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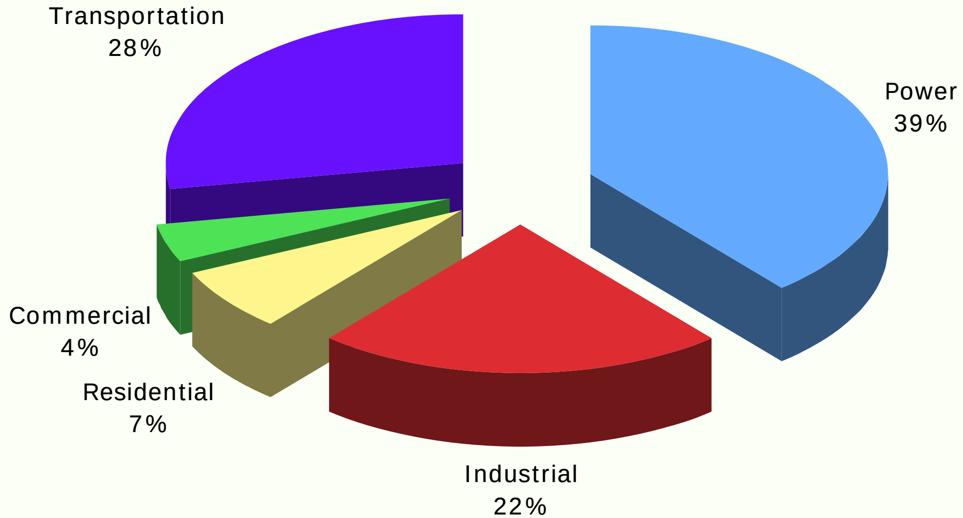
Mobilizing the Sciences and Public Policy to Build a Prosperous and Sustainable Future

Direct Extraction of CO_2 from Air, a Fixed Solution for a Mobile Problem

Dhahran, Saudi Arabia
May 23rd 2006

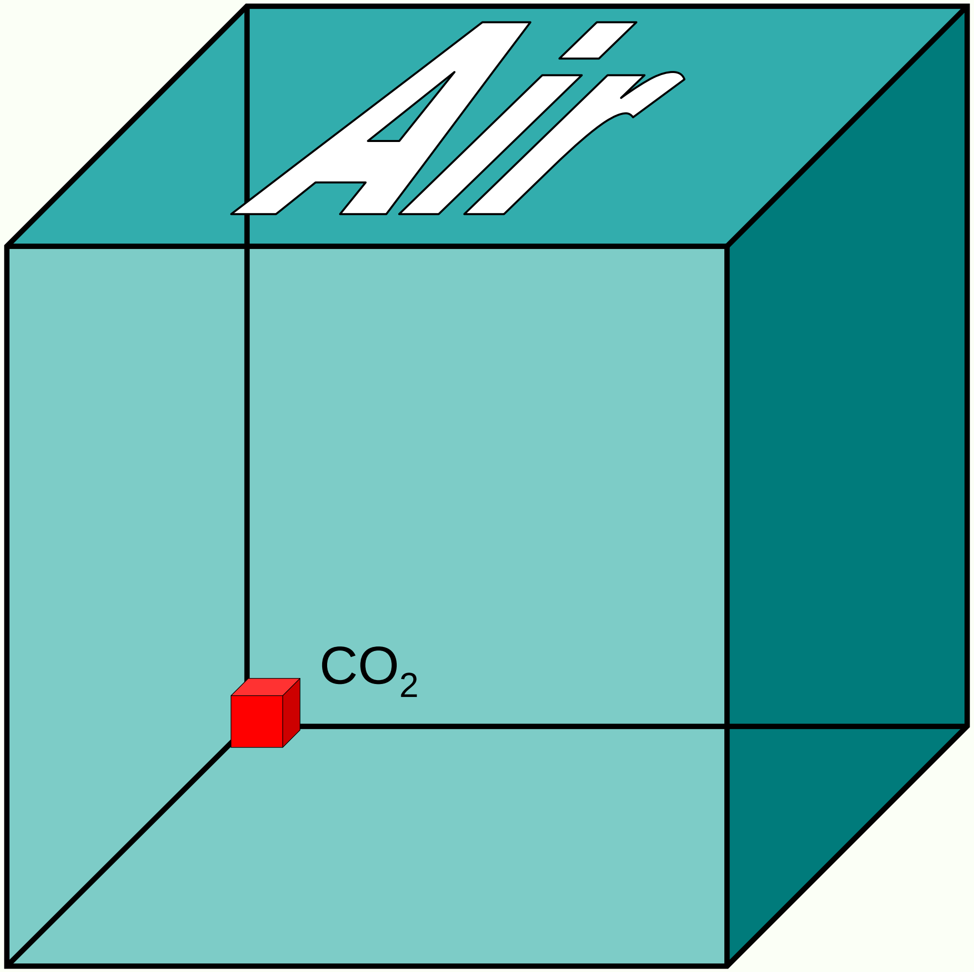
Decoupling CO_2 emission from CO_2 mitigation



