Progress on Carbozyme's HFCLM Permeator Technology Scale-up Project

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CEO, CTO

CCS
Pittsburgh, PA
May 5-8, 2008

Project Structure

Michael Trachtenberg
Technical Manager / CTO

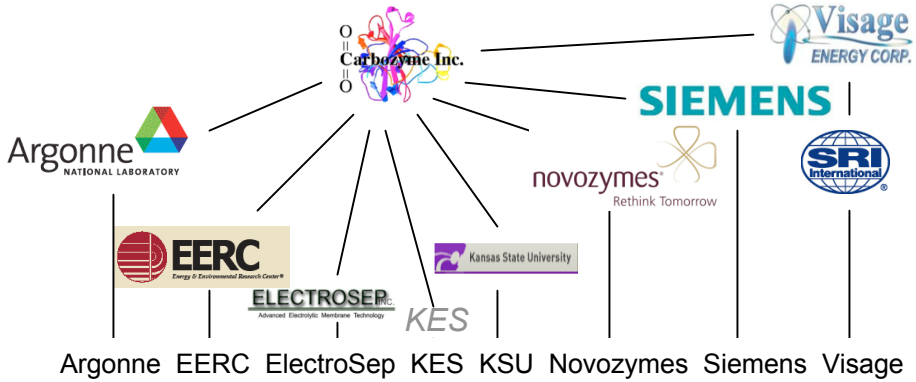
- *Technical management*
- *Technical reporting*
- *Outreach*
- *R, D & E*

John Marciszewski
Program Manager

- *Budget*
- *Contracts (Legal)*
- *Management reporting*
- *Planning*

John Koenst
Project Manager

- *Master schedule*
- *Weekly reports*



- WBS 1: Flue Gas Pre-Treatment
- WBS 2: Enzyme Development / Selection
- WBS 3: Select Membrane (Module) Manufacturer
- WBS 4: EDI Test Cell Design, Construction, Testing and Selection
- WBS 5: SWHF-CLM Scale-up to Pre-Pilot Size
- WBS 6: Engineering & Economic Analysis
- WBS 7: Development of a Commercialization Study
- WBS 8: Pre-Pilot Permeator Skid Scale-up
- WBS 9: EDI Multi-Stack Scale-up & Test
- WBS 10: Management and Reporting

1.0 – Flue Gas Pretreatment Specification

1.1 Flue Gas Specification

1.2 Flue Gas Pretreatment System Procurement

1.3 Flue Gas Pretreatment System Installation

1.4 Test and Verify Pretreatment Clean-up Performance

5.0 – Permeator Scale-Up Development

5.1 Development of Test Plans for SWHF-CLM Scale-up Modules

5.2 Permeator Instrumentation Development and Testing

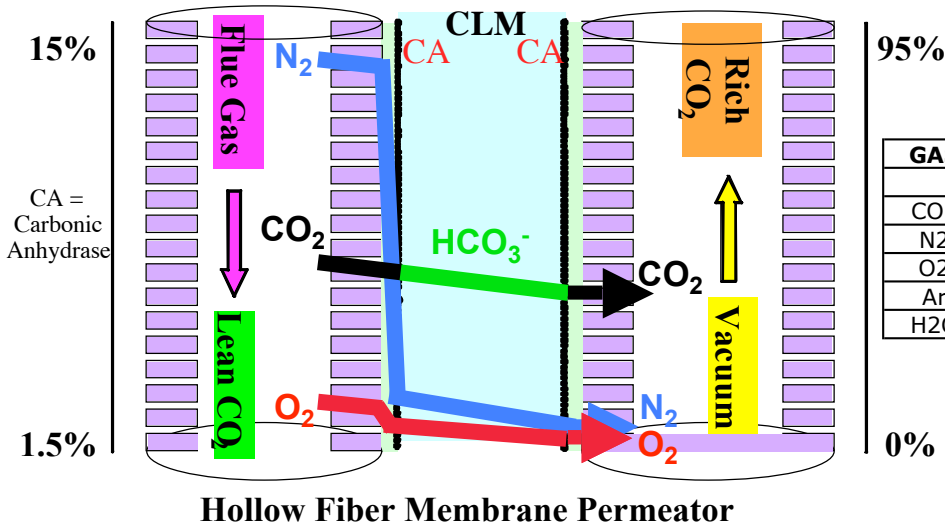
7.0 - Development of a Commercialization Study

7.1 Compilation of Commercialization Issues and Requirements

7.2 Analysis of Commercialization Issues and Requirements

7.3 Commercialization Plan Recommendations

Pre-pilot - HFCLM

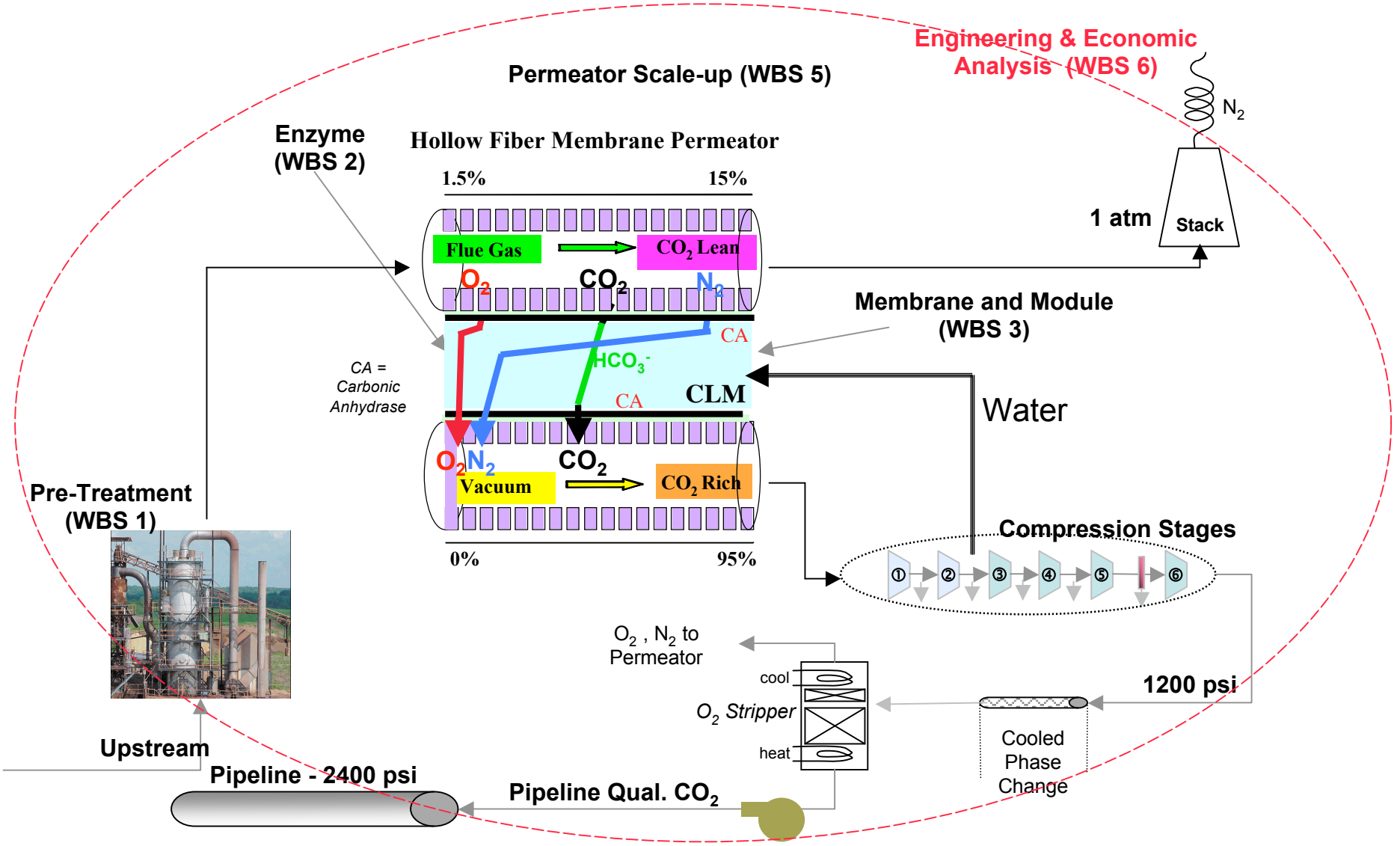


Hollow Fiber Membrane Permeator

GAS	FEED	WET	DRY			
		Vol	Vol	Wt	KM Req	Variance
CO2	13.85%	43.65%	92.40%	94.92%	95%	0.08% too low
N2	71.99%	3.13%	6.61%	4.32%	4%	0.32% too high
O2	5.54%	0.39%	0.83%	0.62%	10ppmw	622 times too high
Ar	0.93%	0.07%	0.14%	0.13%		OK
H2O	7.70%	52.76%	0.01%	3.2 mM	30#/MMcf	15% of specification

