Fifth Annual Conference on Carbon Capture & Sequestration

Steps Toward Deployment

CO_2 Conversion

Details of Chemical Scrubbing of Ambient Air as a means to capture CO_2

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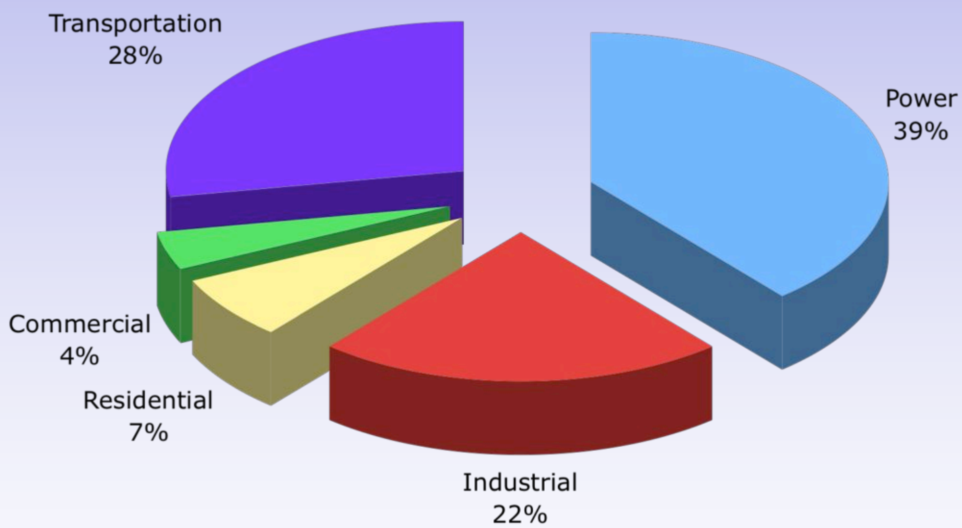
Carbon Capture & Storage



IPCC report targets sources with emissions >0.1 $MtCO_2$/yr.

Totals 7,600 sources and 3.6 GtC per year.

Given 90% nominal capture efficiency, this strategy handles 47% of current emissions.

Chemical Reactions

Reaction	ΔH^o (kJ/mol)	Name	Temp.
$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$	-109.4	Absorption	20^oC
$Na_2CO_3 + Ca(OH)_2 \rightarrow 2NaOH + CaCO_3$	-5.3	Causticization	20^oC
$CaCO_3 \rightarrow CaO + CO_2$	179	Calcination	900^oC
$CaO + H_2O \rightarrow Ca(OH)_2$	-64.5	Hydration	$<100^oC$