IPCC CCS Report criteria
100 ktonne/yr CO_2
with 90% capture
~50% of emissions.

- Distributed and/or mobile sources
- Existing Infrastructure ill suited to retrofit
- Handling leakage from storage sites
- Challenging CO_2 transportation scenarios
- Driving capture to or above 100%

Low Concentration Limitations



Volumes are drawn to scale

375 ppm = 0.015 mol CO_2/m^3

Kinetic Energy @ 10 m/s
4 kJ_e/mol CO_2

Compression to 25 bar
880 kJ_e/mol CO_2
eq. 10-64a Perry's 7th

Fuel Energy (kJ/mol CO_2)

CH_4	CH_2	CH
890.8	688.1	362.3

Coal at 25 MJ/kg 10% ash
Gasoline as heptane.

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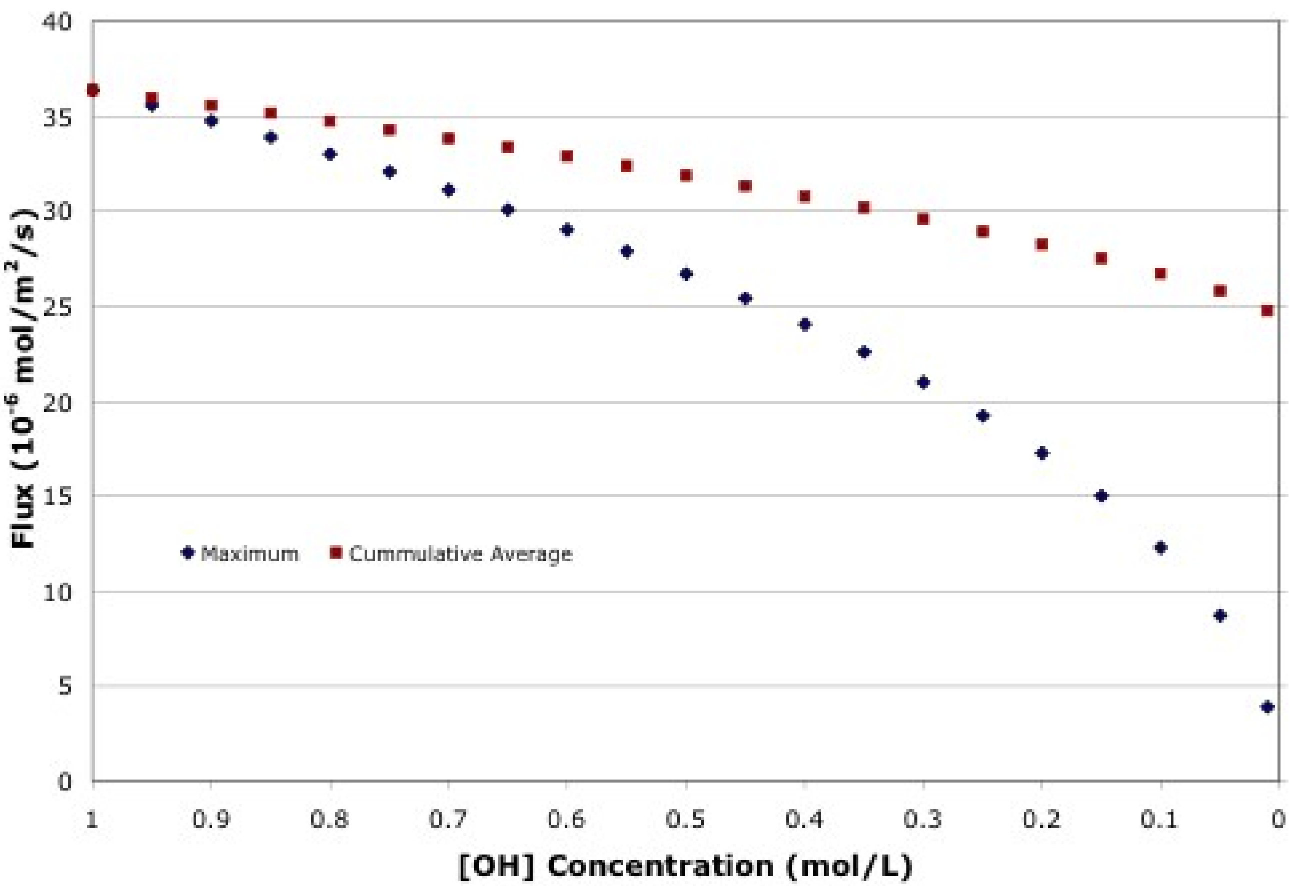
Chemical Absorption

