pressure used for better solvent management

- L/G

L/G ~3, reduced liquid load for 90% capture minimized regeneration energy

- Lean Inlet Temp.

45 °C used. Lower solvent viscosity



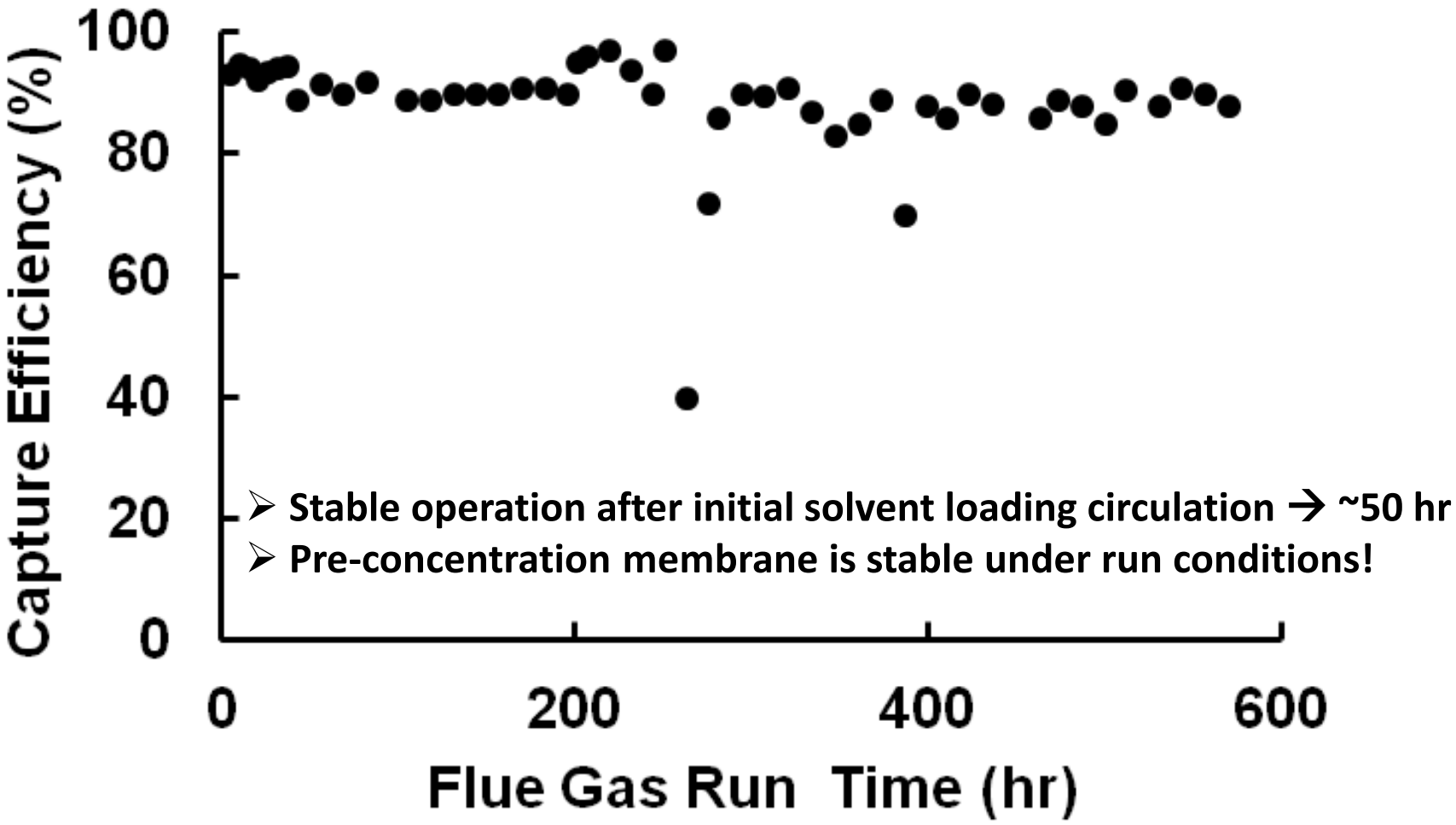
* Only 80% capture achieved

BP3 Activities

Task	Task Name	Description
12	Budget Period 3 Project Management and Planning	Review and Update PMP/SOPO
13	Long-term Verification Study in CAER's 0.1 MWth Bench-scale Unit for the Advanced Catalytic Solvent	500 hr Verification Run to Verify Process Stability
14	Large-Scale Membrane Fabrication	Fabrication of Membrane Modules
15	Membrane Integration, Commissioning and Evaluation	Install Module Prior to Stripper and Run for 100 hr
16	Final Techno-Economic Analysis	Process TEA Performed by WP
17	Final EH&S Assessment	Process EH&S Performed by SMG

- BP3 has focused on testing in our 0.1 MWth bench unit
  - 500 hr verification run
  - Degradation/Stability analysis
- Membrane improvement and module design for pilot integration