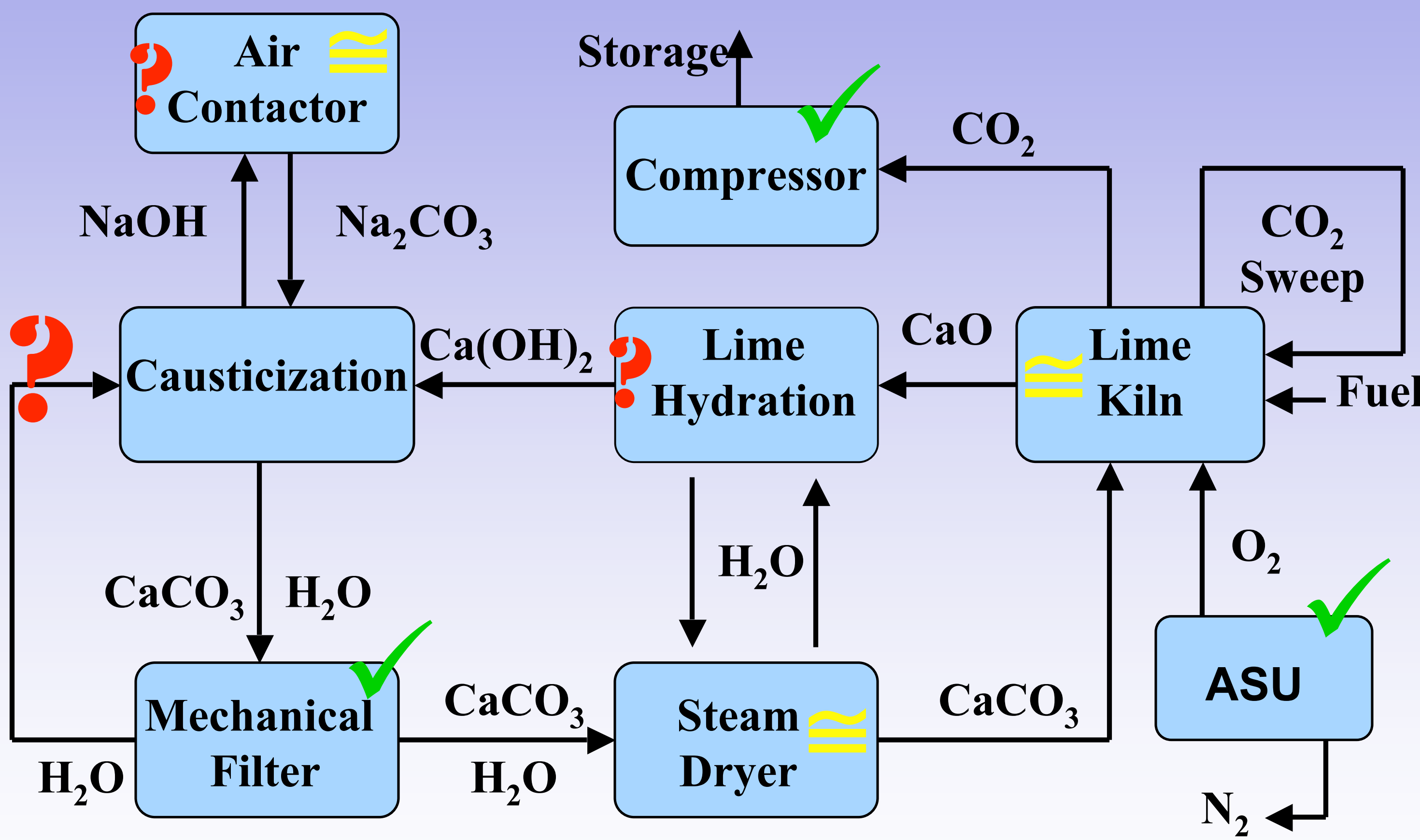
Air has 0.015 mol/m^3, which results in a 1.4^{o}C rise per m^3.

1 mol/L NaOH solution would increase 0.7^{o}C per liter.

Calcination is fixed.

Steam hydration releases -108.5 kJ/mol below 400^{o}C.

Process Overview



Results of Previous Work

Summary of Performance Data from Spector and Dodge (1946)

Air (m^3/hr)	Solution (L/hr)	CO_2 Removal	CO_2 Captured (g/hr)	CO_2 Flux (10^{-6} mol/m^2/s)
290.3	1123.5	71%	114	10.2
179.5	1175.8	81%	81	7.2
143.6	1340.1	77%	61	5.6
80.9	1353.0	90%	40	3.7

The order of magnitude of the flux is consistent.

Packed tower type device is suitable.

