Innovative Combustion and Gasification Concepts to Manage Carbon

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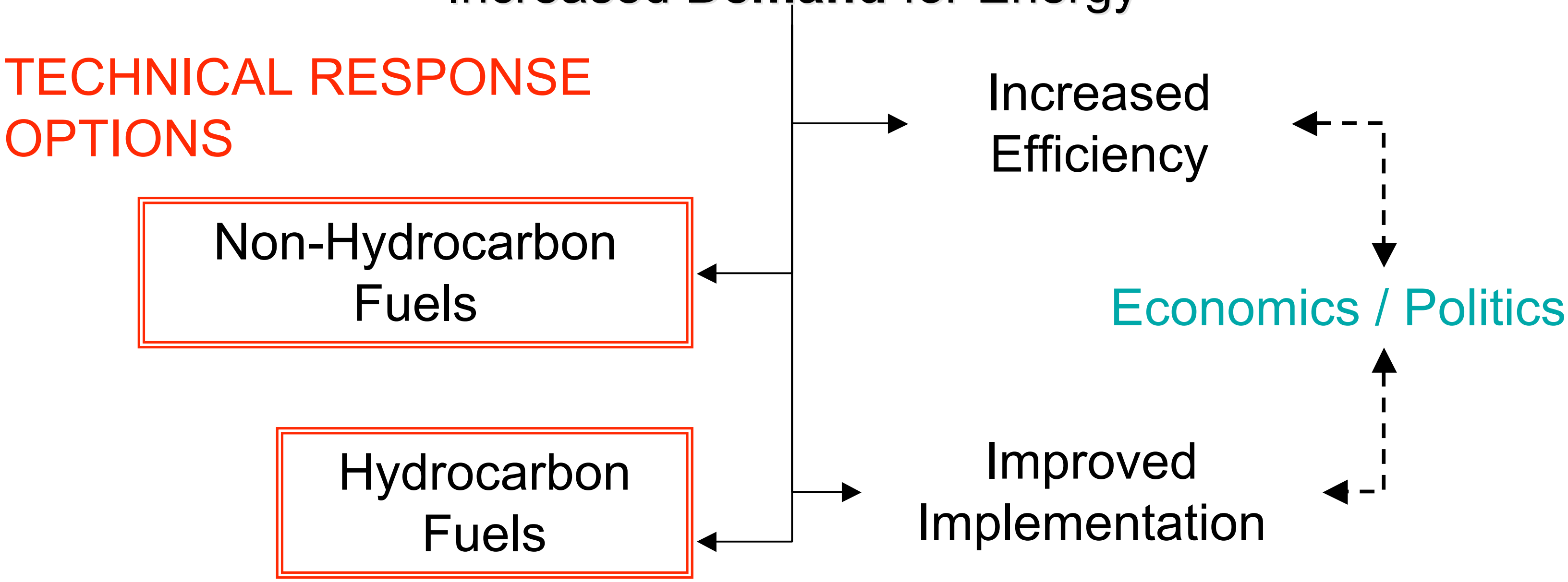
Energy Intensity *CO_2 Intensity*

$$CO_2 = \left\{Pop * \frac{GDP}{Pop}\right\} * \left\{\frac{\text{Energy Cost}}{GDP} * \frac{CO_2\ \text{Produced}}{\text{Energy}}\right\} - S$$

Demand	Efficiency	Sequestration
Significant Increase (↑ Pop, ↑↑↑ GDP/Pop)	Declining (↓ Energy Intensity)	Relatively Flat (↔ CO_2 Intensity)

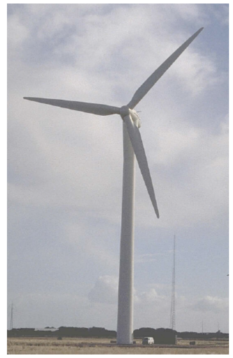
Increased **Demand** for Energy

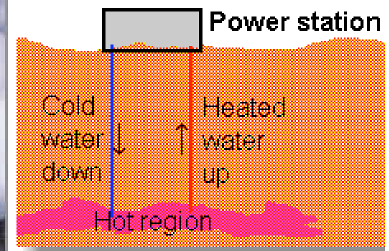


Reference: Kaya, Y. *Costs, Impacts and Benefits of CO_2 Mitigation* (1993) Intl. Inst. Appl. Sys. Anal.

Non-Hydrocarbon Fuels

Wind





Geothermal

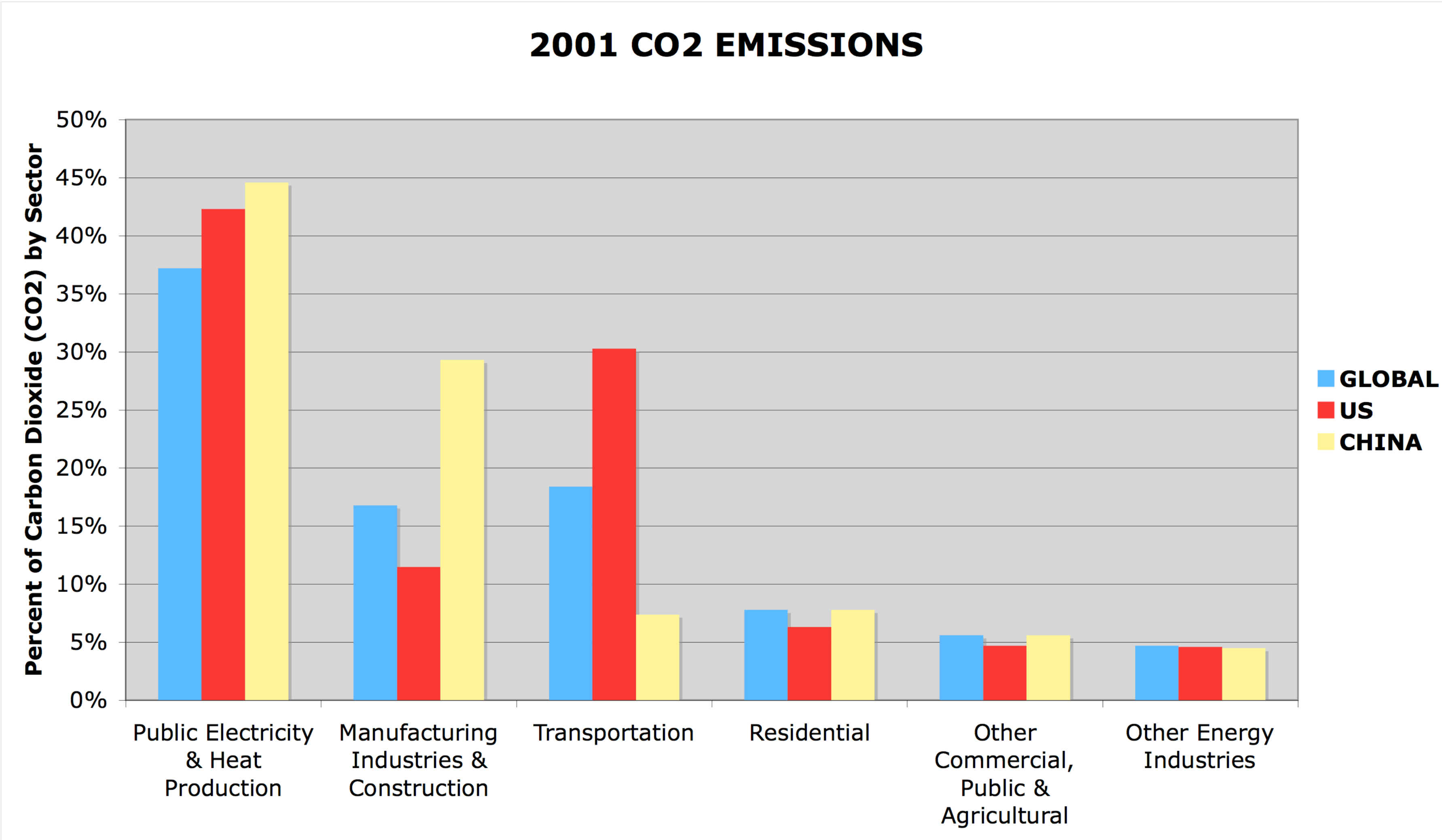
Wave

Solar

Hydro

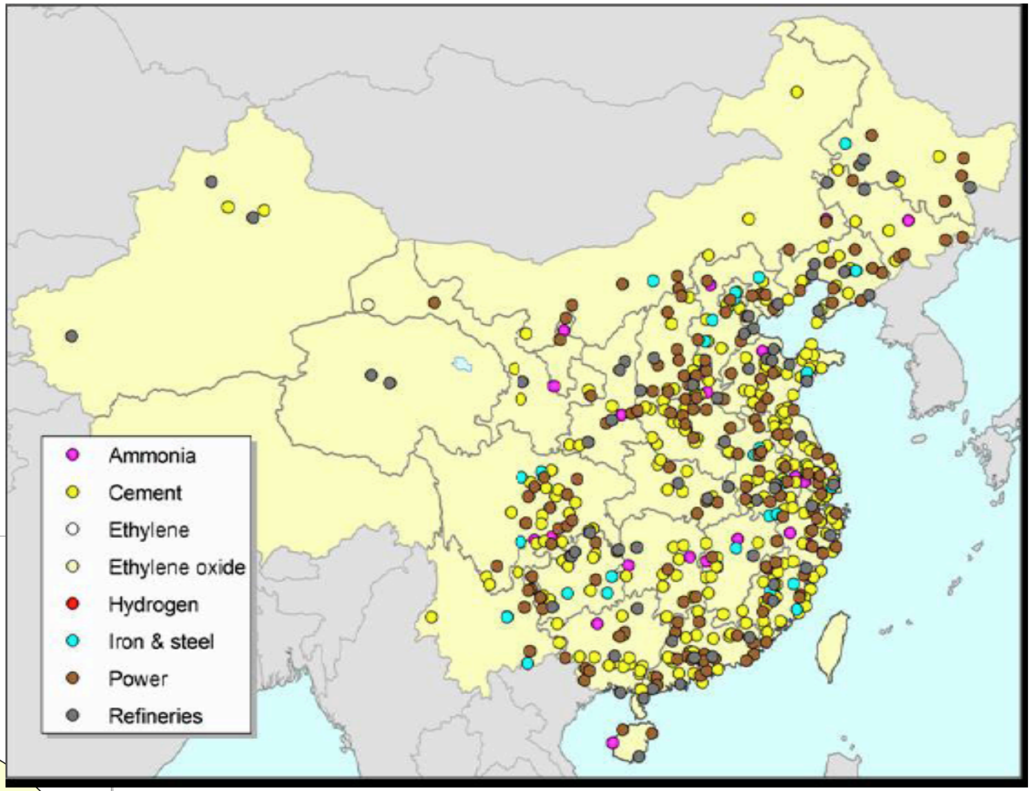
Nuclear

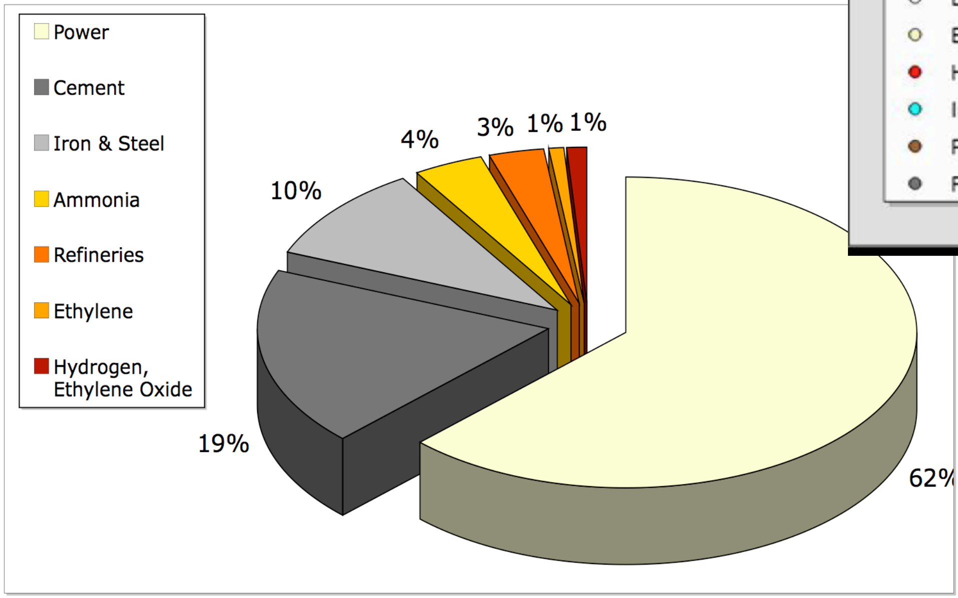
All Sources of CO_2



Reference: *Carbon Dioxide Emissions by Economic Sector 2005*, EarthTrends Data Tables: Climate and Atmosphere and International Energy Agency (IEA).

