Post-Combustion CO_2 Capture for Existing PC Boilers by Self-Concentrating Absorbent

Liang Hu, 3H Company

2012 NETL CO_2 Capture Technology Meeting

Sheraton Station Square, Pittsburgh, PA

July 9 – 12, 2012

Project Overview

- *Project Funding Under DOE Agreement DE-FE0004274*
- *Total Project Cost - $3.48MM over three years with 21.5% Cost Share*
- *DOE share: $2.737MM; LG&E and KU Energy, EPRI and 3H share: $0.737MM*
- *Project Team:*
  - *3H Company, LLC*
  - *LG&E and KU Energy LLC*
  - *EPRI*
  - *Nexant*
- *Project Objective: Perform Bench-Scale R&D to Demonstrate and Develop 3H's 'Self Concentrating Absorbent Process' for Post-Combustion CO_2 Capture from Existing PC Power Plant Flue Gas Meeting DOE's Goals of 90% Removal and No More Than a 35% Increase in Cost of Electricity*

Company Background

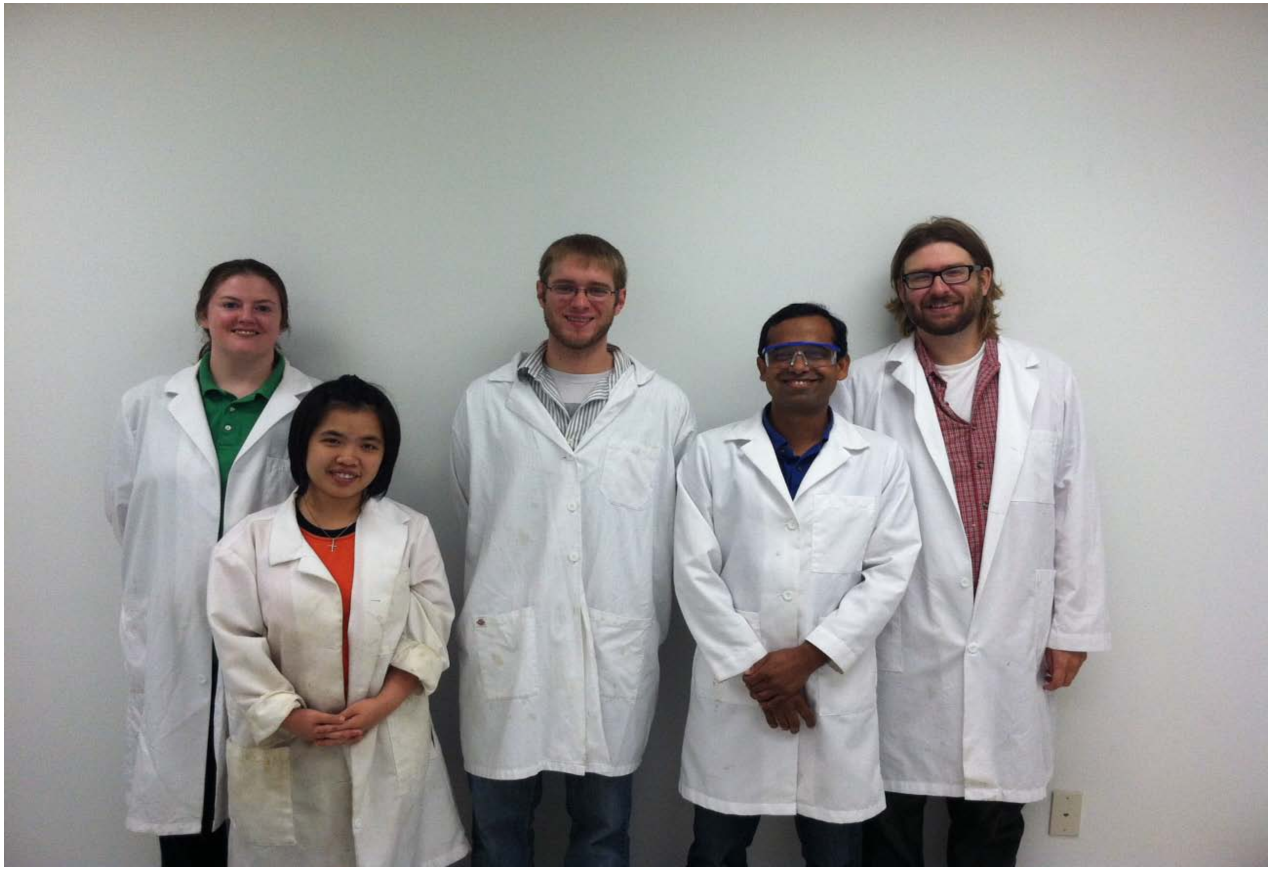
3H Company –

- located in Coldstream Research Campus, University of Kentucky, 1500 Bull Lea Road, Lexington, KY 40511.
- A Startup Technology Company
- Core Business is to Develop CO_2 Capture Technologies

