Bench-Scale Silicone Process for Low-Cost CO_2 Capture

GE Global Research
GE Energy
SiVance

Kickoff Meeting with NETL

November 22, 2011

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Overview

Program Team

GE Global Research

- *Bench-Scale Design and Testing of Absorption/ Desorption Process*
- *Materials of Construction*

GE Energy

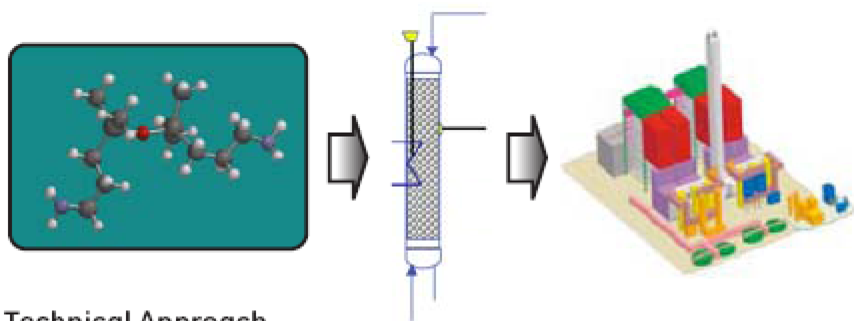
- *Modeling and Design of Integrated Energy Systems*
- *Economic Analysis*
- *Technical and Economic Feasibility Study*

SiVance
Chemistry… for Precision Performance

- *Optimized Process for Solvent Synthesis*
- *Large Scale Manufacture of Silicone Solvent*
- *EH&S Risk Assessment*

24 Month, $3.75M Program to Develop a Silicone Process for CO_2 Capture

Program Objective: *Design and optimize a new process for novel silicone CO_2 capture solvent and establish scalability and potential for commercialization of post-combustion capture of CO_2 from coal-fired power plants. A primary outcome will be a system capable of 90% capture efficiency with less than 35% increase in the cost of energy services (COE).*



Technical Approach

- Design and construct bench-scale unit and obtain parametric data to determine key scale-up parameters
- Perform an EH&S and technical and economic assessment to determine feasibility of commercial scale operation
- Develop material manufacturing plan
- Develop scale-up strategy

Outcomes

- Strategy for future scale-up
- Technical and economic feasibility determined
- Environmental assessment

Anticipated Benefits of the Proposed Technology

- 90% CO_2 capture with <35% COE increase

Team Organization

Department of Energy

Technical Management Team

Dr. Teresa Grocela-Rocha
Technology Leader Fuel & Emissions, GE Global Research

Dr. Timothy Rehg
Advanced Technology Organization Conceptual and Preliminary Systems Leader

Principal Investigator and Project Leader

Dr. Benjamin Wood
Project Leader, Process Engineering, GE Global Research

Business Management Team

Ms. Johanna Wellington
Sustainable Energy Advanced Technology Leader

Mr. Kelly Fletcher
Business Program Manager

Mr. Sam Draper
GE Energy Global Warming Technology

GE Global Research

Basic System Design and Bench Testing

Dr. Robert Perry
Silicone Materials

Ms. Sarah Genovese
Process Engineering

Dr. Hong Lu
System Design

Dr. Wei Wei
System Engineering

GE Energy

COE Modeling and Scale-Up Strategy

Dr. Ravi-Kumar Vipperla
Process Modeling and COE Analysis

Mr. Sam Draper
Modeling Assessment

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Absorption Material Manufacturing Plan

Dr. Michael Wilson
New Product Development

Mr. Paul Sweeney
Process Development

Dr. Paul Kremer
Site Director-Manufacturing

Mr. Jason McCann
EH&S Assessment

Team Members

GRC	GEE	SiVance
Benjamin Wood	Ravi-Kumar Vipperla	Rosanna Stokes
Bob Perry	Lisa Wichmann	Michael Wilson
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Rachel Farnum	Timothy Rehg	Jason McCann
Irina Sultanova		
John McDermott		
Wei Chen		
Harish Acharya		
Terri Grocela-Rocha		

Scope

This two-year project is divided into two phases.

Phase I

- GE Energy will develop preliminary process models and perform preliminary technical and economic feasibility study
- GE Global Research will design and build a bench-scale system
- SiVance will determine manufacturability and estimated price for aminosilicone absorbents
- SiVance will confirm small-scale synthesis of materials and develop a cost-effective plan for large-scale manufacture

Phase II

- SiVance will deliver absorbent to GE Global Research for bench-scale testing and perform an EH&S Risk Assessment
- GE Global Research will operate the bench-scale system to obtain engineering data necessary for scale-up of the process
- GE Energy will use the bench-scale results to refine the process models, perform a final technical and economic feasibility study, update the COE calculations, and develop a scale-up strategy

Budget

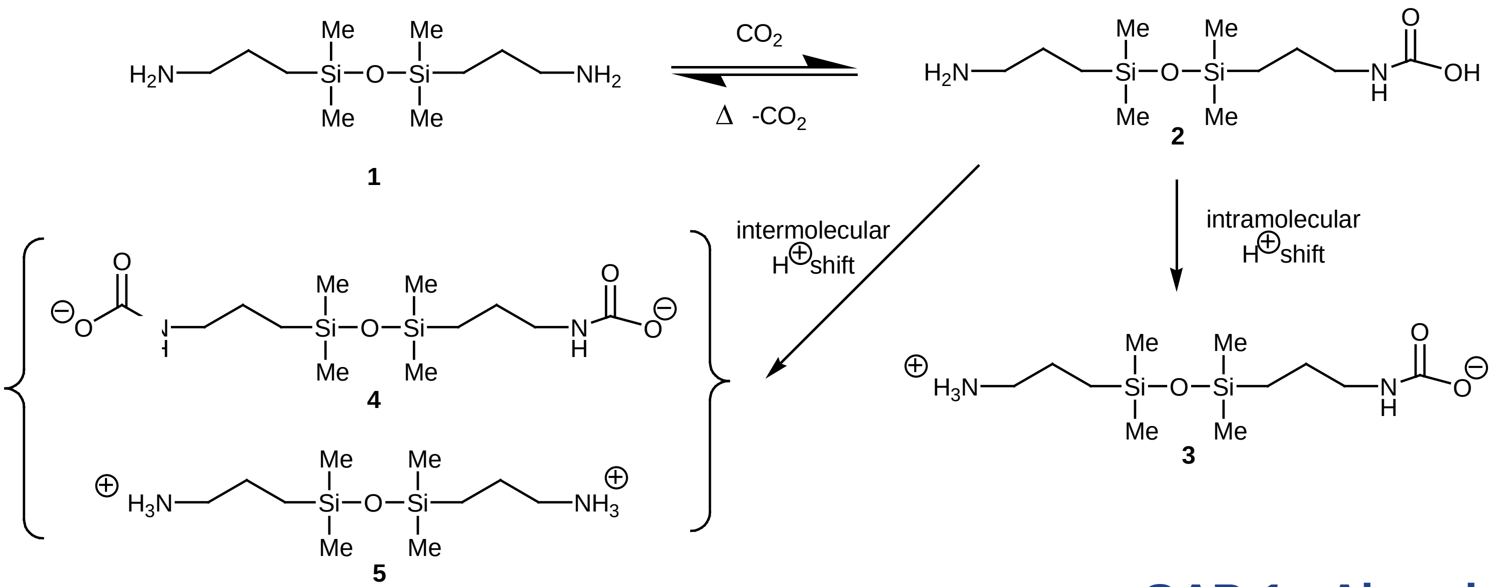
	Budget Period 1 10/01/2011 – 12/31/2012		Budget Period 2 01/01/2013-12/31/2013		Total Program
	Government Share	Cost Share	Government Share	Cost Share	Total
GE Global Research	$1,076,782	$302,477	$1,018,563	$291,477	$2,689,299
GE Energy	$133,127	-	$147,345	-	$280,472
SiVance	$298,902	$74,726	$323,584	$80,896	$778,108
Total	$1,508,811	$377,203	$1,489,492	$372,373	$3,747,879

	Budget Period 1: 10/01/2011 – 12/31/2012									
	10/1/11 – 12/31/11		1/1/12 – 3/31/12		4/1/12 – 6/30/12		7/1/12 – 9/30/12		10/1/12 – 12/31/12	
	Q1	Total Project	Q2	Total Project	Q3	Total Project	Q4	Total Project	Q5	Total Project
Federal Share	$16,237	$16,237	$366,302	$382,539	$370,851	$753,390	$373,627	$1,127,017	$381,794	$1,508,811
Non-Federal Share	$4,059	$4,059	$91,575	$95,635	$92,713	$188,347	$93,407	$281,754	$95,449	$377,203
Total Planned	$20,296	$20,296	$457,877	$478,173	$463,564	$941,737	$467,034	$1,408,771	$477,243	$1,886,014

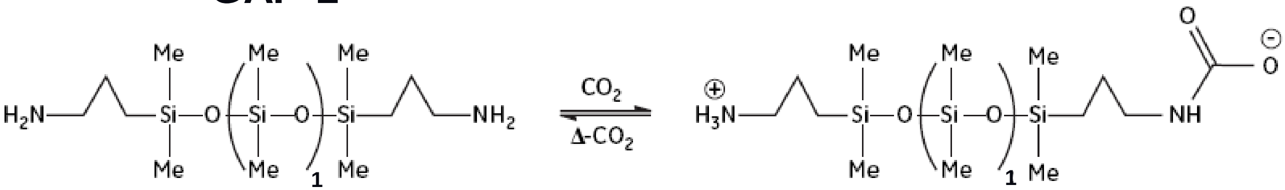
	Budget Period 2: 01/01/2013 – 12/31/2013							
	1/1/13 – 3/31/13		4/1/13 – 6/30/13		7/1/13 – 9/30/13		10/1/13 – 12/31/13	
	Q1	Total Project	Q2	Total Project	Q3	Total Project	Q4	Total Project
Federal Share	$415,882	$1,924,693	$429,759	$2,354,452	$316,817	$2,671,269	$327,034	$2,998,303
Non-Federal Share	$103,970	$481,173	$107,440	$588,613	$79,205	$667,818	$81,758	$749,576
Total Planned	$519,852	$2,405,866	$537,199	$2,943,065	$396,022	$3,339,087	$408,792	$3,747,879

Reaction

GAP-0



GAP-1



GAP-1_m Absorbent Composition

- 40% GAP-0,
- 33% GAP-1
- 19% GAP-2
- 8% GAP-3

- Carbamate salt formation
- GAP-0 demonstrates 17.7% wt gain of CO_2
- Compared to 10.2% wt gain for 30% aqueous MEA benchmark

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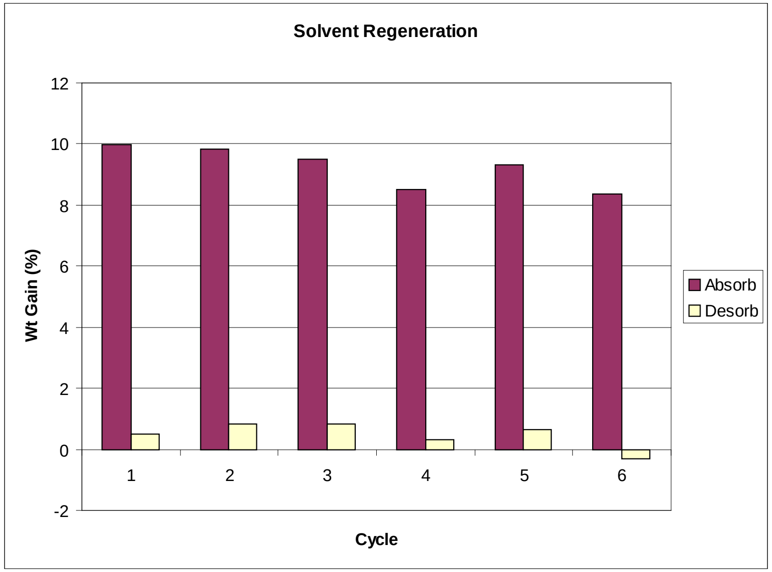
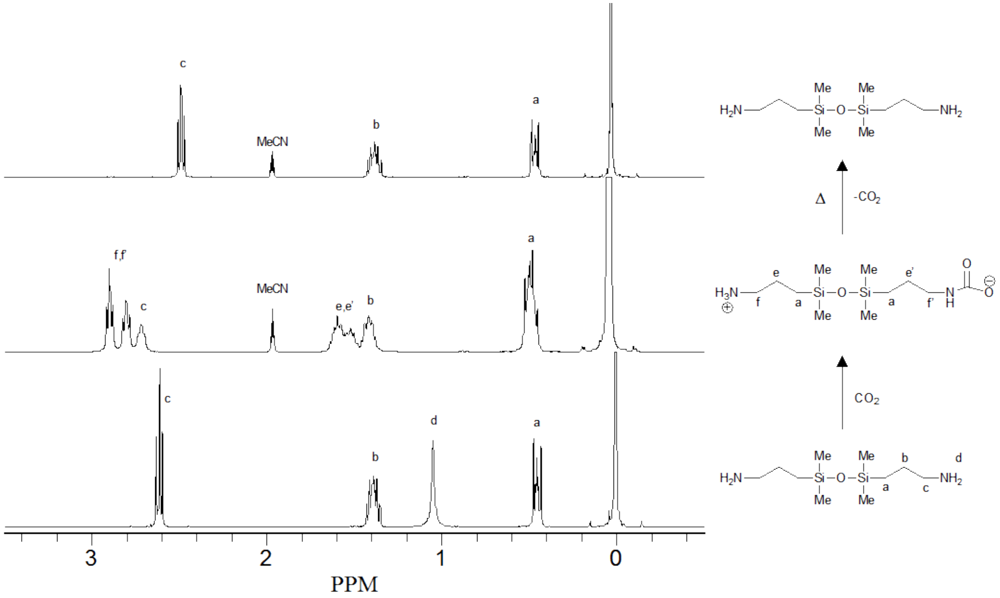
Regeneration