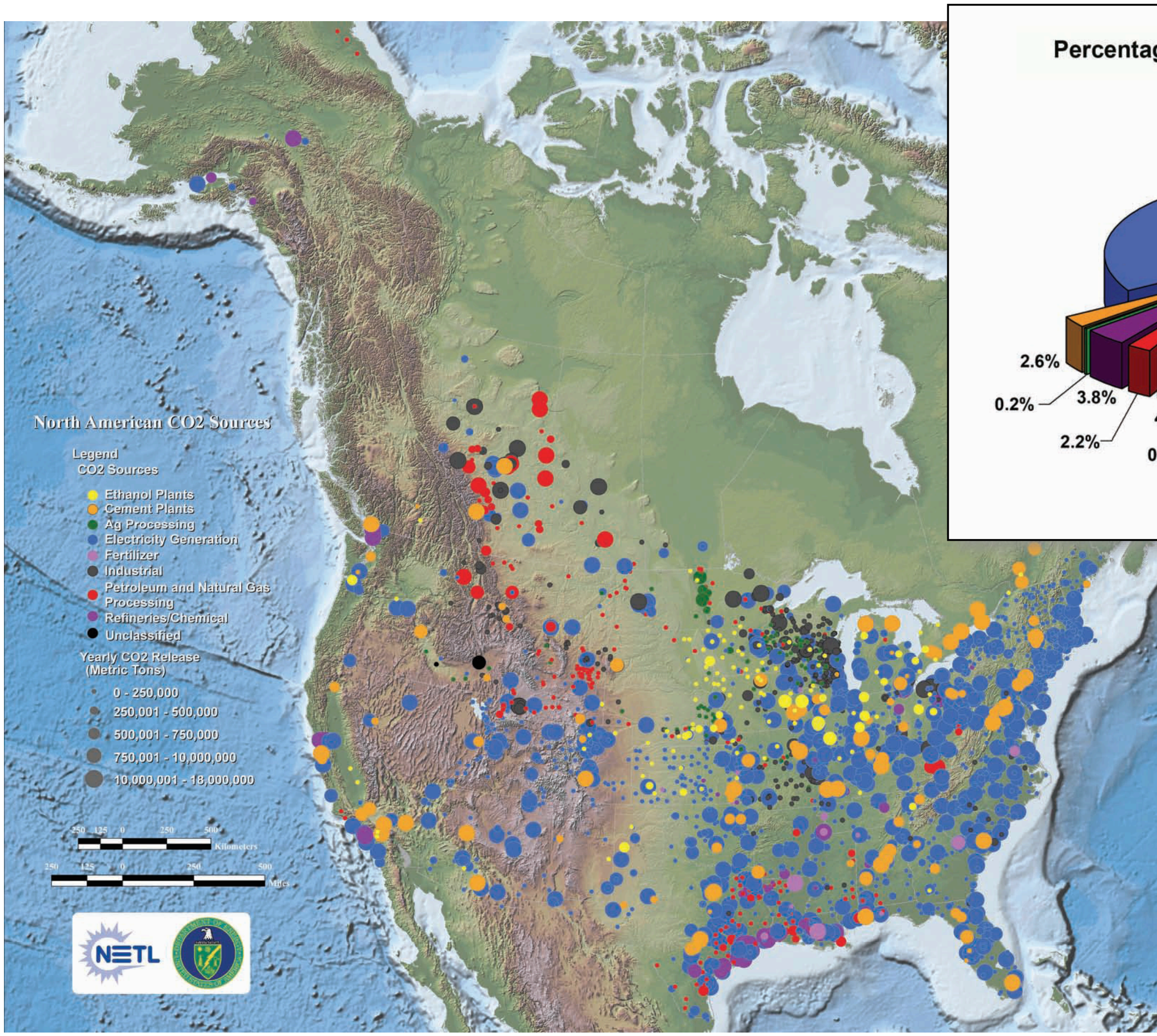
China Industrial Point Sources of CO_2

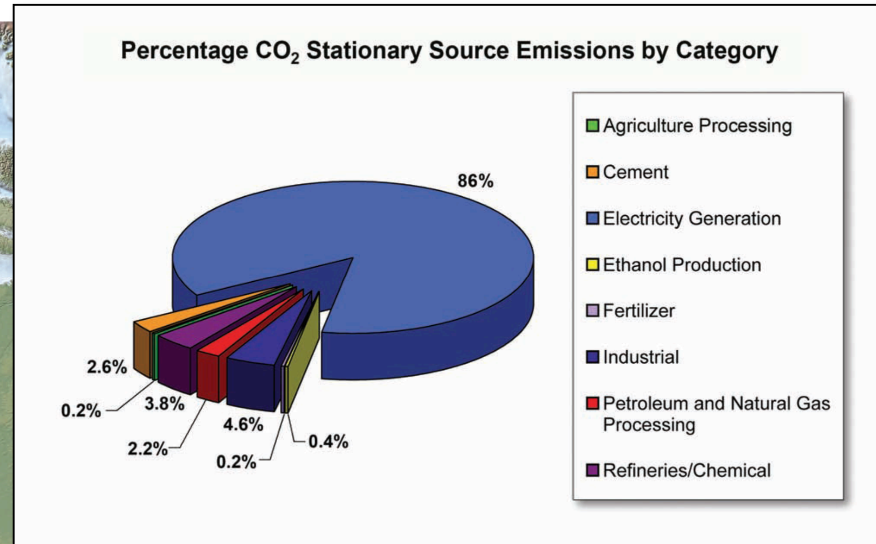




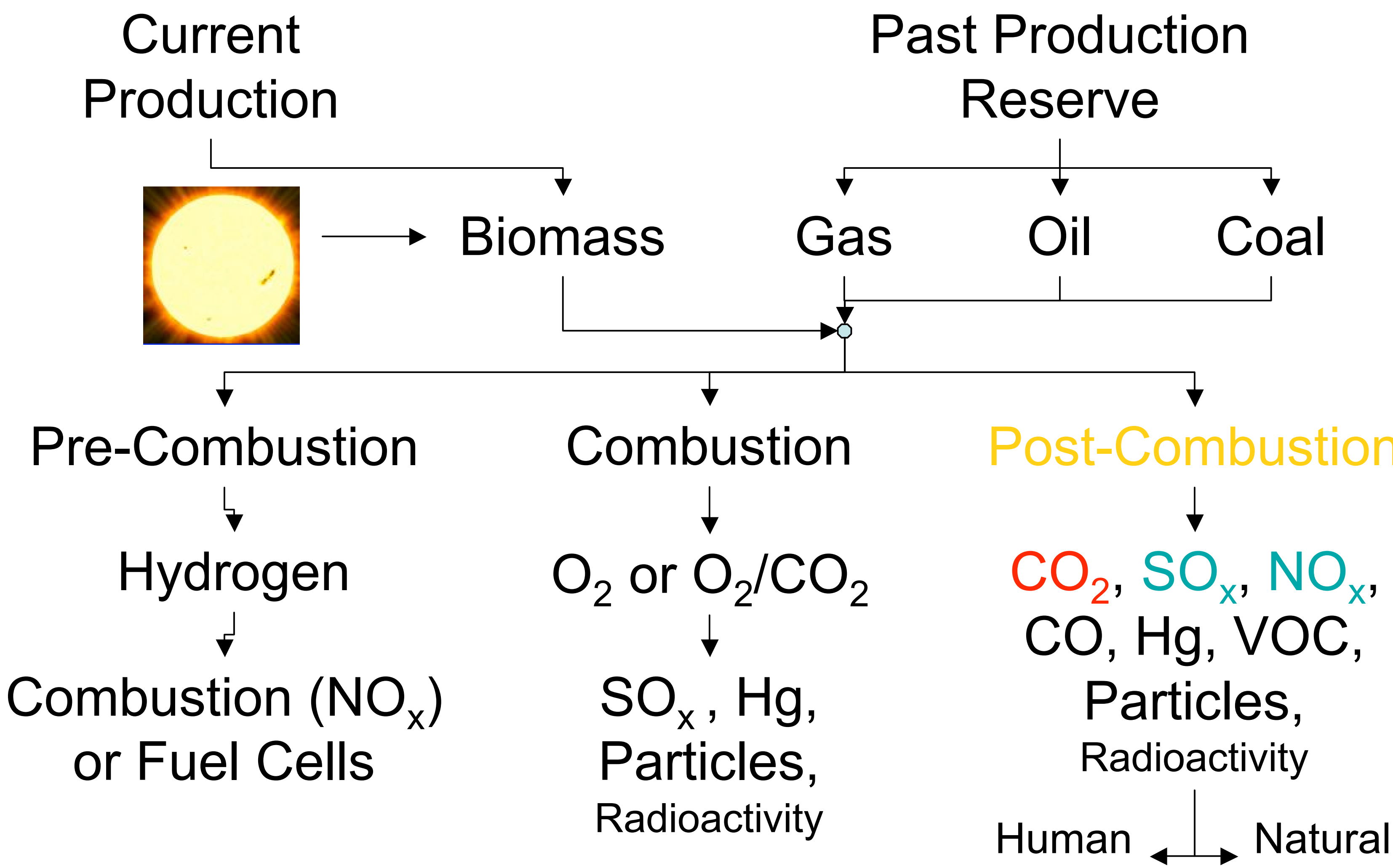
Reference: *Assessing Market Opportunities for CO_2 Capture and Storage (CCS) in China*, Battelle, 2005.

North America Industrial Point Sources of CO_2





Reference: *CO_2 Point Source Emission Estimation Methodologies Summary*, U.S. DOE National Energy Technology Laboratory, 2007.



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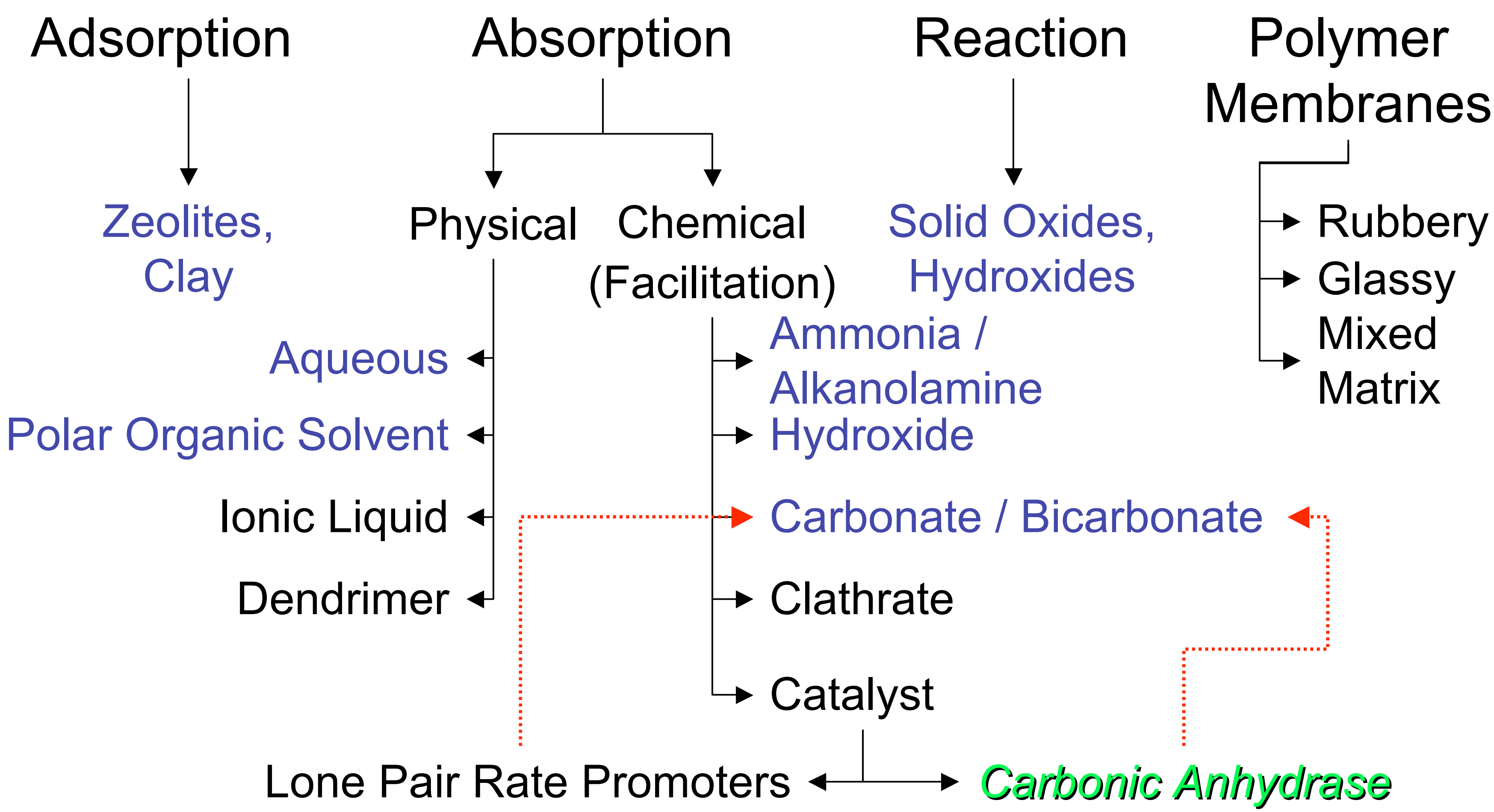
CO_2 Capture Chemistry



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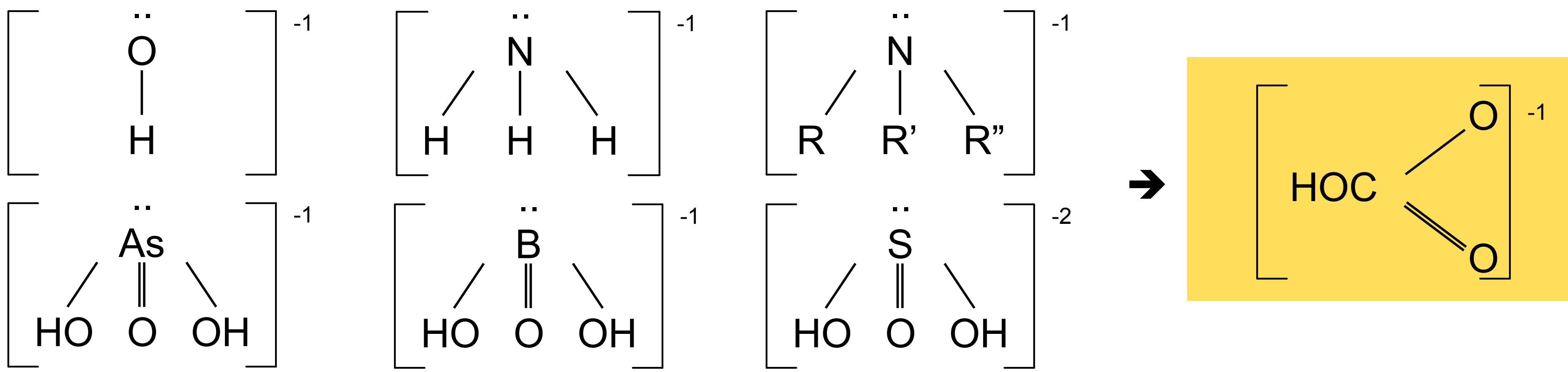
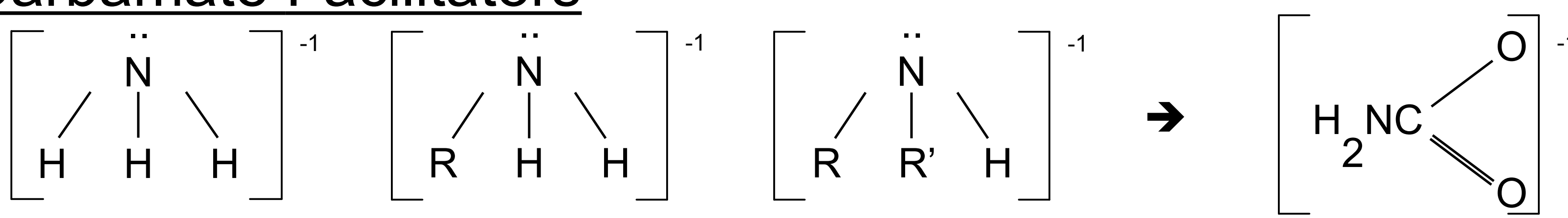
Bicarbonate Facilitators