Coldstream Center Building

3H's Laboratories

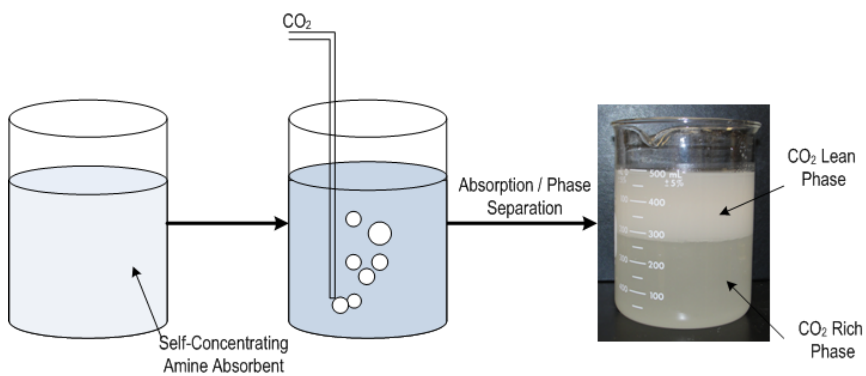
Some Research scientists and Engineers



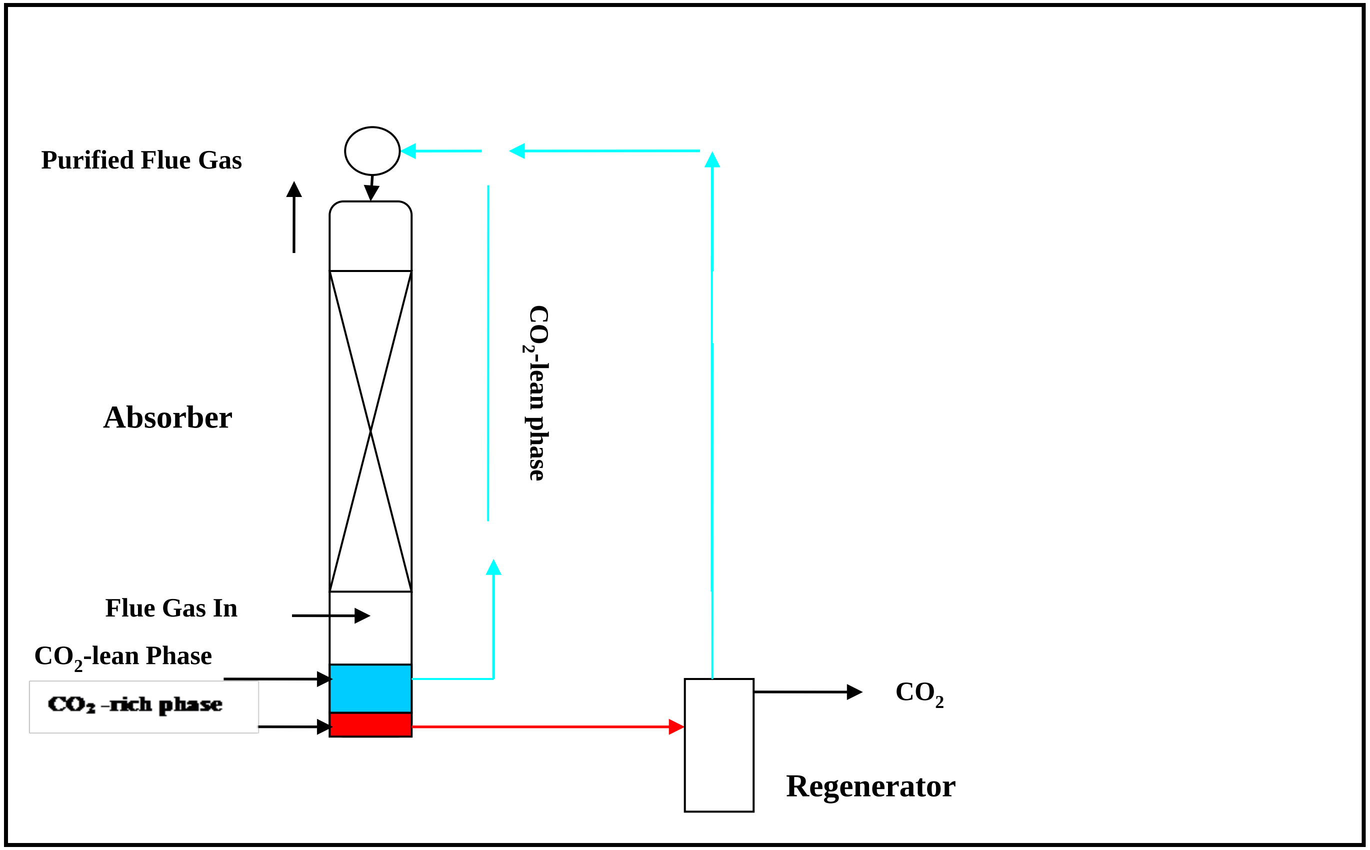
From left to right: Angela, Truc, Bill, Partha, and Matt

3H Self-Concentrating Absorbent Technology

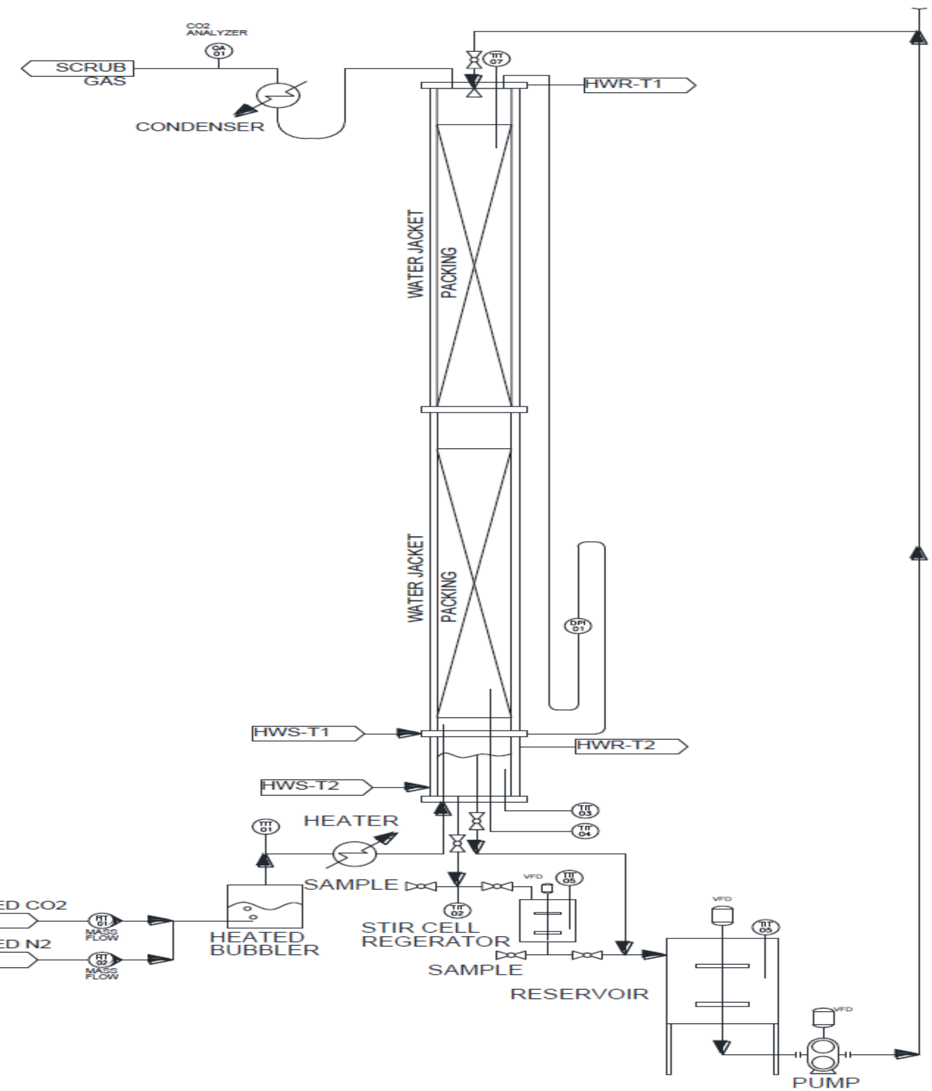
- *Phase Transition during CO_2 Absorption*
- *Only the CO_2 Rich Phase Would Need to be Sent on to Regeneration, Resulting in*
  - *Significant Reduction in Solvent Recirculation, thus Heat of Regeneration*
  - *Significant Increase in CO_2 Capture Process Efficiency*
  - *Capital Cost Saving*



Bench Top System



3H's Self-concentrating Absorption System- Bench Scale



Objective

- The objective of the research in first year is to screen out the promising absorbent for Post-Combustion CO_2 capture