- Facile carbamate formation
- Complete regeneration on heating to 120 °C
- No decomposition observed

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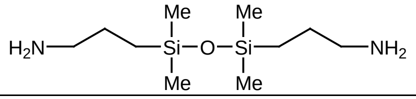
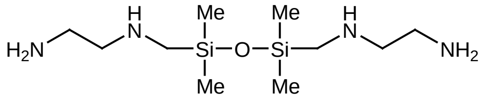
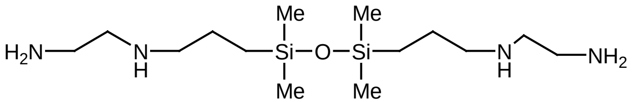
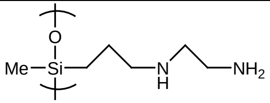
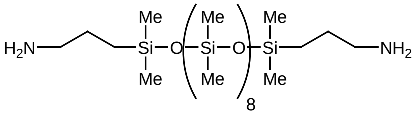
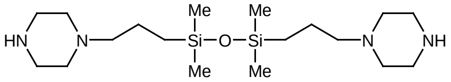
CO_2 Capacity

Cmpd	Structure	CO_2 Wt Gain (%)	Theoretical CO_2 Wt gain (%)	% of Theory
1	GAP-0 	16.5	17.7	94
2		15.3	31.6	48
3		10.9	26.3	41
4		8.5	27.5	31
5		4.6	5.5	84
6		3.8	11.4	33

- Compared to 10.2% wt gain for 30% aqueous MEA benchmark
- All materials became viscous liquids or solids
- Need co-solvent to mitigate mass transfer limitations due to viscosity

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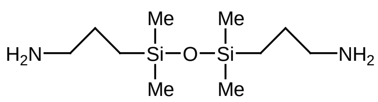
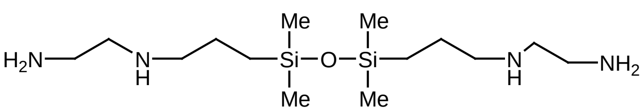
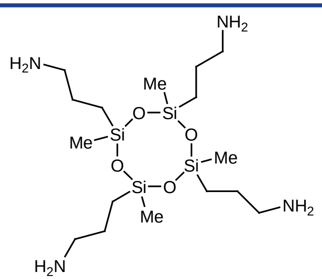
Advantage of Co-Solvent (Triethylene Glycol)

Amine	50% TEG	% Wt Gain (of Theory)	% Wt Gain	State
GAP-0 	no yes	94 114	16.5 10.1	S L
	no yes	64 90	16.7 11.8	S L
	no yes	30 108	5.6 10.1	S L
MEA	30% water	94		10.2

- Decreased viscosity
- Chemical and physical absorption

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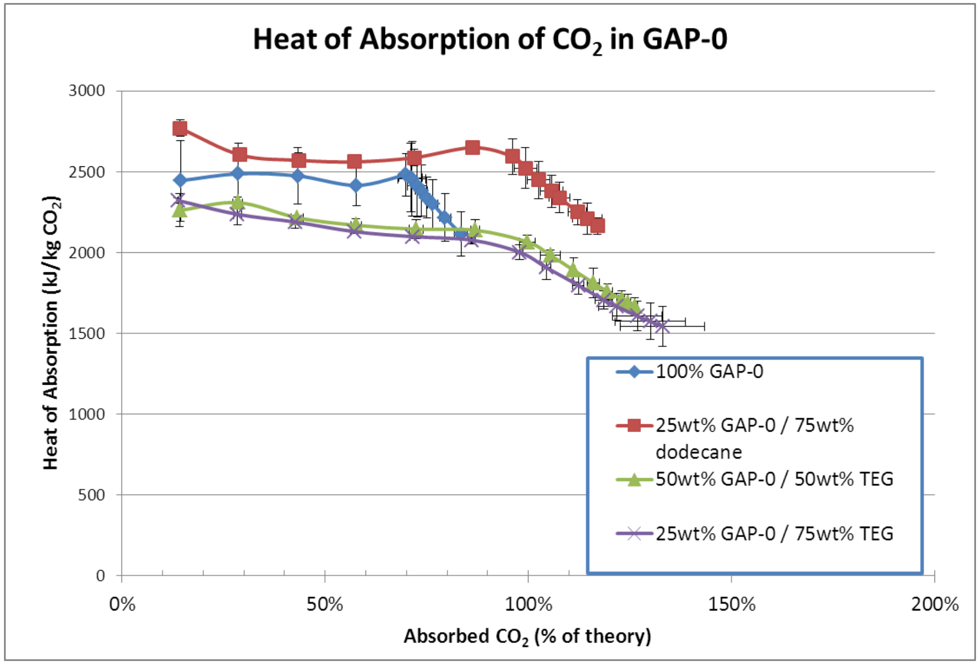
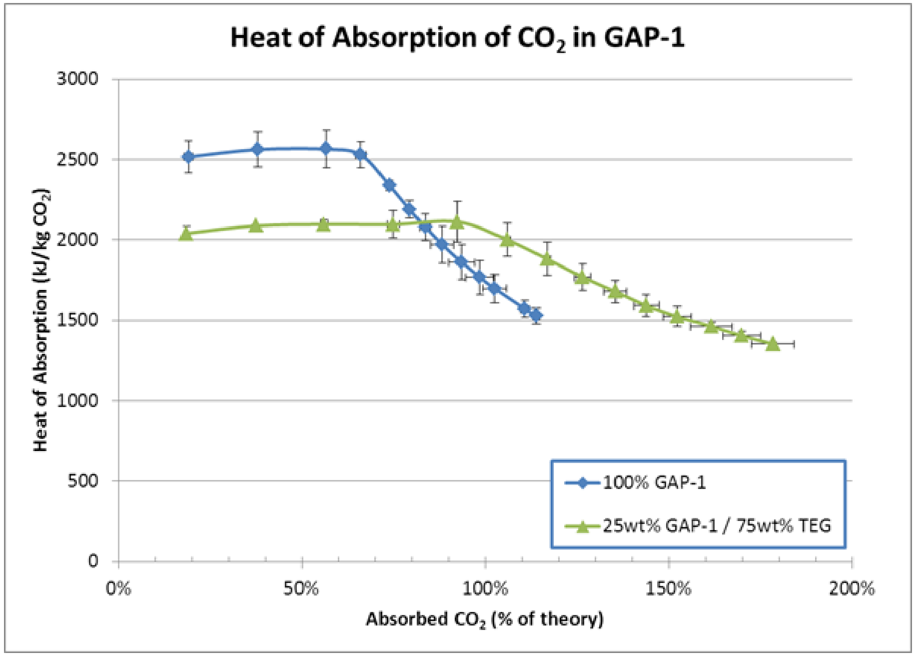
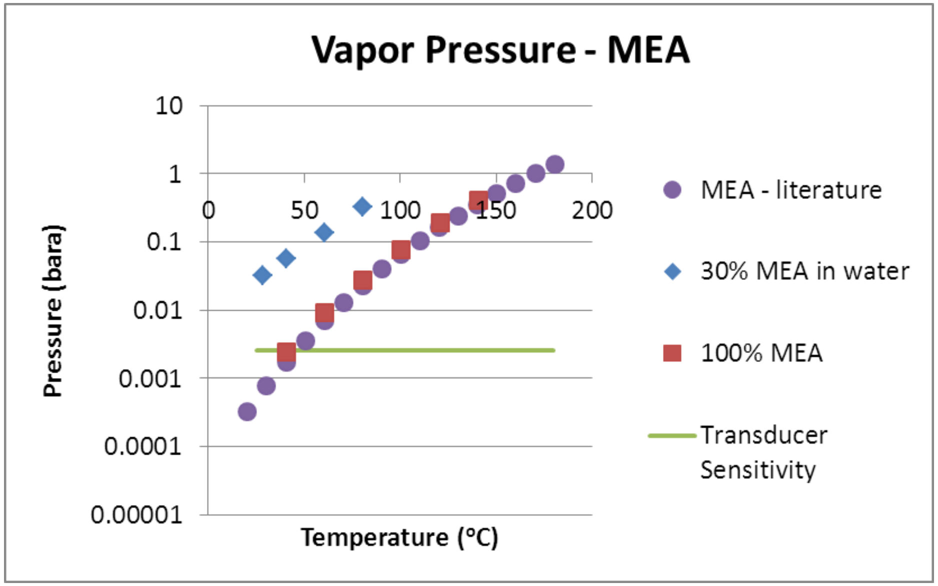
Heat of Absorption of CO_2





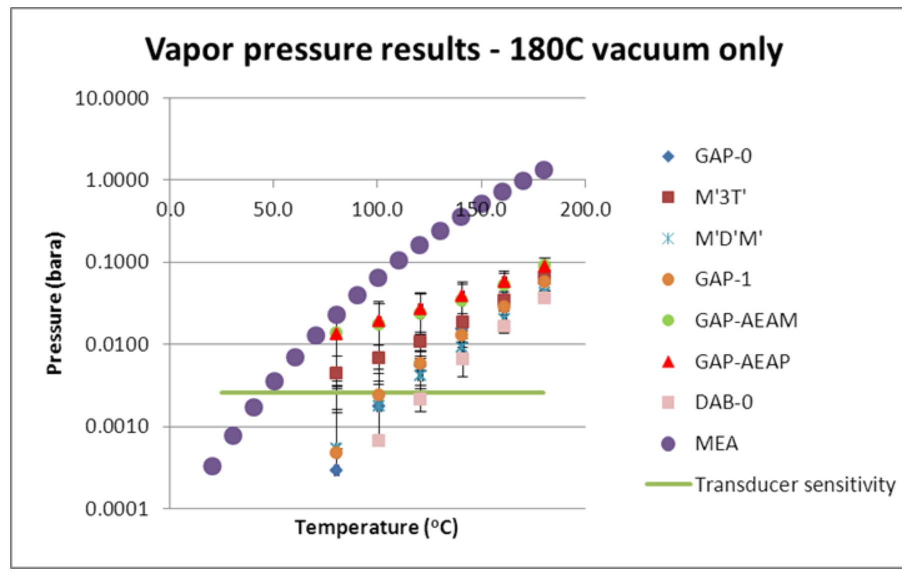
- Triethylene glycol
  - Decreases the heat of chemisorption
  - Increases the heat of physisorption

Vapor Pressure



All aminosilicone materials tested exhibited vapor pressures < MEA

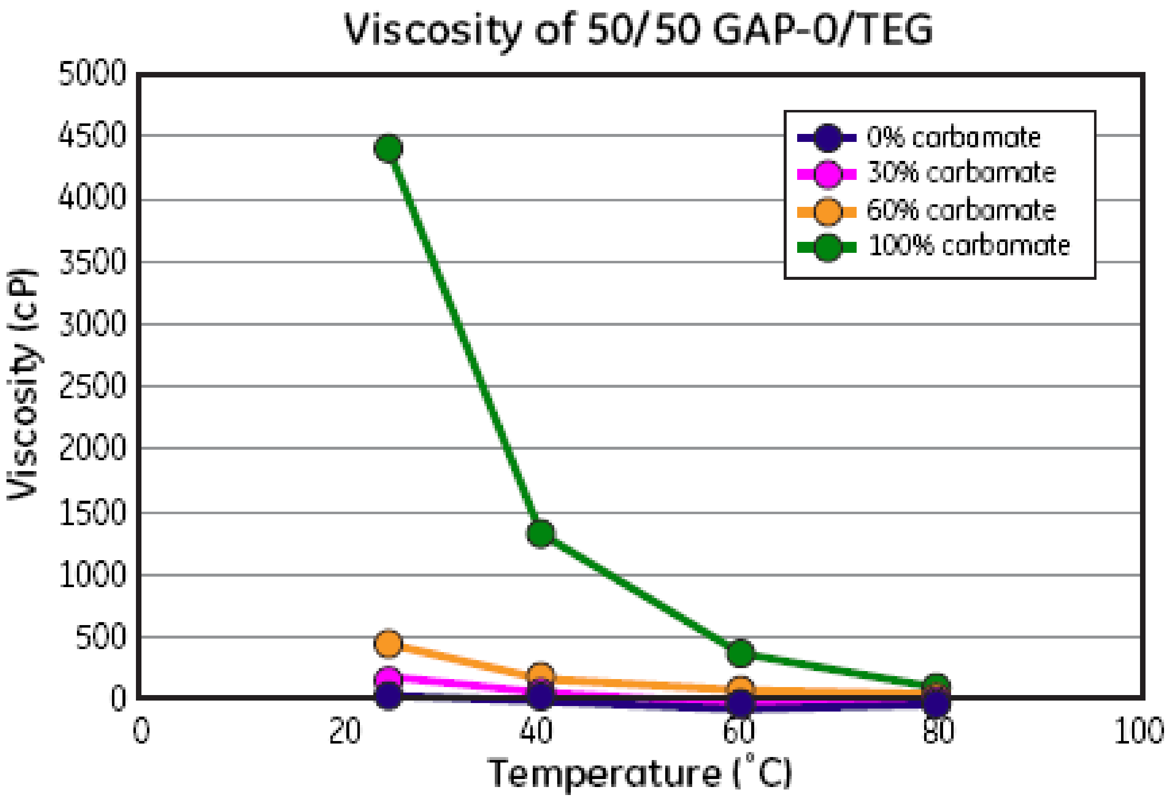
MEA literature data from:
Yaws, C.L. (1999). Chemical Properties Handbook.. McGraw-Hill. Online version available at:
http://www.knovel.com/web/portal/browse/display?_EXT_KNOVEL_DISPLAY_bookid=49&VerticalID=0