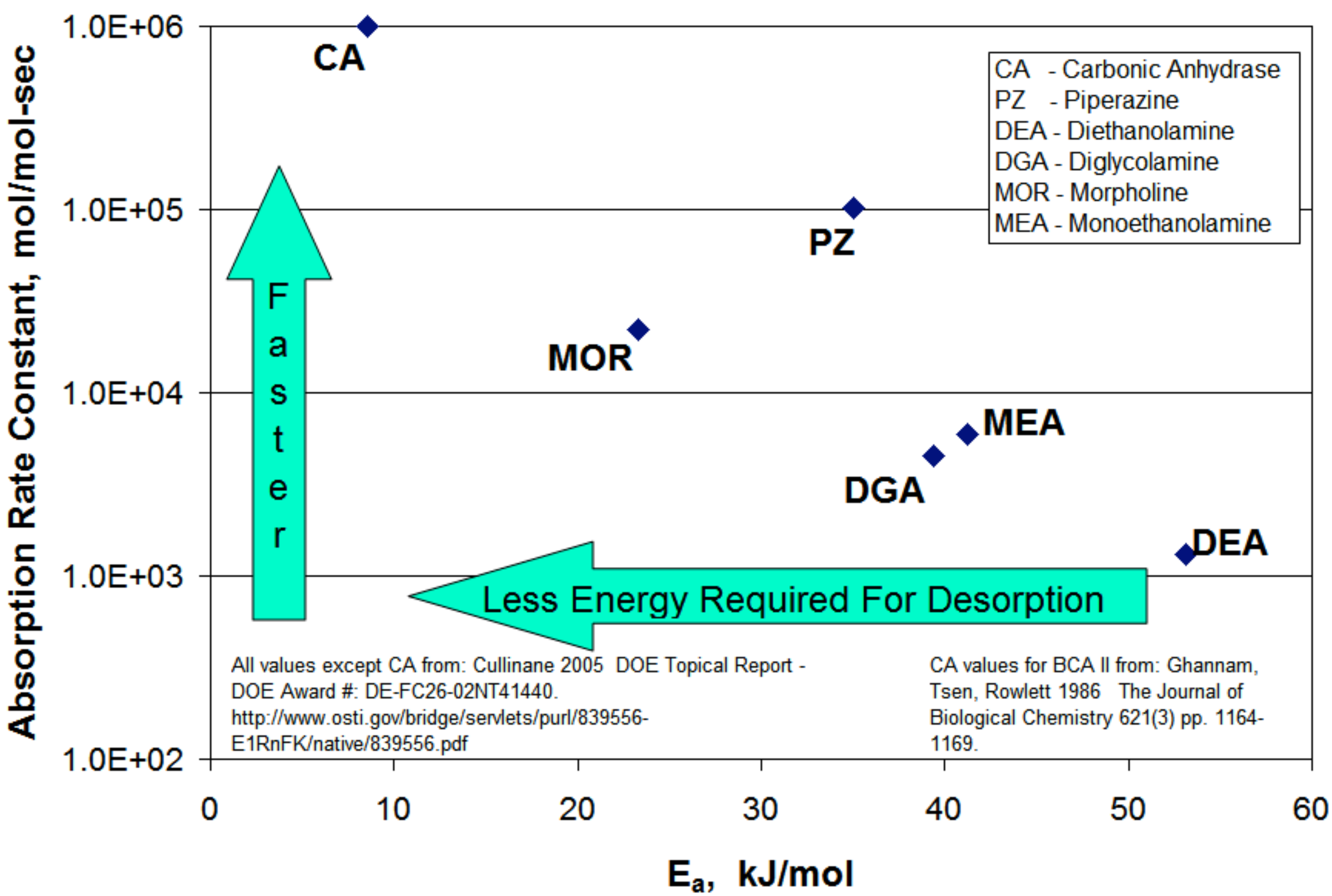
CA [R-Zn-HO:]$^{-1}$

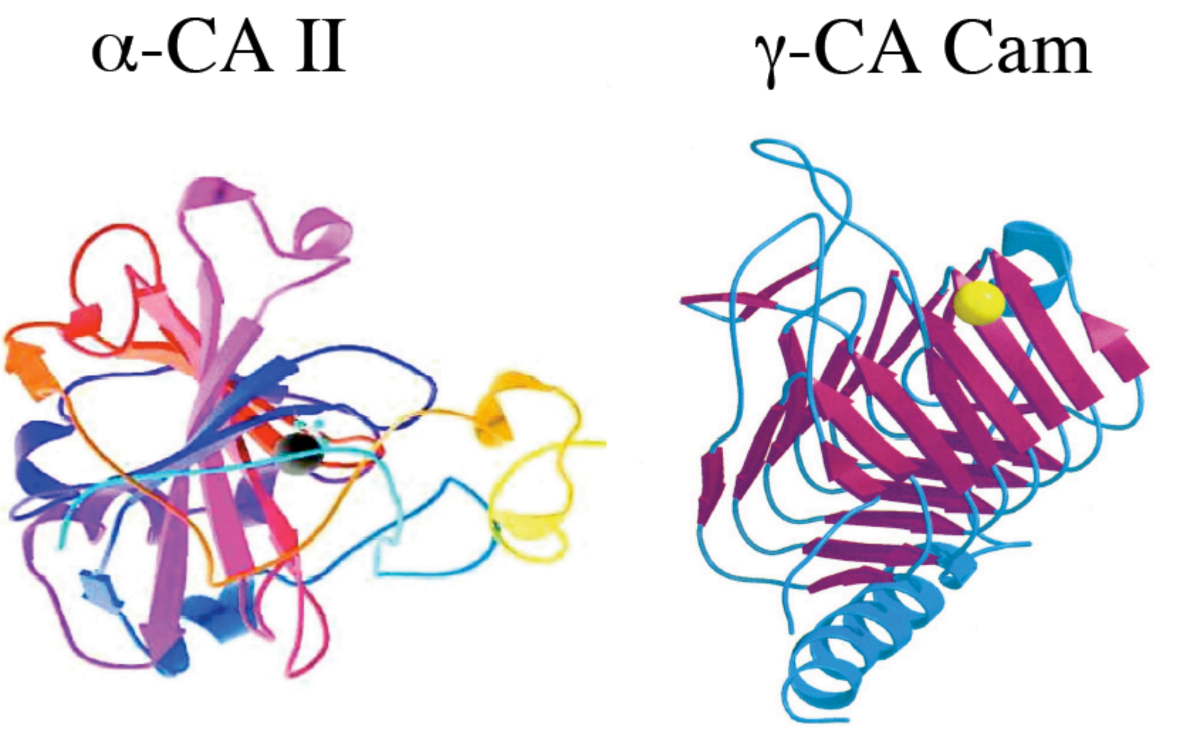


Carbamate Facilitators

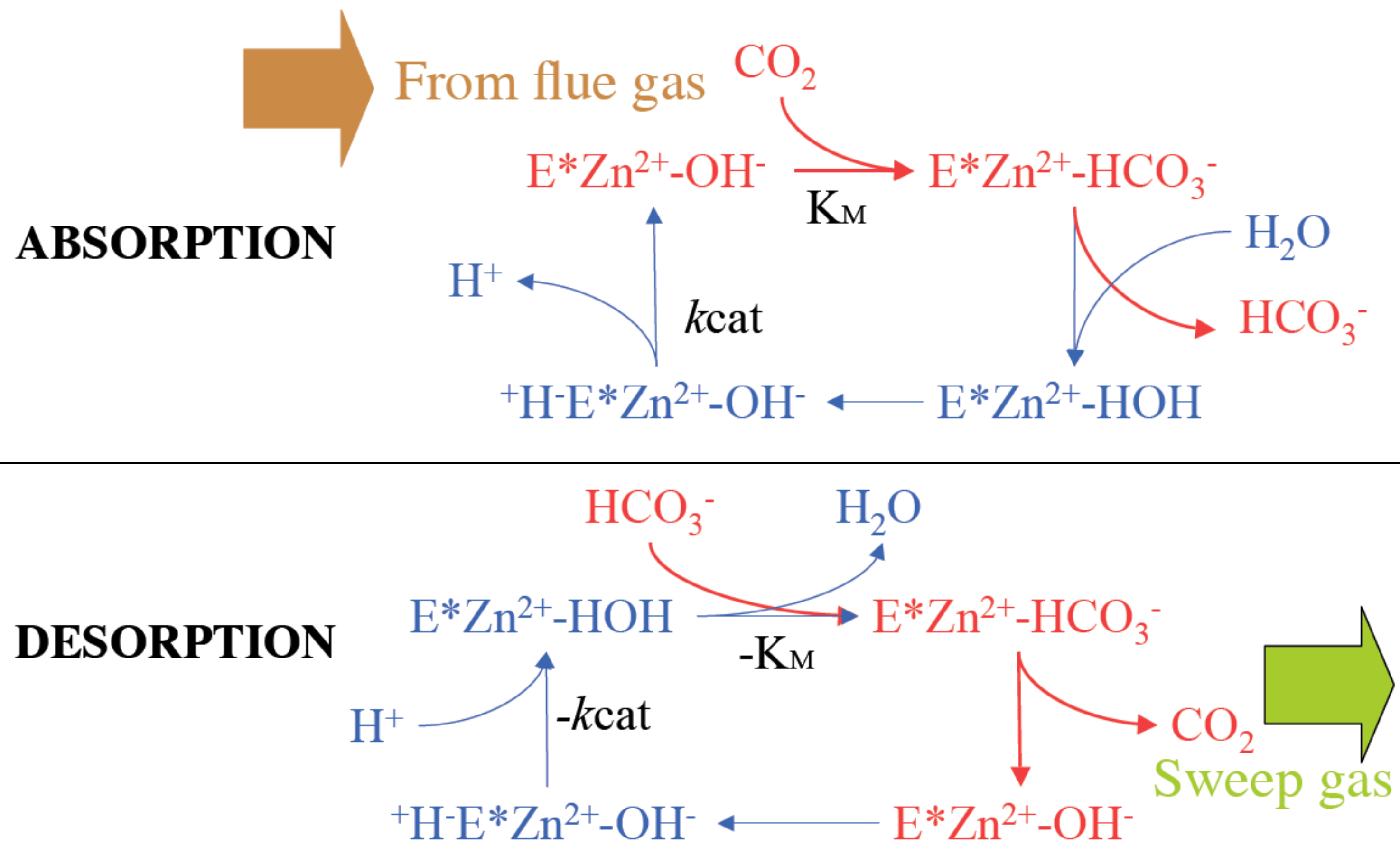


Benefit of CA




α-CA II
γ-CA Cam

Reaction Mechanisms



Mass Transfer Devices

Low Pressure Feed / Low Temperature Desorption

- Membrane Permeator — *Carbozyme*
- Twin Tower: CA Packed Bed Absorber / Stripper — *CO2Solution*

Low Pressure Feed / High Temperature Desorption

- Membrane Contactor Absorber / Stripper — *Kvaerner*
- Membrane Contactor (Absorber) Tower (Stripper) — *TNO*
- Twin Tower: Amine Packed Bed Absorber / Stripper — *Commonplace*

High Pressure Feed

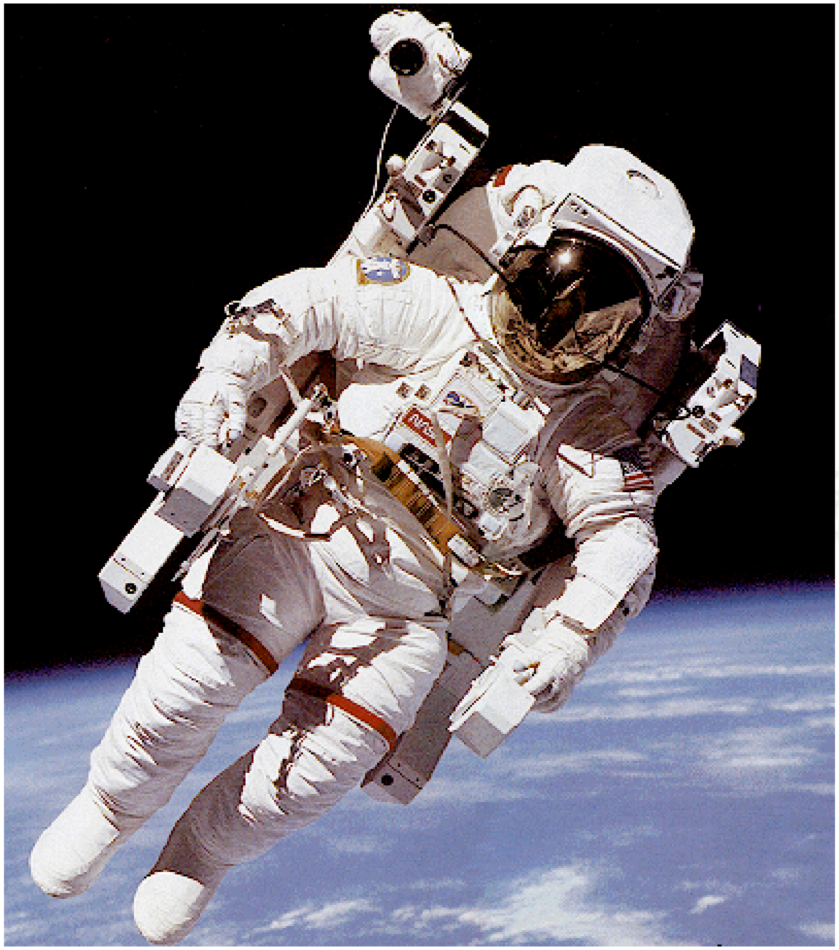
- Polymer Membranes — *Natco*

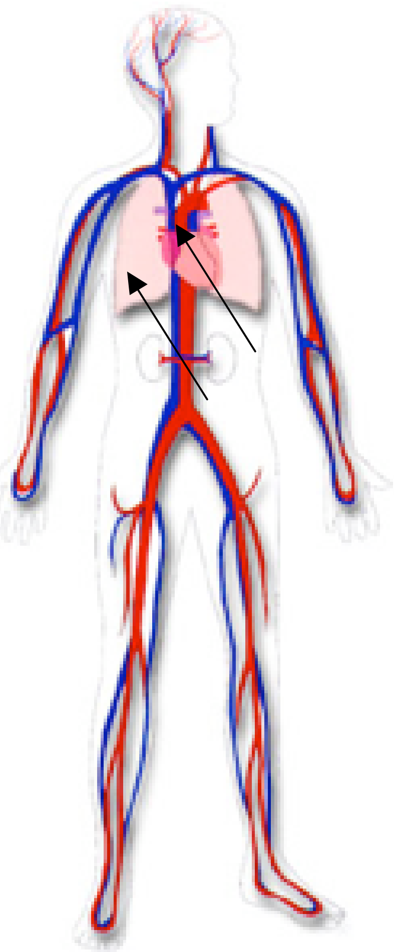
- Keys to high efficiency mass transfer:
  - High packing density
  - Maximal interfacial contact
  - No channeling
  - No dead zones
  - No foaming
- Mass Transfer Option Hierarchy

Structured Membranes
↳ Membranes
↳ Structured Packings
↳ Random Packings
↳ Trays

Efficiency

→ Contact efficiency improvement
Membranes = 10 X Trays





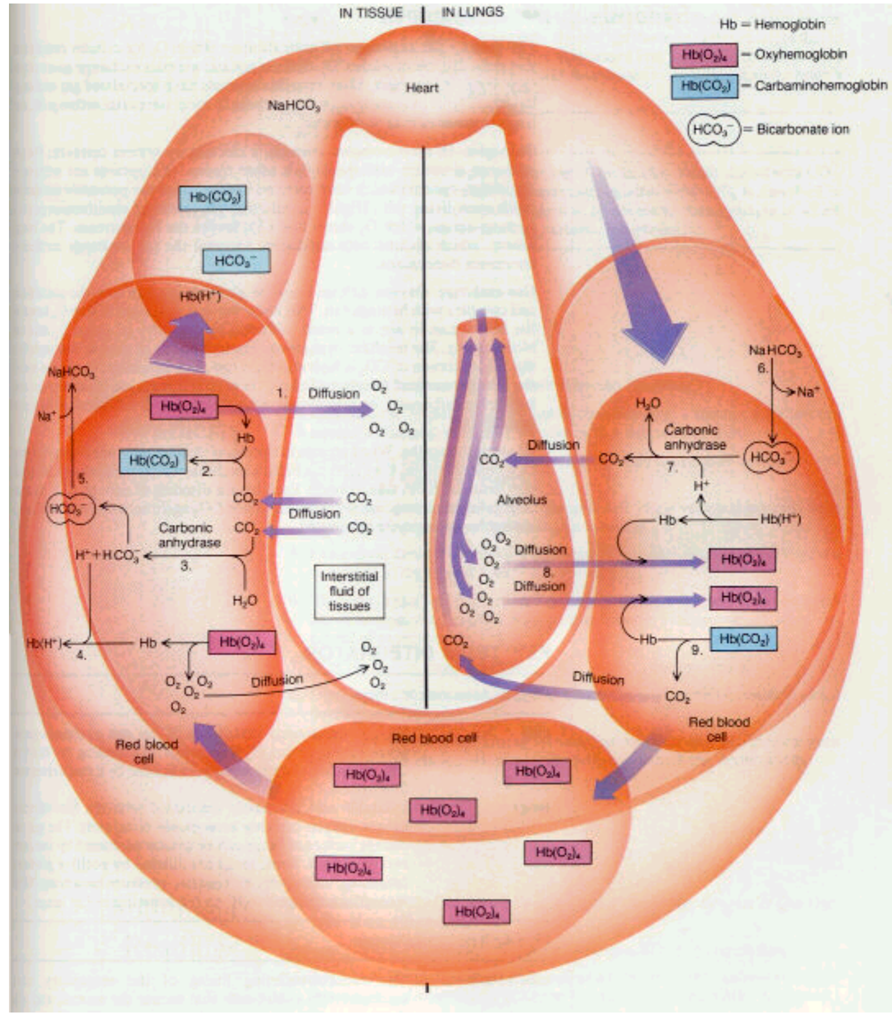
As seen by the Anatomist

Cardio-vascular / Cardio-pulmonary Systems

As seen by the Physiologist / Biochemist

A complex, integrated, multisystem adaptive design maintained in dynamic equilibrium.