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

CLM Process Flow



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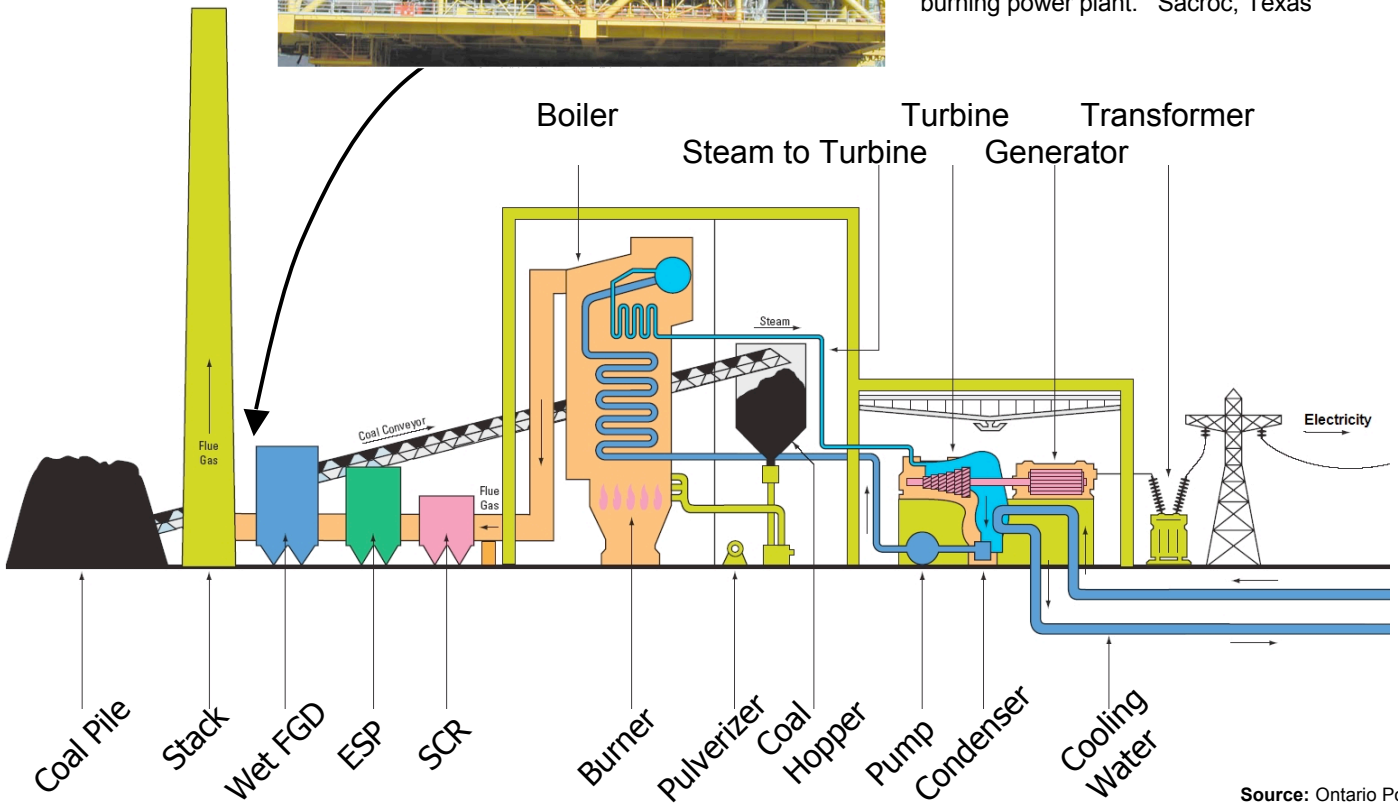
Future Carbozyme CO_2 Capture Skid

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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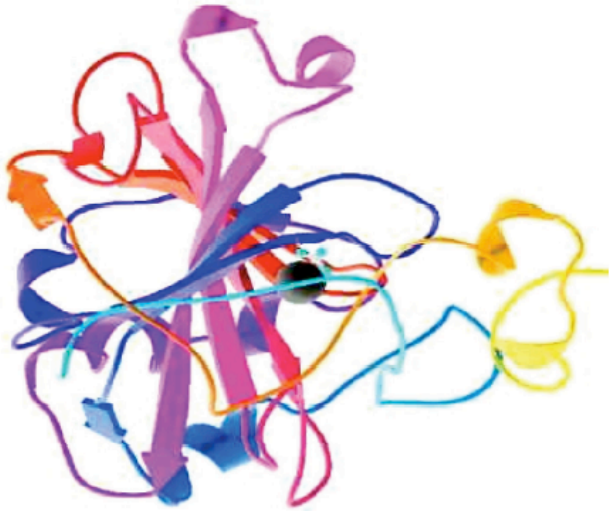
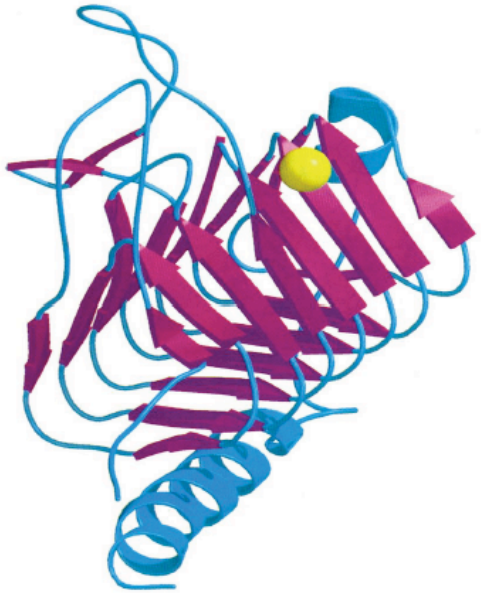
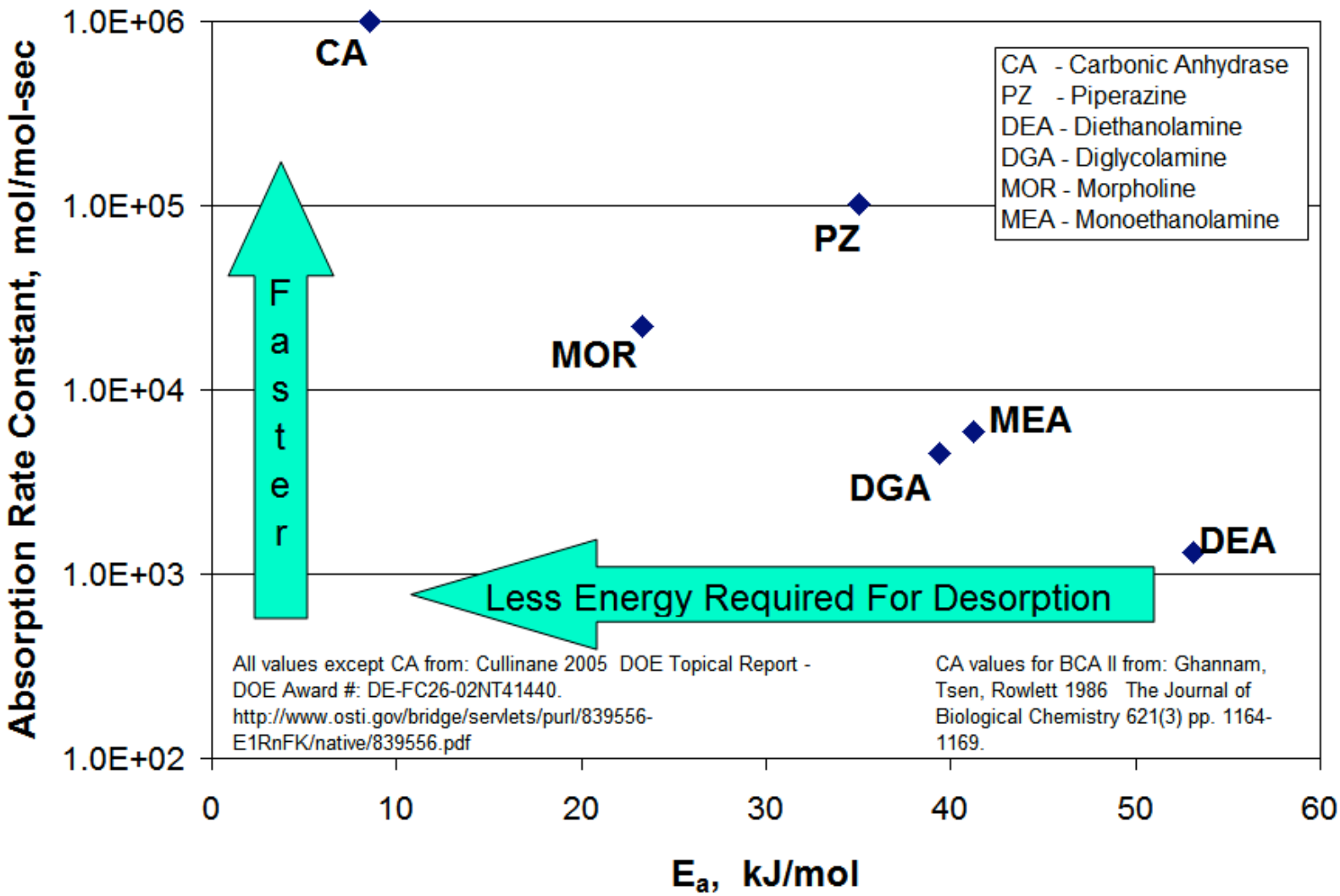
Carbonic Anhydrase