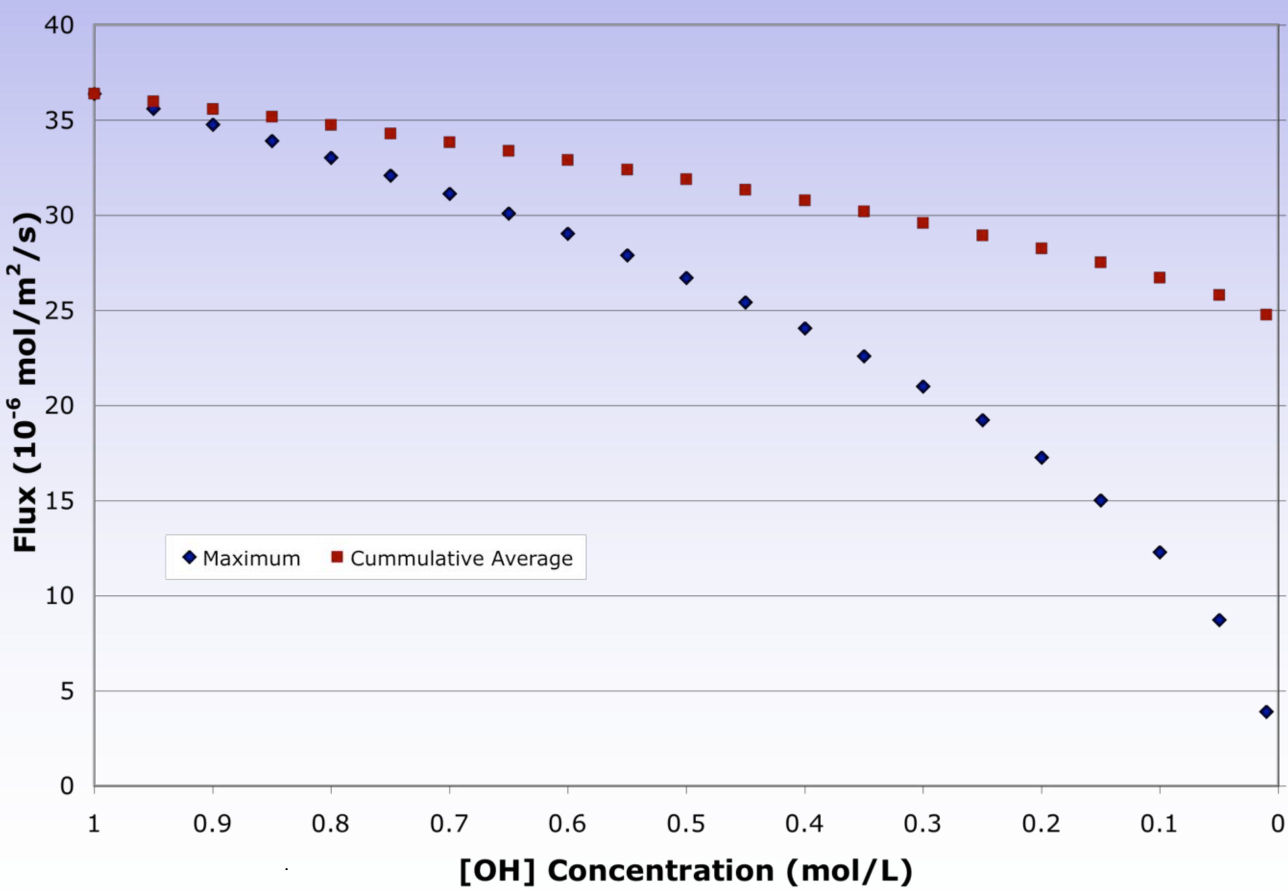
The preferred recovery technique is electrodialysis.

Minimum energy consumption ~450 kJ_e/mol CO_2, of which 100 kJ_e/mol is capture the rest is regeneration.

CO_2 Capture in Alkaline Solutions

(1) $CO_2 + OH^- \rightarrow HCO_3^-$

(2) $HCO_3^- + OH^- \rightarrow CO_3^{2-} + H_2O$



$$J_{CO_2} = \sqrt{D_L k_d b_o \rho'_{CO_2}}$$

D_L is 1.78×10^{-9} m^2/s

$\log k_d = 3.7 + 0.13I$

$b_o = [OH]$

p'_{CO2} is $[CO_2]$.

$[CO_2] = 17$ μmol/L

Calcination

Very mature industry ranging from 70-90% efficiency, which suggests a thermal penalty of 199-256 kJ/mol CO_2.