Capture Efficiency

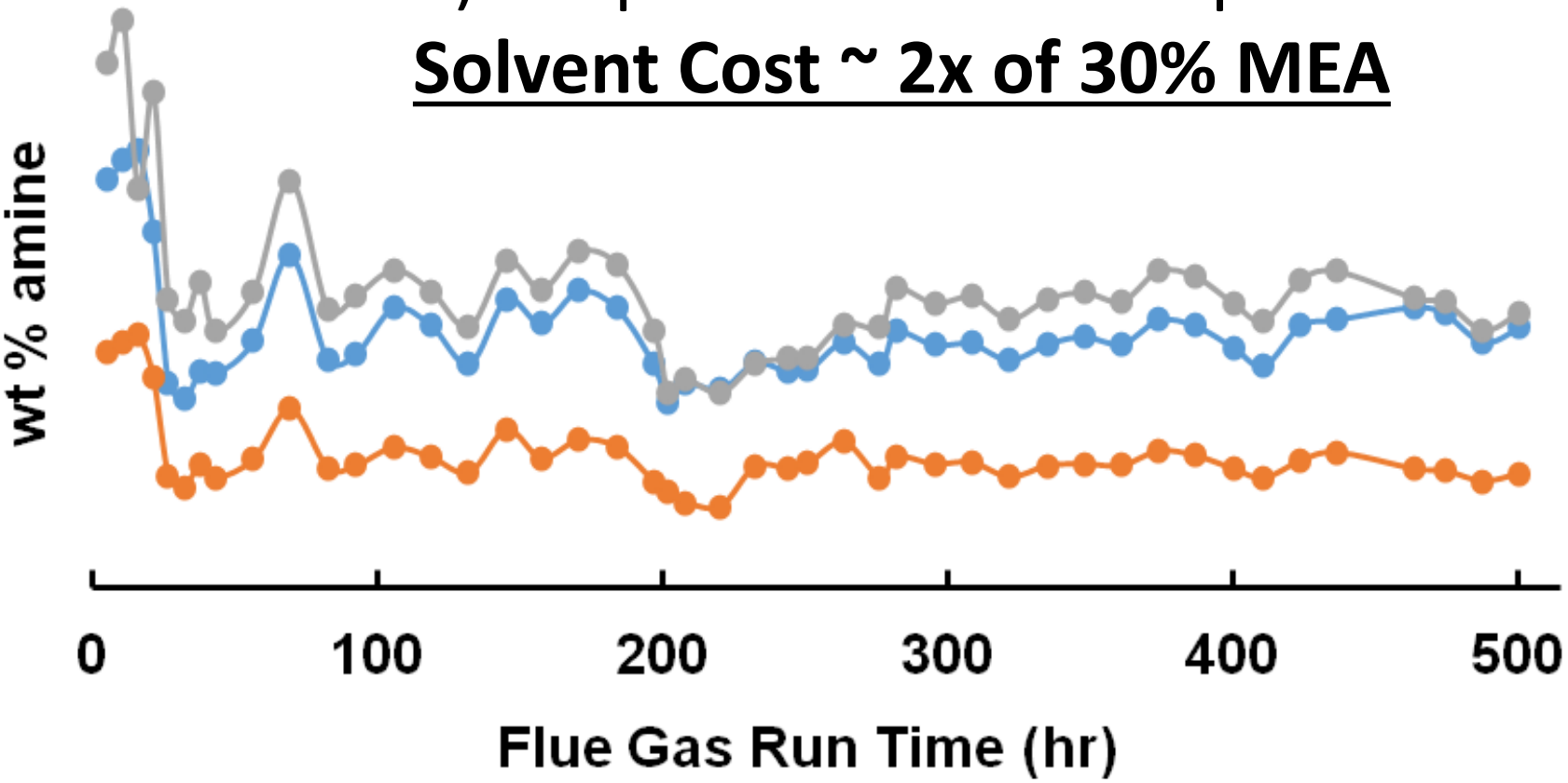


- Stable operation after initial solvent loading circulation → ~50 hr
- Pre-concentration membrane is stable under run conditions!