α-CA II

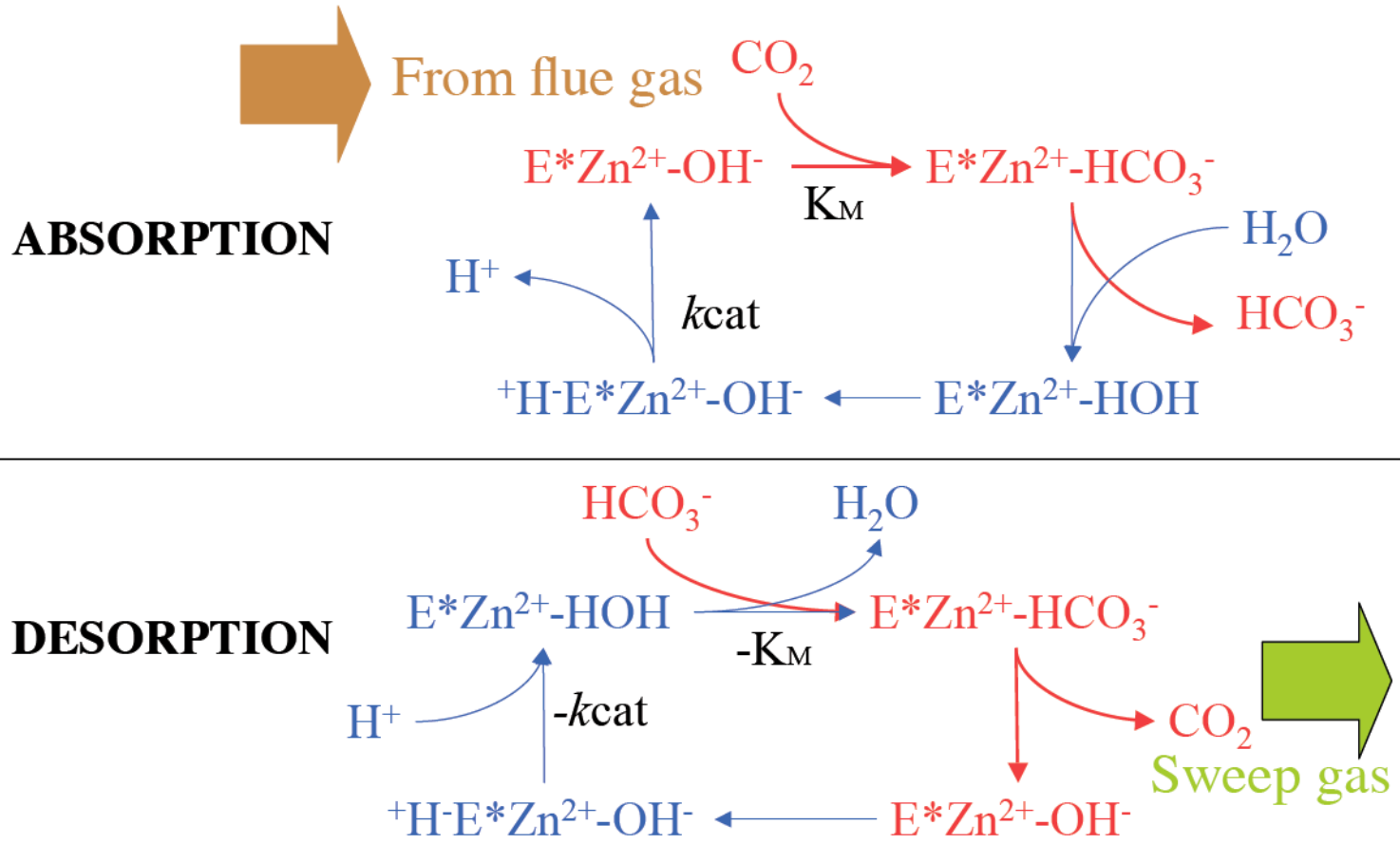


γ-CA Cam




Absorption Rate Constant, mol/mol-sec
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
0
10
20
30
40
50
60
E_a, kJ/mol
CA
PZ
MOR
MEA
DGA
DEA
CA - Carbonic Anhydrase
PZ - Piperazine
DEA - Diethanolamine
DGA - Diglycolamine
MOR - Morpholine
MEA - Monoethanolamine
Faster
Less Energy Required For Desorption
All values except CA from: Cullinane 2005 DOE Topical Report - DOE Award #: DE-FC26-02NT41440. http://www.osti.gov/bridge/servlets/purl/839556-E1RnFK/native/839556.pdf
CA values for BCA II from: Ghannam, Tsen, Rowlett 1986 The Journal of Biological Chemistry 621(3) pp. 1164-1169.