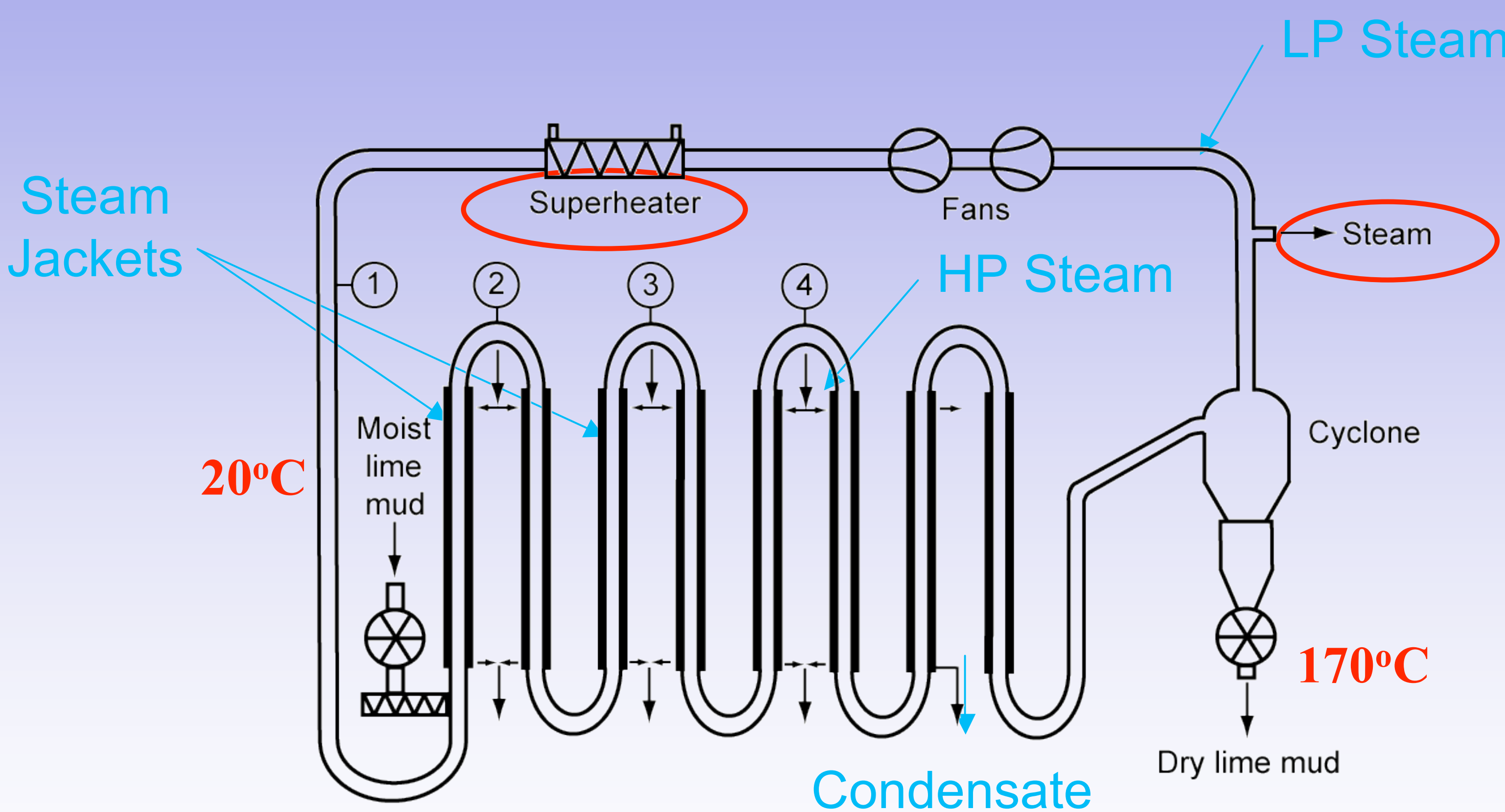
Fuel and Oxygen per mole $CaCO_3$

Fuel	Heat	Amount	Oxygen
CH_4	890.8	0.201	0.401
CO	283.0	0.633	0.317
CH	360.0	0.497	0.621
H_2	285.8	0.627	0.314

In order to avoid CO_2 emissions, the use of oxygen and flue gas recycling is desirable. The production of oxygen requires 25 kJ_e/mol O_2.

Will sintering affect the durability of the lime?