Stable Operation & Simple Solvent Makeup

1) No Secondary Amines
2) No Nitrosamines
3) Simple Solvent Makeup

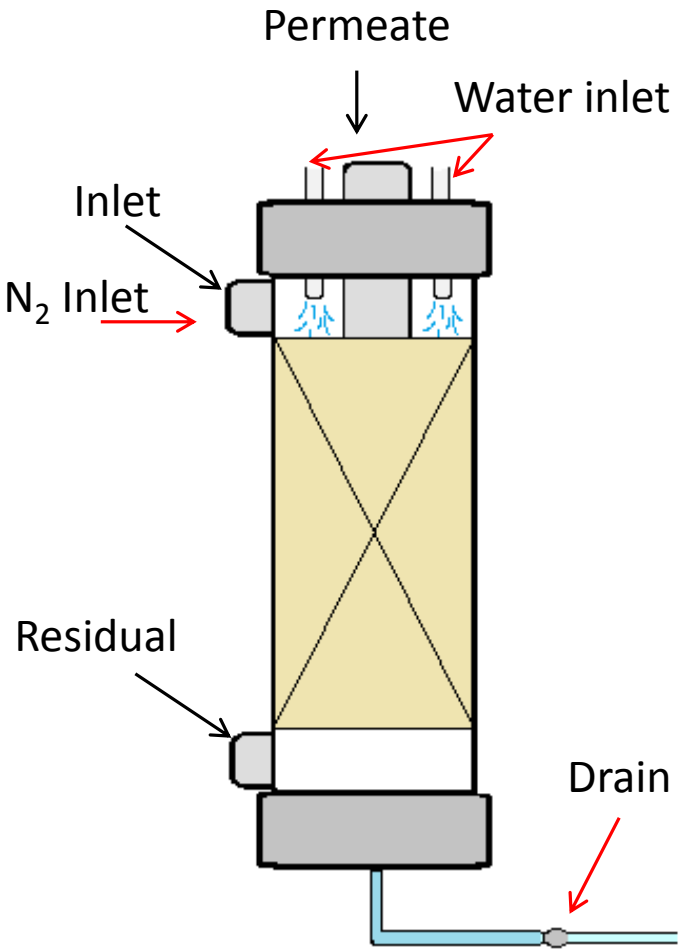
<u>Solvent Cost ~ 2x of 30% MEA</u>



Membrane is Durable

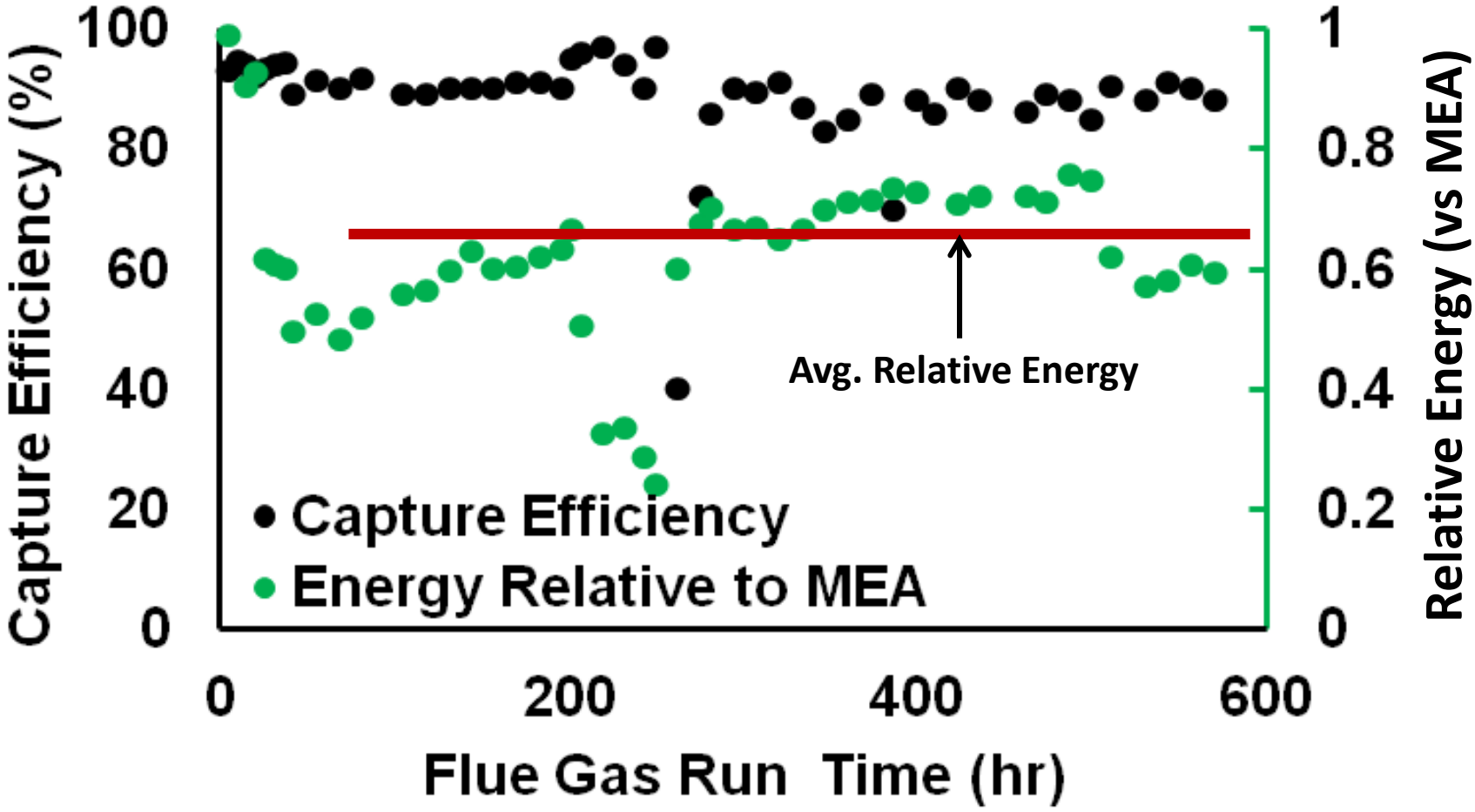
Commercial Membrane