Selection Criteria

- Criteria for Selection is Potential Significant Cost Reduction

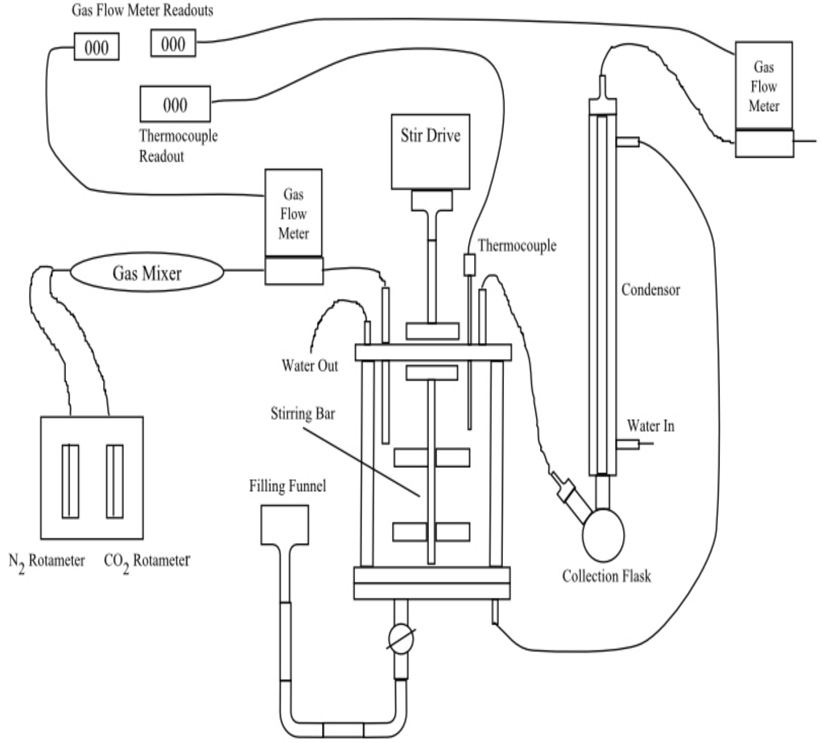
Selection Base

1	Absorption Rate
2	Loading Capacity
3	Working Capacity
4	Regeneration Heat
5	Regeneration Rate
6	Regeneration Temperature
7	Vapor-liquid Equilibrium
8	Thermo-degradation
9	Oxy-degradation
10	Emission

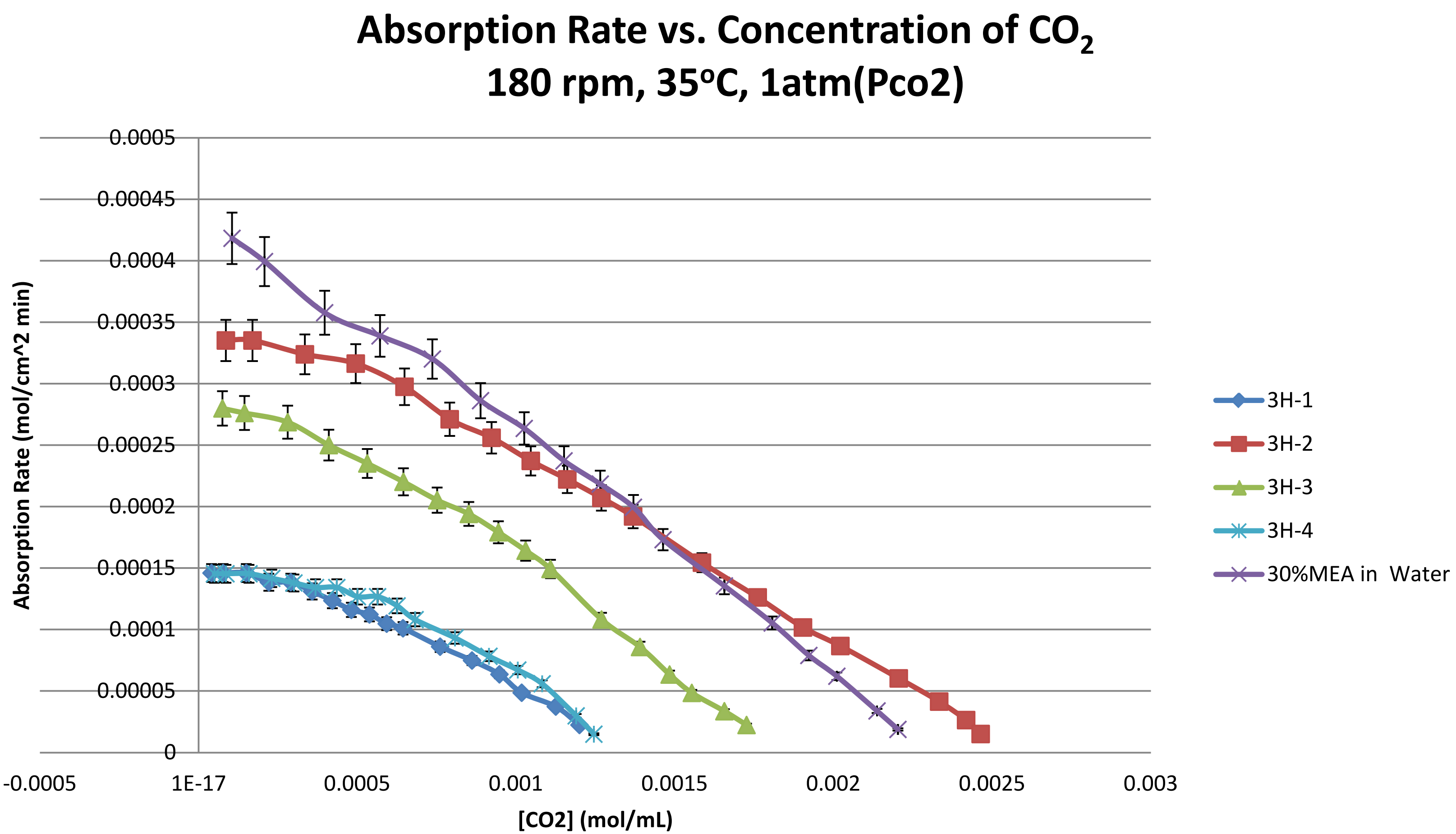
Part I

ABSORPTION

Absorption Rate Measurement Equipment



Absorption Rate Comparison



Loading Capacity

	3H-1	3H-2	3H-3	3H-4	30%MEA
CO_2 Rich Phase (g-CO_2/g)	0.172	0.278	0.219	0.163	0.113
CO_2:Amine mole ratio	0.494	0.535	0.490	0.466	0.588

*Load capacities were measured at following conditions:
Temperature: 35 oC
CO_2 Pressure: 1 atm

Working Capacity

Absorbent	3H-1	3H-2	3H-3	3H-4	30%MEA
CO_2:Amine mole ratio (before regeneration)	0.494	0.535	0.490	0.466	0.588
CO_2:Amine mole ratio (after regeneration)	0.02	0.243	0.149	0.02	0.331

- CO_2:Amine mole ratios (before regeneration) were measured at following conditions: (1) Temperature: 35 oC, (2) CO_2 Pressure: 1 atm
- CO_2:Amine mole ratios (after regeneration) were measured at following conditions: (1) Temperature: 115 oC for 3H-1 and 3H-4, 125 oC for 3H-2 and 3H-3, (2) CO_2 Pressure: 1 atm
- For 30% MEA aqueous solution, CO_2:Amine mole ratios (after regeneration) were measured at following conditions: (1) Temperature: 105 oC , (2) CO_2 Pressure: 0.1 atm

Part II

REGENERATION

30% MEA Regeneration Heat Analysis

	ΔT = 10 oC	ΔT = 20 oC
Vaporization Heat (MMBTU/Ton CO_2)	2.85 (46%)	2.85 (37%)
Sensible Heat (MMBTU/Ton CO_2)	1.49 (24%)*	2.98 (39%)**
Reaction Heat (MMBTU/Ton CO_2)	1.86 (30%)	1.86 (24%)
Total Heat (MMBTU/Ton CO_2)	6.2	7.69

