INTEGRATED DRY NOx/SO2 EMISSIONS CONTROL SYSTEM

FINAL REPORT, VOLUME 2: PROJECT PERFORMANCE AND ECONOMICS

Appendix G

CALCULATION PRCEDURES

A CALCULATION PROCEDURES

During the course of the test program, a number of parameters had to be calculated in order to characterize the dry sorbent processes, humidification process and SNCR process. These key calculations are included in this appendix and include:

- Flue Gas Flow Rate : Q_{fg} (dscfm)
- SNCR Process : N/NO (molar basis)
- Dry Sodium Injection : 2Na/S (molar basis)
- Dry Calcium Injection : Ca/S (molar basis)
- Duct Humidification : ΔT_{app} (adiabatic approach to saturation)

The methodology and procedures used for these calculations are documented below.

A.1 Flue Gas Flow Rate

As part of the particulate measurements, the moisture content was measured and an EPA Method 1 and 2 traverse of velocity made at the air heater exit locations. The results of the measurements was a dry flue gas flow rate measured at an O_2 concentration of 4.6% and load of 100 MWe of 220,000 dscfm. To calculate the flue gas flow rate at other loads and O_2 levels, the following relationship was used:

$$Q\,(L,O_2) = 220{,}000\left(\frac{L}{100}\right)\left(\frac{20.9-4.6}{20.9-O_2}\right)(NHR) \tag{1}$$

NHR = normalized function accounting for a change in plant net heat rate with load.

L = load, MWe.

O_2 = measured O_2 at the economizer exit, % dry.

The NHR function was calculated from the following PNHR data measured by PSCo in 1988.

Load Net MWe	PHNR Btu/Kwhr
35.2	11640
45.3	11270
70.7	10710
79.7	10610
94.8	10450
112.9	10570

The above heat rate data was normalized to 100 MWe and curve fit:

$$NHR = 2.342 \times 10^{-5}\ (Load) - 4.91 \times 10^{-3}\ (Load)\ + 1.255 \qquad (2)$$

Equation 1 along with Equation 2 were used throughout the test program to determine the SNCR parameters N/NO molar ratio, dry sodium normalized stoichiometric ratio, 2Na/S, and the dry calcium parameters Ca/S molar ratio.

Late in the test program, PSCo installed a flue gas flow rate monitor as required by the 1990 Clean Air Act Amendments. Following certification of the flue gas flow rate monitor, flue gas flow rate data was collected and compared to the algorithm using load, O_2 and the normalized heat rate. The average ratio of the measured flue gas flow rate to calculated flue gas flow rate was 1.05 with a standard duration of 4.3%.

A.2 Dry Sodium Injection 2Na/S

To form sodium sulfate (Na_2SO_4) two moles of sodium are needed to react with one mole of SO_2. To characterize the amount of sodium injected, the "normalized stoichiometric" ratio, or 2Na/S ratio was used. The 2Na/S molar ratio was calculated using the following quantities:

$\dot{m}_{Na}$ = sodium sorbent feedrate, lb/min.

X_{SO_2} = measured inlet SO_2 level, ppm wet.

X_{H_2O} = measured inlet H_2O level, %.

X_{O_2} = measured inlet O_2 level, % wet.

Q_{fg} = flue gas flow rate, calculated as described above, scfm dry.

Y_{Na} = mass fraction of sodium in the sorbent (sodium bicarbonate: 0.274; sodium sesquicarbonate: 0.297).

MW_{na} = molecular weight of sodium, 22.99.

N_v = normal molar density, 0.002635 moles/ft^3, P = 14.7 psia, T = 60°F.

$$\frac{2\,Na}{S} = \frac{\dot{m}_{Na}\; Y_{Na}\left(1 - H_2O/100\right)}{2\, Q_{fg}\, N_v\, X_{SO_2}\left(1\times 10^{-6}\right) M_{Na}} \qquad (3)$$

A.3 Calcium Injection Ca/S

The dry calcium injection rate is characterized as the molar ratio of calcium to sulfur since one mole of calcium reacts with one mole of SO_2 to form calcium sulfate (Ca SO_4). The Ca/S ratio was calculated as follows:

$\dot{m}_{Ca}$ = calcium hydroxide feedrate, lb/min.

X_{SO_2} = measured inlet SO_2 level, ppm wet.

X_{H_2O} = measured inlet H_2O level, %.

Q_{fg} = calculated flue gas flow rate, scfm dry.

Y_{CaO} = calcium oxide content of the calcium hydroxide, 0.68.

MW_{CaO} = molecular weight of calcium oxide, 56.

N_v = normal molar density, 0.002635 moles/ft^3 @ P = 14.7 psia, T = 60°F.

$$\frac{Ca}{S} = \frac{\dot{m}_{Ca}\; Y_{CaO}\left(1 - H_2O/100\right)}{Q_{fg}\, N_v\, X_{SO_2}\left(1\times 10^{-6}\right) MW_{CaO}} \qquad (4)$$

A.4 SNCR N/NO Ratio

The SNCR ratio is characterized by the molar ratio of moles of nitrogen in the injected SNCR chemical to the moles of NO in the flue gas. This quantity was calculated using the following quantities (the procedure shown below is for urea).