In-line membrane cleaning



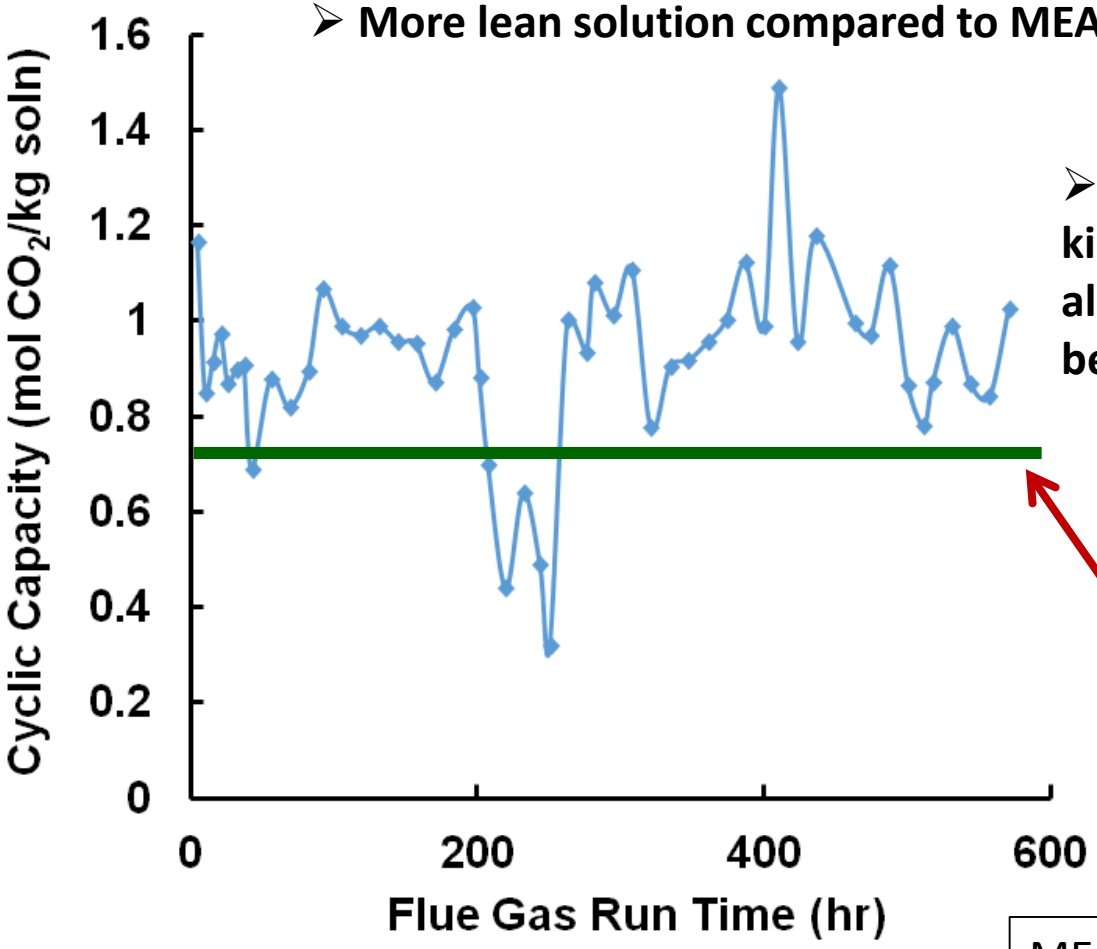
CAER-adCCS Energy Cost is Low

35% less Energy



Improved Cyclic Capacity

- ~25% increase in cyclic capacity
- More lean solution compared to MEA

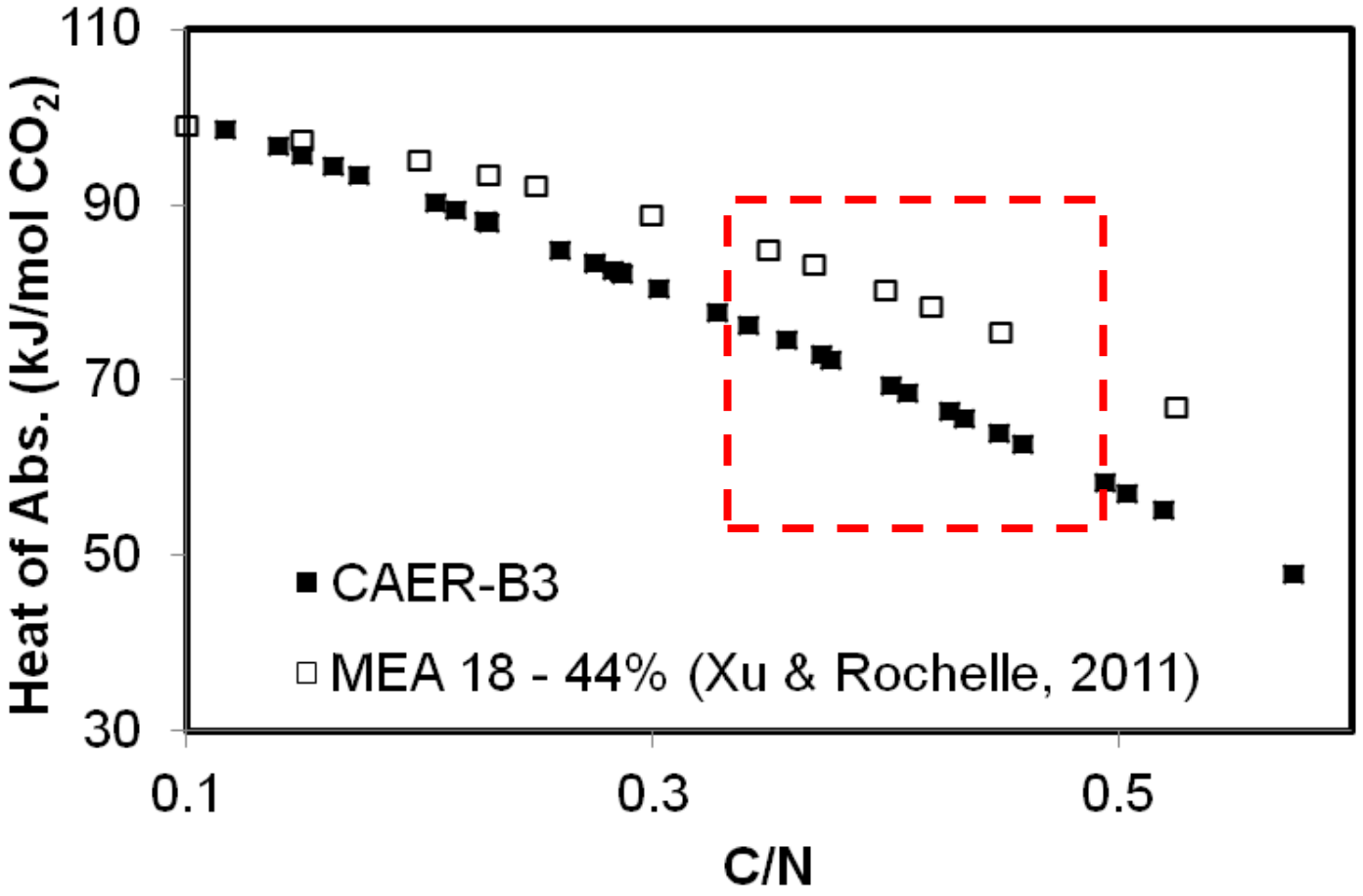