Reaction Mechanisms



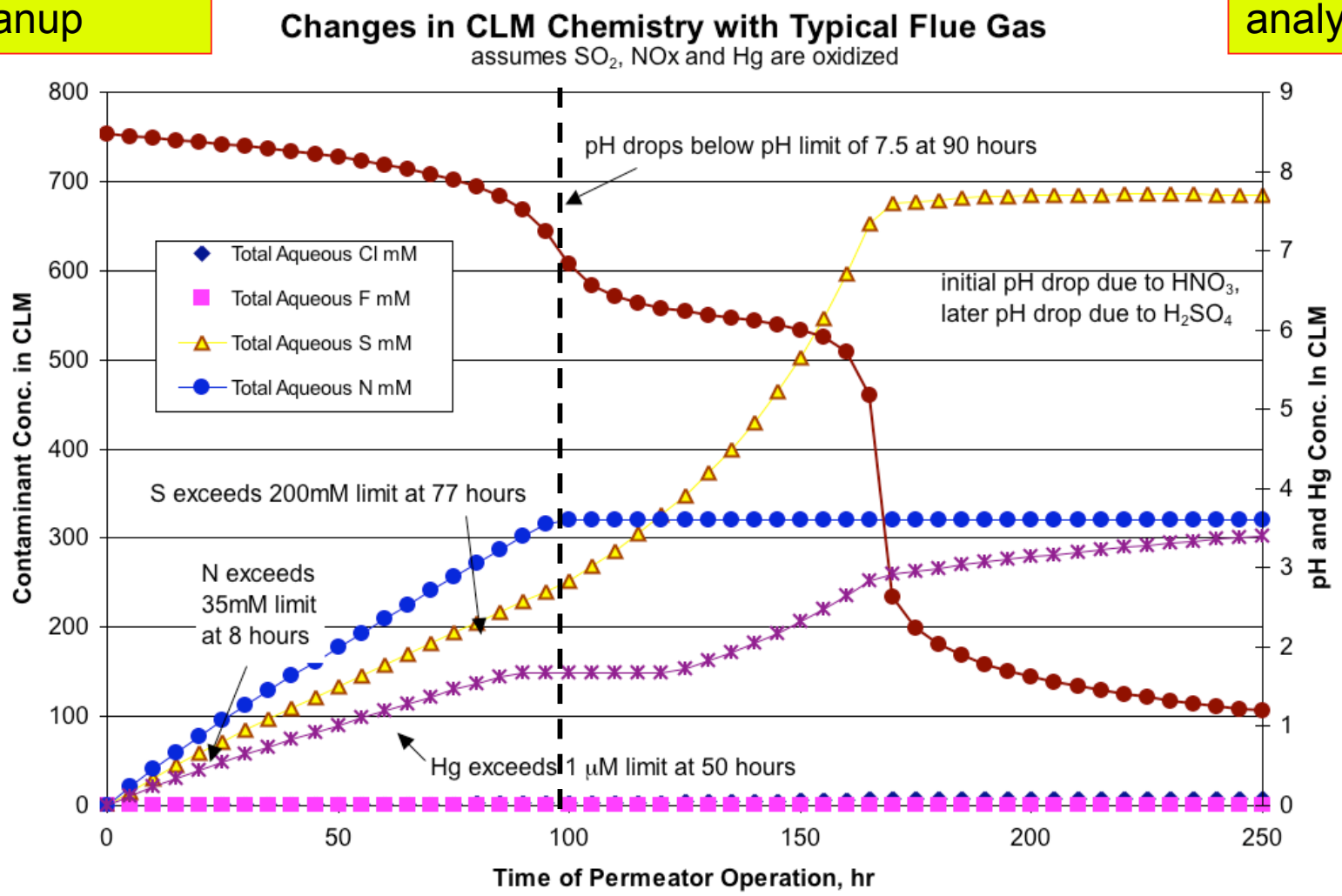
Acceptance Limits

Contaminant	Acceptance Concentration	Flue Gas
HCl	7 ppmv	3.25 ppmv
HF	7 ppmv	0.108 ppmv
SO_x (SO_2 + SO_3)	7 ppmv	200 ppmv
NO[a]	190 ppmv	400 ppmv
NO_2[b]	20 ppmv	
Hg (as Hg^{2+})	4 ×	
Hg°	2.17 ppbv	2.17 ppbv

No Treatment - Model

No additional cleanup

Worst case analysis



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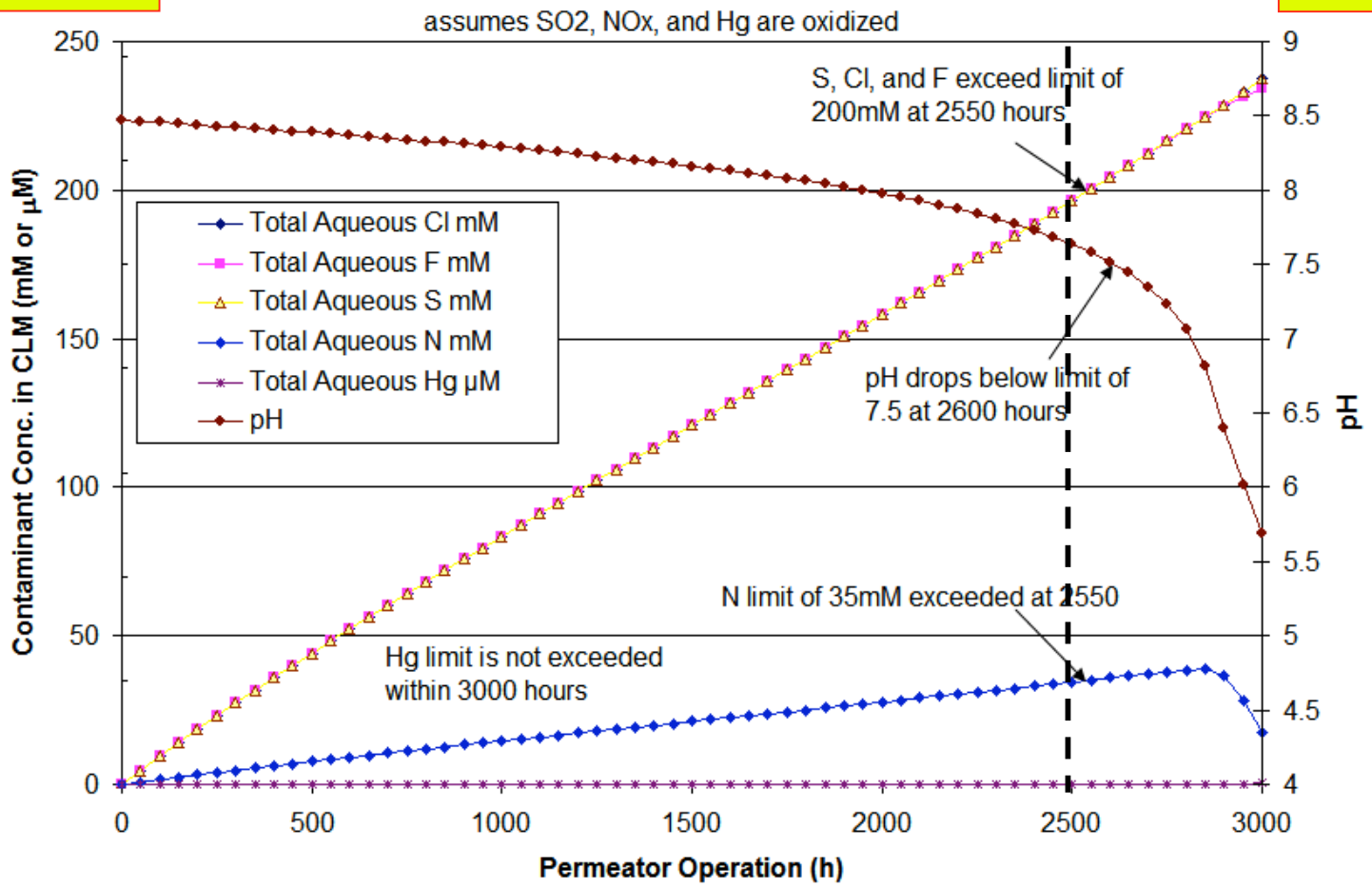
Treated Stream - Model