Lower absorbent vapor pressure simplifies CO_2 desorption process

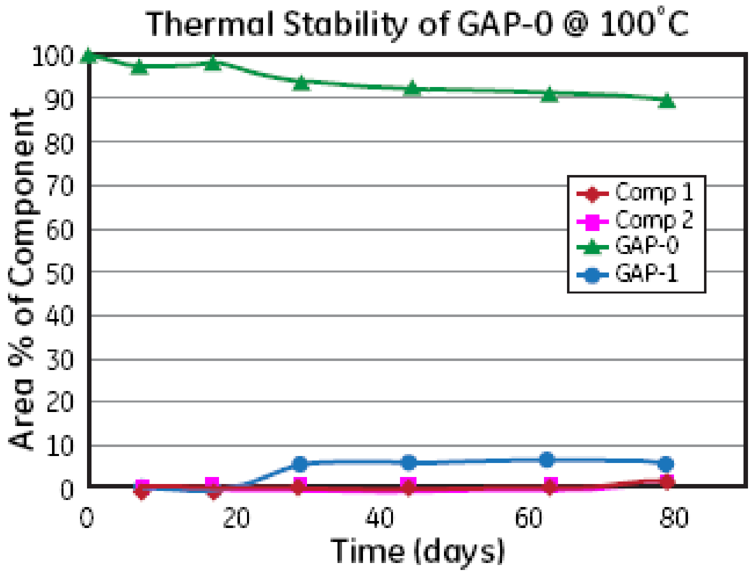
R. Farnum, T. Perry, S. Genovese

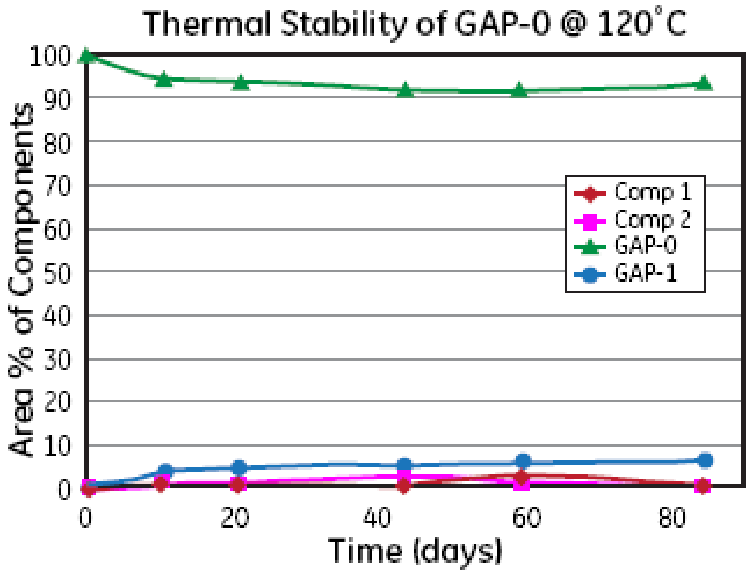
Viscosity

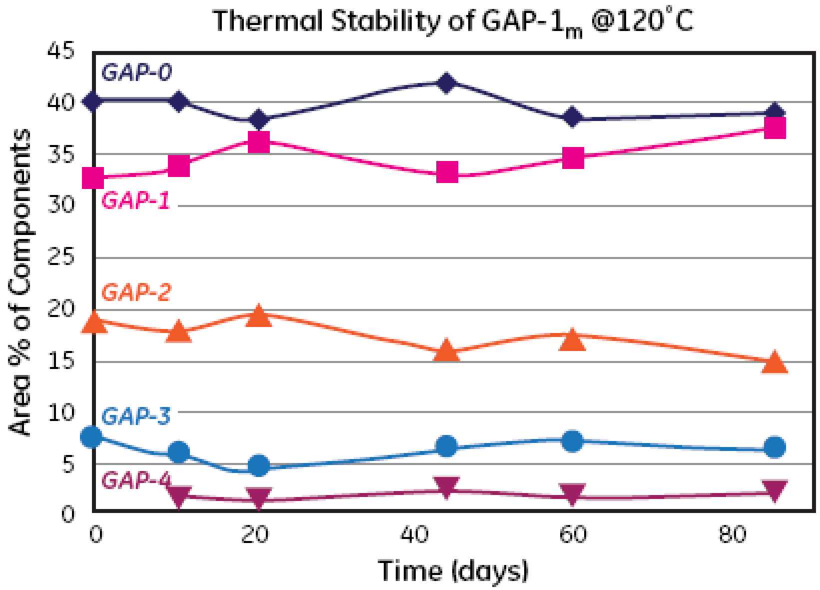


- Viscosity increase significantly with CO_2 loading and low temperatures
- For aminosilicone-based CO_2 capture process, viscosity < 1500 cP

Thermal Stability







- Thermal stability of GAP materials is high

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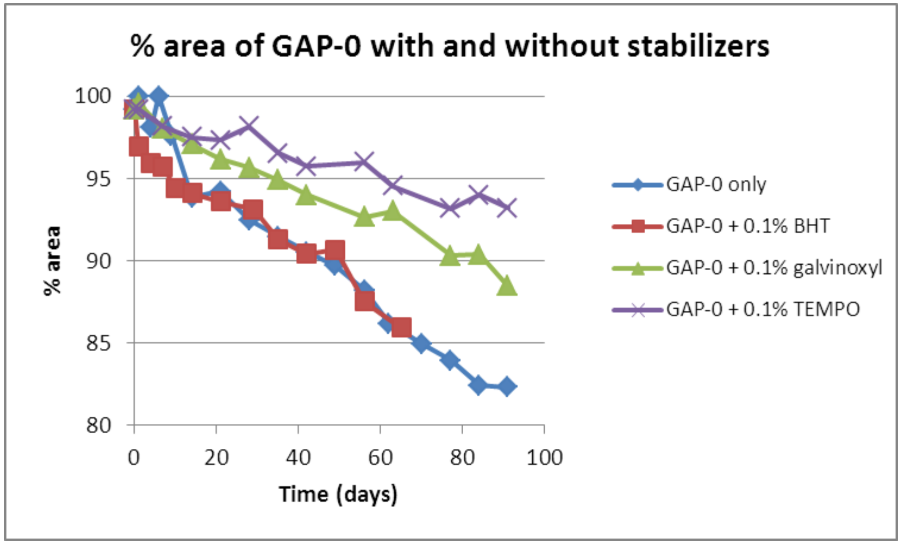
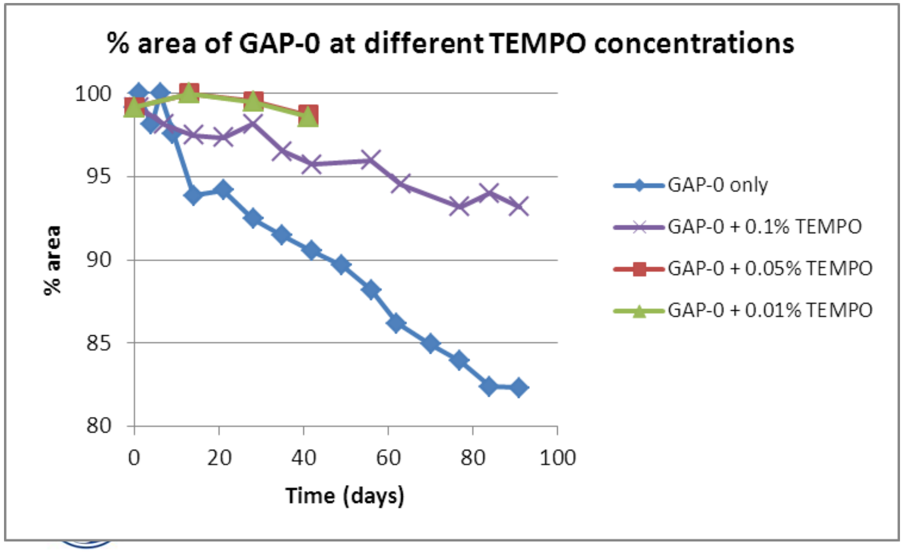
Effect of stabilizers – GAP-0

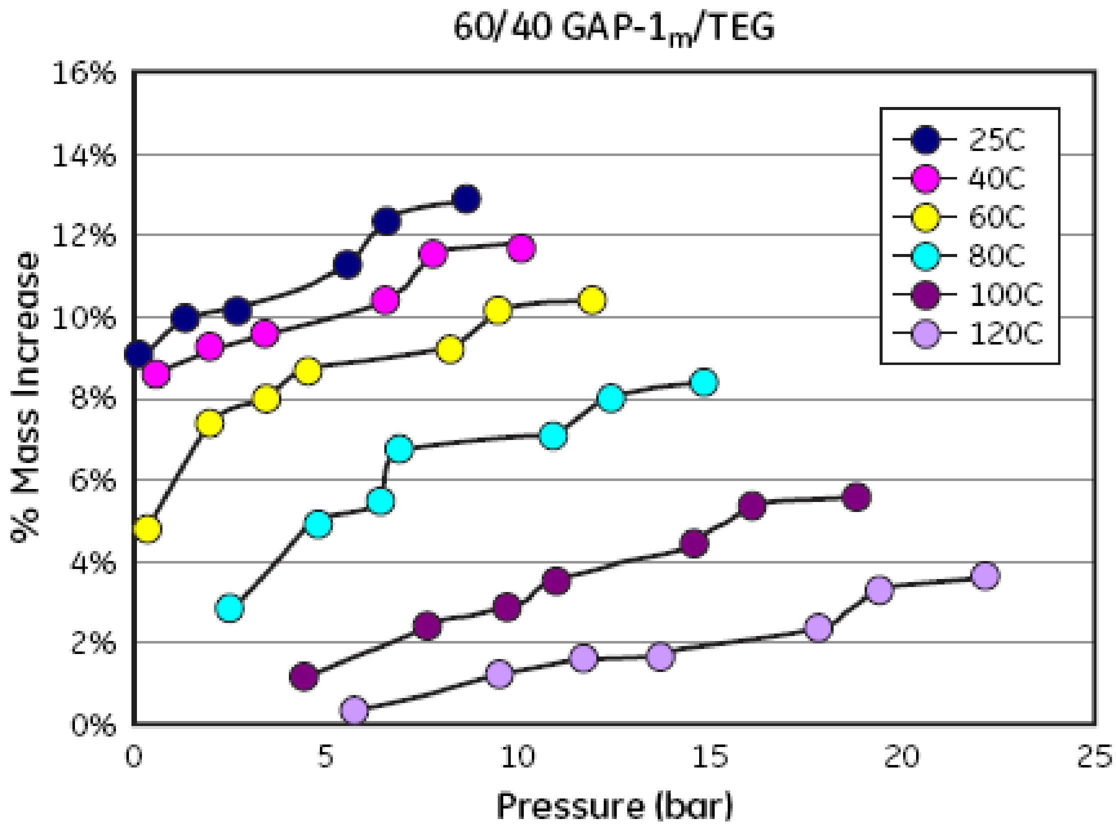


- BHT not effective
- Galvinoxyl and TEMPO improved thermal stability
- TEMPO better than galvinoxyl
- Lower TEMPO concentrations showing similar results to 0.1 % wt as of day 41



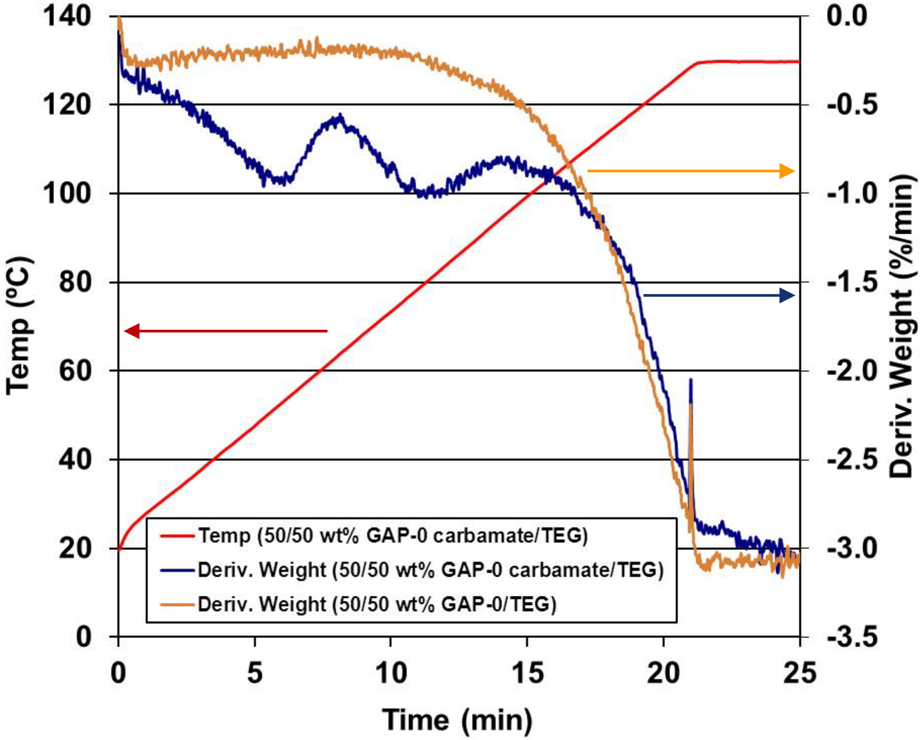
Material	Number of days heating	CO_2 absorption (% weight gain)
GAP-0	0	17.3
GAP-0	91	12.5
GAP-0 with 0.1% galvinoxyl	91	13.6
GAP-0 with 0.1% TEMPO	91	14.4