*In the calculation of Sensible Heat, ΔT = 10 oC
** In the calculation of Sensible Heat, ΔT = 20 oC

- **Regeneration heat is responsible for about 80% operation energy consumption in absorption process**
- **Regeneration heat is composed of vaporization heat, sensible heat, and reaction heat**

Regeneration Heat Comparison

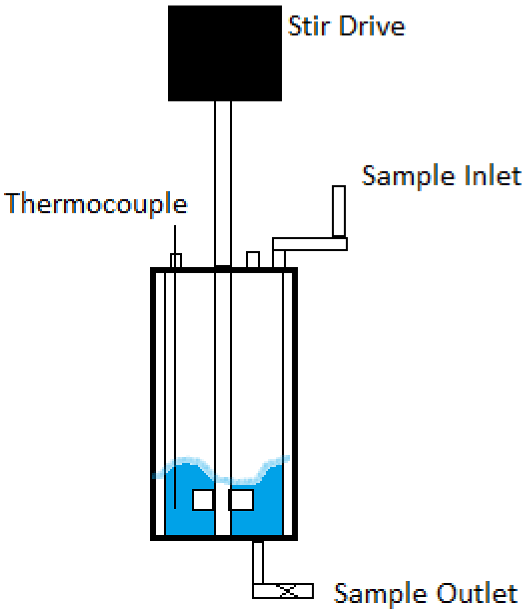
Absorbent	3H-1	3H-2	3H-3	3H-4	30% MEA
Vaporization Heat (MMBTU/Ton CO_2)	0.5 (33.3%)	0.49 (16.8%)	0.49 (21.3%)	0.5 (33.3%)	2.85 (46%)
Sensible Heat (MMBTU/Ton CO_2)	0.6 (40.3%)	*1.37 (46.9%)	*1.11 (48.3%)	0.6 (40.3%)	1.49 (24%)
Reaction Heat (MMBTU/Ton CO_2)	0.4 (26.4%)	1.06 (36.3%)	0.70 (30.4%)	0.4 (26.4%)	1.86 (30%)
Total (MMBTU/Ton CO_2)	1.5	2.92	2.3	1.5	6.2

(1) **Assume:** Flue gas was saturated by water at 40 C. All water (100%) in flue gas was transferred into absorbent.
(2) Regeneration temperature at 125 C.
(3) Regeneration CO2 Pressure at 1 atm. Except 30% MEA
(4) In the calculation of Sensible Heat, ΔT = 10 oC
(5) Working capacity: for 3H-1, 0.4 – 0.02; for 3H-2, 0.4 – 0.2; for 3H-3, 0.4 – 0.1; for 3H-4, 0.4 – 0.02; for 30% MEA, 0.4 – 0.16

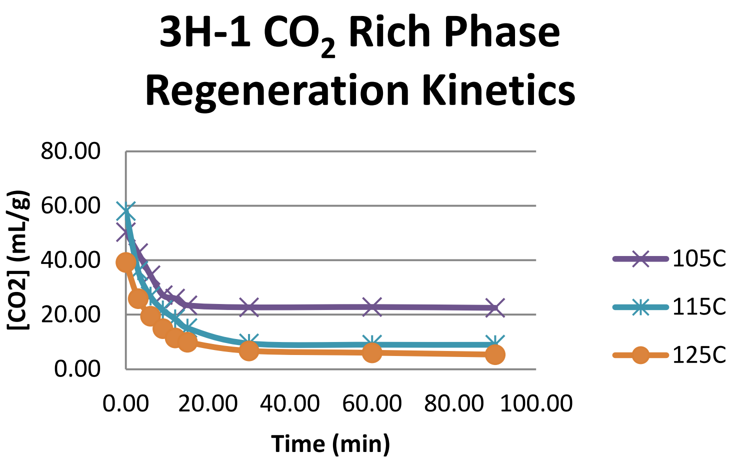
Regeneration
Experimental Setup

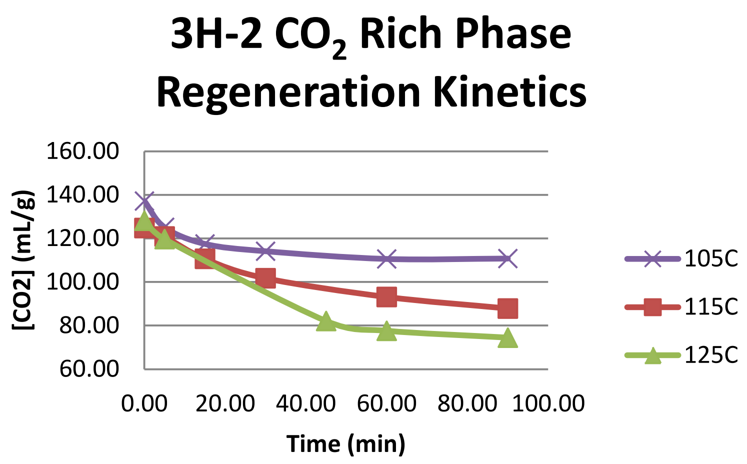
<u>Experimental Conditions</u>

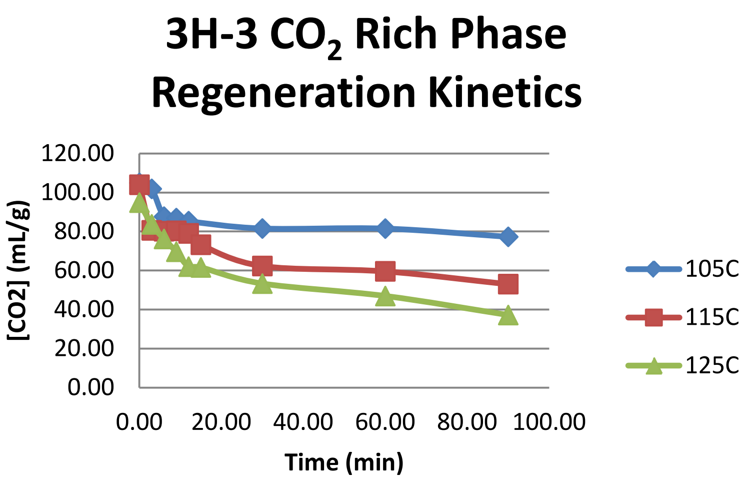
- CO_2 pressure 1 atm
- Stirring speed 600 rpm

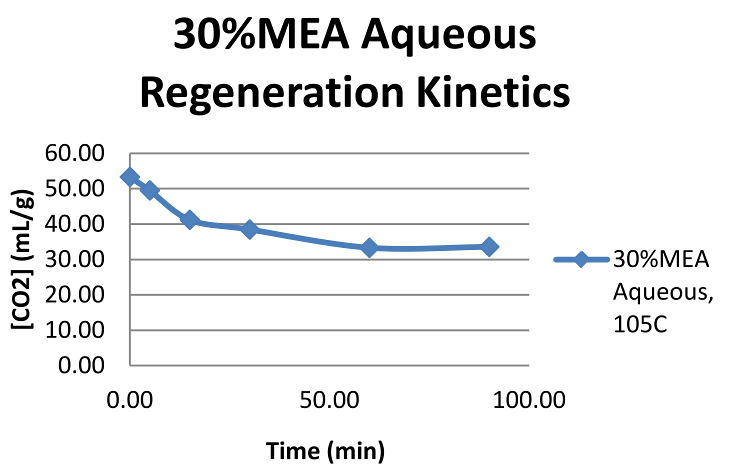


Regeneration Rate









1. The regeneration was conducted in the stirring cell
2. The regeneration CO_2 pressure for 3H absorbents was 1 atm
3. The regeneration total pressure is 1 atm for 30% MEA aqueous solution