Additional cleanup

Worst case analysis



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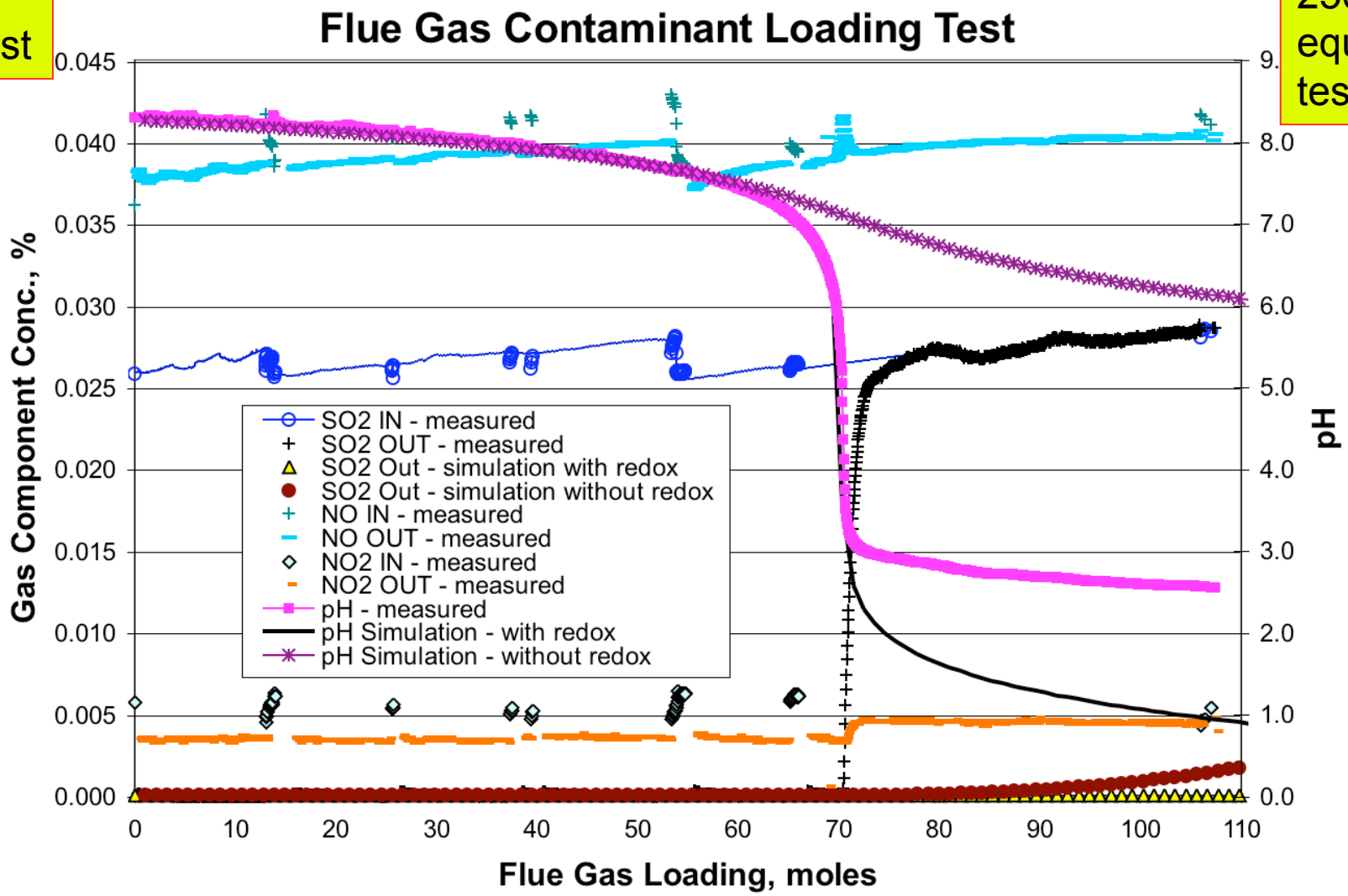
Worst case test

2500h equiv. test



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Flue Gas Specification

- **Purpose:** Determine the range of flue gas components that could be expected and the pretreatment needed to meet the CLM requirements.
- The EPA's Information Collection Request database of mercury emissions from power plants was used to identify the most commonly used bituminous and subbituminous coals and lignite as well as the most common plant configurations for each coal.
- The USGS coal analysis database was accessed for compositional information.
- The coal type, coal analysis, and plant configuration data were entered into the IECM and the model run for each of the 92 combinations to produce an estimated flue gas composition.

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

Most Common Existing U.S. Power Plant Configurations – Bituminous Coals

Boiler Type and Pollution Control Devices	Number of Units	Percentage of Total U.S. Fleet [a]
Bituminous Coal		
Wall-Fired, In-Furnace NO_x Control, Cold-Side ESP, No SO_x Scrubber	89	8.2
Wall-Fired, No NO_x Control, Cold-Side ESP, No SO_x Scrubber	63	5.8
Tangentially Fired, In-Furnace NO_x Control, Cold-Side ESP, No SO_x Scrubber	94	8.7
Tangentially Fired, No NO_x Control, Cold-Side ESP, No SO_x Scrubber	66	6.1
Wall-Fired, In-Furnace NO_x Control, Cold-Side ESP, Wet SO_x Scrubber	42	3.9
Wall-Fired, In-Furnace NO_x Control, Fabric Filter, No SO_x Scrubber	6	0.5
Tangentially Fired, In-Furnace NO_x Control, Fabric Filter, No SO_x Scrubber	4	0.4
Total Plants, All Coals	**364**	**33.6**

[a] Assuming 1084 units in the United States (total from the EERC mercury ICR database).

Most Common Existing U.S. Power Plant Configurations – Subbituminous Coals

Boiler Type and Pollution Control Devices	Number of Units	Percentage of Total U.S. Fleet [a]
Subbituminous Coal		
Wall-Fired, In-Furnace NO_x Control, Cold-Side ESP, No SO_x Scrubber	22	2.0
Wall-Fired, No NO_x Control, Cold-Side ESP, No SO_x Scrubber	14	1.3
Tangentially Fired, In-Furnace NO_x Control, Cold-Side ESP, No SO_x Scrubber	37	3.4
Tangentially Fired, No NO_x Control, Cold-Side ESP, No SO_x Scrubber	25	2.3
Tangentially Fired, In-Furnace NO_x Control, Cold-Side ESP, Wet SO_x Scrubber	6	0.5
Tangentially Fired, No NO_x Control, Cold-Side ESP, Wet SO_x Scrubber	5	0.5
Wall-Fired, In-Furnace NO_x Control, Fabric Filter, No SO_x Control	9	0.8
Tangentially Fired, In-Furnace NO_x Control, Fabric Filter, No SO_x Control	5	0.5
Total Plants, All Coals	**123**	**11.3**

[a] Assuming 1084 units in the United States (total from the EERC mercury ICR database).

Most Common Existing U.S. Power Plant Configurations – Lignite Coals

Boiler Type and Pollution Control Devices	Number of Units	Percentage of Total U.S. Fleet [a]
Lignite		
Wall-Fired, In-Furnace NO_x Control, Cold-Side ESP, No SO_x Scrubber	2	0.2
Tangentially Fired, In-Furnace NO_x Control, Cold-Side ESP, Wet SO_x Scrubber	4	0.4
Tangentially Fired, No NO_x Control, Cold-Side ESP, Wet SO_x Scrubber	4	0.4
Tangentially Fired, In-Furnace NO_x Control, Dry SO_x Scrubber, Fabric Filter	3	0.3
Total Plants, All Coals	**13**	**1.2**

[a] Assuming 1084 units in the United States (total from the EERC mercury ICR database).

Predicted Flue Gas Compositions

Flue Gas Component	Bituminous Coals			PRB[1] Subbituminous Coals			Lignites		
	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum	Median
N_2, wt%	65.34	69.83	69.13	62.91	67.69	67.03	62.31	68.75	62.96
O_2, wt%	5.58	5.99	5.92	5.39	5.82	5.74	5.34	5.89	5.41
H_2O, wt%	4.79	10.56	5.45	6.72	12.53	7.53	7.73	14.81	12.28
CO_2, wt%	17.11	18.29	17.87	17.25	19.12	18.31	16.94	18.48	17.66
CO, wt%	0	0	0	0	0	0	0	0	0
HCl, ppmw	0.58	56.1	20.0	0.748	16.9	7.9	0.71	12.4	4.2
SO_2, ppmw	296.2	5137	1324	328.1	2252	850	384.3	2137	397
Sulfuric Acid (equivalent SO_3), ppmw	0.32	19.4	4.4	0.04	0.31	0.3	0.01	1.01	0.25
NO, ppmw	165.9	374.6	200.5	160.7	484	214.0	151.2	459.3	175.6
NO_2, ppmw	13.4	30.2	16.2	13.0	39.0	17.3	12.2	37.1	14.2
NH_3, ppmw	0	2.4	2.4	0	2.5	2.4	0	2.5	2.4
Ar, wt%	1.11	1.19	1.18	1.07	1.15	1.14	1.06	1.14	1.07
Mercury									
Elemental, µg/Nm³	1.4	4.74	2.73	8.07	13.7	10.32	9.55	22.64	12.66
Oxidized, µg/Nm³	0.18	11.07	6.36	0.13	4.57	3.09	0.16	7.55	1.78
Total, µg/Nm³	1.76	15.81	9.08	8.2	18.26	12.89	9.71	30.19	14.54

[1] Powder River Basin.