Isotherms

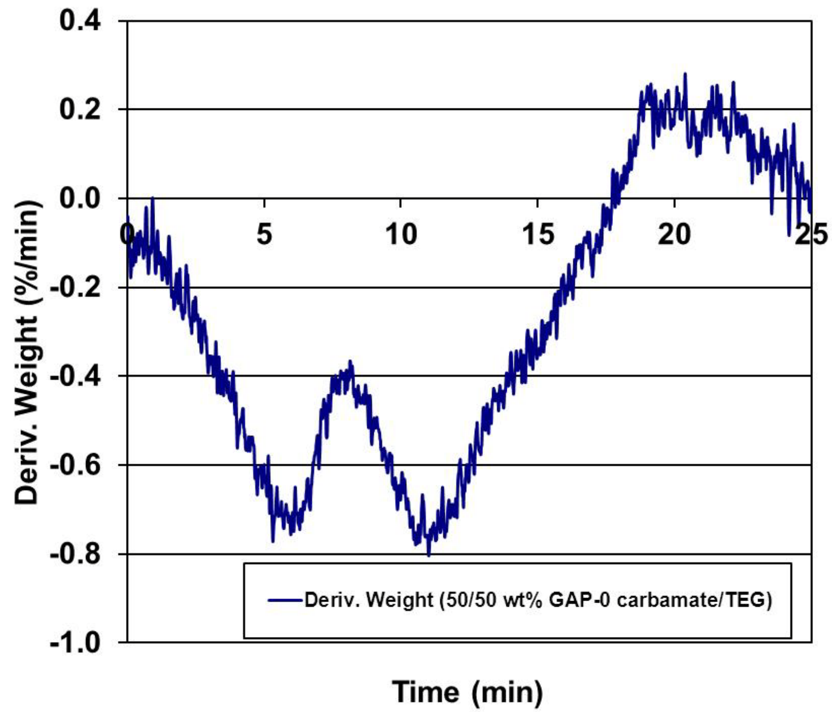


- The maximum possible working CO_2 capacity can be determined

CO_2 Desorption from 50/50 GAP-0 Carbamate/TEG



- A 50/50 GAP-0/triethylene glycol solution was studied to avoid solid/gas mass transfer
- CO_2 desorption peaks isolated

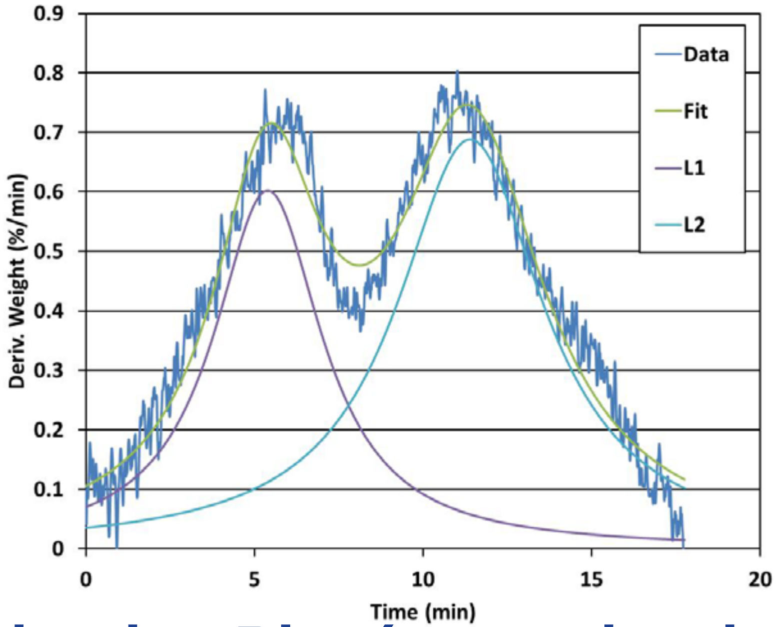


Assumptions for kinetic analysis

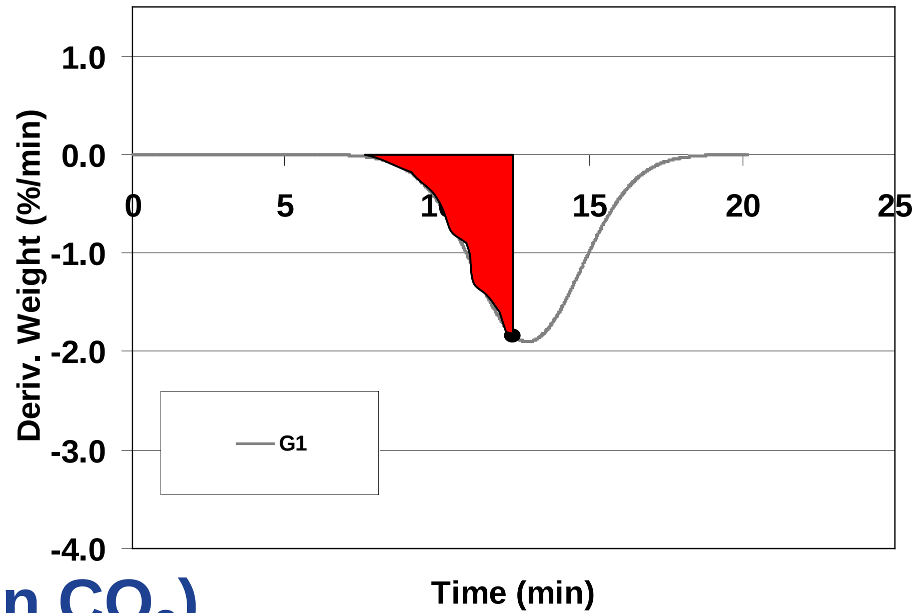
- Not mass transfer limited
- No reverse reaction (sweep gas)
- Heating rate slow compared to induction time
- No physisorption

Kinetic Fit

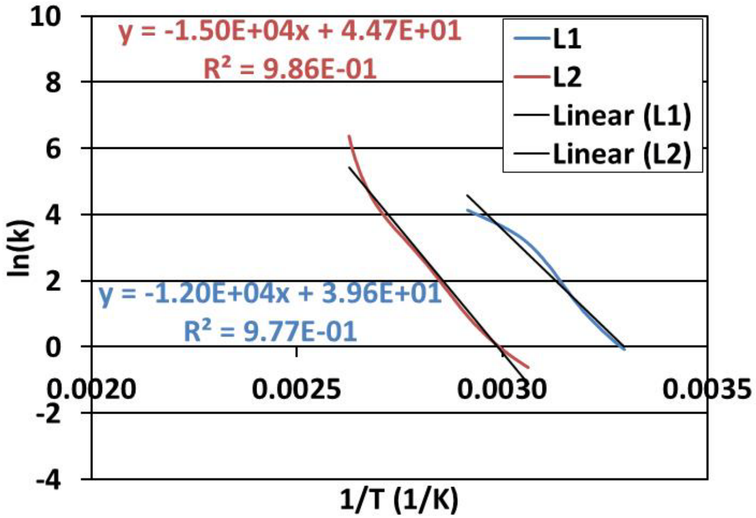
Lorentzian Fit



$r_{CO2} = k[CO_2]^x \rightarrow k = r_{CO2}/[CO_2]$



Arrhenius Plot (second order in CO_2)



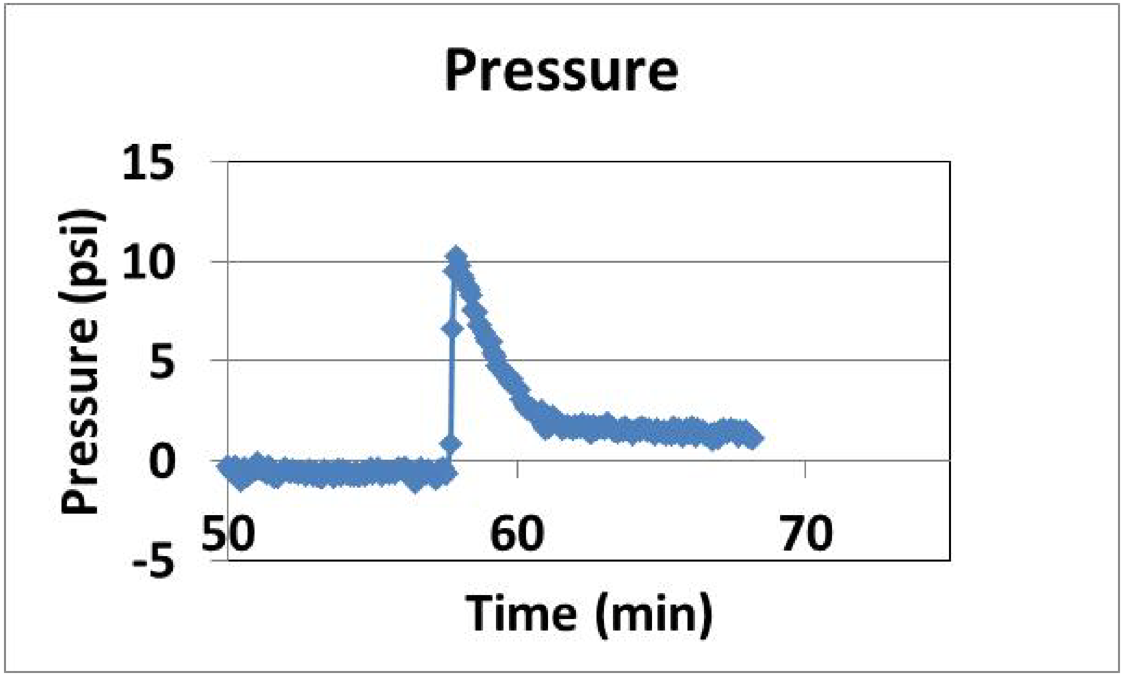
$k = Ae^{-Ea/RT} \rightarrow \ln(k) = \ln(A) - E_a/RT$

E_1 = 23.8 kcal/mol

E_2 = 29.7 kcal/mol

$r_{CO2} = k[CO_2]^2$

CO_2 Absorption in 20% (wt) GAP-0/ 80% (wt) TEG



Assumptions

- Not mass transfer limited (liquid phase is well mixed)
- No reversible reaction (initial rate is used)
- TEG does not affect the chemistry or kinetics
- No physisorption

$$-\frac{dN_{CO2}}{dt} = VkP_{CO2}^{X}C_{GAP-0}^{Y}$$

$$ln\left(-\frac{dN_{CO2}}{dt}\right) - Yln(C_{GAP-0}) = \ln(V) + \ln(k) + Xln(P_{CO2})$$

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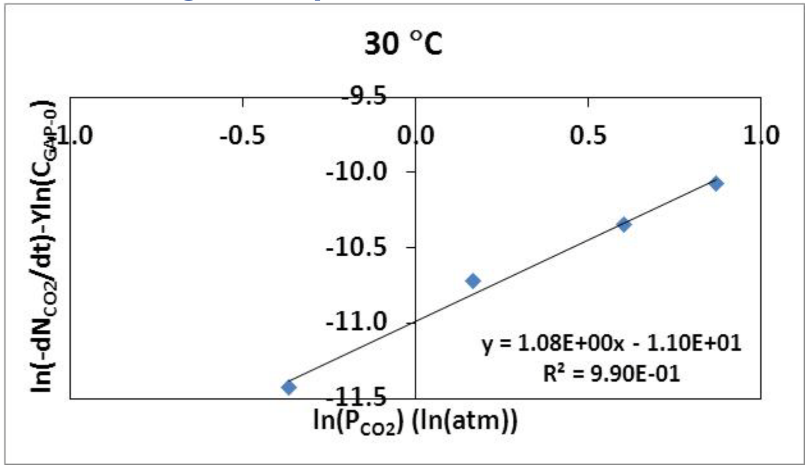
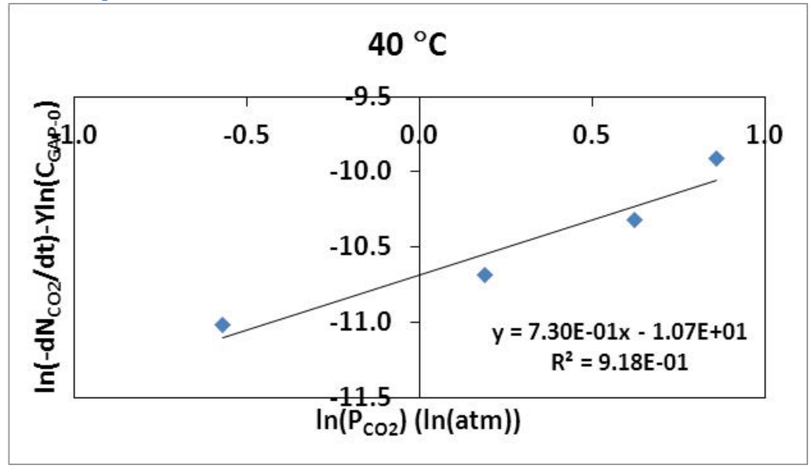
CO_2 Absorption in 20% (wt) GAP-0/ 80% (wt) TEG