- Cardiopulmonary System
- Cardiovascular System
- Respiratory System
- Cell/Tissue Transport/Enzyme Subsystems



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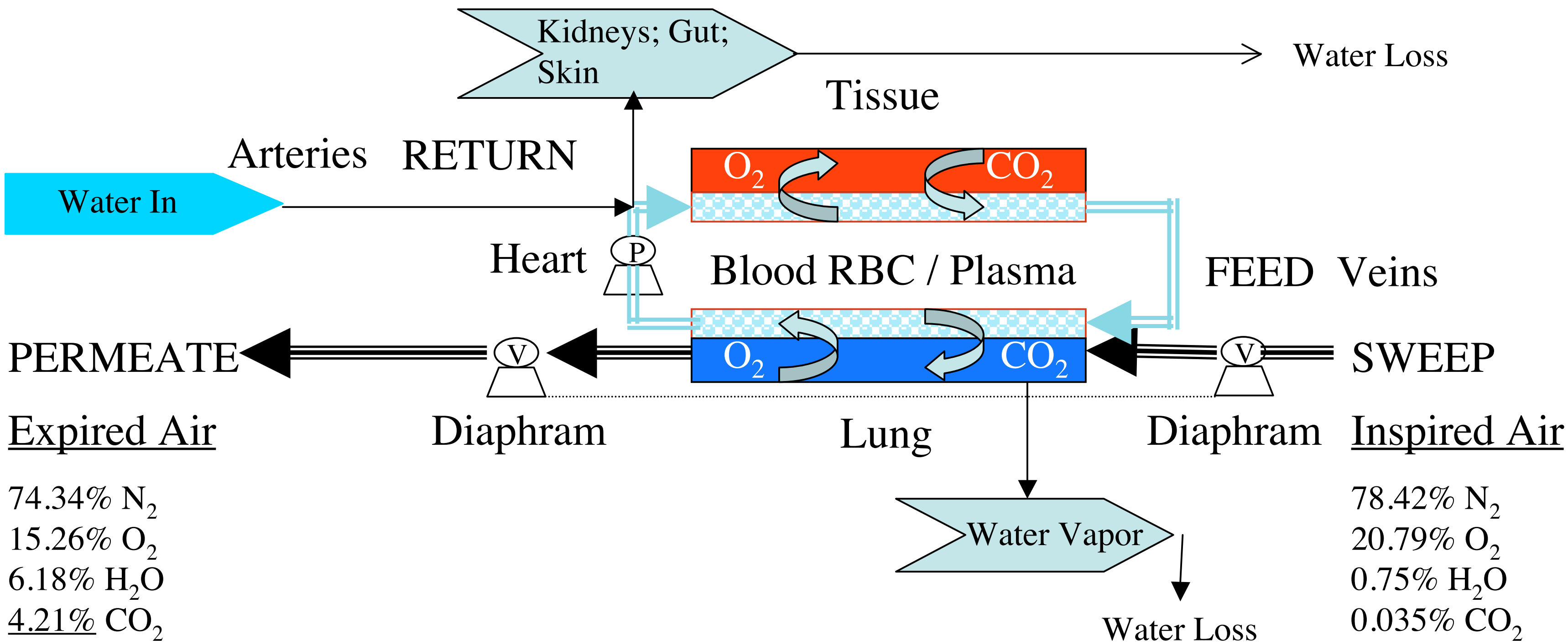
Chemical Engineer's View



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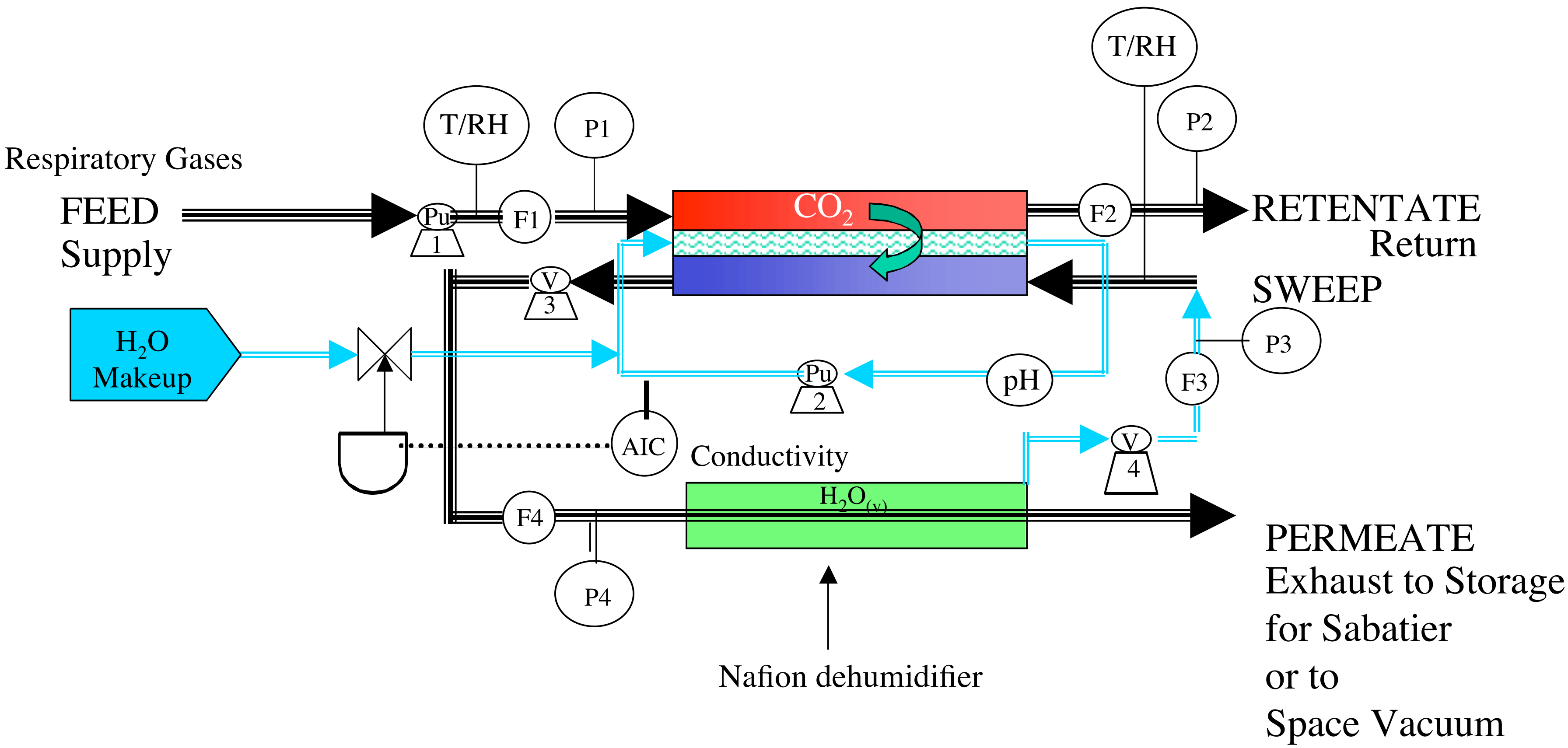
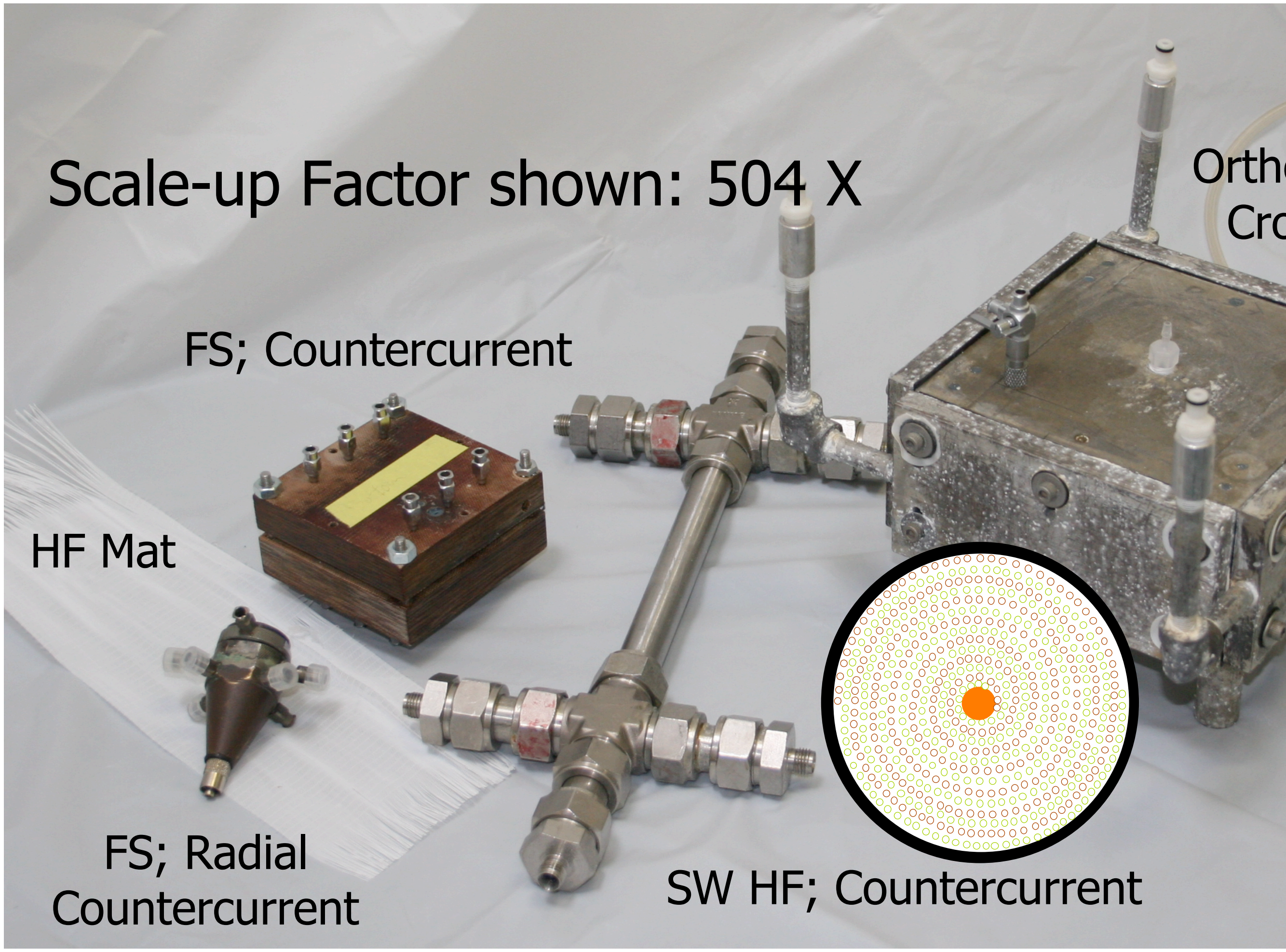
System Schematic