$$2OH^-_{(aq)} + CO_{2(g)} \rightarrow CO^{2-}_{3(aq)} + H_2O_{(l)}$$

Flux into hydroxide 10^3 times carbonate



First Order Flux

$$J = \sqrt{D_L k_d [OH] K_H \rho_{CO_2}}$$

D_L is 1.78×10^{-9} m^2/s

$\log k_d = 3.7 + 0.13I$

$K_H = 0.7$ (Henry's)

$p_{CO2} = 0.015$ mol/m^3

$[CO_2] = 17$ µmol/L

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Experimental Data

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

Theoretical Flux for 200 ppm using 2M NaOH is 32 μmol/m^2/s

Packed tower type device is suitable.

Conventional packings require 88 kJ_e/mol CO_2 captured.

Sorbent Regeneration

The recovery technique in the literature is electrodialysis.

$$CO_{3(aq)}^{2-} + H_2O_{(l)} \rightarrow 2OH_{(aq)}^{-} + CO_{2(g)}$$

Estimate energy consumption ~308 kJ_e/mol CO_2.

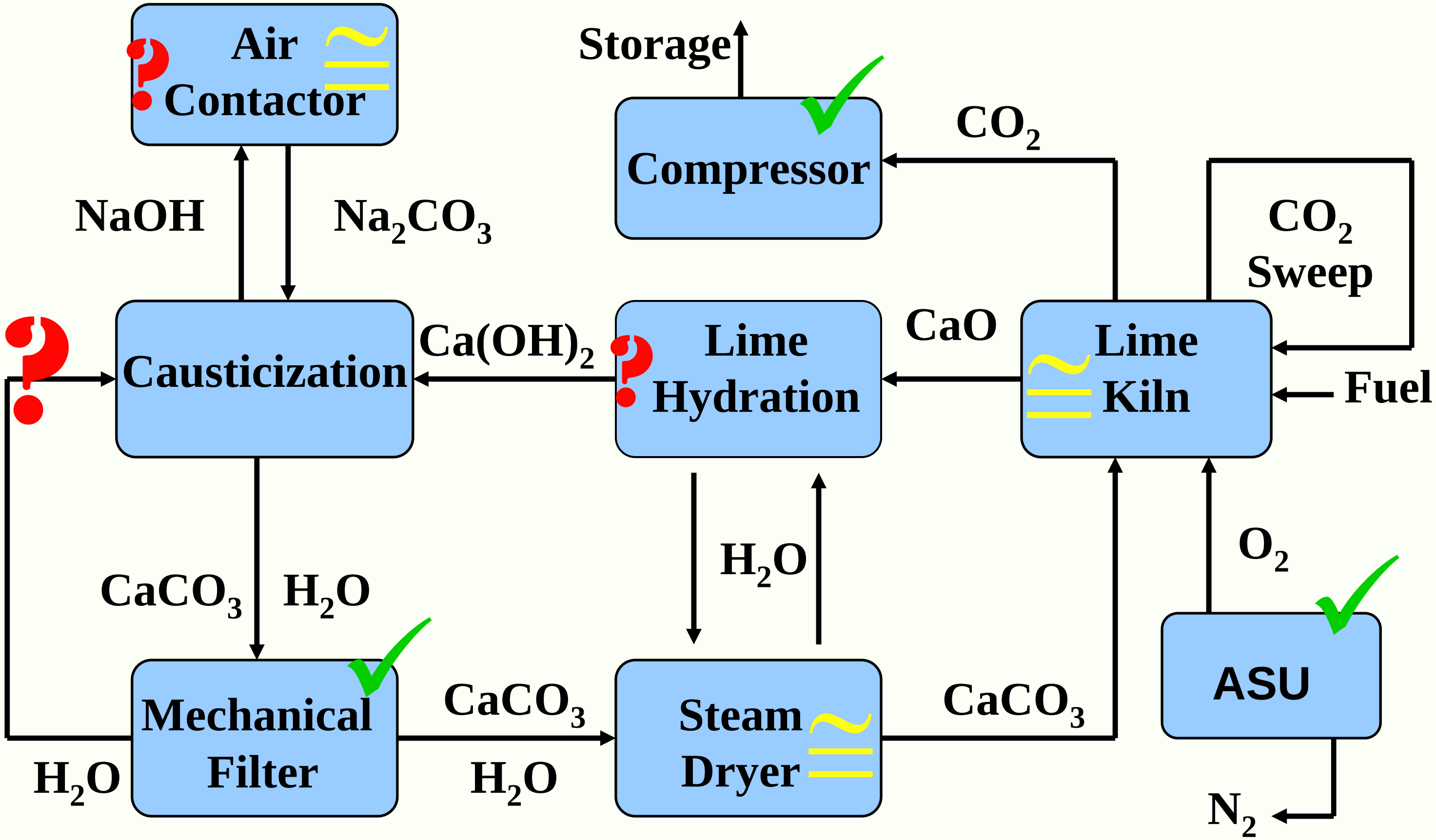
An alternative method can be found in the Paper Industry.

$$Na_2CO_{3(aq)} + Ca(OH)_{2(s)} \rightarrow 2NaOH_{(aq)} + CaCO_{3(s)}$$

$$CaCO_{3(s)} + 179.2kJ \rightarrow CaO_{(s)} + CO_{2(g)}$$

Efficiencies of Lime Kilns range from 70-90% meaning the energy penalty ranges from 200-250 kJ/mol CO_2

Process Overview



Energy Balance

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%	

Balance is 121 kJ_e and 225 kJ_{th} per mole of CO_2.

A 50% passive air movement system uses 36% less electricity.