Q_{urea} = urea solution injection rate, gpm.

C_{urea} = concentration of urea in solution, gm-urea/gm-solution.

X_{NO} = measured inlet NO level at the economizer probe, ppm

ρ_{H_2O} = density of water, 8.34 lb/gal.

sg = specific gravity of the urea solution.

Q_{fg} = calculated flue gas flow rate, scfm dry.

MW_{urea} = molecular weight of urea, NH_2 CO NH_2, 60.

N_v = normal molecular density, 0.002635 moles/ft^3.

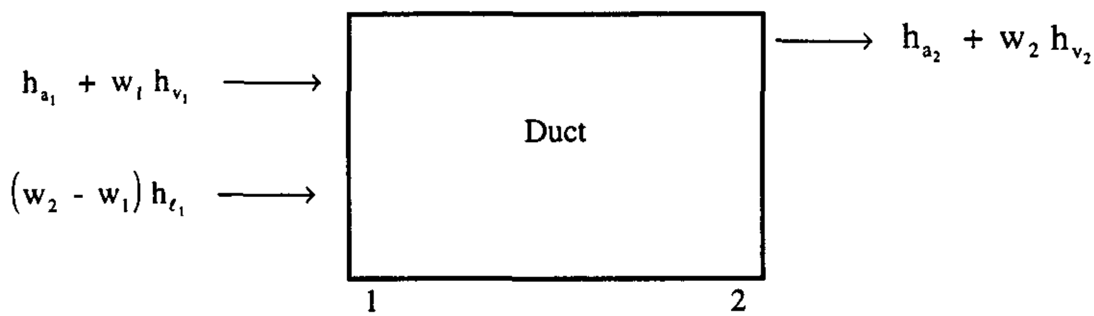
$$\frac{N}{NO} = \frac{Q_{urea}\, C_{urea}\, (sg)\, \rho_{H2O}\, 2}{MW_{urea}\, Q_{fg}\, N_v\, X_{NO}\left(1\times10^{-6}\right)} \qquad (5)$$

where the factor of 2 in the above equation accounts for the two moles of nitrogen per mole of urea.

A.5 Approach Temperature to Adiabatic Saturation

During the duct humidification tests, the key parameter used to characterize the humidification process was the approach to adiabatic saturation temperature. Ideally, this could be determined by measuring the wet bulb and dry bulb temperature in the duct. However, as the test program progressed, it became apparent that the thermocouple grid downstream of the humidification nozzles, and just at the entrance to the FFDC, was not providing an accurate dry bulb temperature. The thermocouples would collect a deposit of wet or damp ash and sorbent, resulting in a reading that was lower than the actual dry bulb temperature. To provide a supplemental way to determine the approach to saturation temperature, an energy balance was performed on the duct, and the approach temperature calculated.

The energy balance was done as shown in the figure below.



$$h_{a_1} + w_1 h_{v_1} + (w_2 - w_1) h_{\ell_1} = h_{a_2} + w_2 h_{v_2} \tag{6}$$

w_1	=	absolute humidity upstream of the atomizers, lb_{H2O}/lb_{dry} air.
w_2	=	absolute humidity downstream of the fabric filter after the injected water has evaporated, lb H_2O/lb dry air.
h_{v_1}, h_{v_2}	=	enthalpy of the water vapor at locations 1 and 2, Btu/lb H_2O.
h_{a_1}, h_{a_2}	=	enthalpy of the dry flue gas at locations 1 and 2, Btu/lb.
$(w_2 - w_1)$	=	additional water vapor added by the injected H_2O.
Q_{H_2O}	=	water injection rate, gpm.
Q_{fg}	=	flue gas flow rate, dscfm (see above).
$X_{H_2O_{1,2}}$	=	water vapor content measured upstream of the atomizers (1) and downstream of the fabric filter (2).
T_1	=	measured temperature upstream of the water atomizers.
ρ_{H_2O}	=	density of water, 8.34 lb/gal.
MW_{H_2O}	=	18.
MW_{fg}	=	30.
Cp	=	0.242 Btu/lbm °F.

$$w_2 - w_1 = \frac{Q_{H_2O}\,\rho_{H_2O}}{Cp_{fg}} \tag{7}$$

$$w_1 = \frac{X'_{H_2O_1}}{1 - X'_{H_2O_1}} \times \frac{MW_{H_2O}}{MW_{flue\ gas}} \tag{8}$$

taking the enthalpy of the dry flue gas as h_a = Cp T, the dry bulb temperature after the injected water has evaporated is given by

$$T_2 = T_{a1} + \frac{w_1 h_{v_1} + (w_2 - w_1) h_{\ell_1} - w_2 h_{v_2}}{Cp} \tag{9}$$