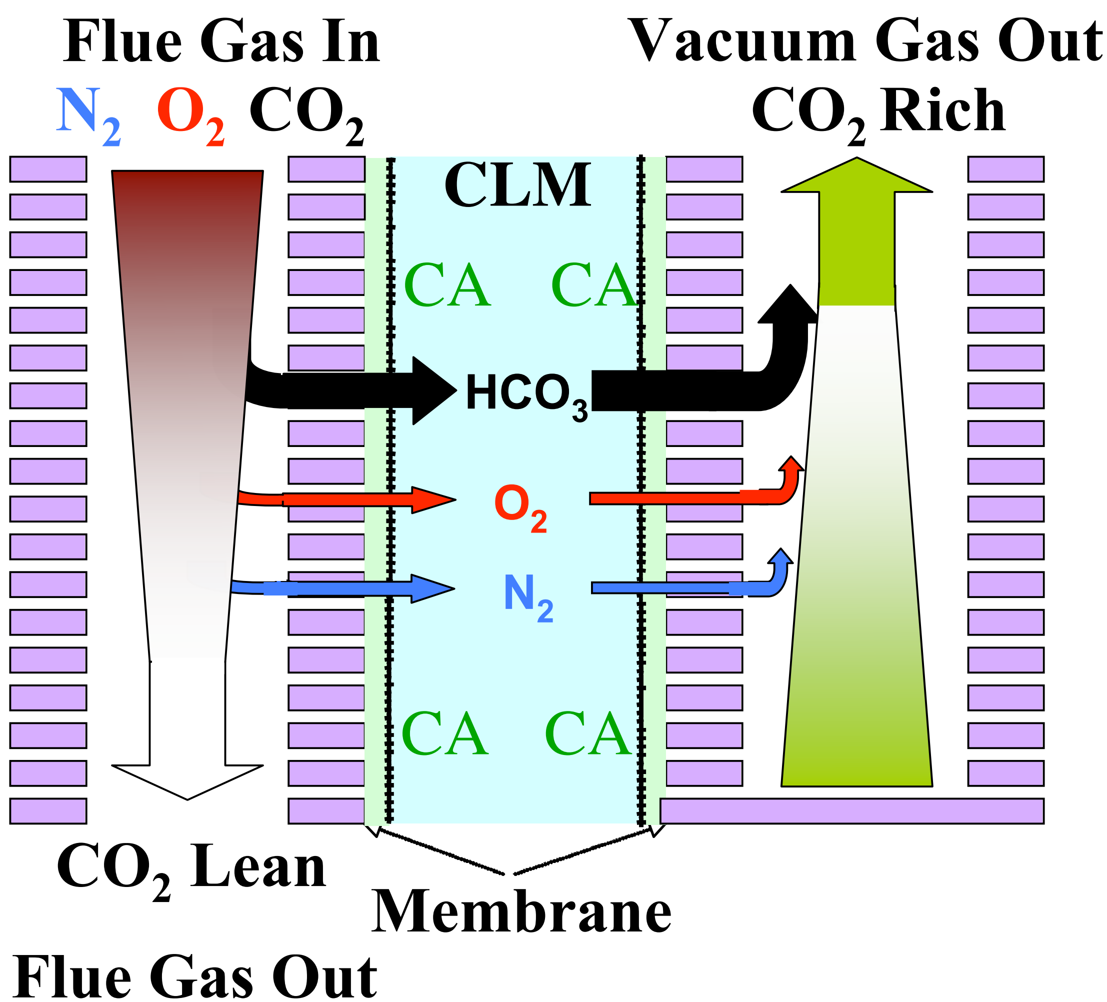
Mass Transfer Permeator Module Designs



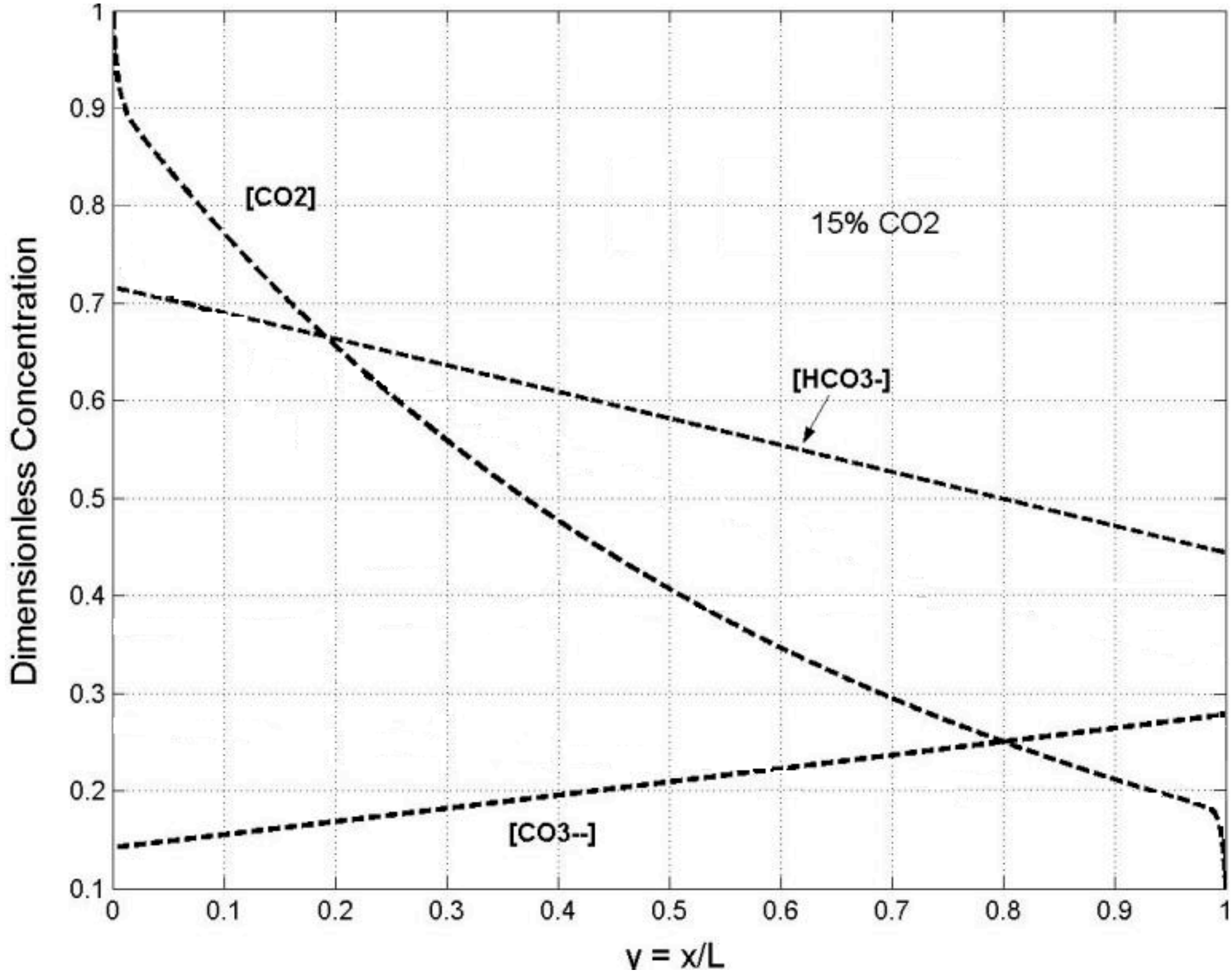
Cynara Membranes are easy to install

Carbozyme Permeation Process

CA = Carbonic Anhydrase



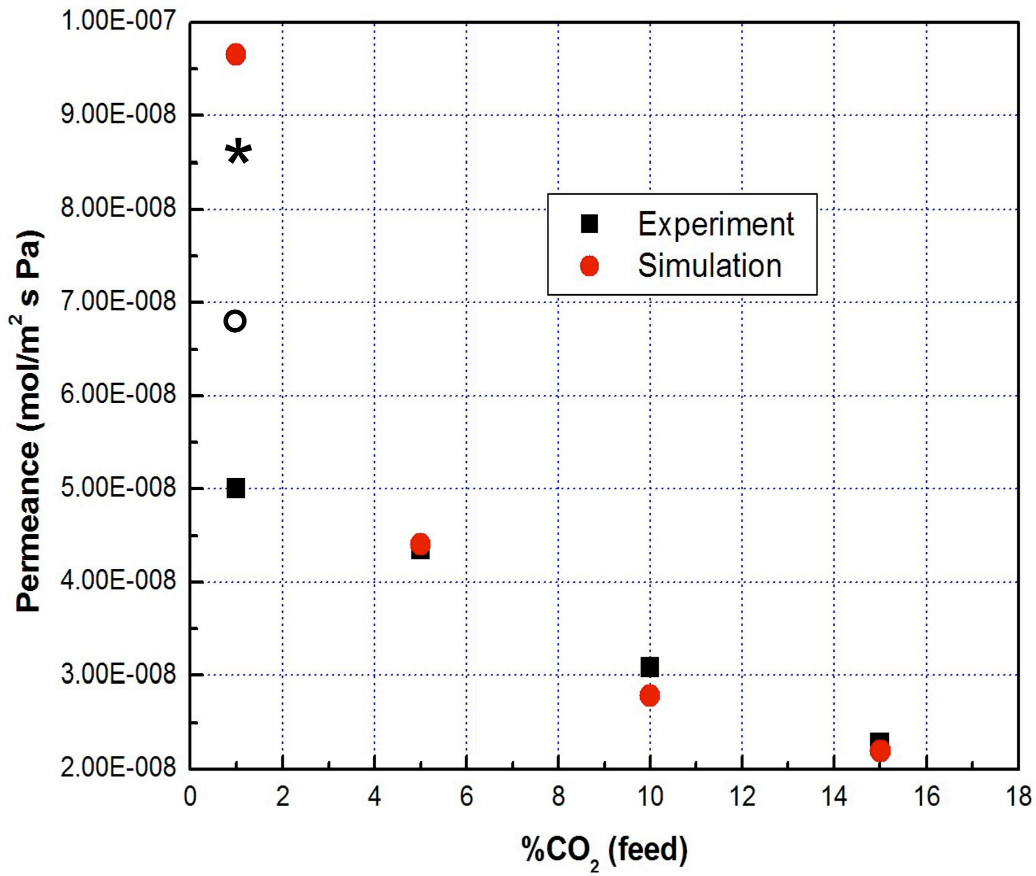
CLM Species Distribution



Experimental vs. Modeled Performance

- Celgard X40-200 micro-porous hollow fiber
- # of feed fibers = # of sweep fibers
- nominal porosity = 30%
- Total membrane surface area = 0.19 m^2
- Effective membrane area = 0.076 m^2
- No CLM pumping

In the simulation
$k\text{cat} = 1E6\ (s^{-1})$



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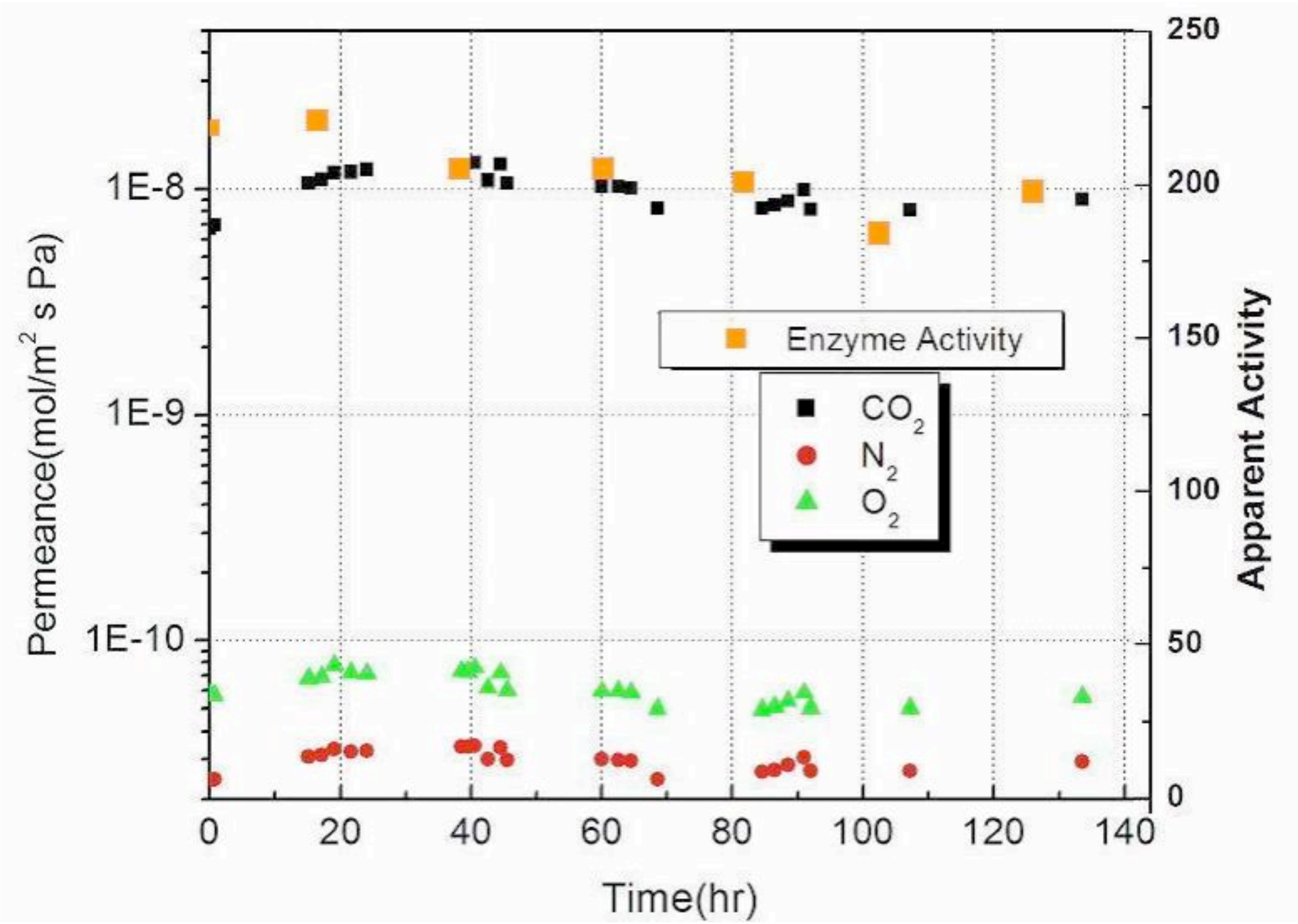
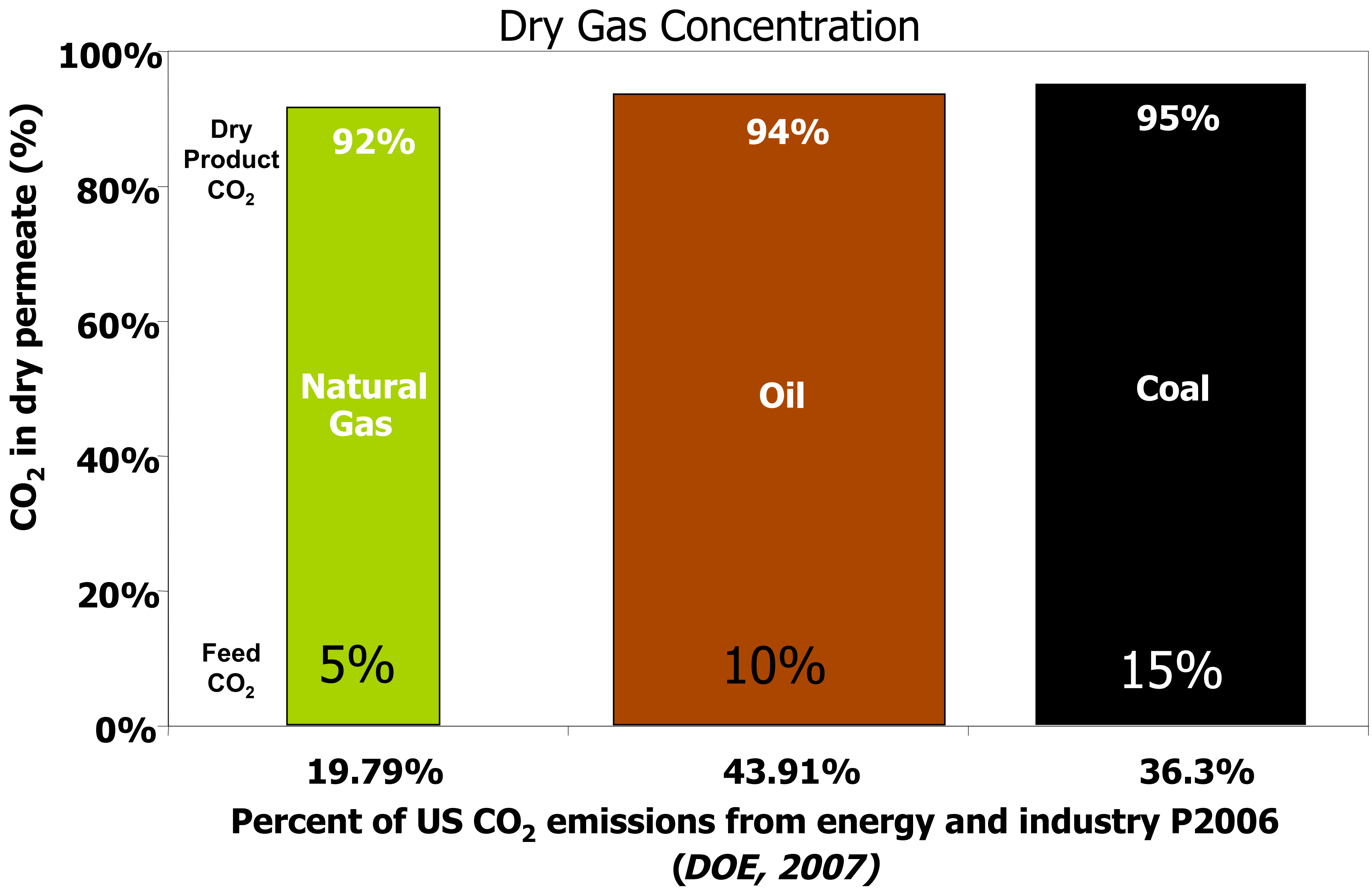
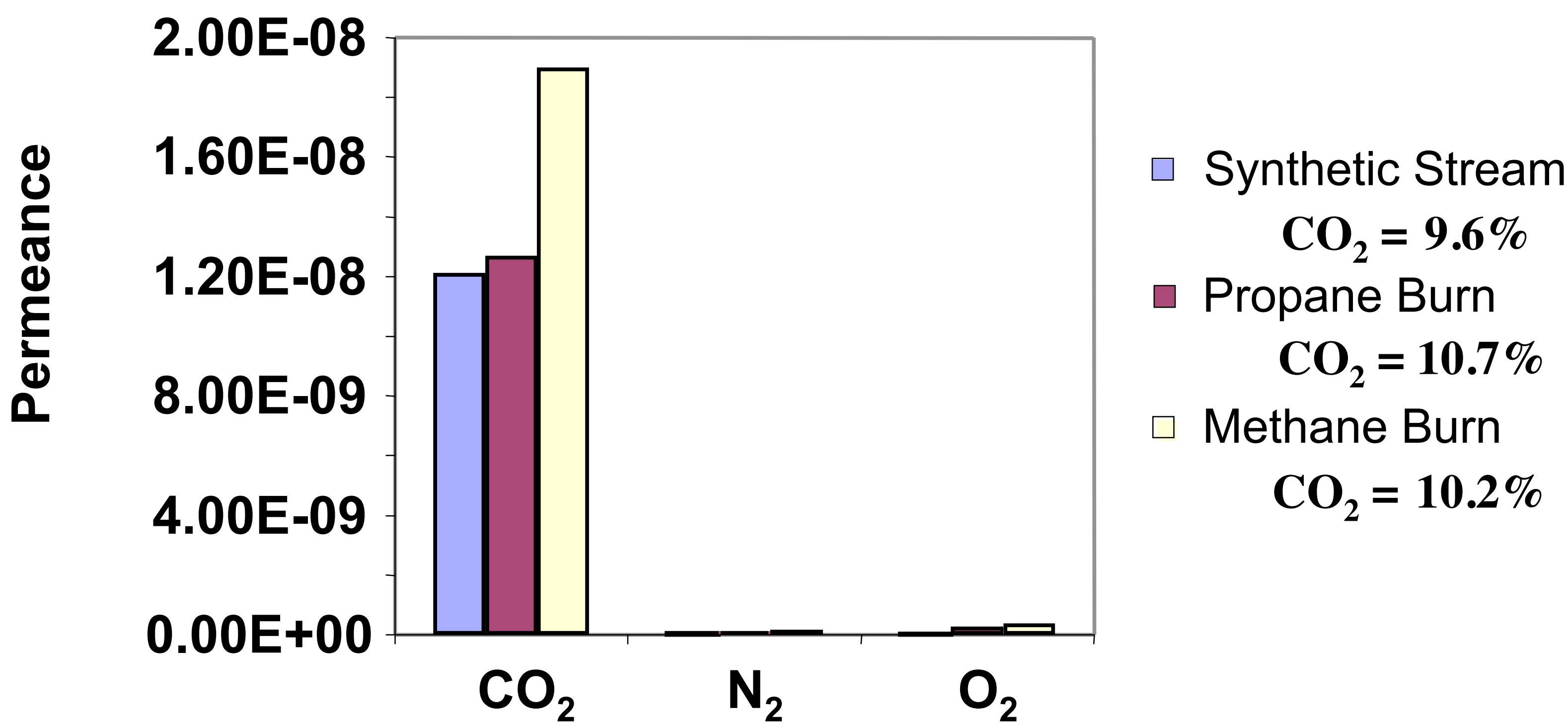
5-Day Permeate Gas Composition