Summary for Regeneration Rate

Absorbent	Regeneration Time (min)
3H-1	20 – 30
3H-2	60
3H-3	90
4H-4	20 – 30
30% MEA Aqueous Solution	60

Regeneration Temperature

Absorbent	3H-1	3H-2	3H-3	3H-4	30%MEA
Regeneration Temp (C)	115	125	125	115	105
% CO2 removed	94%	50%	65%	94%	45%

1. The regeneration was conducted in the stirring cell
2. The regeneration CO_2 pressure was 1 atm for 3H Absorbents
3. The regeneration total pressure was 1 atm for 30% MEA aqueous solution
4. %CO2 removed – after 90 min regeneration except absorbent 3H-1 and 3H-4 for 30 minutes

Part III

VAPOR – LIQUID EQUILIBRIUM

Vapor – Liquid Equilibrium

Absorbent	3H-1	3H-2	30% MEA*
CO_2 partial pressure (PSIA)	199.5	80.8	14.5
CO_2 amine mol ratio (CO_2:amine)	0.38	0.387	0.4
CO_2 partial pressure (PSIA)	100	24.3	2.9
CO_2 amine mol ratio (CO_2:amine)	0.319	0.326	0.3

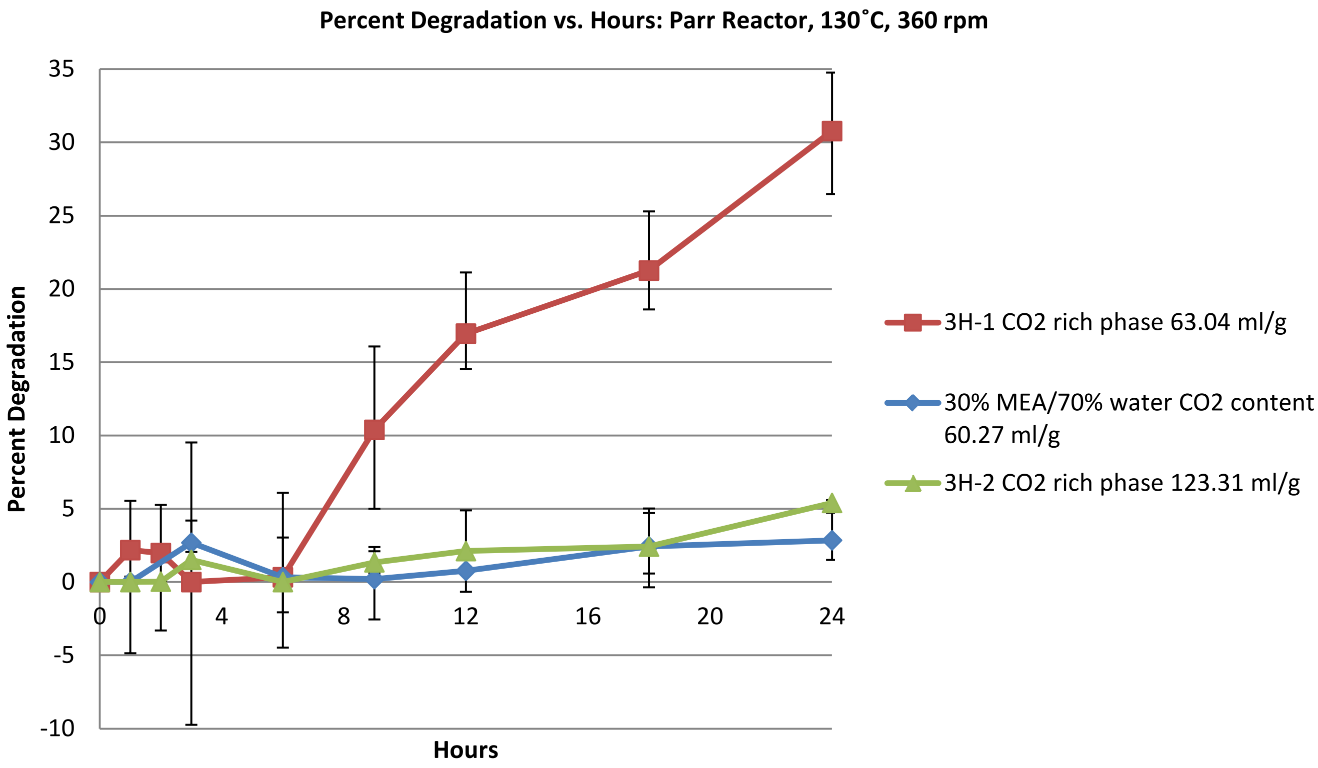
(1) temperature at 120 C.

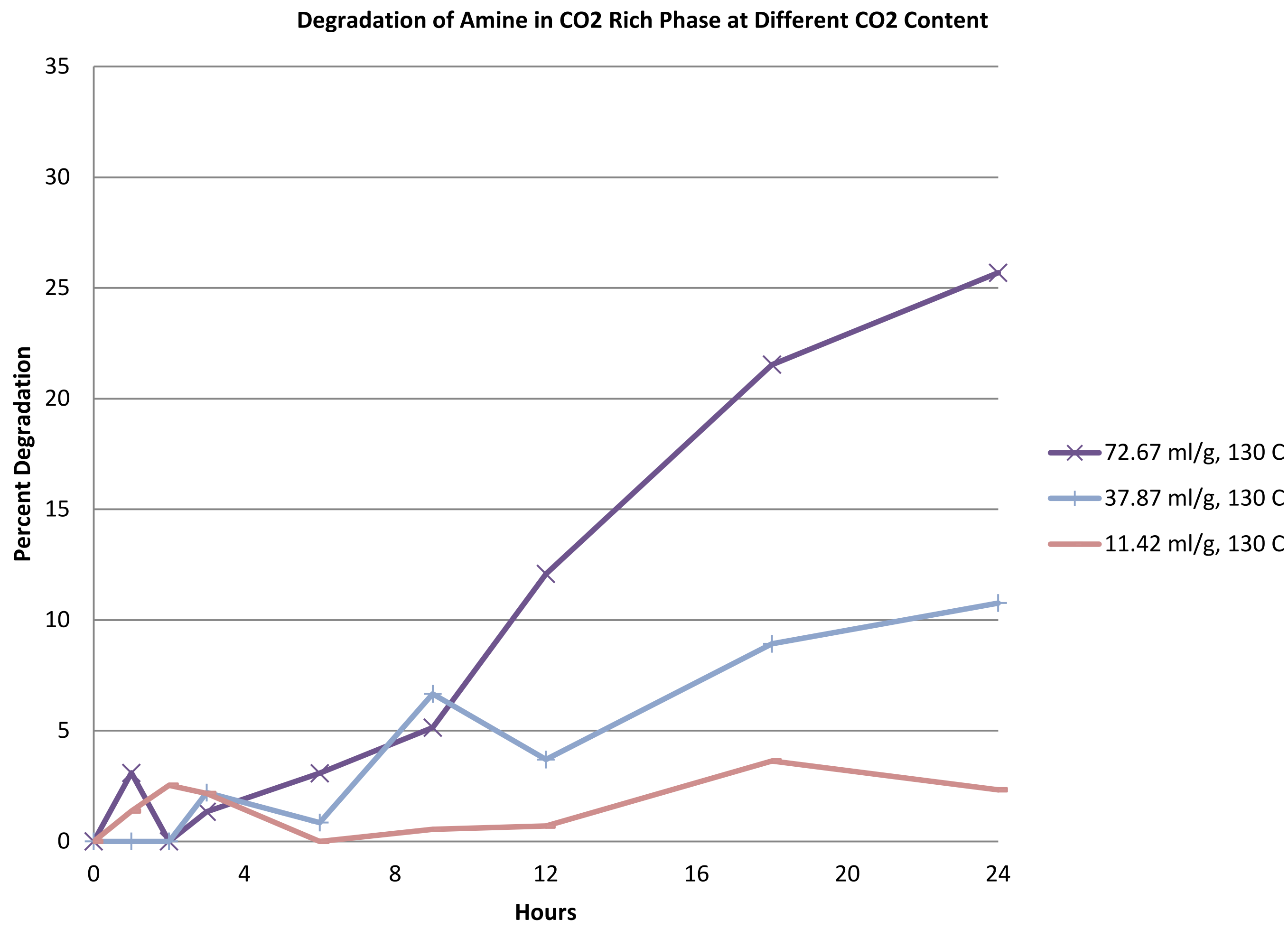
* Ugochukwu E. Aronu, Shahla Ghondal, etc. "Equilibrium in the H_2O-MEA-CO_2 system: new data and modeling", IEAGHG Forum, 1st Post Combustion Capture Conference. Abu Dhabi, UAE, May 17-19, 2011