- Catalyst provides increased kinetics at bottom of absorber allowing a more rich solution to be obtained

MEA Solvent Cyclic Capacity

Energy Savings: Low ΔH (10%)

$$E_{sys} = \mathbf{E_{\Delta H}} + E_S + E_{Vap}$$

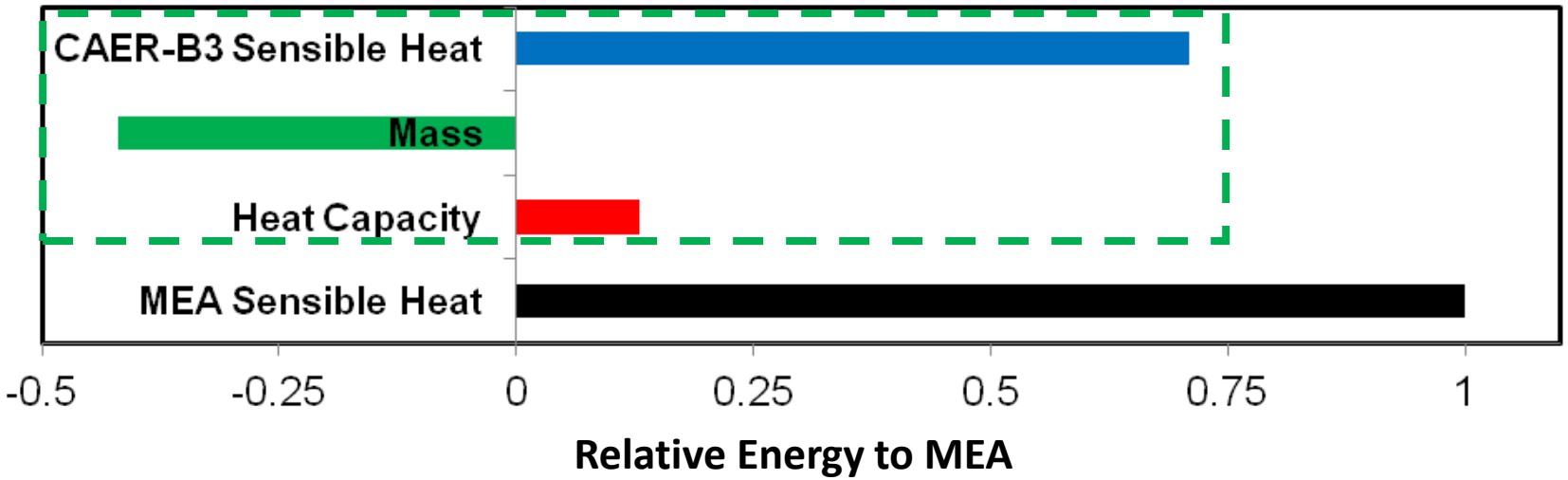


Energy Savings: Low Sensible Heat (30%)