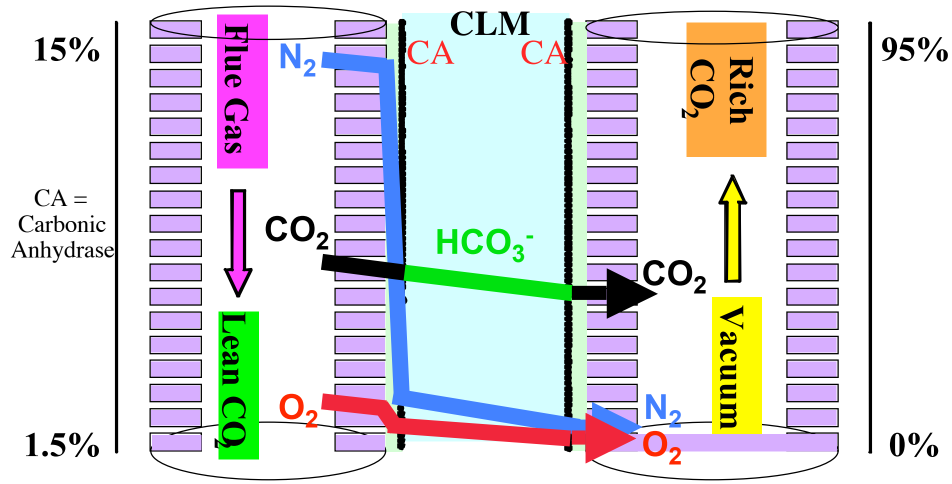
Demonstrated Performance



Pure Gas vs. Combustion Products



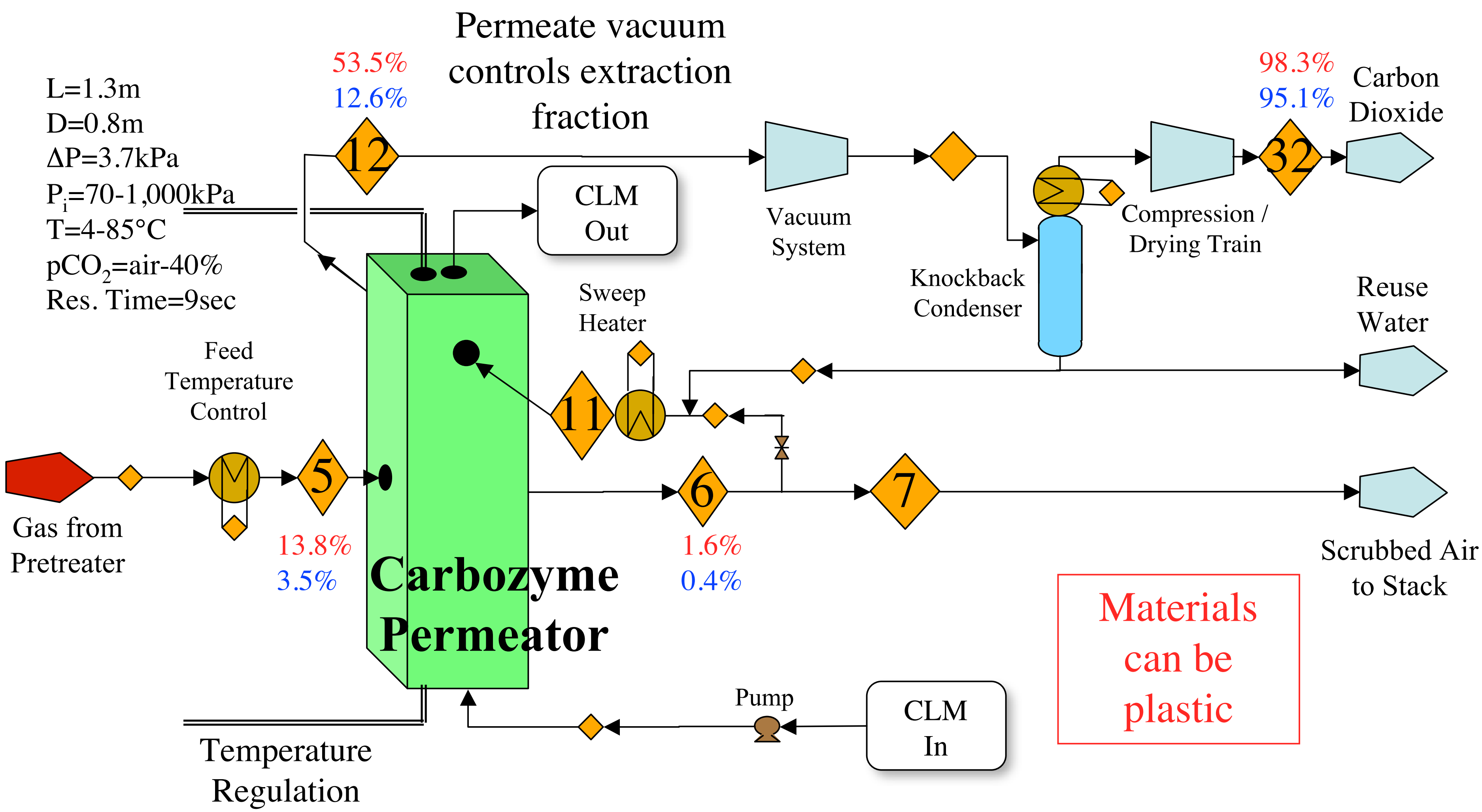
Pre-pilot - HFCLM



Hollow Fiber Membrane Permeator

Features	Benefits
Enzyme catalyzed rate promotion	Rapid, low energy, specific CO_2 reactions
Pressure Swing Absorption	Low pressure, no temperature swings
Hollow fiber G-L-G design, contained liquid membrane (CLM)	Efficient mass transfer, maximal surface / volume

Process Engineering Design



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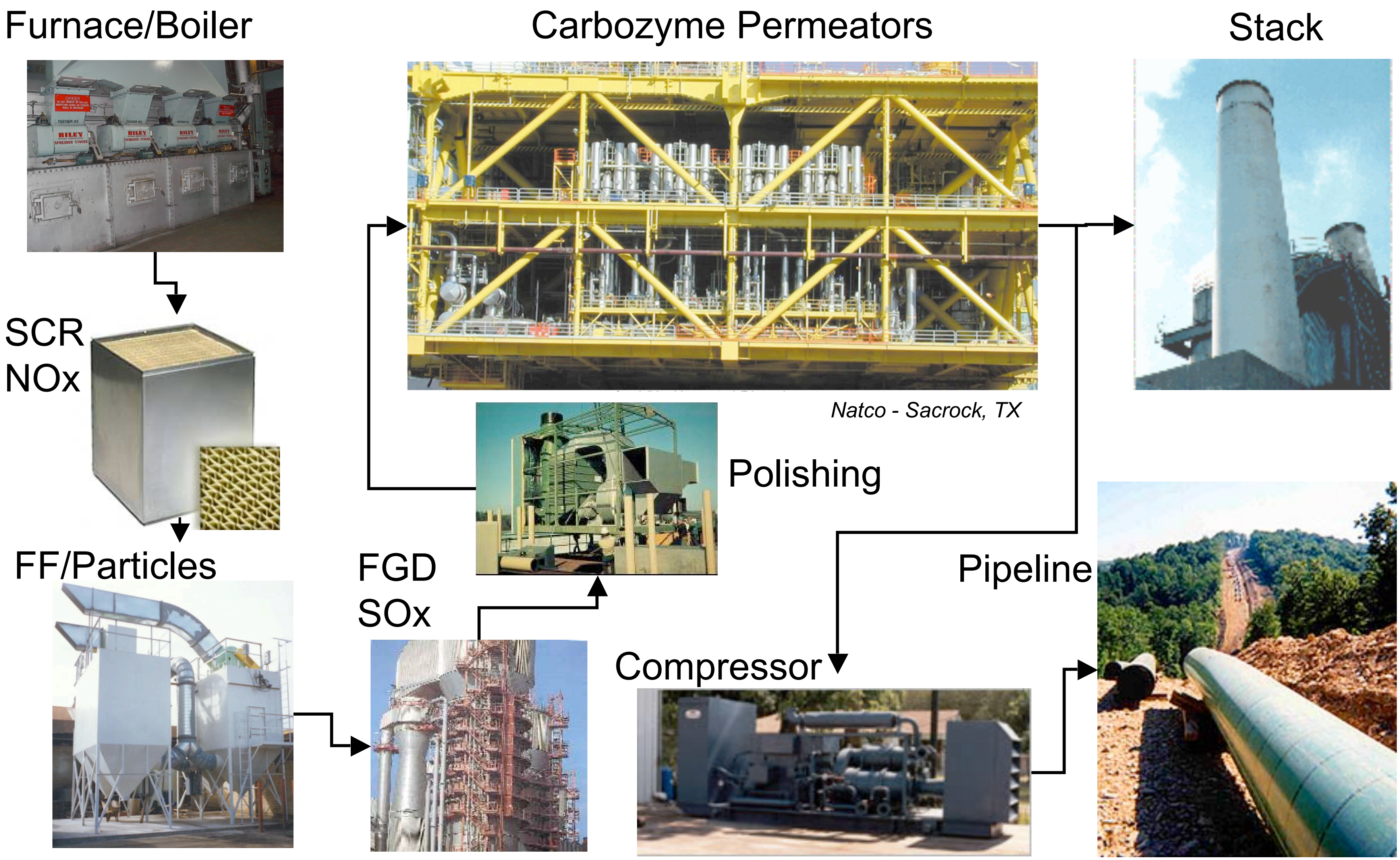
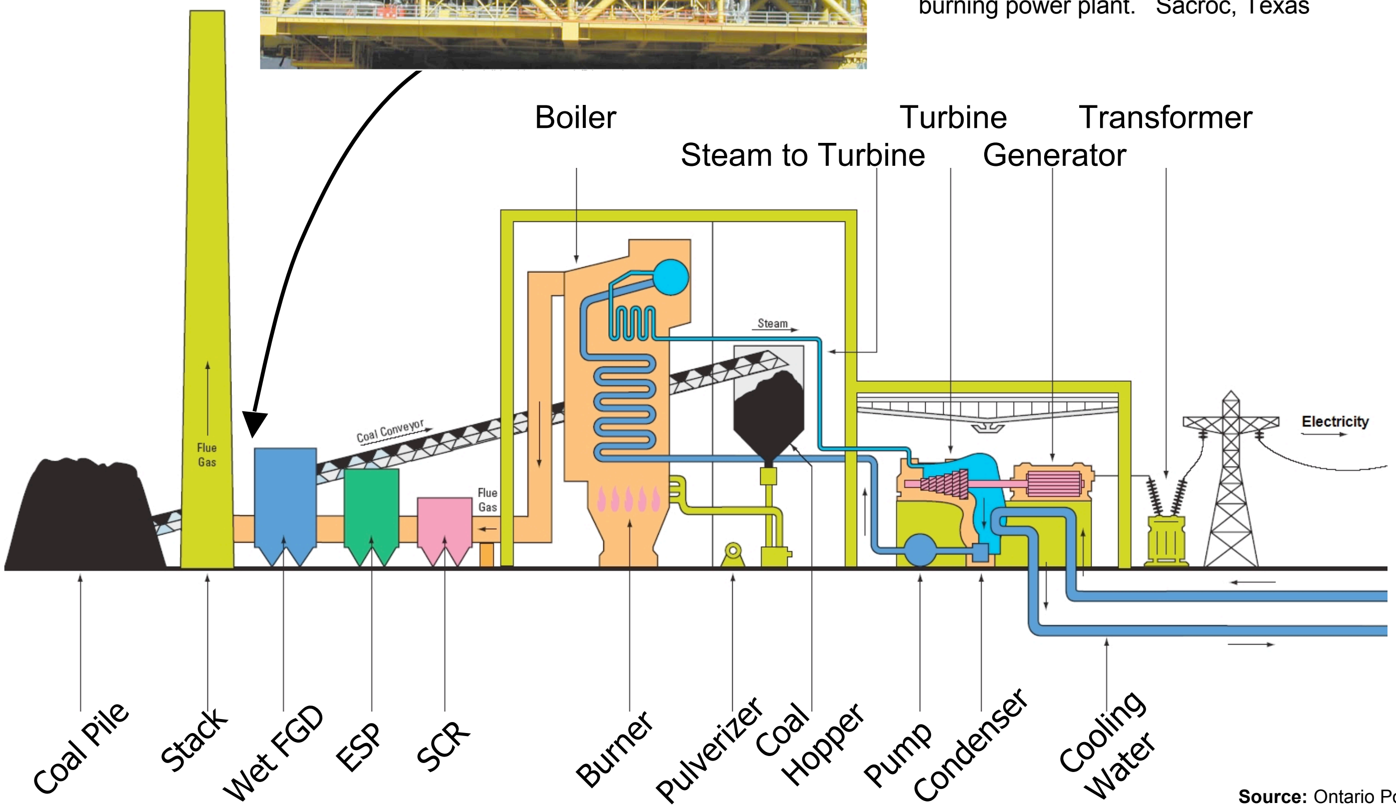
Representation of Flue Gas CO_2 Capture



Future Carbozyme CO_2 Capture Skid

Natco HF membrane high pressure post-EOR CO_2 capture facility. Daily volume = 1/2 that of a 400MW coal burning power plant. Sacroc, Texas



Source: Ontario Power Generation

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Composition / Characteristics of the Exhaust (Feed) Gas Stream

- *Acid gases*
  - *NOx-derived acids*
  - *SOx-derived acids*
  - *Halide acids*
- *Divalent cations*
  - *Hg^{++}*
- *Particles*

- *Inlet temperature*

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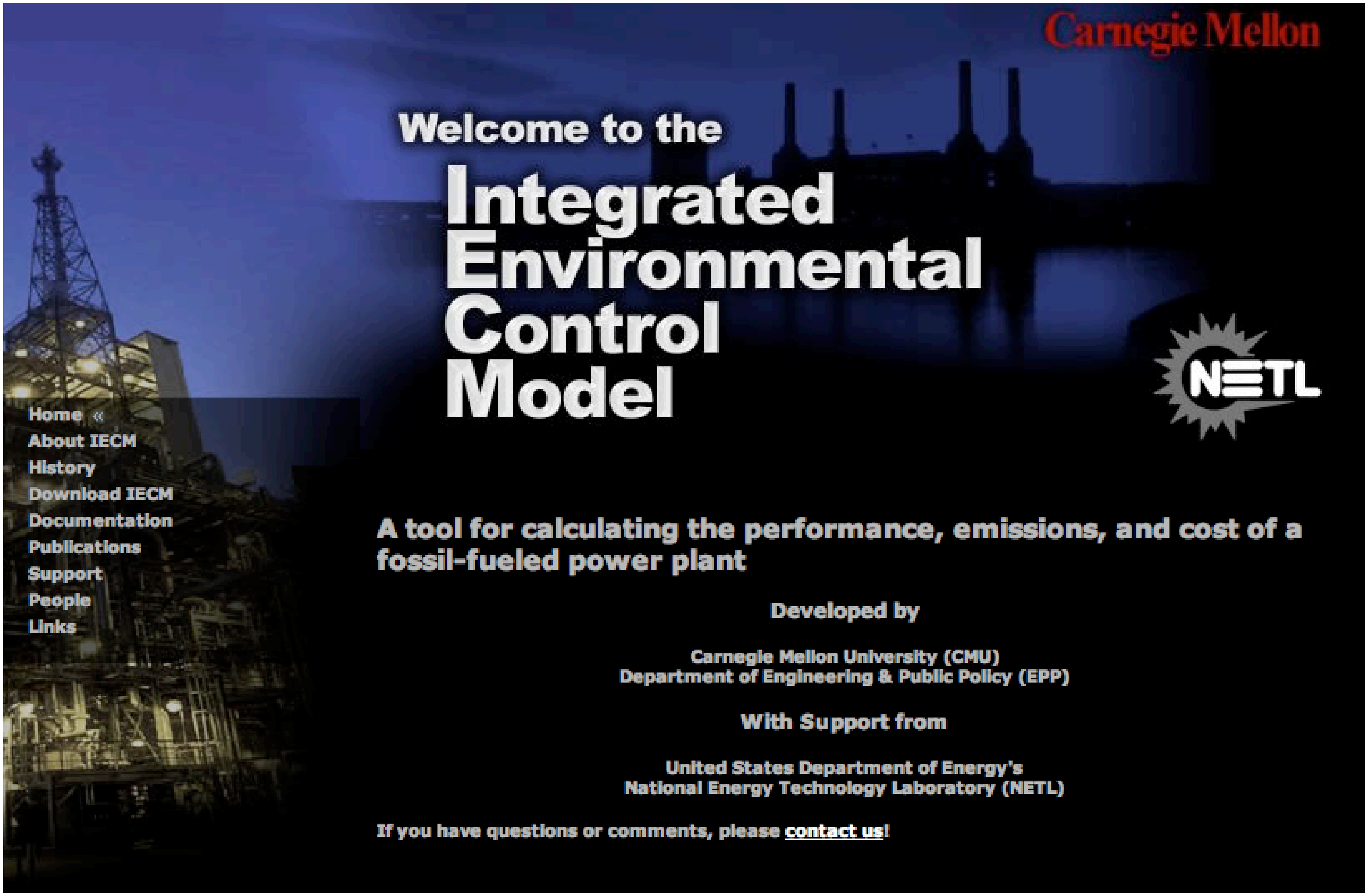
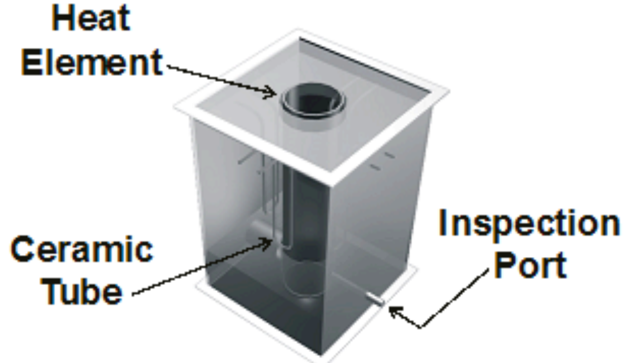
Integrated Environmental Control Model