Part IV

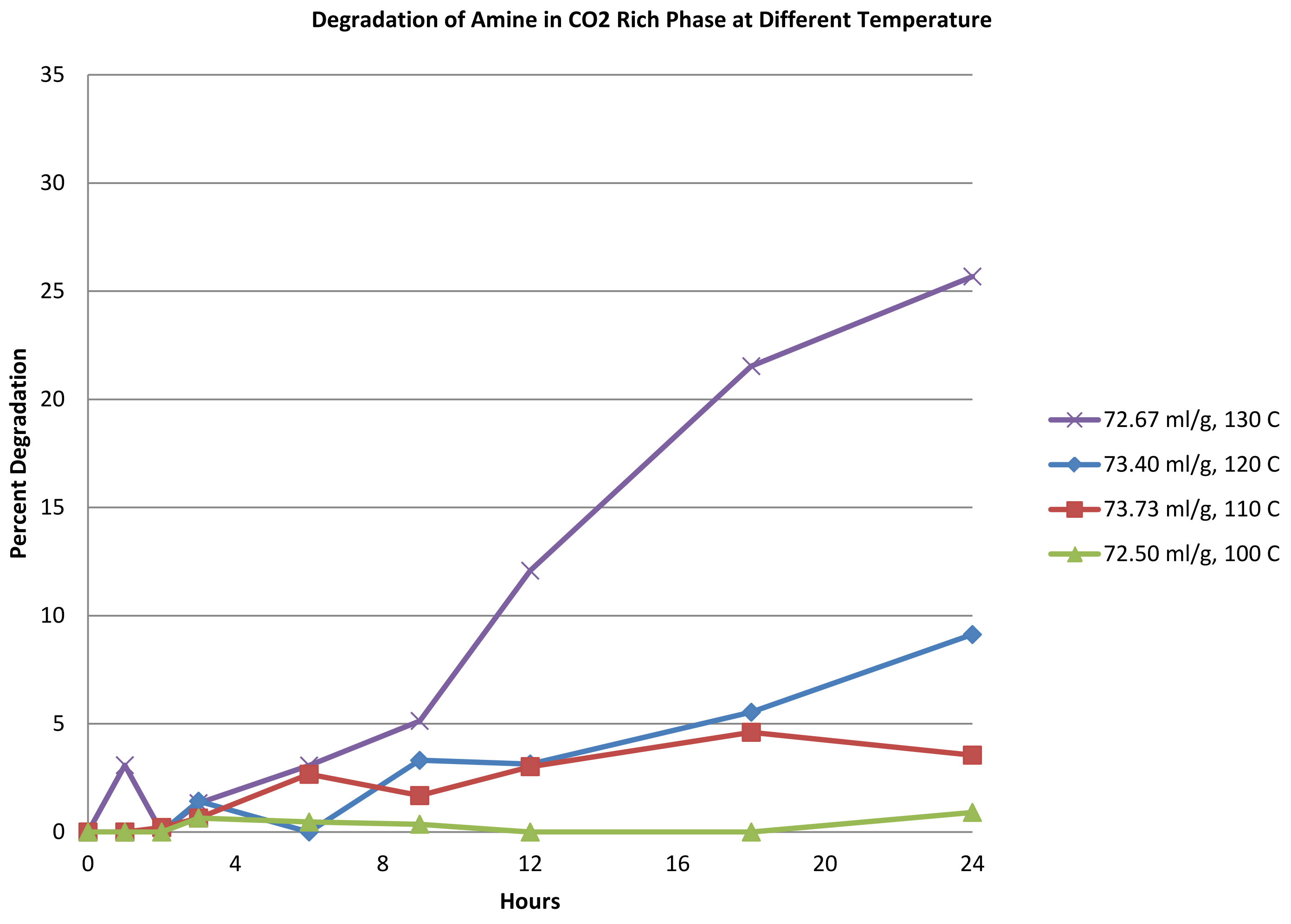
ABSORBENT DEGRADATION

Thermo Degradation





Degradation of Amine in CO2 Rich Phase at Different CO2 Content
Percent Degradation
35
30
25
20
15
10
5
0
0
4
8
12
16
20
24
Hours
72.67 ml/g, 130 C
37.87 ml/g, 130 C
11.42 ml/g, 130 C