$$E_{sys} = E_{\Delta H} + \mathbf{E_S} + E_{Vap}$$

	L/G wt/wt	Liquid Load $m^3/(m^2*h)$	Absorber Log Mean Temp. (°C)	Stripper Pressure (bar)	Stripper Bottom Temp. (°C)	Capture Efficiency (%)
CAER-B3	3.0	10.8	49	3.1	139	90
MEA	5.3	19	48	3.1	139	90

$$Q_S = mCp\Delta T$$



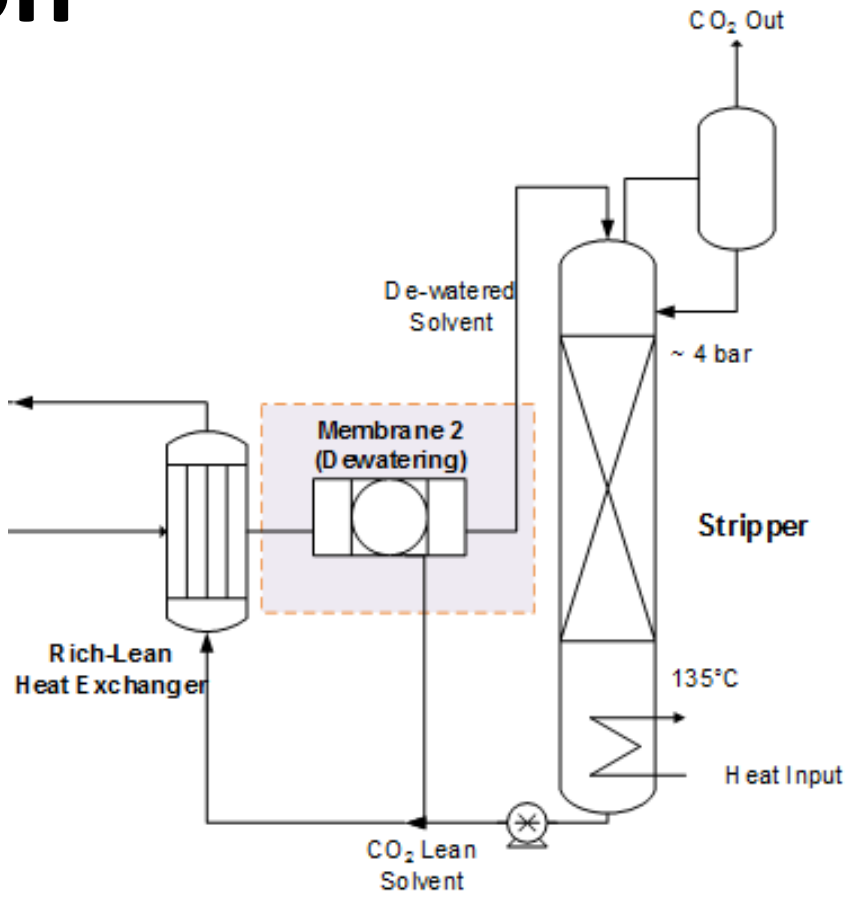
Degradation and Emissions

Analytes	Degradation Rates	Notes
Flue Gas HSS	41 ppm/hr	Mainly from SO2 at 39 ppm/hr
Oxidative Degradation	8.8 ppm/hr	Primarily as Formate, similar to previous solvent campaigns
Thermal Degradation	6.9 ppm/hr	Comparable to previous solvent campaigns with high reboiler temperatures
Metals: Fe, Ni, Cr	81, 5, 2 ppb/hr respectively	Some corrosion of pumps likely resulting in the observed accumulation of Fe, Ni and Cr
Solvent Emissions	5 – 38 ppmV range	Mainly as aerosols
Ammonia Emissions	11-120 ppmV range	Some solvent oxidation observed, likely due to Fe in solvent