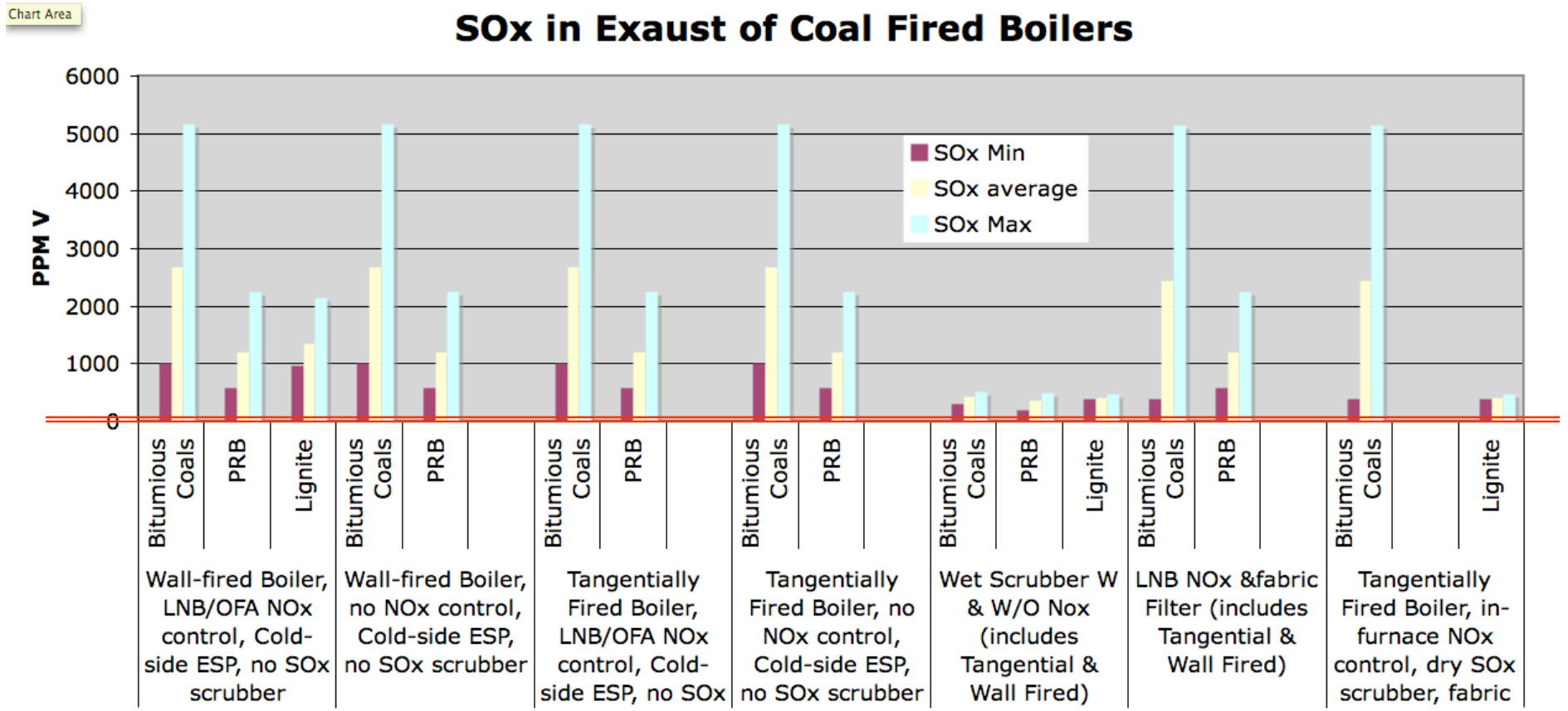


Chart Area
SOx in Exaust of Coal Fired Boilers
PPM V
6000
5000
4000
3000
2000
1000
0
SOx Min
SOx average
SOx Max
Bitumious Coals
PRB
Lignite
Wall-fired Boiler, LNB/OFA NOx control, Cold-side ESP, no SOx scrubber
Wall-fired Boiler, no NOx control, Cold-side ESP, no SOx scrubber
Tangentially Fired Boiler, LNB/OFA NOx control, Cold-side ESP, no SOx
Tangentially Fired Boiler, no NOx control, Cold-side ESP, no SOx scrubber
Wet Scrubber W & W/O Nox (includes Tangential & Wall Fired)
LNB NOx &fabric Filter (includes Tangential & Wall Fired)
Tangentially Fired Boiler, in-furnace NOx control, dry SOx scrubber, fabric

Comparison of Flue Gas Component Ranges with Permeator Acceptance Requirements

Flue Gas Component	Minimum	Maximum	Median	Carbozyme Permeator Requirements	Typical Removal Required, %
HCl, ppmw	0.58	56.10	7.9	8.46	None
SO_2, ppmw	296.2	5100	1000	18.57	98.1
SO_3, ppmw	0.01	19.4	0.5		
NO, ppmw	151.2	484.0	200.5	195	2.7
NO_2, ppmw	12.2	39.1	16.2	20.8	None
Oxidized Mercury, $\mu g/Nm^3$	0.13	11.07	3.24	0.033	None (with EDTA)

Pretreatment Technology Options Considered

Condensing Heat Exchanger

- While not difficult to design, somewhat more effort required for fabrication
- Not as readily tailored to a given process
- Likely would not condense SO_3 aerosols
- Class C fly ashes might form concrete when combined with the condensate