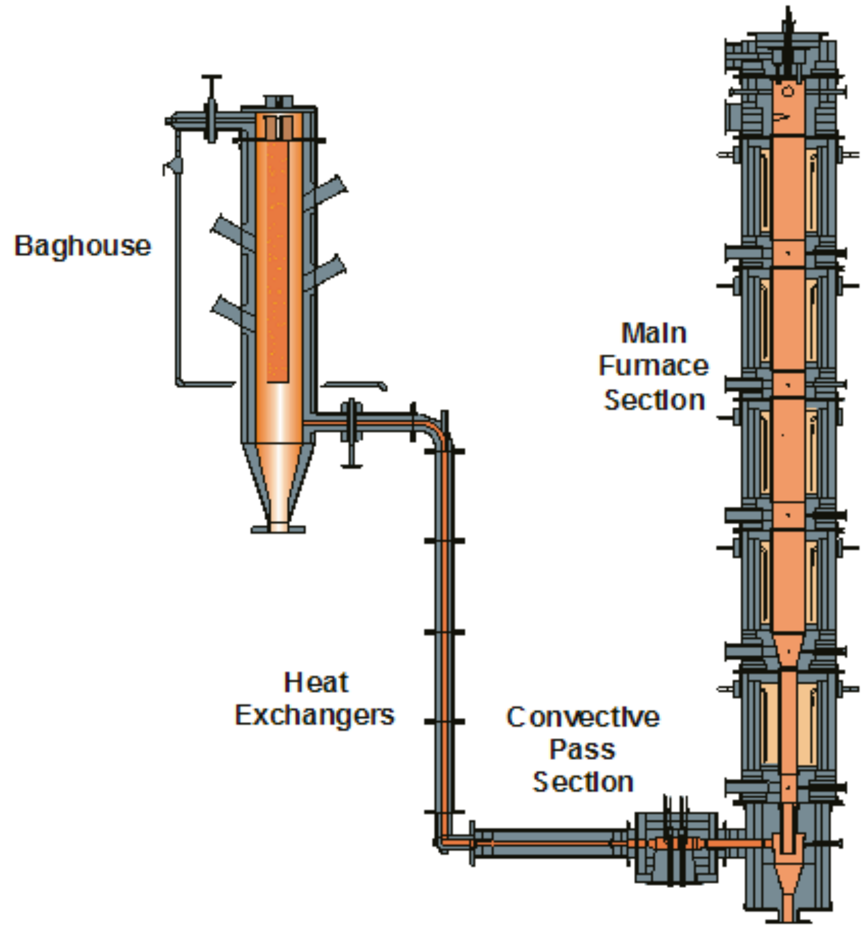
Most-Mined Coals in the U.S.

Seam or Mine(s) Name	State
Bituminous Coal	
Pittsburgh No. 8	Pennsylvania and West Virginia
Foidel Creek	Colorado
Sufco	Utah
Century	Ohio
Powder River Basin Subbituminous Coal	
Black Thunder	Wyoming
North Antelope–Eagle Butte	Wyoming
Cordero	Wyoming
Rosebud	Wyoming
Caballo	Wyoming
Buckskin–Belle Ayr–Antelope	Wyoming
Lignite	
Freedom	North Dakota
Falkirk	North Dakota
Big Brown	Texas
Center	North Dakota

EERC Conversion and Environmental Process Simulator (CEPS)



Typical Furnace Section



EERC's Combustion and Environmental Process Simulator

Second Floor

Ground Floor

Carbozyme

Solutions for Affordable Clean Energy™

NETL Data Analysis

Exhibit 4-12 Case 9 Total Plant Cost Summary

Client: USDOE/NETL — Report Date: 09-May-07
Project: Bituminous Baseline Study

TOTAL PLANT COST SUMMARY

Case: Case 9 - Subcritical PC w/o CO2
Plant Size: 550.4 MW,net — Estimate Type: Conceptual — Cost Base (Dec) 2006 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost $	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING	$16,102	$4,348	$9,748	$0	$0	$30,198	$2,706	$0	$4,936	$37,840	$69
2	COAL & SORBENT PREP & FEED	$10,847	$829	$2,750	$0	$0	$14,227	$1,247	$0	$2,321	$17,795	$32
3	FEEDWATER & MISC. BOP SYSTEMS	$37,503	$0	$18,011	$0	$0	$55,514	$5,071	$0	$9,963	$70,548	$128
4	PC BOILER											
4.1	PC Boiler & Accessories	$127,763	$0	$82,570	$0	$0	$210,334	$20,391	$0	$23,072	$253,797	$461
4.2	SCR (w/4.1)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4.3	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4.4-4.9	Boiler BoP (w/ ID Fans)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 4	**$127,763**	**$0**	**$82,570**	**$0**	**$0**	**$210,334**	**$20,391**	**$0**	**$23,072**	**$253,797**	**$461**
5	FLUE GAS CLEANUP	$83,756	$0	$28,598	$0	$0	$112,354	$10,675	$0	$12,303	$135,332	$246
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$0
6.2-6.9	Combustion Turbine Other	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 6	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$0
7.2-7.9	HRSG Accessories, Ductwork and Stack	$17,476	$1,006	$11,965	$0	$0	$30,447	$2,787	$0	$4,336	$37,570	$68
	SUBTOTAL 7	**$17,476**	**$1,006**	**$11,965**	**$0**	**$0**	**$30,447**	**$2,787**	**$0**	**$4,336**	**$37,570**	**$68**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$47,000	$0	$6,220	$0	$0	$53,220	$5,095	$0	$5,832	$64,147	$117
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$22,612	$1,045	$12,107	$0	$0	$35,764	$3,134	$0	$5,418	$44,316	$81
	SUBTOTAL 8	**$69,612**	**$1,045**	**$18,328**	**$0**	**$0**	**$88,984**	**$8,230**	**$0**	**$11,249**	**$108,463**	**$197**
9	COOLING WATER SYSTEM	$11,659	$6,571	$11,683	$0	$0	$29,913	$2,792	$0	$4,499	$37,204	$68
10	ASH/SPENT SORBENT HANDLING SYS	$4,383	$138	$5,829	$0	$0	$10,350	$985	$0	$1,166	$12,502	$23
11	ACCESSORY ELECTRIC PLANT	$15,802	$6,032	$17,773	$0	$0	$39,607	$3,506	$0	$5,366	$48,479	$88
12	INSTRUMENTATION & CONTROL	$8,006	$0	$8,413	$0	$0	$16,419	$1,503	$0	$2,204	$20,126	$37
13	IMPROVEMENTS TO SITE	$2,833	$1,629	$5,752	$0	$0	$10,214	$1,003	$0	$2,243	$13,460	$24
14	BUILDINGS & STRUCTURES	$0	$22,304	$21,358	$0	$0	$43,662	$3,934	$0	$11,899	$59,495	$108
	TOTAL COST	$405,742	$43,703	$242,779	$0	$0	$692,224	$64,830	$0	$95,558	$852,612	$1,549

Total Cost $853M

Reference: *Cost and Performances Baseline for Fossil Energy Plants*, DOE/NETL, 2007.

NETL Data Analysis

Exhibit 4-22 Case 10 Total Plant Cost Summary

Client: USDOE/NETL — Report Date: 09-May-07
Project: Bituminous Baseline Study

TOTAL PLANT COST SUMMARY

Case: Case 10 - Subcritical PC w/ CO2
Plant Size: 549.6 MW,net — Estimate Type: Conceptual — Cost Base (Dec) 2006 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost $	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING	$20,525	$5,540	$12,420	$0	$0	$38,485	$3,449	$0	$6,290	$48,223	$88
2	COAL & SORBENT PREP & FEED	$13,990	$807	$3,544	$0	$0	$18,342	$1,608	$0	$2,992	$22,942	$42
3	FEEDWATER & MISC. BOP SYSTEMS	$53,307	$0	$25,510	$0	$0	$78,817	$7,217	$0	$14,343	$100,377	$183
4	PC BOILER											
4.1	PC Boiler & Accessories	$167,758	$0	$108,417	$0	$0	$276,176	$26,774	$0	$30,295	$333,245	$606
4.2	SCR (w/4.1)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4.3	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4.4-4.9	Boiler BoP (w/ ID Fans)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 4	**$167,758**	**$0**	**$108,417**	**$0**	**$0**	**$276,176**	**$26,774**	**$0**	**$30,295**	**$333,245**	**$606**
5	FLUE GAS CLEANUP	$109,618	$0	$37,721	$0	$0	$147,340	$14,000	$0	$16,134	$177,474	$323
5B	CO_2 REMOVAL & COMPRESSION	$243,432	$0	$74,100	$0	$0	$317,532	$30,138	$56,039	$80,742	$484,450	$881
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$0
6.2-6.9	Combustion Turbine Other	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 6	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$0
7.2-7.9	HRSG Accessories, Ductwork and Stack	$19,363	$1,062	$13,228	$0	$0	$33,653	$3,074	$0	$4,824	$41,551	$76
	SUBTOTAL 7	**$19,363**	**$1,062**	**$13,228**	**$0**	**$0**	**$33,653**	**$3,074**	**$0**	**$4,824**	**$41,551**	**$76**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$52,758	$0	$6,989	$0	$0	$59,747	$5,720	$0	$6,547	$72,014	$131
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$26,773	$1,170	$15,006	$0	$0	$42,949	$3,737	$0	$6,617	$53,303	$97
	SUBTOTAL 8	**$79,532**	**$1,170**	**$21,995**	**$0**	**$0**	**$102,697**	**$9,457**	**$0**	**$13,163**	**$125,317**	**$228**
9	COOLING WATER SYSTEM	$21,405	$11,272	$20,092	$0	$0	$52,768	$4,916	$0	$7,834	$65,518	$119
10	ASH/SPENT SORBENT HANDLING SYS	$5,440	$171	$7,234	$0	$0	$12,844	$1,223	$0	$1,448	$15,515	$28
11	ACCESSORY ELECTRIC PLANT	$20,789	$10,729	$30,669	$0	$0	$62,187	$5,554	$0	$8,642	$76,384	$139
12	INSTRUMENTATION & CONTROL	$9,150	$0	$9,615	$0	$0	$18,765	$1,718	$938	$2,635	$24,056	$44
13	IMPROVEMENTS TO SITE	$3,201	$1,840	$6,500	$0	$0	$11,541	$1,133	$0	$2,535	$15,210	$28
14	BUILDINGS & STRUCTURES	$0	$24,892	$23,781	$0	$0	$48,672	$4,385	$0	$7,959	$61,016	$111
	TOTAL COST	**$767,510**	**$57,483**	**$394,827**	**$0**	**$0**	**$1,219,819**	**$114,645**	**$56,977**	**$199,835**	**$1,591,277**	**$2,895**

Total Cost $1,591M

Reference: *Cost and Performances Baseline for Fossil Energy Plants*, DOE/NETL, 2007.

Additional CZ capex $250M

Table 10: PC Capital Summary

Capital Cost Summary	No CO_2 Capture (Case 7C) x $1000	With CO_2 Capture (Case 7A) x $1000
Coal and Sorbent Handling	$15,822	$15,822
Coal and Sorbent Preparation and Feed	$12,409	$12,409
Feedwater Systems	$24,854	$24,854
PC Boiler and Accessories	$109,564	$105,988
Flue Gas Cleanup	$61,486	$61,486
Mercury Removal	$0	$0
CO_2 Removal and Compression	$0	$110,516
Combustion Turbine/Generator and Accessories	$0	$0
HRSG & Stack	$20,544	$20,544
Steam Turbine Generator and Accessories	$72,885	$72,885
Cooling Water System	$19,584	$19,584
Ash/Spent Sorbent Handling System	$19,252	$19,252
Accessory Electric Plant	$24,152	$24,152
Instrumentation & Controls	$9,341	$9,341
Buildings & Structures	$35,699	$33,695
Process Capital	$425,592	$530,528
Engineering Fees	$25,536	$31,832
Process Contingency	$0	$5,957
Project Contingency	$65,296	$82,752
Allowable Funds Used During Construction	$42,842	$52,929
Land Cost	$512	$544
Inventory Capital	$5,530	$6,316
Preproduction Costs	$15,064	$18,379
Total Capital Requirement (TCR)	$580,372	$729,237
Levelized Capital Charge Factor (%)	14%	14%
Capacity Factor (%)	65%	65%
Capital c/kWh	3.09	4.37
Production c/kWh	2.04	2.64
Total c/kWh	5.13	7.01
$/ton CO_2 Removed	N/A	N/A
$/ton CO_2 Avoided	N/A	24.81

Notes

References:

Updated Cost and Performance Estimates for Fossil Fuel Power Plants with CO_2 Removal, EPRI, 2002.

Evaluation of Innovative Fossil Fuel Power Plants with CO_2 Removal, EPRI, 2000.