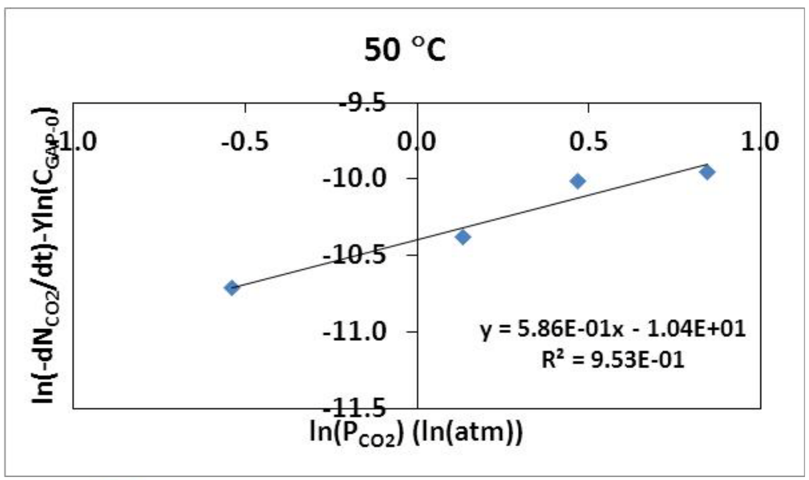
$$ln\left(-\frac{dN_{CO2}}{dt}\right) - Yln(C_{GAP-0}) = \ln(V) + \ln(k) + Xln(P_{CO2})$$

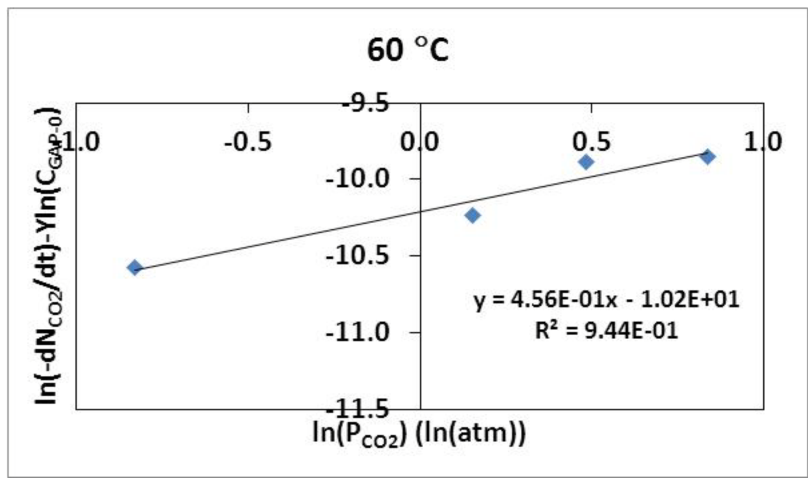
- **Order starts at 1 for P_{CO2} and decreases to 0.5 at higher T**

Assuming Y = 1 (first order in GAP-0 concentration)



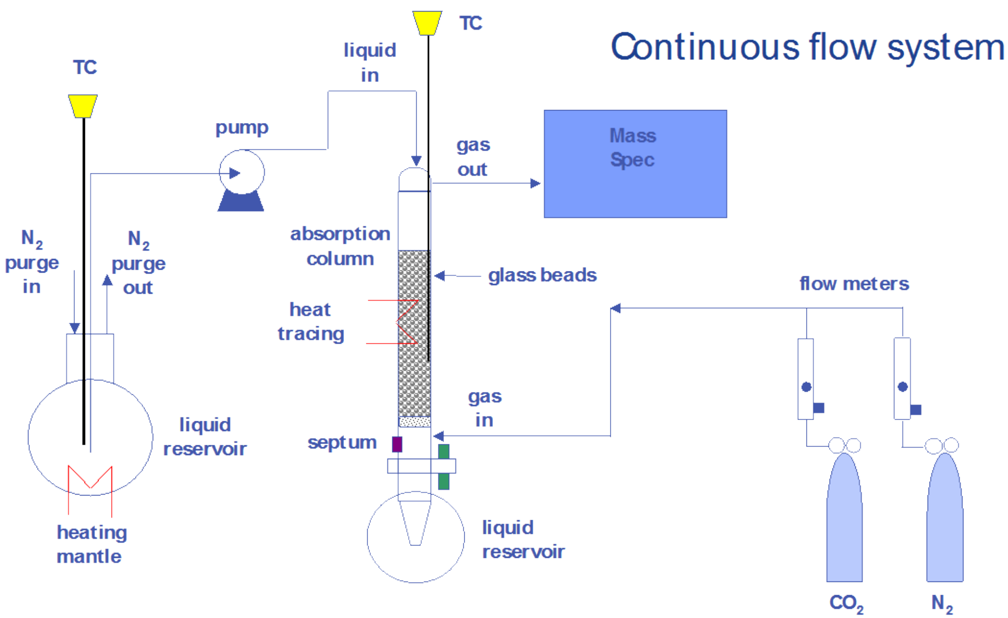




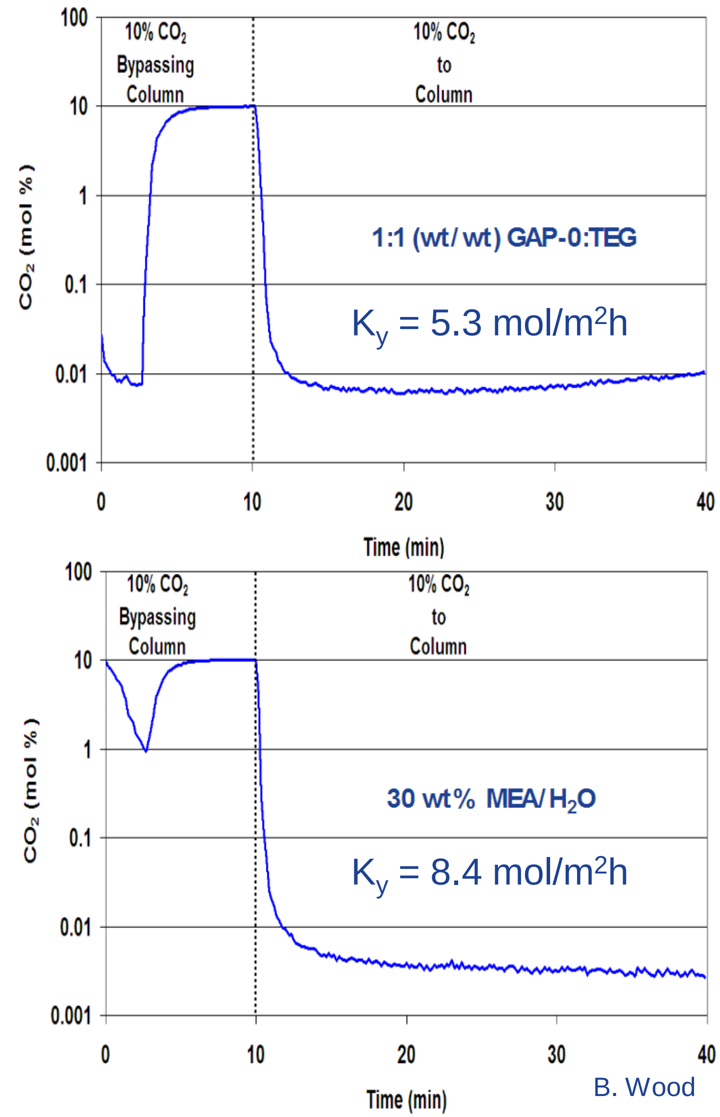


T (°C)	ln(k)
30	-5.80
40	-5.49
50	-5.21
60	-5.02

Continuous Absorption



- Bypass column during MS equilibration
- Introduce 10% CO_2/N_2 gas to solvent
- Immediate reaction with solvent
- >99% absorption for both systems



B. Wood

Gas Flow = 50 ml/min

Liquid Flow = 0.9 ml/min

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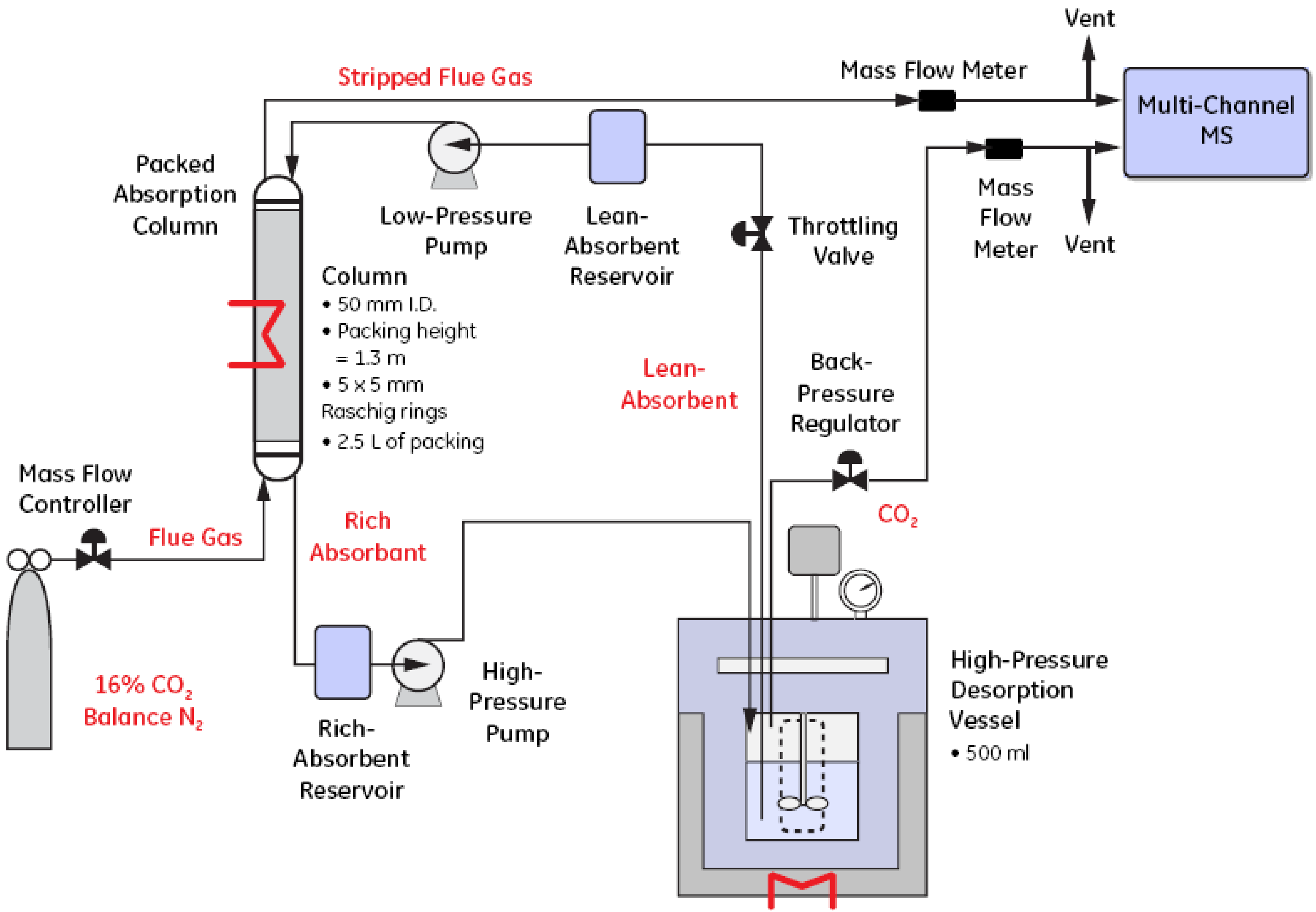
Lab-Scale Schematic