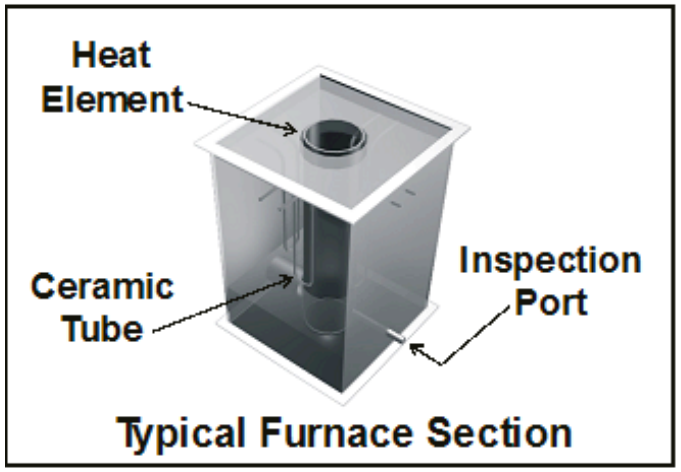
Wet ESP

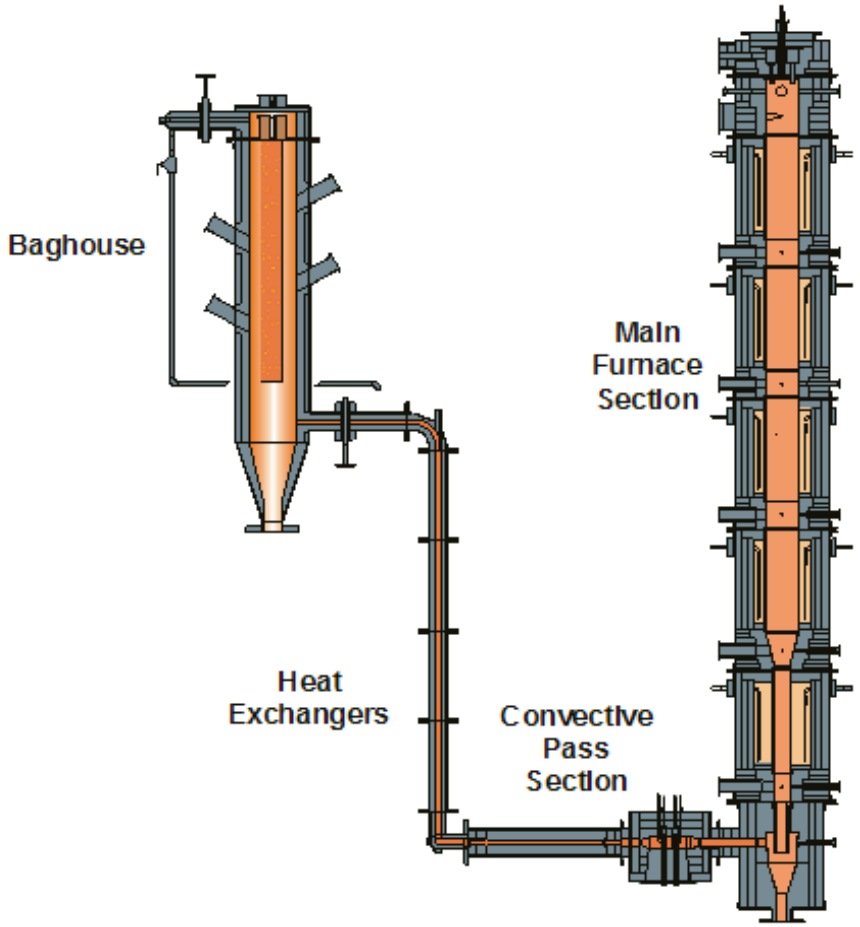
- Design and fabrication may be more difficult than other options
- Not as readily tailored to a given process
- Effective in removing SO_3 mists, submicron particulate; provide additional Hg control
- Not appropriate for Class C fly ash as it will likely form concrete in the wet ESP.

Wet Scrubber

- Relatively simple to design and fabricate
- Can be tailored to the specific needs of a process
- Can be employed where ultrafine Class C fly ash is present
- With proper design, is likely to capture SO_3 aerosols

EERC Conversion and Environmental Process Simulator (CEPS)