Thermal Dewatering using Steam



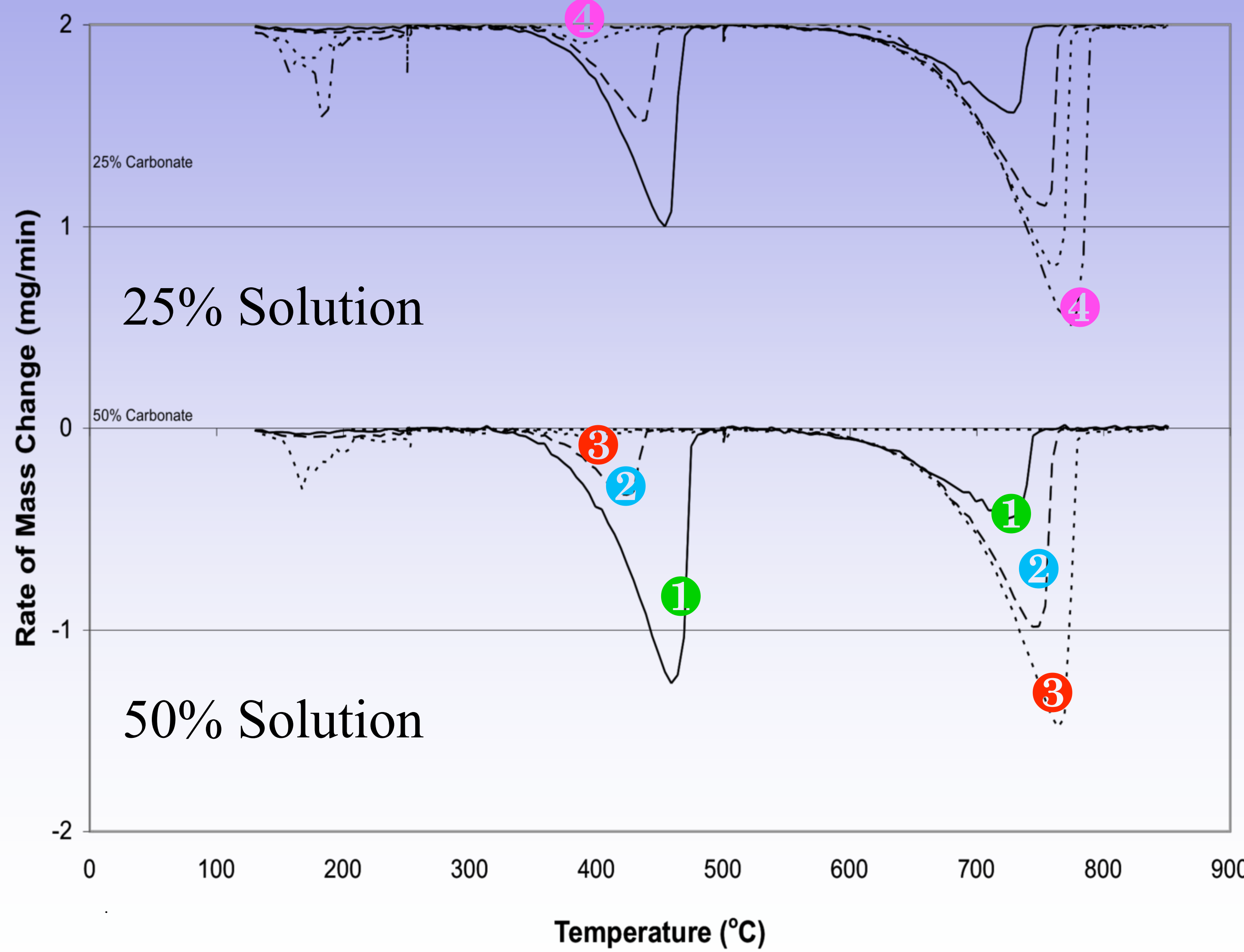
Use the heat of hydration as the superheater and condense the excess steam on the moist lime mud.

Q1

Can we efficiently causticize at room temperature using a mixture of sodium hydroxide and carbonate?