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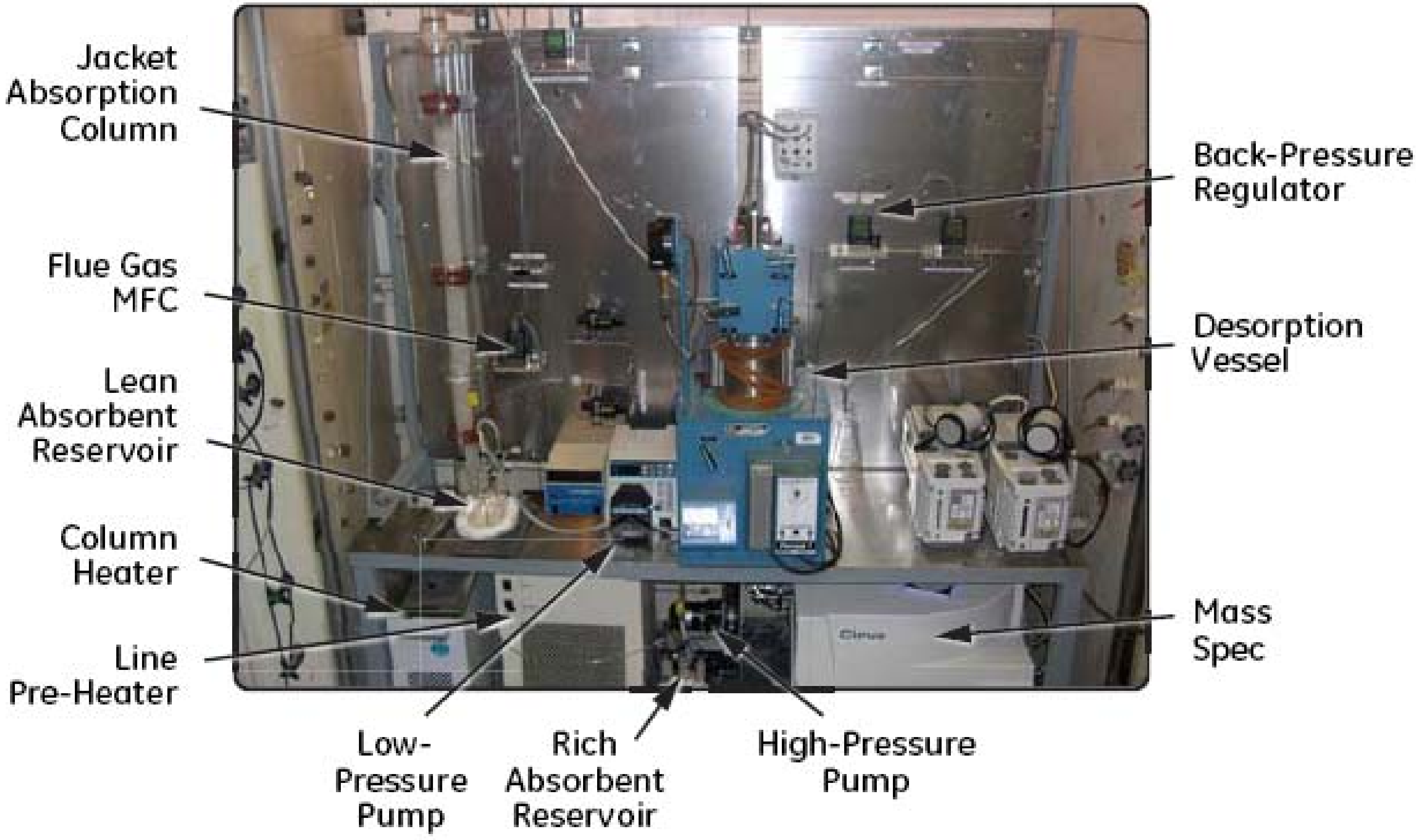
Lab-Scale System



CO_2-Capture System Tests

For 50/50 GAP-0/TEG:

- Flue gas flow rate = 0.54 LPM (at 1 bar and 25 °C)
- Liquid flow rate = 4.4 ml/min
- Column temp = 40 °C
- Desorber liquid volume = 250 ml
- Desorber pressure = 0.5 bar (gauge)
- Column packing volume = 2.5 L
- Packing type = 5x5 mm glass Raschig rings

Results

- 80% CO_2 capture
- Desorbed gas 87% CO_2 with balance N_2 and a small amount of H_2O
- Problems with solidification of absorbent

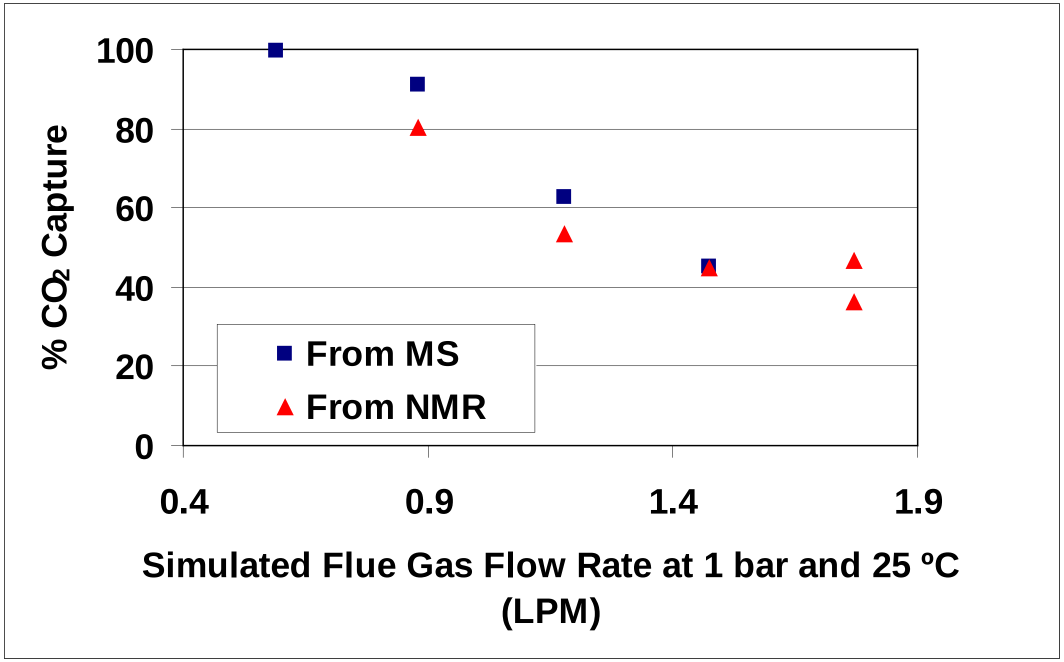
For 60/40 GAP-1/TEG

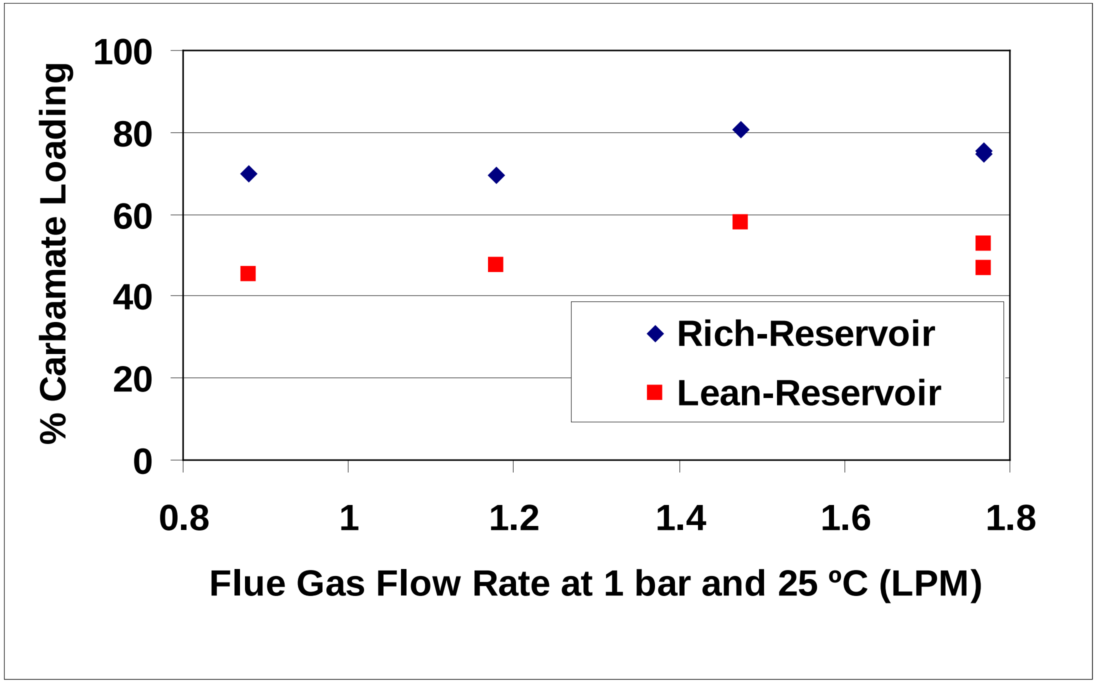
Ran a series of tests where liquid flow rate was maintained at 10 ml/min and the flue gas flow rate was varied

- Flue gas flow rate = 0.59-1.77 LPM (at 1 bar and 25 °C)
- Liquid flow rate = 10 ml/min
- Desorber residence time = 25 min

Process Performance

100% carbamate loading = 8.3% wt gain





- % CO_2 capture can be determined by analysis of the liquid CO_2 concentration in the lean and rich reservoirs or by mass spec analysis of the flue gas before and after the column
  - The two methods show the same trends

Lab-Scale Performance

	Units	Measured/Estimated Performance	Projected Performance
Pure Solvent			
Molecular Weight	mol^{-1}	322.67 (GAP-1_m) / 150.17 (TEG)	322.67 (GAP-1_m) / 150.17 (TEG)
Normal Boiling Point	°C	310 (GAP-1_m) / 287 (TEG)	310 (GAP-1_m) / 287 (TEG)
Normal Freezing Point	°C	-85 (GAP-0) / -7 °C (TEG)	-85 (GAP-0) / -7 °C (TEG)
Vapor Pressure @ 15°C	bar	<0.01 mm Hg @ 20 °C (TEG) 11 mmHg @ 132-139 °C (GAP-0)	<0.01 mm Hg @ 20 °C (TEG) <11 mmHg @ 132-139 °C (GAP-1_m)
Working Solution			
Concentration	kg/kg	60/40 GAP-1_m/TEG	60/40 GAP-1_m/TEG
Specific Gravity (22 °C/20 °C)	-	0.913 (GAP-1_m) /1.124 (TEG)	0.913 (GAP-1_m) /1.124 (TEG)
Specific Heat Capacity @ 40 °C and 1 bar	kJ/kg-K	2.319 (60/40 GAP-1_m/TEG)	2.319 (60/40 GAP-1_m/TEG)
Viscosity @ STP	cP	4.37 (GAP-1_m) / 49 (TEG)	4.37 (GAP-1_m) / 49 (TEG)
Surface Tension @ STP	dyn/cm	To be determined (GAP-1_m) / 45.5 (TEG)	To be determined (GAP-1_m) / 45.5 (TEG)
Absorption			
Pressure	bar	0 (gauge)	0 (gauge)
Temperature	°C	40-60 °C	40-60 °C
Equilibrium CO_2 Loading	mol/mol	0.7-0.8 (CO_2) / 1 (GAP-1)	0.9 (CO_2) / 1 (GAP-1)
Heat of Absorption	kJ/mol CO_2	53 (GAP-1_m)	53 (GAP-1_m)
Solution Viscosity (@40°C)	cP	1340 (50/50 GAP-0/TEG)	<1340 (60/40 GAP-1_m/TEG)
Desorption			
Pressure	bar	0.5 (gauge)	10 (gauge)
Temperature	°C	120 °C	120 °C
Equilibrium CO_2 Loading	mol/mol	0.45-0.50 (CO_2) / 1 (GAP-1)	0.2 (CO_2) / 1 (GAP-1)
Heat of Desorption	kJ/mol CO_2	53 (GAP-1_m)	53 (GAP-1_m)

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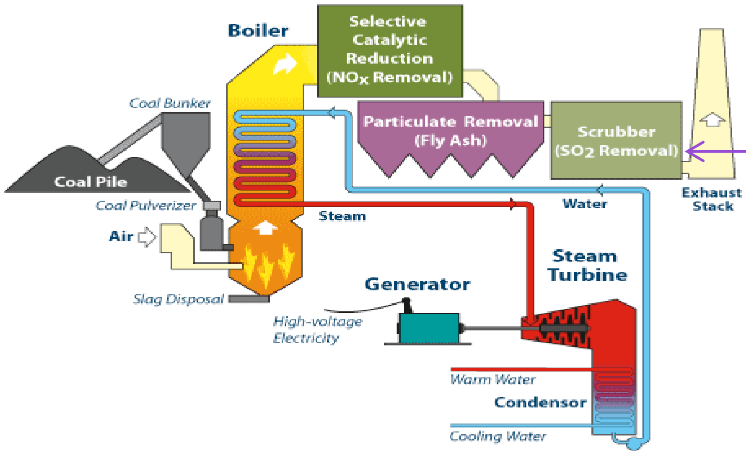
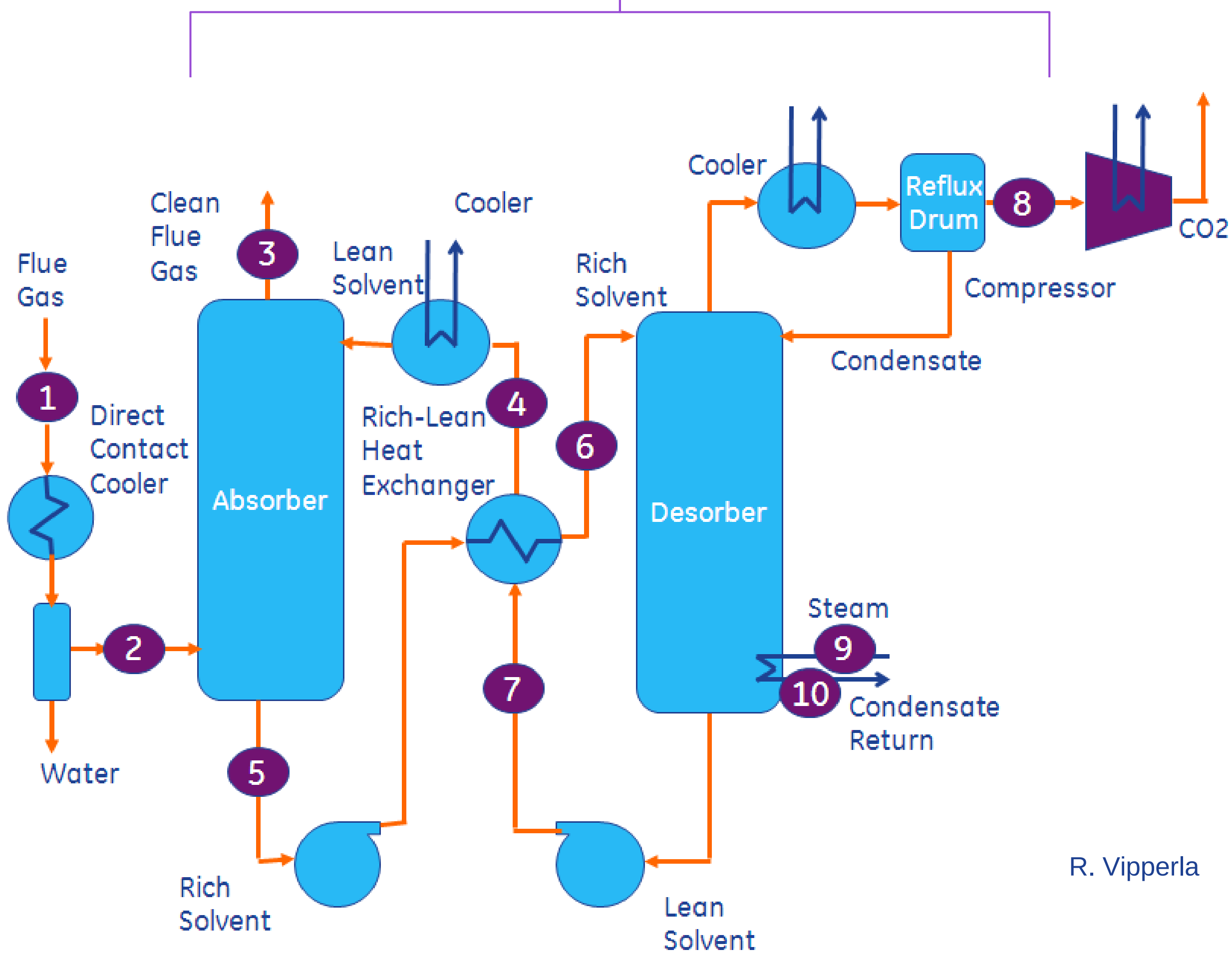
CO_2 Capture Process Schematic