Zeolite Dewatering Membrane

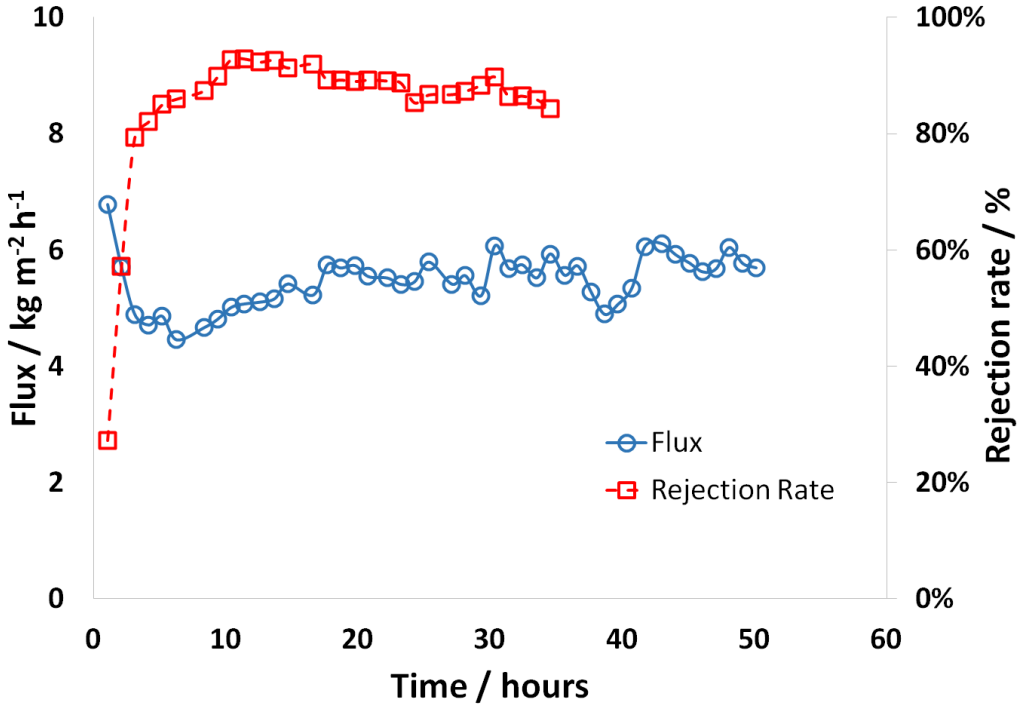
Energy Comparison

- Liquid CO_2 Enrichment – 20% Dewatering
- High CO_2 Partial Pressure
- Reduce Reboiler Duty



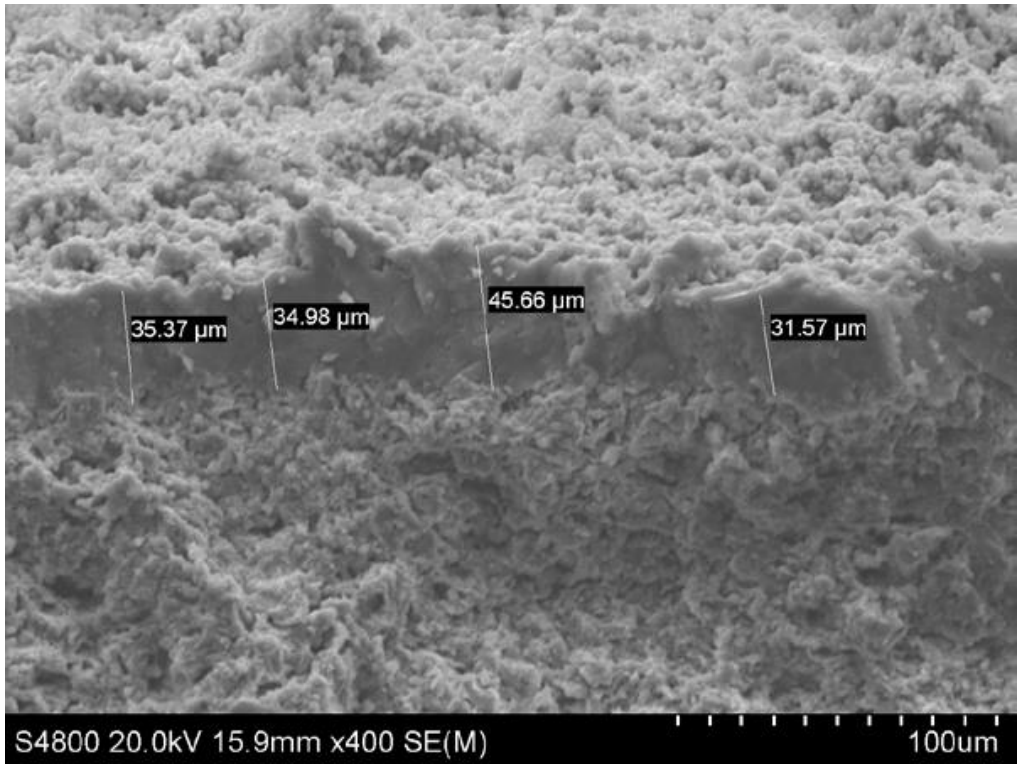
Membrane	Pressure (psi)	Energy (kW/(ton/hr))
Polymer	1200	2.7
CAER	150	0.28

Assembled Membrane Module



➢ **Stable fluxes and high selectivity (>10, rejection rate >90%) are achieved with the new "carousel" method for zeolite membrane production.**

Zeolite Membrane Scale-up



➢ **Eight membranes can be synthesized every 3 days with similar zeolite surface layers (approximately 30 µm) to the previous autoclave process.**