$CaCO_3 \cdot H_2O$
$CaCO_3 \cdot 6H_2O$
$Na_2Ca(CO_3)_2 \cdot 2H_2O$

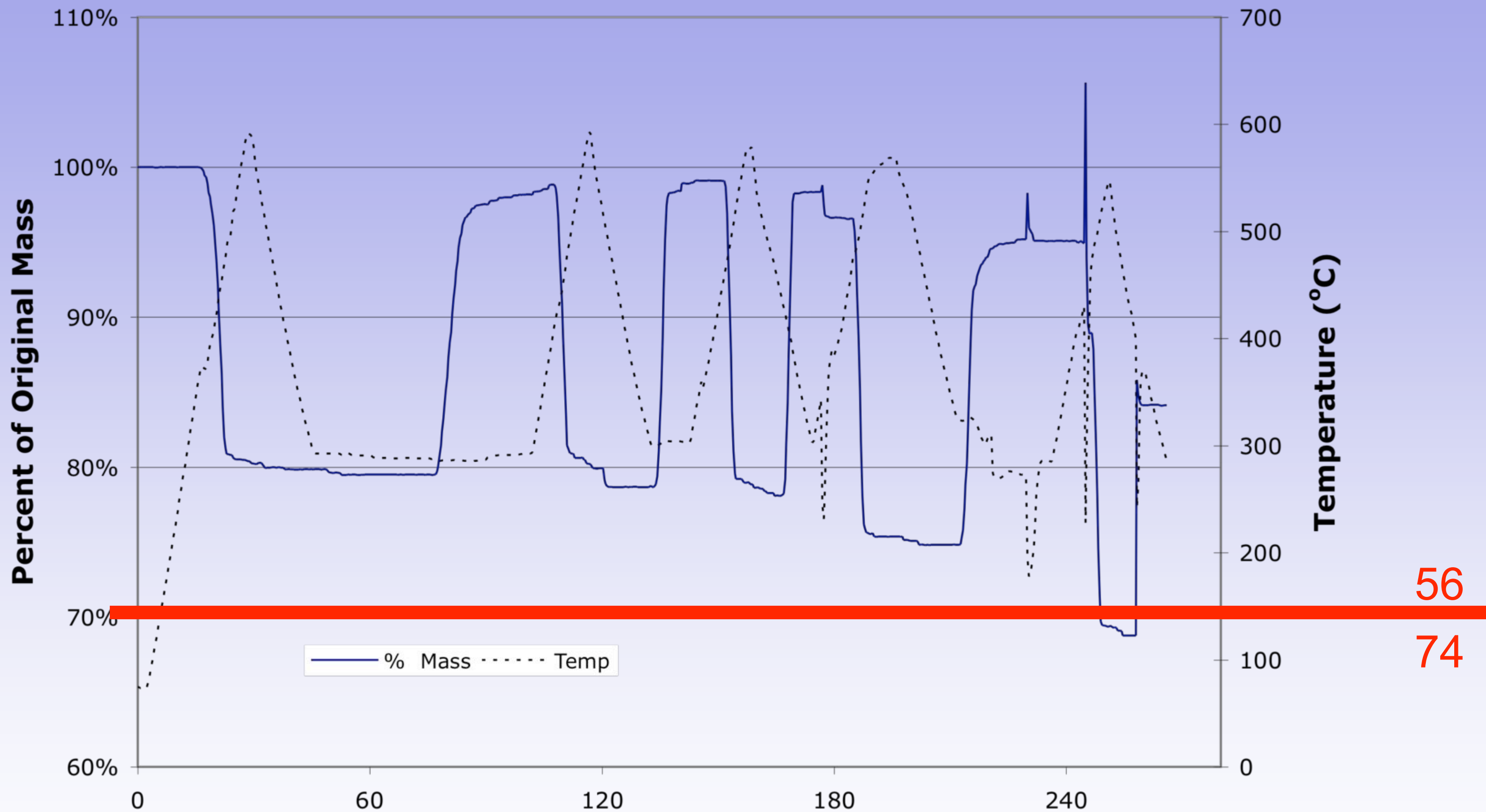
$NaOH/Na_2CO_3$ Mixtures



Q2

Can we hydrate lime using steam and does it reverse the effects of sintering?

Steam Hydration



Compound	CaO	$Ca(OH)_2$	$CaCO_3$
Molar Volume (cm^3/mol)	17	33	37

Q3 & Q4

Can we improve on the CO_2 flux and what considerations are relevant to the entire process?