A coal system injects ~1.6 moles for every mole CO_2 captured.

Assumes a 75% efficient steam dryer.

Material Balance

A 1tCO_2/hr Reference Plant

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

At 100% capture air flow is 1.5 Mtonnes/hr.

A flux of 20 μmol/m^2/s requires a surface area of 315,000 m^2.

The volume of solution required is 190 m^3 (0.6mm film).

This would convert 25% of the Na to Na_2CO_3.

Hi-flow packing materials achieve 300 m^2/m^3 or 1,050 m^3.

A cross flow device 10m high, 3 m thick and 35m wide.

Cost Considerations

We can initially consider \$100 tCO_2 or 366 \$tC.

Product	Amount	Unit Cost	Cost
Coal	625 kg	\$0.035	\$22
Power	764 kWh	\$0.06	\$46

A 90% efficient kiln with 50% passive draft has a cost of \$48.

Costs with respect to automobiles

\$0.90	per gallon of gasoline
\$42	per barrel of oil equivalent
\$1,800	car averaging 100 mpg
\$3,600	car averaging 50 mpg

Assumes 9kg CO_2 per gallon gasoline and 200,000 mile life of vehicle.

How Feasible is it?

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%

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


100% passive draft system
Above boundary layer
Stand alone setting
Long flow path
No visible regeneration
No visible power source
No visible CO_2 system
Desert (evaporation)
CO_2 shadows
Likely electrodialysis
No forced draft option