Capture CO_2 after SO_2 scrubber & before stack



- Absorb CO_2 at 50 ^oC/ 1 atm
- Rich solvent heated to 120 ^oC to release CO_2
- Lean solvent recycled to absorber
- CO_2 compressed for storage

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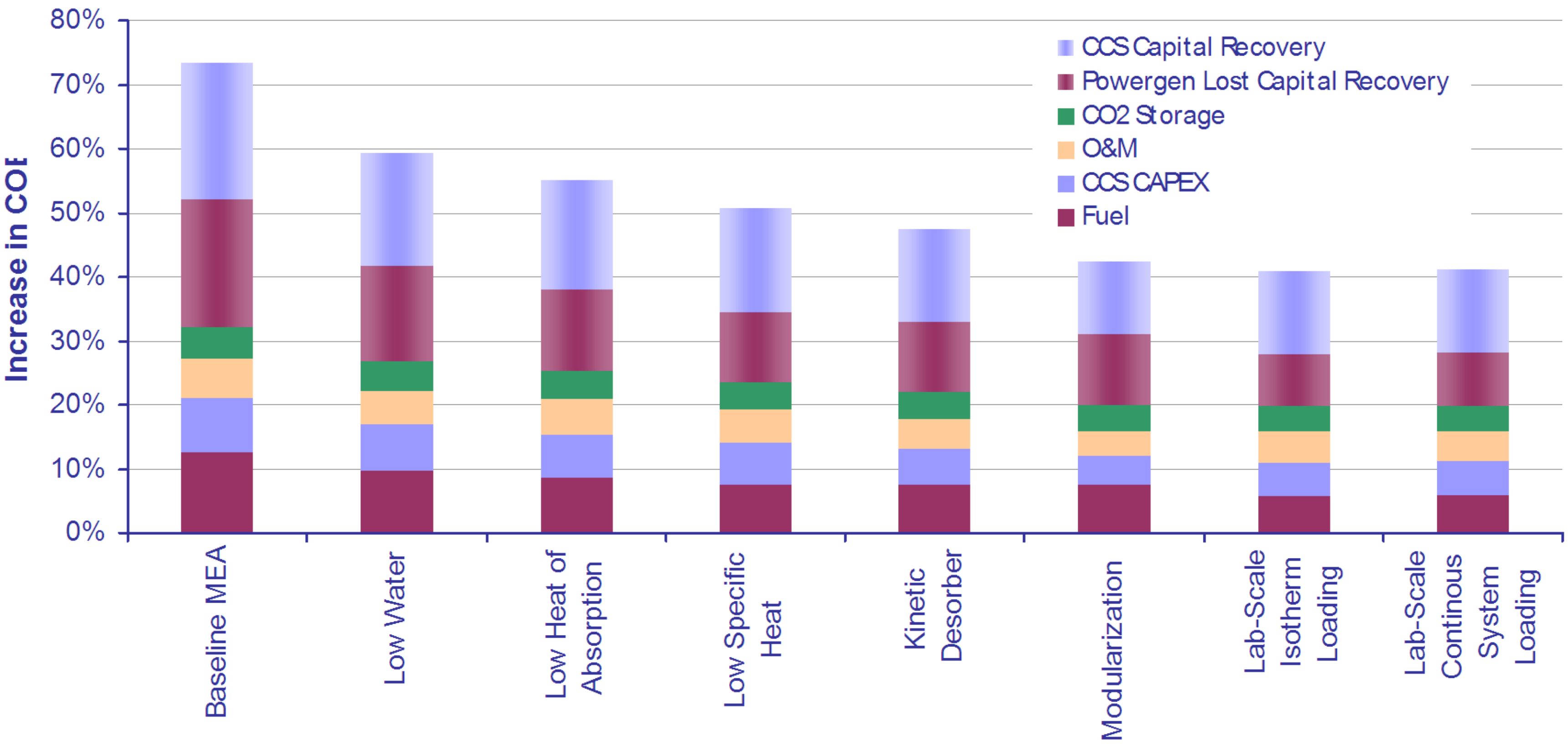
R. Vipperla

CO_2 Solvent – Cost of Electricity



- Significant benefit with low water system
- Lower C_p advantageous
- Agreement between isotherm and continuous system results
- Calculated 41% increase in COE vs 74% for optimized MEA system

Schedule

	Start Date	End Date	Task Interdependencies	Cost ($)	GE GRC	GE Energy	SiVance
Task 1 Project management and planning	10/1/2011	12/31/2013	All	364,198	●	○	
1.1 Project management and planning	10/1/2011	12/31/2011	None				
1.2 Briefings and reports	10/1/2011	12/31/2013	All				
Milestones							
-Update of Project Management Plan							
-Kick-off meeting							
Task 2 Conduct preliminary technical and economic feasibility study	1/1/2012	12/31/2012		167,065		●	
2.1 Develop preliminary process models	1/1/2012	12/31/2012	None				
2.2 Perform preliminary technical and economic feasibility study	7/1/2012	12/31/2012	2.1				
Milestones:							
-Determination of energy required for CO2 separation sub-system							
-Preliminary technical and economic feasibility study							
-Go /no go decision based on predicted performance of >90% CO2 capture with <45% increase in COE							
Task 3 Design and build bench-scale system	1/1/2012	12/31/2012		1,028,067	●		
3.1 Design bench-scale system	1/1/2012	6/30/2012	2.1, 2.2				
3.2 Build bench-scale system	7/1/2012	12/31/2012	3.1				
3.3 Develop a bench-scale test plan	10/1/2012	12/31/2012	None				
Milestones:							
-Design of a continuous bench-scale absorption/desorption unit							
-Assembly of operational bench-scale system							
-Bench-scale system test plan							
Task 4 Develop absorption material manufacturing plan	1/1/2012	12/31/2012		503,574	○		●
4.1 Determine manufacturability, raw material supply adequacy, and estimated price for top material candidates	1/1/2012	6/30/2012	None				
4.2 Confirm small-scale synthesis of top material candidates	4/1/2012	9/30/2012	None				
4.3 Develop cost effective plan for large-scale manufacture	7/1/2012	12/31/2012	4.1				
Milestones:							
-Manufacturability analysis of aminosilicone-based solvent for bench-scale testing							
-Plan for large-scale raw material supply and manufacturing price model							
-Establish capital requirements for material manufacturing and material price model							
-Delivery of synthesized aminosilicone-based solvent							
Task 5 Supply materials for bench-scale testing	1/1/2013	6/30/2013		373,120	○		●
5.0 Large-scale synthesis of materials for bench-scale testing	1/1/2013	6/30/2013	4.2				
Milestones:							
-Absorption material for bench-scale testing delivered from SiVance to GE Global Research							
Task 6 Perform technology EH&S risk assessment	7/1/2013	12/31/2013		92,163			
6.0 Perform technology EH&S Risk Assessment	7/1/2013	12/31/2013	None		○		●
Milestones:							
-Technology EH&S risk assessment							
Task 7 Perform bench-scale testing	1/1/2013	12/31/2013		866,102			
7.1 Obtain engineering data	1/1/2013	6/30/2013	3.2, 6.0		●		
7.2 Determine scale-up effects	7/1/2013	12/31/2013	7.1		●		
7.3 Determine necessary physical properties of capture materials	4/1/2012	9/30/2012	4.2		●		○
7.4 Determine suitable materials of construction	4/1/2012	9/30/2012	7.1		●		○
Milestones:							
-Updated state-point table							
-Design parameters identified and reported							
Task 8 Economic and scale-up analysis	1/1/2013	12/31/2013		353,590			
8.1 Develop model of bench-scale system performance	1/1/2013	6/30/2013	7.1, 7.2		○	●	
8.2 Perform final technical and economic feasibility study and update COE calculations	7/1/2013	12/31/2013	4.3, 5.0, 6.0, 7.1, 7.2		○	●	
8.3 Develop scale-up strategy	7/1/2013	12/31/2013	4.3, 8.1, 8.2		○	●	
Milestones:							
-Scale-up strategy							
-Bench-scale process model							
-Final technical and economic feasibility study							

Timeline: Phase 1 (Q4 / 11, Q1 / 12, Q2 / 12, Q3 / 12, Q4 / 12); Phase 2 (Q1 / 13, Q2 / 13, Q1 / 13, Q4 / 13)

Legend: ◇ Milestone ◆ Decision Point ▽ Deliverable ● Task Leader ○ Task Participant

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Task 1: Project Management and Planning (**GE GRC**/GE Energy)

Subtasks

1.1 Project Management and Planning

1.2 Briefings and Reports

Milestones

- Update of Project Management Plan
- Kick-off meeting

Task 2: Conduct Preliminary Technical and Economic Feasibility Study (**GE Energy**)

Subtasks

2.1 Develop Preliminary Process Models

2.2 Perform Preliminary Technical and Economic Feasibility Study

Milestones

- Determination of energy required for CO_2 separation sub-system
- Preliminary technical and economic feasibility study
- Go/no go decision based on predicted performance of >90% CO_2 capture with <45% increase in COE

Task 3: Design and Build Bench-Scale System (**GE GRC**)