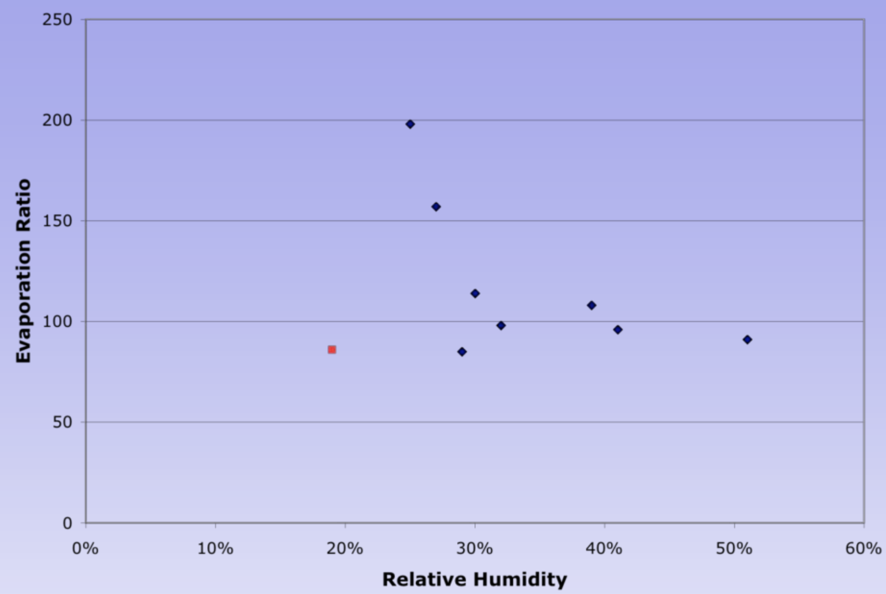
System Performance

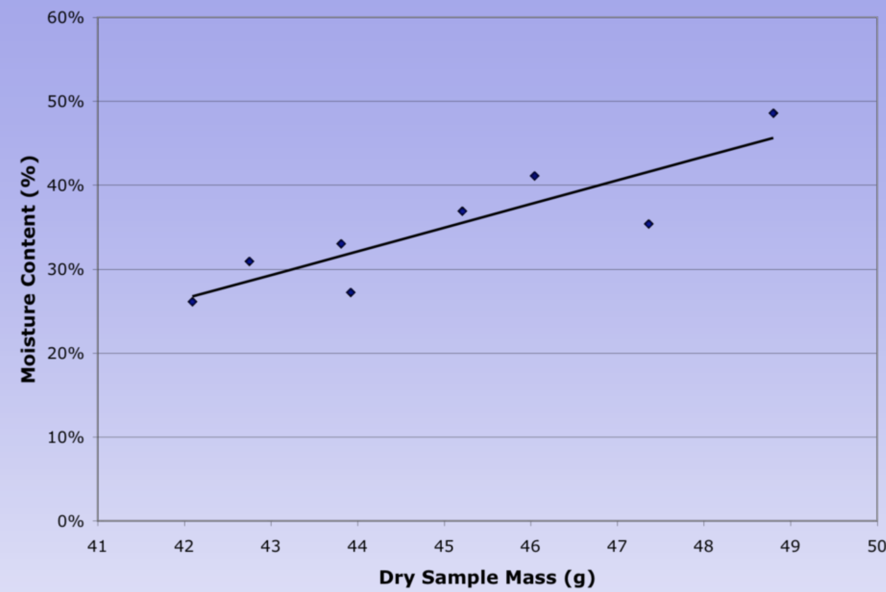
Date	[OH]/[Na]	Captured CO_2 (g)	Evap. Ratio	CO_2 Flux ($\mu mol/m^2/s$)	Corrected Flux	Energy (kJ/mol)	
10/22	0.901	9.7	96	7.46	9.51	2,586	P & F 60V
10/26	0.845	15.4	85	11.81	15.0	1,097	F 60V
10/28	0.753	9.7	198	7.46	12.4	966	P
10/30	0.715	12.5	98	9.59	16.06	965	F 50V
11/3	0.730	13.8	114	10.56	15.82	1,463	F 70V
11/6	0.754	13.6	91	10.45	17.18	360	iP
11/8	0.849	16.6	157	12.71	16.84	1,398	F 90V
11/9	0.885	15.2	108	11.61	15.61	1,067	F 60V
11/11	0.842	11.4	86	8.70	12.69	744	iF 60V