Finalized Dewatering Membrane Module

- Five membrane modules composed of six 18 cm Y zeolite-coated mullite membranes.
- Three reactors are in series to reach ~15-25% dewatering while two separation trains are in parallel to increase the total volume of dewatered solvent.
- In-line particle filters are used to protect the zeolite membranes from ash contaminants.
- Yield ~7% energy savings in stripper

Project Completion Plan

9/2015 –12/2016

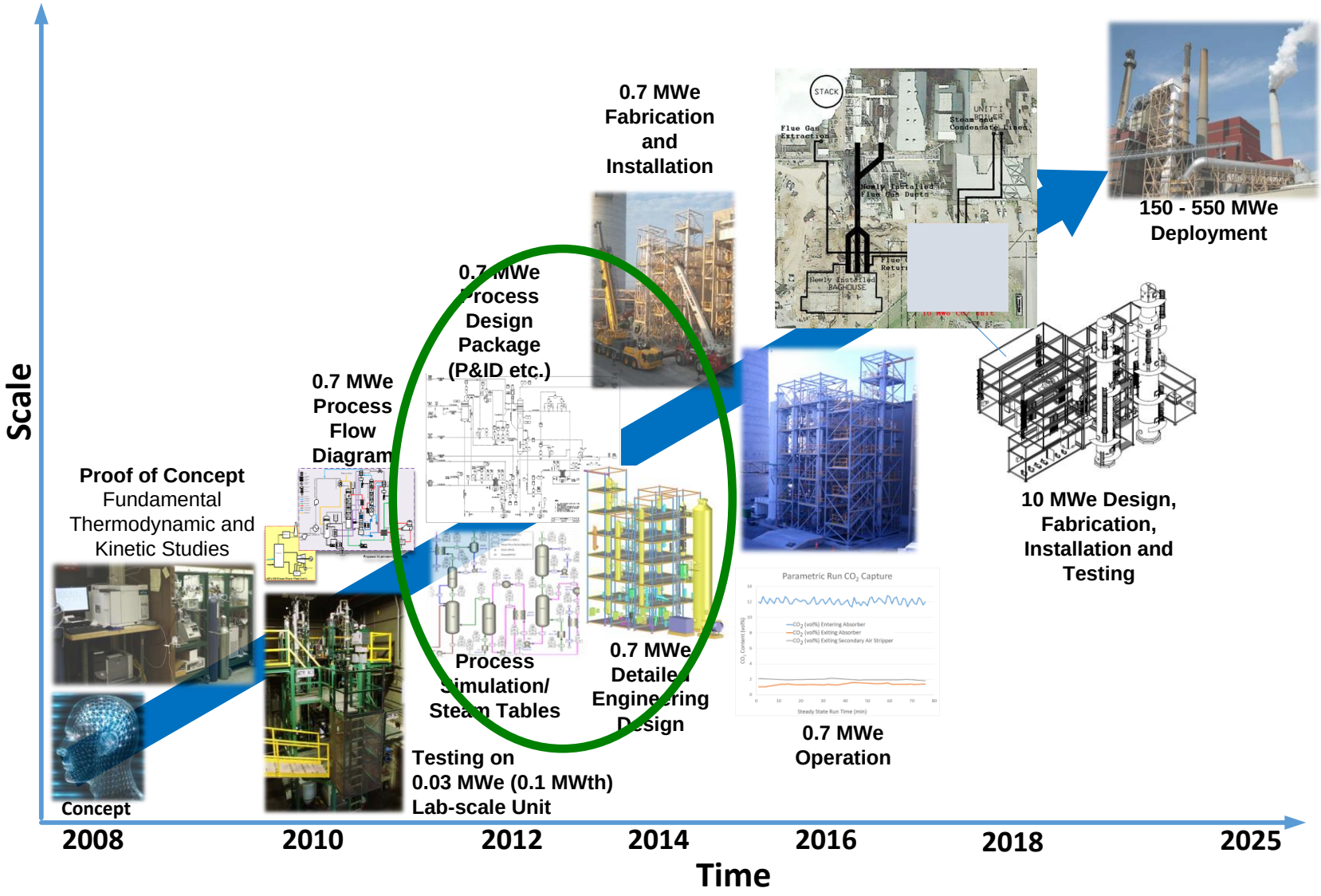
Budget Period 3 Task Plan

- **100hr dewatering membrane verification run**
- **Final EH&S Report**
- **Final TEA**

Project Success Criteria

- A 500 h long-term verification study with coal derived flue gas completed on the 0.1 MWth bench-scale test facility using carbon loading enrichment technique and the CAER catalyzed, advanced amine solvent verifies the long term stability of CAER amine and catalyst to thermal compression (> 3 bar) conditions and to flue gas contaminants from coal combustion.
- Verification testing of the CAER process using the catalyzed advanced amine solvent, dewatering and gas preconcentration membranes together confirm stripping energy reduced by at least 25% when compared to 30 wt% MEA.

Technology Development Pathway



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Thank You