Subtasks

3.1 Design Bench-Scale System

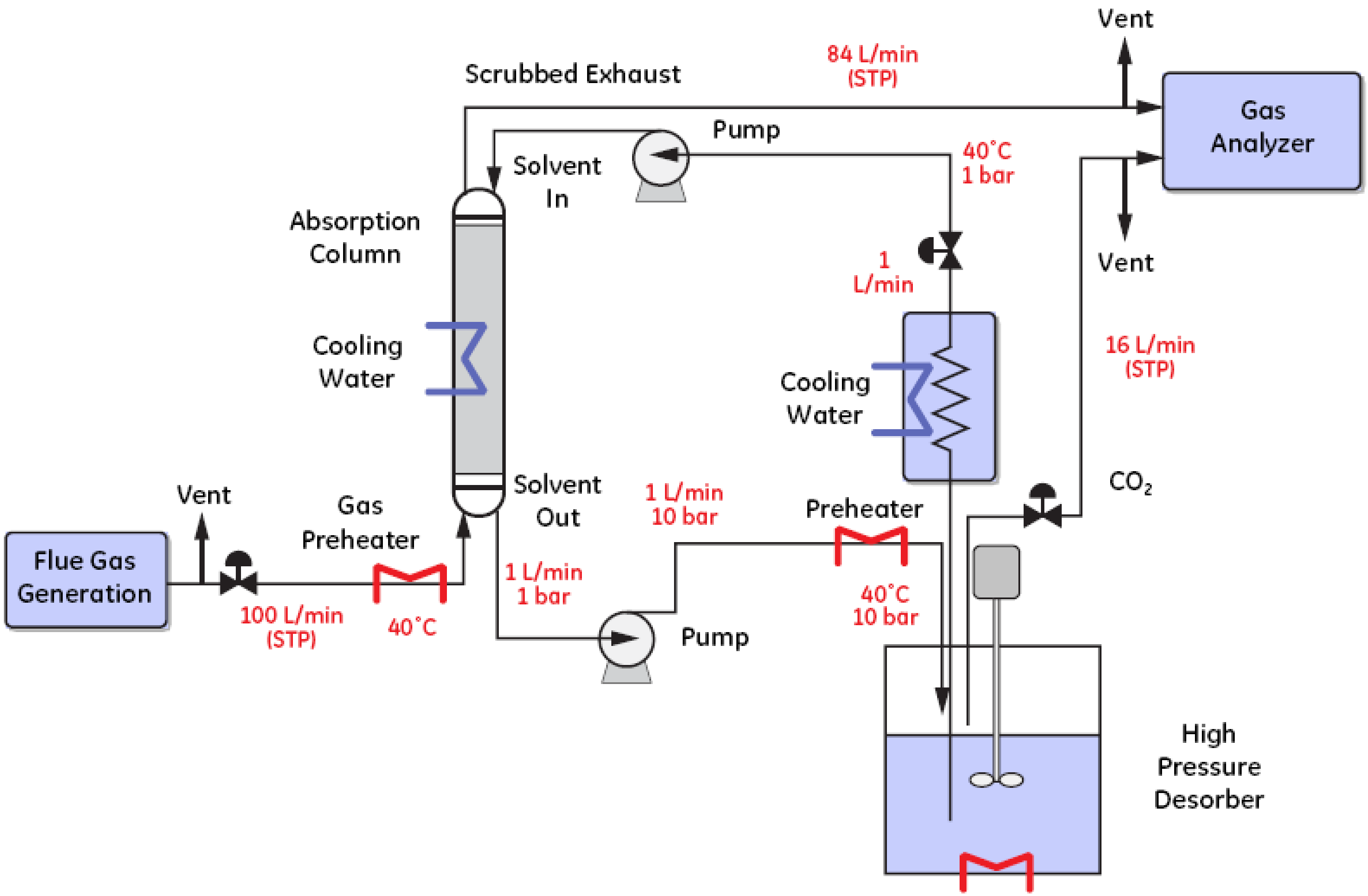
3.2 Build Bench-Scale System

3.3 Develop a Bench-Scale Test Plan

Milestones

- Design of a continuous bench-scale absorption/desorption unit
- Assembly of operational bench-scale system
- Bench-scale system test plan

Bench-Scale Schematic



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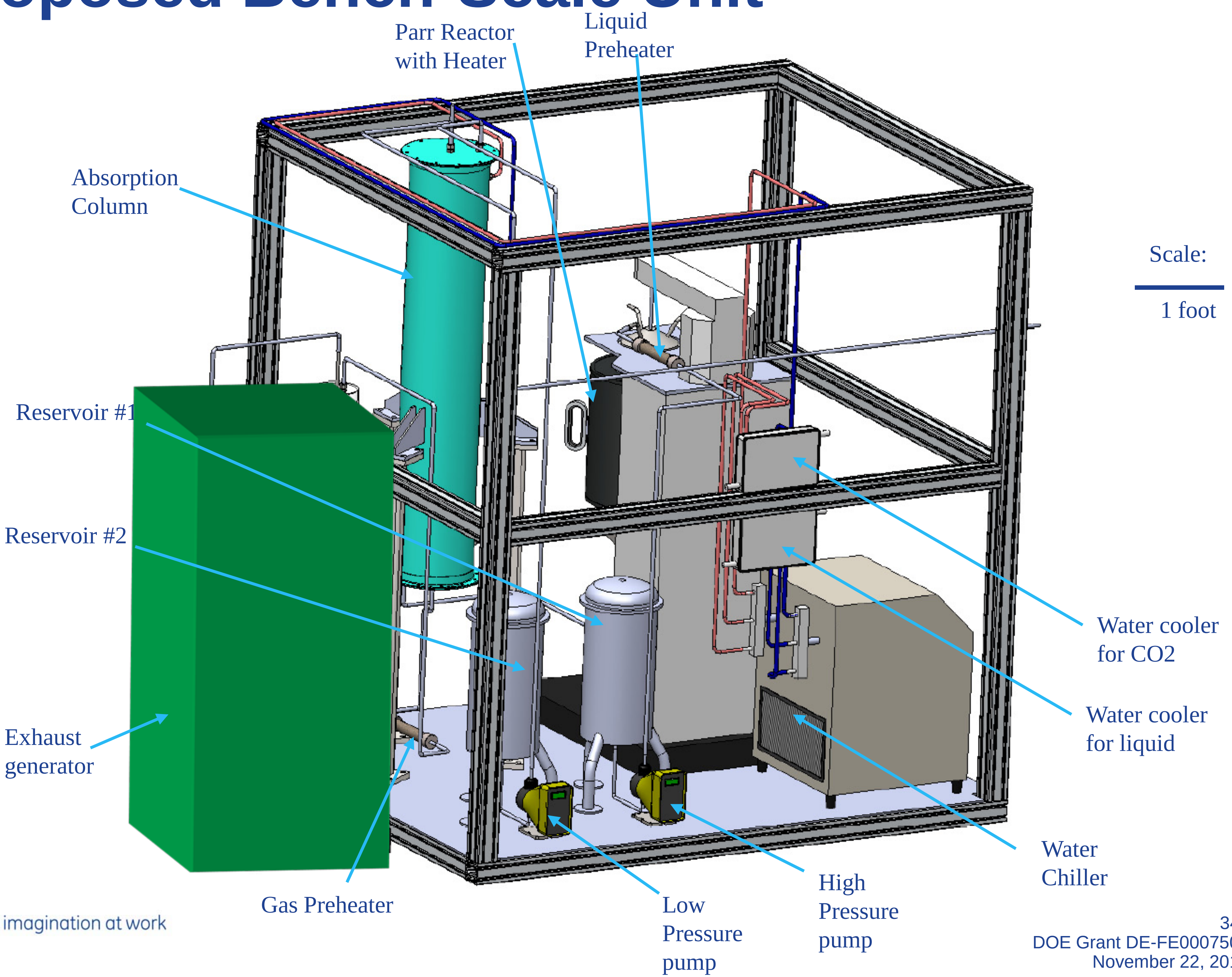
Proposed Bench-Scale Unit



Task 4: Develop Absorption Material Manufacturing Plan (**SiVance**/GE GRC)

Subtasks

4.1 Determine Manufacturability, Raw Material Supply Adequacy, and Estimated Price for Top Material Candidates

4.2 Confirm Small-Scale Synthesis of Top Material Candidates

4.3 Develop Cost Effective Plan for Large-Scale Manufacture

Milestones

- Manufacturability analysis of aminosilicone-based solvent for bench-scale testing
- Plan for large-scale raw material supply and manufacturing price model
- Establish capital requirements for material manufacturing and material price model
- Delivery of synthesized aminosilicone-based solvent

Task 5: Supply Materials for Bench-Scale Testing (**SiVance**/GE GRC)

Subtasks

5.0 Large-Scale Synthesis of Materials for Bench-Scale Testing

Milestones

- Absorption material for bench-scale testing delivered from SiVance to GE Global Research

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Task 6: Perform Technology EH&S Risk Assessment (**SiVance**/GE GRC)

Subtasks

6.0 Perform Technology EH&S Risk Assessment

- Will have a specialist perform this task

Milestones

- Technology EH&S risk assessment

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Task 7: Perform Bench-Scale Testing (**GE GRC**/SiVance)

Subtasks

7.1 Obtain Engineering Data

7.2 Determine Scale-Up Effects

7.3 Determine Necessary Physical Properties of Capture Materials

7.4 Determine Suitable Materials of Construction

Milestones

- Update state-point table
- Design parameters identified and reported

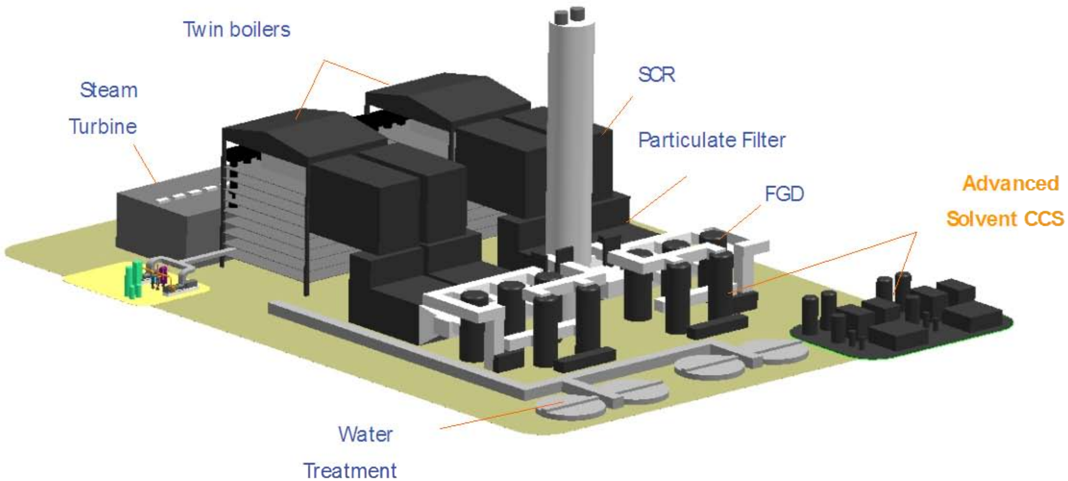
Task 8: Economic and Scale-up Analysis (**GE Energy**/GE GRC)

Subtasks

8.1 Develop Model of Bench-Scale System Performance

8.2 Perform Final Technical and Economic Feasibility Study and Update COE Calculations

8.3 Develop Scale-Up Strategy



Milestones

- Scale-up strategy
- Bench-scale process model
- Final technical and economic feasibility study

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Schedule/Milestones

Budget Period	Task	Milestone Description	Planned Completion
1	1	Complete update of Project Management Plan	11/30/2011
1	1	Complete kick-off meeting	12/31/2011
1	2	Complete determination of energy required for CO_2 separation sub-system	6/30/2012
1	2	Complete preliminary technical and economic feasibility study that analyzes the impact of the proposed process on the COE	10/31/2012
1	3	Complete design of a continuous bench-scale absorption/desorption unit that will operate with a solvent flow rate on the order of 1 L/min	6/30/2012
1	3	Complete assembly of operational bench-scale system	12/31/2012
1	3	Complete bench-scale system test plan that details the planned bench-scale testing including the purpose and duration of test runs, the range of operational parameters to be tested during each test run, and the essential properties and process conditions to be measured during each test run, etc	12/31/2012
1	4	Complete manufacturability analysis of aminosilicone-based solvent for bench-scale testing	6/30/2012
1	4	Complete plan for large-scale raw material supply and manufacturing price model	12/31/2012
1	4	Establish capital requirements for material manufacturing and material price model	9/30/2012
1	4	Delivery of synthesized aminosilicone-based solvent	9/30/2012

Budget Period	Task	Milestone Description	Planned Completion
2	5	Absorption material for bench-scale testing delivered from SiVance to GE Global Research	3/31/2013
2	6	Complete technology EH&S risk assessment aimed at identifying any EH&S concerns associated with the aminosilicone capture system	12/31/2013
2	7	Complete updated state-point table	9/30/2013
2	7	Design parameters identified and reported	12/31/2013
2	8	Complete scale-up strategy identifying suitable process configurations for commercial-scale operations, preliminary absorber/desorber and heat transfer equipment designs and architectures, desorber steam requirements, and estimated pressure drops expected in the absorption-cycle components	12/31/2013
2	8	Complete bench-scale process model	6/30/2013
2	8	Complete final technical and economic feasibility study	12/31/2013

Project Risks

Description of Risk	Probability (Low, Moderate, High)	Impact (Low, Moderate, High)	Risk Management (Mitigation and Response Strategies)
Technical Risks			
Insufficient chemical and thermal stability of chosen solvent	Moderate	High	• Use of inhibitors • Identification of additional flue gas clean-up unit operations required prior to CO_2-capture system
Bench-scale tests do not examine all important variables	Moderate	Moderate	• Experiments will be designed so that the relevant design space will be explored
Bench-scale system does not scale to larger scales	Moderate	High	• Comparison of bench-scale performance to previously obtained lab-scale performance to better estimate effect of scale on key performance parameters
Flooding occurs in the absorption column	High	Moderate	• Adjustments will be made to absorber design to avoid flooding • Alternate packing materials will be examined
High viscosity of solvent upon absorption of CO_2 negatively affects mass transfer in unit operations	Moderate	Moderate	• Unit operations will be designed to optimize mass transfer • Adjustment to the ratio of GAP-1_m to TEG can be used to modify the solvent viscosity
Resource Risks			
Solvent too expensive	Moderate	Moderate	• Identification and analysis of synthetic options to determine most cost effective manufacturing method
Solvent supply is delayed	Low	Moderate	• Synthetic approach identified and verified well before solvent is needed for bench-scale testing
Management Risks			
Construction of bench scale system delayed/overrun	Moderate	High	• Priorities communicated to facilities group early in design process • Material, equipment, and time estimates obtained during design phase • Lead time for equipment identified early in process to ensure delivery when needed

Summary

Previous Work

- Designed novel CO_2 capture solvent system
- Physical properties modeled and experimentally determined
- Confirmed continuous CO_2 absorption/desorption capability of solvent
- Plant and process models developed
- GAP-1 chosen as GEN-2 solvent
- COE calculations indicate substantial improvement over baseline 30% MEA system

Work for Current Project

- Obtain additional continuous data at bench scale
- Generate BEP for system scale-up
- Develop large-scale aminosilicone synthesis plan
- Refine COE models

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