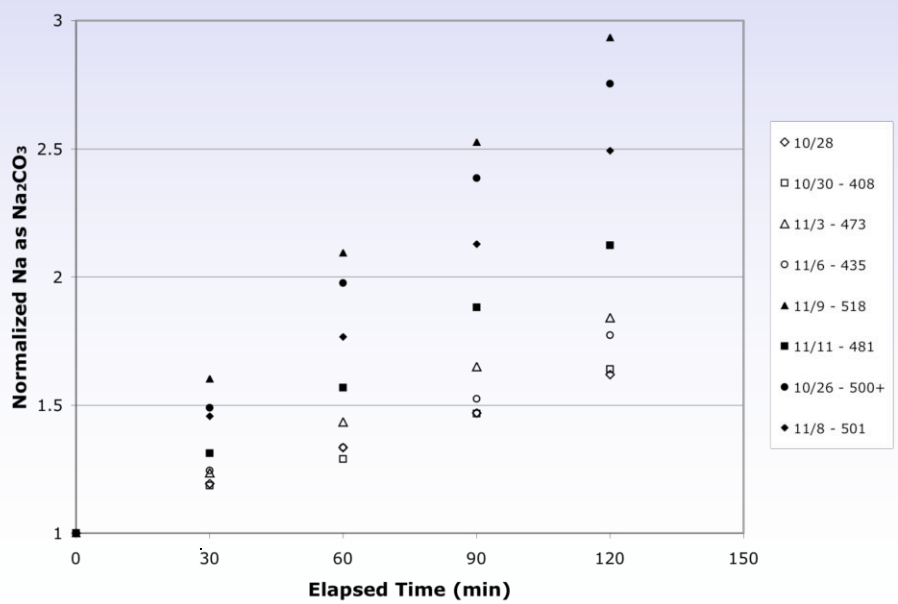
$$Flux_{Corrected} = Flux_{Measured}\left(\frac{375}{P_{CO_2}}\right)\sqrt{\frac{1}{[OH]_{avg}}}$$

	Meas.	1M	2M
Avg	10.0	14.6	20.6
Max	17.8	23.6	33.4
Min	6.1	8.9	12.6

Operational Considerations







Ca^{2+}	6 Nov	8 Nov	9 Nov	11 Nov
Mass	51.58	51.50	52.11	51.01
Extra				7.96
Mass	88.79	89.02	86.01	96.16
Ratio	0.58	0.58	0.61	0.61
Eff.	0.849	0.885	0.842	0.954

A 1tCO_2/hr Reference Plant

Air Flow is 1.5 million m^3/hr at 100%

M A S S

Material	Flow (kg/hr)	Material	Flow (kg/hr)
$CaCO_3$	2,290	CaO	1,285
$Ca(OH)_2$	1,700	CH_4	93
O_2	371	CO_2	1,264
H_2O	389	H_2O with CO_2	209
Steam Loop	3,600	CO_2 Loop	1,501

E N E G R Y

Component	**Energy Penalty (kJ/mol)**	**Percent of Total**	**Source**
Blowers	88	25.5%	Electrical
Cryogenic Oxygen	14	4.0%	Electrical
Dryer (at 35% MC)	78	--	Hydration
Kiln (at 80%)	225	65.0%	Thermal
CO_2 Compression	19	5.5%	Electrical
Hydration	105	--	Source
Total	346	100%	

Comparison of Air Capture

Energy (kJ/mol)	Air Capture	MEA		KS-1	
		NG	Coal	NG	Coal
Thermodynamics	19.5	8.4	5.3	8.4	5.3
Actual	327	181	181	141	141
Efficiency	6.0%	4.6%	2.9%	5.9%	3.8%

$$Thermo\_Eff. = \frac{RT\ln(P_2/P_1)}{\Sigma Energy_{Process}}$$

"Thermodynamically, there is an insanity to what they're proposing, … now, it still may [make economic sense] if oil prices are high enough."

Randy Udall, director
Community Office for Resource Efficiency
US News & World Report 4/24/06