CO2 Emitted @ 65% Op Factor

Tons/yr	2,245,430	223,303
Tons/kWhr	0.000853465	9.548E-05

NETL Data Analysis

Exhibit 4-14 Case 9 Initial and Annual Operating and Maintenance Costs

INITIAL & ANNUAL O&M EXPENSES		
Case 9 - Subcritical PC w/o CO2	Cost Base (Dec)	2006
	Heat Rate-net(Btu/kWh):	9,276
	MWe-net:	550
	Capacity Factor: (%):	85

OPERATING & MAINTENANCE LABOR

Operating Labor		
Operating Labor Rate(base):	33.00	$/hour
Operating Labor Burden:	30.00	% of base
Labor O-H Charge Rate:	25.00	% of labor

		Total
Skilled Operator	2.0	2.0
Operator	9.0	9.0
Foreman	1.0	1.0
Lab Tech's, etc.	2.0	2.0
TOTAL-O.J.'s	14.0	14.0

	Annual Cost $	Annual Unit Cost $/kW-net
Annual Operating Labor Cost	$5,261,256	$9.558
Maintenance Labor Cost	$5,602,943	$10.179
Administrative & Support Labor	$2,716,050	$4.934
TOTAL FIXED OPERATING COSTS	**$13,580,249**	**$24.672**

VARIABLE OPERATING COSTS

Consumables	Consumption Initial	Consumption /Day	Unit Cost	Initial Cost		$/kWh-net
Maintenance Material Cost					**$8,404,415**	**$0.00205**
Water(/1000 gallons)	0	4,472.64	1.03	$0	**$1,429,266**	**$0.00035**
Chemicals						
MU & WT Chem.(lb)	151,553	21,650	0.16	$24,976	$1,106,970	$0.00027
Limestone (ton)	3,661	523	20.60	$75,419	$3,342,699	$0.00082
Carbon (Mercury Removal) (lb)	0	0	0.00	$0	$0	$0.00000
MEA Solvent (ton)	0	0	2,142.40	$0	$0	$0.00000
NaOH (tons)	0	0	412.96	$0	$0	$0.00000
H2SO4 (tons)	0	0	132.15	$0	$0	$0.00000
Corrosion Inhibitor	0	0	0.00	$0	$0	$0.00000
Activated Carbon(lb)	0	0	1.00	$0	$0	$0.00000
Ammonia (28% NH3) ton	550	79	123.60	$67,984	$3,013,146	$0.00074
Subtotal Chemicals				**$168,379**	**$7,462,815**	**$0.00182**
Other						
Supplemental Fuel(MBtu)	0	0	0.00	$0	$0	$0.00000
SCR Catalyst(m3)	w/equip.	0.47	5,500.00	$0	$794,147	$0.00019
Emission Penalties	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$794,147**	**$0.00019**
Waste Disposal						
Flyash (ton)	0	102	15.45	$0	$488,290	$0.00012
Bottom Ash(ton)	0	407	15.45	$0	$1,953,046	$0.00048
Subtotal-Waste Disposal				**$0**	**$2,441,336**	**$0.00060**
By-products & Emissions						
Gypsum (tons)	0	823	0.00	$0	$0	$0.00000
Subtotal By-Products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$168,379**	**$20,531,979**	**$0.00501**
Fuel(ton)	157,562	5,252	42.11	**$6,634,942**	**$68,616,356**	**$0.01674**

Exhibit 4-24 Case 10 Initial and Annual Operating and Maintenance Costs

INITIAL & ANNUAL O&M EXPENSES		
Case 10 - Subcritical PC w/ CO2	Cost Base (Dec)	2006
	Heat Rate-net(Btu/kWh):	13,724
	MWe-net:	550
	Capacity Factor: (%):	85

OPERATING & MAINTENANCE LABOR

Operating Labor		
Operating Labor Rate(base):	33.00	$/hour
Operating Labor Burden:	30.00	% of base
Labor O-H Charge Rate:	25.00	% of labor

		Total
Skilled Operator	2.0	2.0
Operator	11.3	11.3
Foreman	1.0	1.0
Lab Tech's, etc.	2.0	2.0
TOTAL-O.J.'s	16.3	16.3

	Annual Cost $	Annual Unit Cost $/kW-net
Annual Operating Labor Cost	$6,138,007	$11.168
Maintenance Labor Cost	$10,295,213	$18.732
Administrative & Support Labor	$4,108,305	$7.475
TOTAL FIXED OPERATING COSTS	**$20,541,525**	**$37.375**

VARIABLE OPERATING COSTS

Consumables	Consumption Initial	Consumption /Day	Unit Cost	Initial Cost		$/kWh-net
Maintenance Material Cost					**$15,442,820**	**$0.00377**
Water(/1000 gallons)	0	10,151	1.03	$0	**$3,243,688**	**$0.00079**
Chemicals						
MU & WT Chem.(lb)	343,946	49,135	0.16	$56,682	$2,512,244	$0.00061
Limestone (ton)	5,372	767	20.60	$110,669	$4,905,029	$0.00120
Carbon (Mercury Removal) (lb)	0	0	0.00	$0	$0	$0.00000
MEA Solvent (ton)	1,174	1.67	2,142.40	$2,515,178	$1,108,686	$0.00027
NaOH (tons)	82	8.18	412.96	$33,863	$1,048,541	$0.00026
H2SO4 (tons)	79	7.91	132.15	$10,440	$324,224	$0.00008
Corrosion Inhibitor	0	0	0.00	$162,300	$7,730	$0.00000
Activated Carbon(lb)	0	1,992	1.00	$0	$618,018	$0.00015
Ammonia (28% NH3) ton	813	116	123.60	$100,439	$4,451,615	$0.00109
Subtotal Chemicals				**$2,989,571**	**$14,976,086**	**$0.00366**
Other						
Supplemental Fuel(MBtu)	0	0	0.00	$0	$0	$0.00000
SCR Catalyst(m3)	w/equip.	0.68	5,500.00	$0	$1,168,014	$0.00029
Emission Penalties	0	0	0.00	$0	$0	$0.00000
Subtotal Other				**$0**	**$1,168,014**	**$0.00029**
Waste Disposal						
Flyash (ton)	0	144	15.45	$0	$690,819	$0.00017
Bottom Ash(ton)	0	577	15.45	$0	$2,763,393	$0.00068
Subtotal-Waste Disposal				**$0**	**$3,454,212**	**$0.00084**
By-products & Emissions						
Gypsum (tons)	0	1,196	0.00	$0	$0	$0.00000
Subtotal By-Products				**$0**	**$0**	**$0.00000**
TOTAL VARIABLE OPERATING COSTS				**$2,989,571**	**$38,284,819**	**$0.00936**
Fuel(ton)	232,764	7,759	42.11	**$9,801,707**	**$101,365,989**	**$0.02477**

Electricity cost increment $/kWh-net - Amine 0.00803 // CZ 0.006

Reference: *Cost and Performances Baseline for Fossil Energy Plants*, DOE/NETL, 2007.

NETL Data Analysis

Exhibit 4-46 Estimated Performance and Cost Results for Pulverized Coal Cases

	Pulverized Coal Boiler			
	PC Subcritical		PC Supercritical	
	Case 9	Case 10	Case 11	Case 12
CO_2 Capture	No	Yes	No	Yes
Gross Power Output (kW_e)	583,315	679,923	580,260	663,445
Auxiliary Power Requirement (kW_e)	32,870	130,310	30,110	117,450
Net Power Output (kW_e)	550,445	549,613	550,150	545,995
Coal Flowrate (lb/hr)	437,699	646,589	411,282	586,627
Natural Gas Flowrate (lb/hr)	N/A	N/A	N/A	N/A
HHV Thermal Input (kW_{th})	1,496,479	2,210,668	1,406,161	2,005,660
Net Plant HHV Efficiency (%)	36.8%	24.9%	39.1%	27.2%
Net Plant HHV Heat Rate (Btu/kW-hr)	9,276	13,724	8,721	12,534
Raw Water Usage, gpm	6,212	12,187	5,441	10,444
Total Plant Cost ($ x 1,000)	852,612	1,591,277	866,391	1,567,073
Total Plant Cost ($/kW)	1,549	2,895	1,575	2,870
LCOE (mills/kWh)[1]	64.0	118.8	63.3	114.8
CO_2 Emissions (lb/MWh)[2]	1,780	225	1,681	209
CO_2 Emissions (lb/MWh)[3]	1,886	278	1,773	254
SO_2 Emissions (lb/MWh)[2]	0.7426	Negligible	0.7007	Negligible
NOx Emissions (lb/MWh)[2]	0.613	0.777	0.579	0.722
PM Emissions (lb/MWh)[2]	0.114	0.144	0.107	0.134
Hg Emissions (lb/MWh)[2]	1.00E-05	1.27E-05	9.45E-06	1.18E-05

[1] Based on an 85% capacity factor
[2] Value is based on gross output
[3] Value is based on net output

CZ COE - <15%

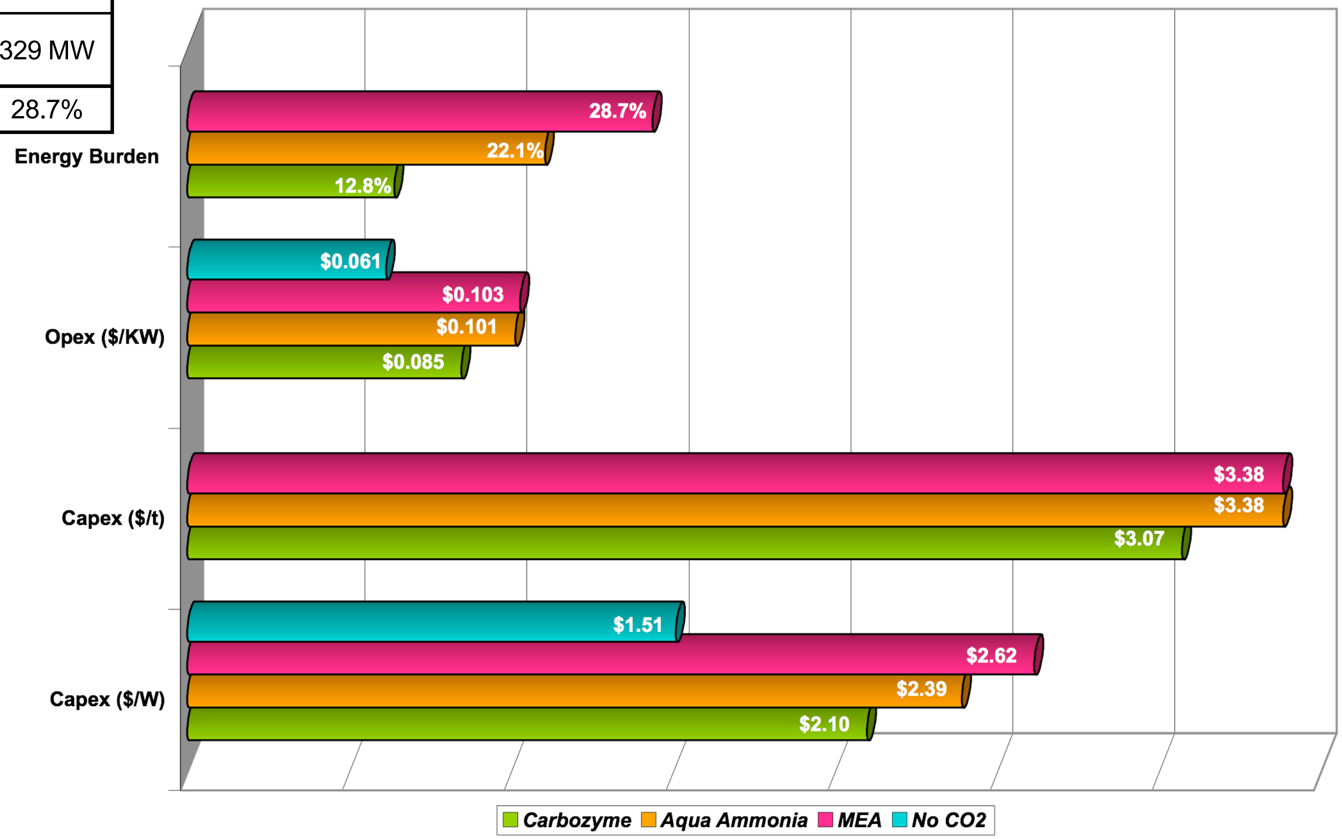
Reference: *Cost and Performances Baseline for Fossil Energy Plants*, DOE/NETL, 2007.

Carbozyme

Solutions for Affordable Clean Energy™

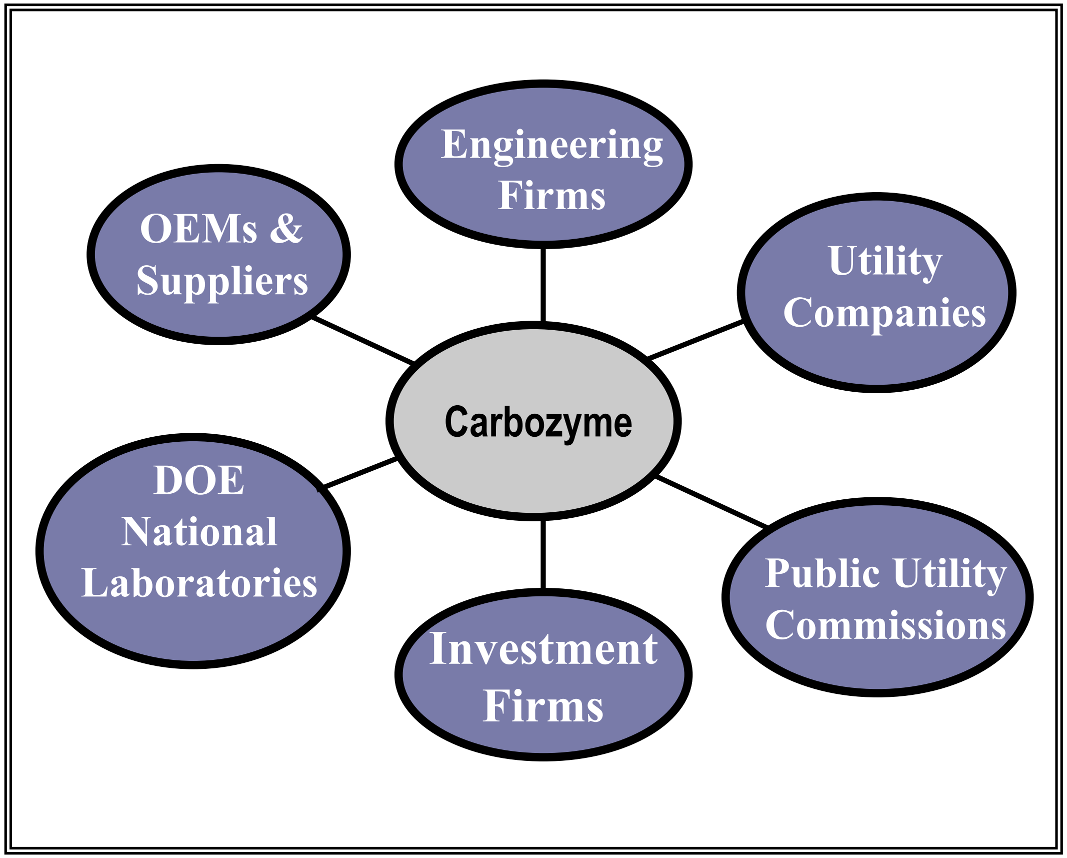
CO_2 Capture Technology Alternatives

EPRI Power Plant Model			
Power	**CZ**	**Cold Ammonia**	**MEA**
Gross Steam Turbine Power	498 MW		
Delivered Power w/o CO_2 Recovery	462 MW		
Delivered Power with CO_2 Recovery	403 MW	360 MW	329 MW
Energy Burden	12.8%	22.1%	28.7%



Carbozyme Inc.

CCS Public-Private Partnership Formation



- Develop partnerships of technology developers, financial institutions, and regulatory bodies to ensure acceptance by marketplace
- Form multi-institutional teams, understanding the needs of multiple stakeholders to direct the commercialization of new technologies
- Explore commercialization of promising CCS technologies for both present and future plants

CCS Commercialization Stakeholders

Frame Setters

- **Federal Stakeholders** –to provide the overarching federal policy commitments and funding vehicles to acceleration of deployment of CCS projects.
- **NETL/Other Technology Sources** – clearly critical to the future development and commercialization of CCS technologies.
- **State Stakeholders** –to develop the regulatory framework and provide ratepayer funding to create necessary incentives.
- **End users/Utility Companies** –to collaborate with PUCs to determine the appropriate degree of involvement in the RD&D process.
- **Environmental Groups** – critical to gaining public acceptance of Geologic Carbon Sequestration as a safe and viable climate change mitigation tool.

Enablers

- **Insurance Companies** –to be engaged in the process in an effort to begin to model the risk associated with sequestration.
- **Financial Institutions** – with the alignment of groups I through VI, should be willing to provide funding to CCS projects that have Federal and State policies and funding support.

Project Team Members

Carbozyme Inc.

EERC Energy & Environmental Research Center®

novozymes®

SIEMENS

Visage ENERGY CORP.

SRI International®

Argonne NATIONAL LABORATORY

ELECTROSEP INC.
Advanced Electrolytic Membrane Technology

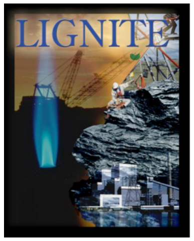
Kansas State University

Cogentrix

OTTER TAIL POWER COMPANY

MONTANA-DAKOTA UTILITIES CO.
A Division of MDU Resources Group, Inc.

GREAT RIVER ENERGY®



OLI systems, Inc.

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DOE NETL - José Figueroa

DOE NETL - Coop. Agreement DE-FC26-07NT43084


Questions?