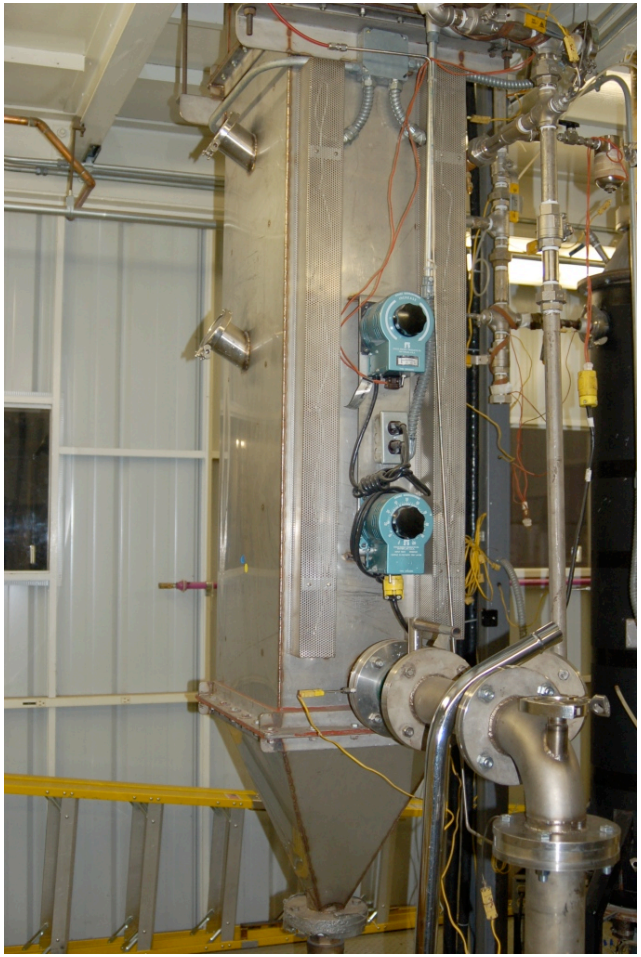


EERC's Combustion and Environmental Process Simulator

Second Floor

Ground Floor

CEPS Baghouse



Existing CEPS Wet FGD Unit

Slurry Bed

Mist Eliminator

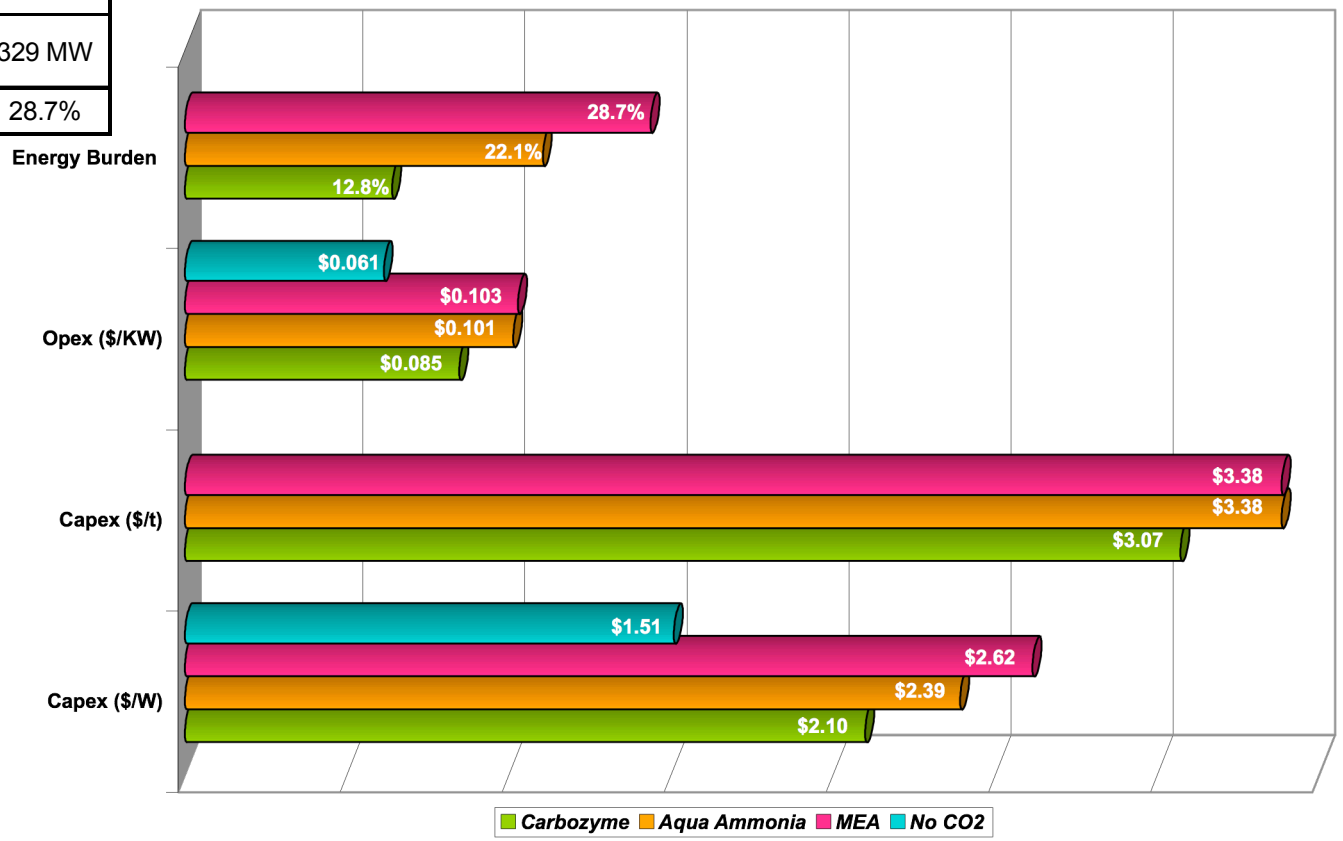
Packing

Carbozyme Scrubber Scaffolding

Scrubber Rack →

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%



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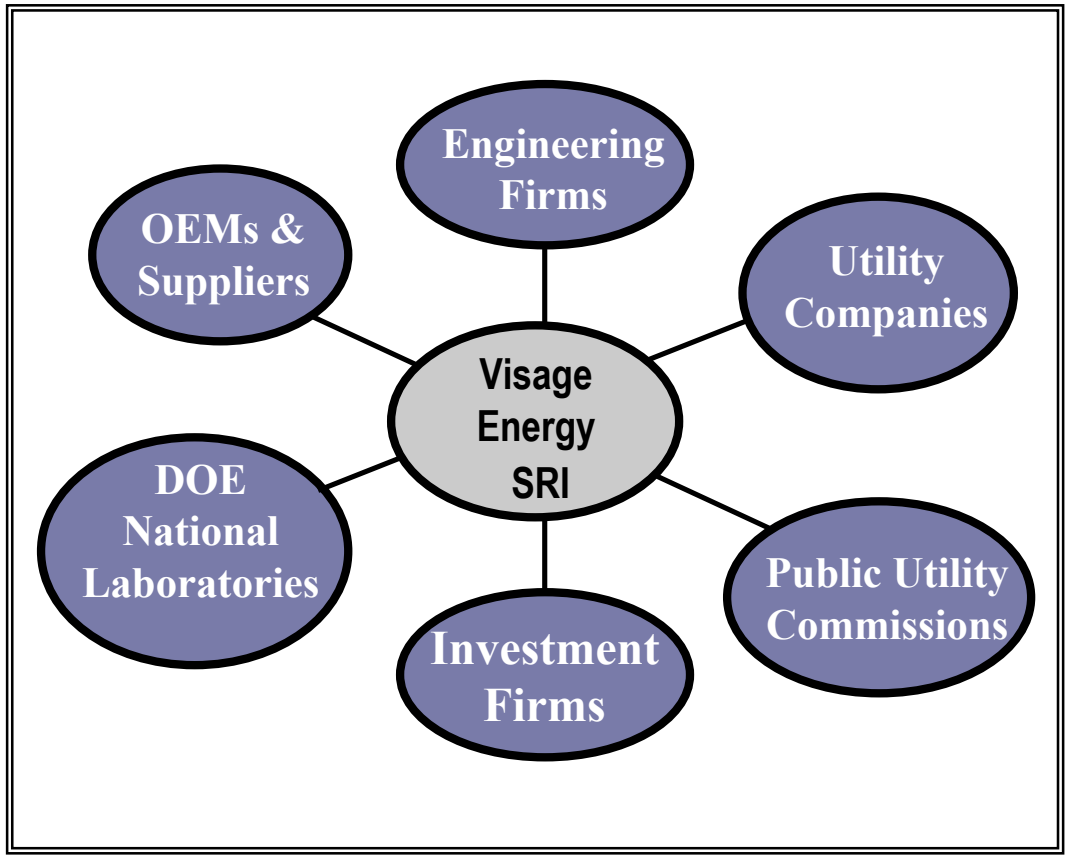
CCS Public-Private Partnership Formation



- 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.

Acknowledgements

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The Department of Energy
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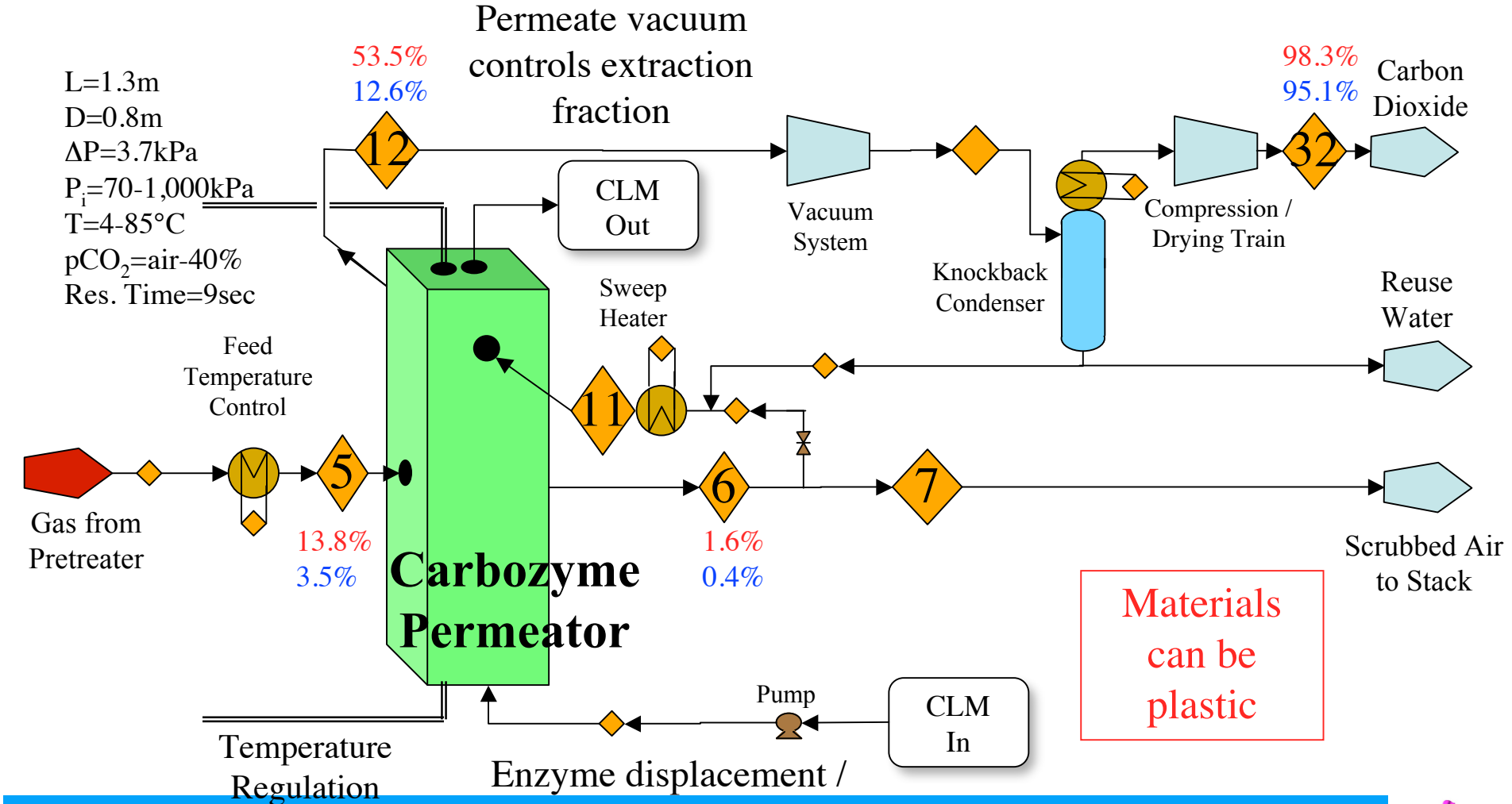
The Carbozyme Benefit


Permeate vacuum controls extraction fraction
L=1.3m
D=0.8m
ΔP=3.7kPa
P_i=70-1,000kPa
T=4-85°C
pCO_2=air-40%
Res. Time=9sec
53.5%
12.6%
12
CLM Out
Vacuum System
98.3%
95.1%
Carbon Dioxide
32
Compression / Drying Train
Knockback Condenser
Sweep Heater
Reuse Water
Feed Temperature Control
11
5
6
7
Gas from Pretreater
13.8%
3.5%
Carbozyme Permeator
1.6%
0.4%
Scrubbed Air to Stack
Materials can be plastic
Pump
CLM In
Temperature Regulation
Enzyme displacement / replacement done *in situ*

Pictorial Representation of Flue Gas CO_2 Capture

Furnace/Boiler

SCR
NOx

FF/Particles

FGD
SOx

Carbozyme Permeators

Natco - Sacrock, TX

Polishing

Compressor

Pipeline

Stack