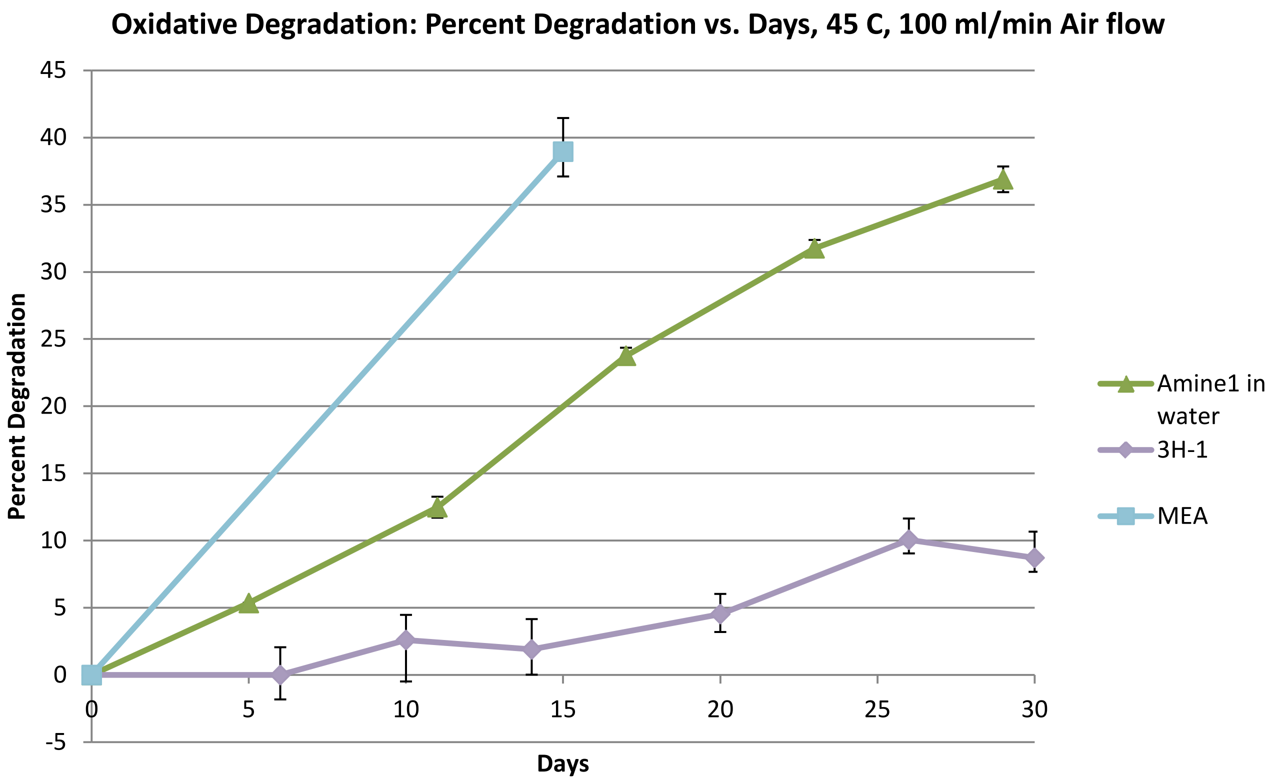

Degradation of Amine in CO2 Rich Phase at Different Temperature
Percent Degradation
35
30
25
20
15
10
5
0
0
4
8
12
16
20
24
Hours
72.67 ml/g, 130 C
73.40 ml/g, 120 C
73.73 ml/g, 110 C
72.50 ml/g, 100 C

Conclusion for Thermo-degradation

1. Thermo-degradation rate was increased with temperature
2. Thermo-degradation rate was increased with CO_2 content or CO_2:amine mole ratio
3. No degradation was found at regeneration

Oxidative Degradation

Temperature = 45 C, Air flow rate = 100 ml/min



Absorbent Selection Criteria

1. Low Operation Energy Consumption
- Working capacity,
- Regeneration heat,
- Pco_2, Vapor Liquid Equilibrium

2. Competitive Capital Investment
- Absorption rate
- Regeneration rate

3. Amine Degradation
4. Emission
5. Process Issues

Summary

	3H-1	3H-2	3H-3	3H-4	30%MEA
Absorption Rate	Low	High	Medium	Low	High
Loading Capacity (g-CO2/g)	0.172	0.278	0.219	0.163	0.113
Working Capacity (g-CO2/g)	0.164	0.133	0.148	0.155	0.046
Regeneration Rate	Very High	Medium	High	Very High	Low
Regeneration Column	No	No	No	No	Large Column
Regeneration Temperature	115	125	125	115	125
Regeneration Heat (MMBTU/Ton CO_2)	1.5	2.92	2.3	1.5	6.2
Pco_2, Vapor Liquid Equilibrium (PSI)	199.5	80.8	N/a	199.5	14.5
Thermo-degradation in regeneration period (no inhibitor added)	Not detected	Not detected	Not detected	Not detected	Not detected
Oxy-degradation (no inhibitor added)	Low	High	Medium	Low	High
Emission (without wash, at room T)	2 - 4 ppm	>120 ppm	>60 ppm	< 4 ppm	>140 ppm

Process Issues

	3H-1	3H-2	3H-3	3H-4	30%MEA
Foaming	No	No	No	No	Yes
Phase Separation	Easy Sep	Easy Sep	Easy Sep	Easy Sep	N/A

Final Absorbent Selection

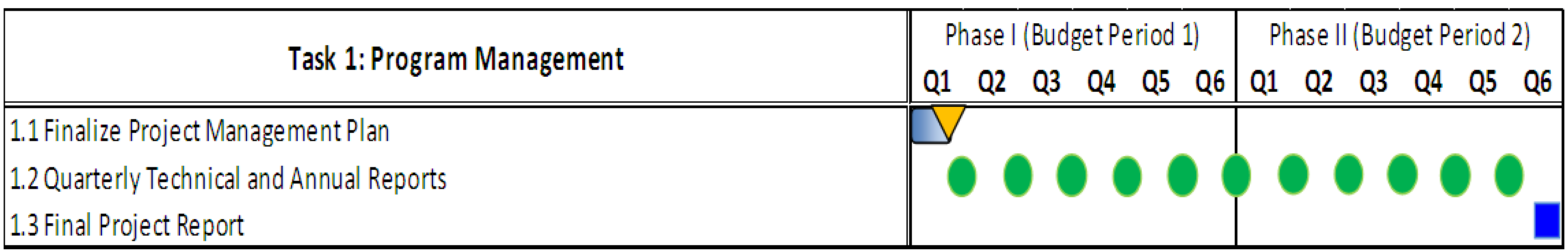
- 3H-1

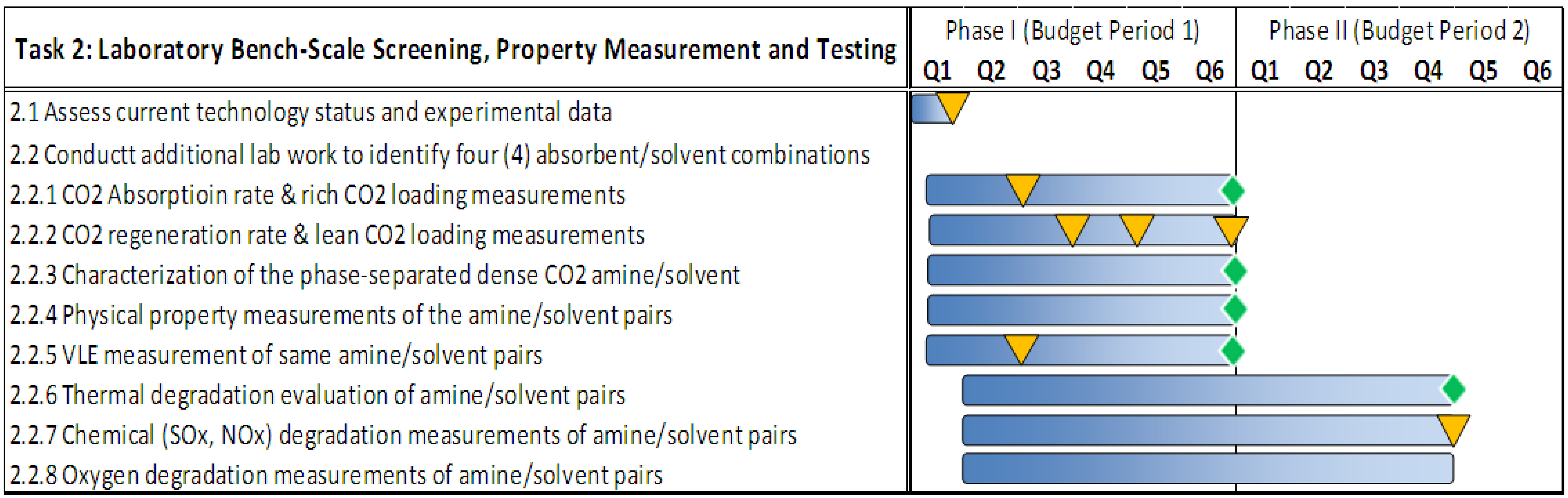
Reason:

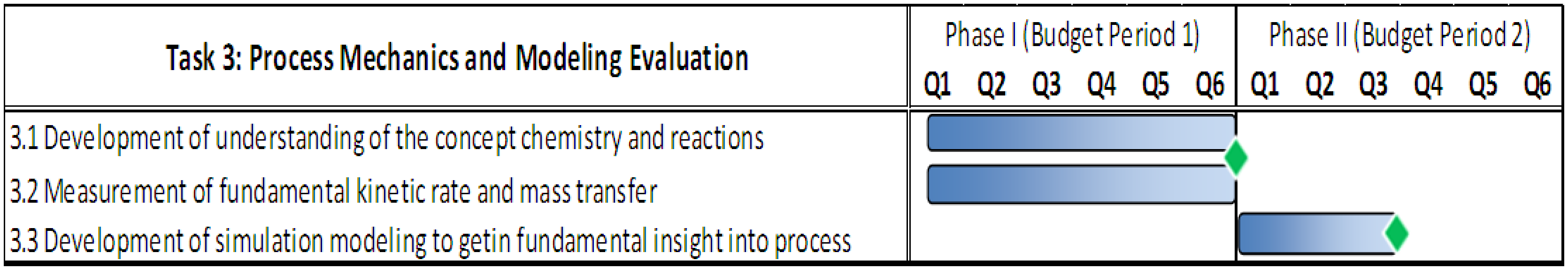
1. Very low operation energy consumption
- Very low regeneration heat
- Very high working capacity
- Very high CO_2 regeneration pressure
2. Competitive Capital Investment
- Larger absorption column (disadvantage)
- Low cost material for absorption column
- No regeneration column needs
3. Absorbent Loss
- No thermo-degradation observed in regeneration condition (regeneration completed in less than 40 minutes)
- Much lower oxy-degradation by comparing MEA
4. Emission
- Very low emission

Part V

PROJECT TIMELINE

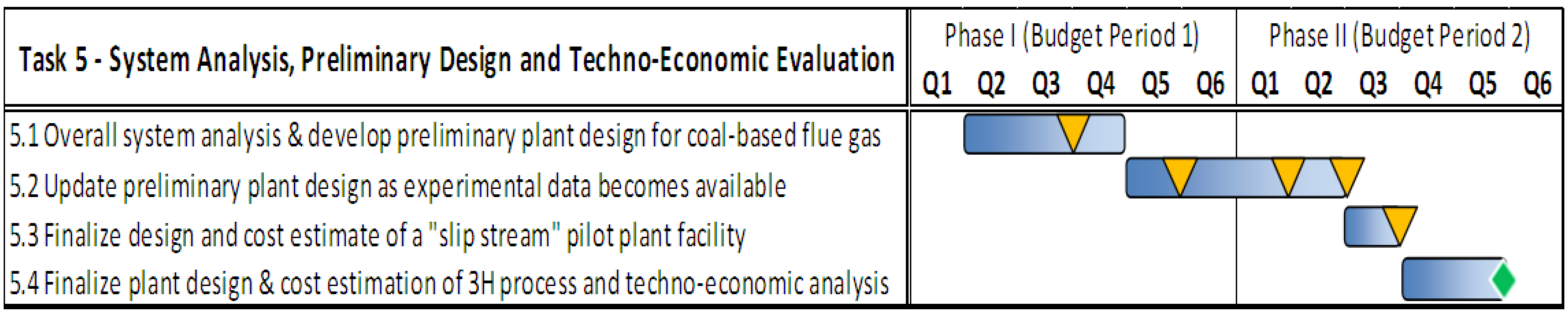

Task 1: Program Management
Phase I (Budget Period 1)
Phase II (Budget Period 2)
Q1 Q2 Q3 Q4 Q5 Q6
Q1 Q2 Q3 Q4 Q5 Q6
1.1 Finalize Project Management Plan
1.2 Quarterly Technical and Annual Reports
1.3 Final Project Report


Task 2: Laboratory Bench-Scale Screening, Property Measurement and Testing
Phase I (Budget Period 1)
Phase II (Budget Period 2)
Q1 Q2 Q3 Q4 Q5 Q6
Q1 Q2 Q3 Q4 Q5 Q6
2.1 Assess current technology status and experimental data
2.2 Conductt additional lab work to identify four (4) absorbent/solvent combinations
2.2.1 CO2 Absorptioin rate & rich CO2 loading measurements
2.2.2 CO2 regeneration rate & lean CO2 loading measurements
2.2.3 Characterization of the phase-separated dense CO2 amine/solvent
2.2.4 Physical property measurements of the amine/solvent pairs
2.2.5 VLE measurement of same amine/solvent pairs
2.2.6 Thermal degradation evaluation of amine/solvent pairs
2.2.7 Chemical (SOx, NOx) degradation measurements of amine/solvent pairs
2.2.8 Oxygen degradation measurements of amine/solvent pairs



Task 3: Process Mechanics and Modeling Evaluation
Phase I (Budget Period 1)
Q1 Q2 Q3 Q4 Q5 Q6
Phase II (Budget Period 2)
Q1 Q2 Q3 Q4 Q5 Q6
3.1 Development of understanding of the concept chemistry and reactions
3.2 Measurement of fundamental kinetic rate and mass transfer
3.3 Development of simulation modeling to getin fundamental insight into process

Task 4: Bench Scale Column Absorption and Regeneration Testing	Phase I (Budget Period 1)						Phase II (Budget Period 2)					
	Q1	Q2	Q3	Q4	Q5	Q6	Q1	Q2	Q3	Q4	Q5	Q6
4.1 Design and construction of a bench-scale absorber column												
4.2 A similar design/construction for a stripper column as well, if needed												
4.3 Demonstration testing of the proposed concept under dynamic mult-contact testing												


Task 5 - System Analysis, Preliminary Design and Techno-Economic Evaluation
Phase I (Budget Period 1)
Phase II (Budget Period 2)
Q1 Q2 Q3 Q4 Q5 Q6 Q1 Q2 Q3 Q4 Q5 Q6
5.1 Overall system analysis & develop preliminary plant design for coal-based flue gas
5.2 Update preliminary plant design as experimental data becomes available
5.3 Finalize design and cost estimate of a "slip stream" pilot plant facility
5.4 Finalize plant design & cost estimation of 3H process and techno-economic analysis

Thanks to:

3H is appreciative to the DOE, LG&E and KU Energy LLC, and EPRI funding this project. Special thanks go to

- *Mike Mosser (NETL Project Manager)*
- *John Moffett, David Link (LG&E and KU)*
- *Abhoyjit Bhown, Brice Freeman (EPRI)*
- *Bob Chu (Nexant)*

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