To solve for T_2 the following parameters were curve fit from the steam tables over a temperature range from 100-300°F

$$\text{saturation pressure}: P_v\,(\text{psia}) = 20.73 + 0.4512T - 0.003298T^2 + \left(9.215x20^{-6}\right)T^3 \tag{10}$$

$$\text{enthalpy of water vapor}: h_v = (\text{Btu/lb})1056.9 + 0.51198T - 0.0003398T^2 \tag{11}$$

$$\text{enthalpy of liquid water}: h_\ell(\text{Btu/lb}) = -33.119 + 1.007T \tag{12}$$

$$\text{latent heat of vaporization}: h_{fg}(\text{Btu/lb}) = 1087.0 - 0.4621T - 4.177 \times 10^{-4} T^2 \tag{13}$$

The above equation was solved iteratively on a spreadsheet since hv_2 is a function of T_2. Once the dry bulb temperature T_2 was found, the wet bulb temperature was found by mathematically increasing the amount of water vapor injected until the calculated partial pressure of water vapor in the duct was equal to the saturation pressure and a relative humidity of unity, for this calculation the atmospheric pressure was taken as P_{atm} = 12.25 psig

$$RH = \frac{\left(X_{H_2O_2}\right)_2 P_{atm}}{P_v} \tag{14}$$

$$X_{H_2O_2} = \frac{w_2\left(MW_{fg}/MW_{H_2O}\right)}{1 + w_2\left(MW_{fg}/MW_{H_2O}\right)} \tag{15}$$

Table A.5-1 shows a sample calculation in the spreadsheet format. In the calculation T_2(guess) is changed until it matches T_{2calc}. Then the water injection rate Q_{H_2O} is changed until the relative humidity is 100% (R-Hum). For the case shown in Table A.5-1 this corresponds to a water injection rate of 69.1 gpm which results in T_2 of 117°F; this is the wet bulb temperature. The approach temperature can then be calculated. For instance assume for the 80 MW case shown in Table A.5-1 that the water injection rate was, $Q_{H_2O} = 54$ gpm.

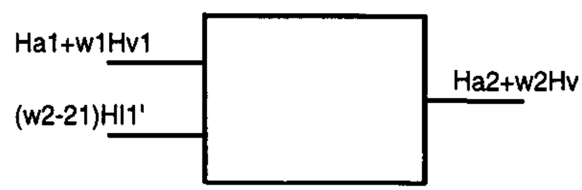
T_2 (dry bulb) = 151°F

T_{wb} = 117°F

$\Delta T_{App} = 151 - 117$ = 34°F

HUMIDIFICATION CALCULATION

LOAD	80 MW		
O2econ dry	5.85%		
T1w/oH2O	281°F	(O2)1w:	5.40
Tl(water)	64°F	(H2O)1:	8.27
H2O econcak	8.29%	(O2)1d:	5.89



Q-H2O	w1	w2	T2calc	T2guess	(H2O)2	R-HUM	P(H2O)	Pv	w1Hv1	w2-w1	(W2-W1)Hl	w2Hv2
10.0	0.0542	0.0600	256	256	9.09	3.4	1.11	33.14	63.67	0.0058	0.1809	69.95
20.0	0.0542	0.0658	231	231	9.88	5.7	1.21	21.15	63.67	0.0115	0.3617	76.11
30.0	0.0542	0.0716	207	207	10.66	10.0	1.31	13.05	63.67	0.0173	0.5426	82.17
40.0	0.0542	0.0773	183	183	11.42	17.7	1.40	7.89	63.67	0.0231	0.7234	88.09
54.0	0.0542	0.0854	151	151	12.56	39.1	1.53	3.91	63.67	0.0312	0.9766	96.21
60.0	0.0542	0.0889	137	137	12.90	54.6	1.58	2.89	63.67	0.0346	1.0852	99.60
70.0	0.0542	0.0946	115	115	13.63	107.7	1.67	1.55	63.67	0.0404	1.2660	105.18
80.0	0.0542	0.1004	93	93	14.34	1404.1	1.76	0.13	63.67	0.0462	1.4469	110.62
90.0	0.0542	0.1062	72	72	15.04	-95.1	1.84	-1.94	63.67	0.0520	1.6277	115.96
69.1	0.0542	0.0941	117	117	13.56	99.8	1.66	1.66	63.67	0.0399	1.2497	104.68
55.0	0.0542	0.0860	148	148	12.53	41.2	1.54	3.73	63.67	0.0318	0.9947	96.76
56.0	0.0542	0.0866	146	146	12.61	43.6	1.54	3.54	63.67	0.0323	1.0128	97.34
57.0	0.0542	0.0871	144	144	12.68	46.2	1.55	3.37	63.67	0.0329	1.0309	97.91
58.0	0.0542	0.0877	141	141	12.76	48.9	1.56	3.20	63.67	0.0335	1.0490	98.49

Table A.5-1. Sample Calculation of the Dry Bulb and Wet Bulb Temperatures with Duct Humidification

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Appendix H

AIR TOXICS SUMMARY SECTION

FOR

CALCIUM-BASED DRY SORBENT INJECTION SYSTEM RETROFIT

IV. Summary of Air Toxics Monitoring Results

A total of 21 potential air toxics was measured at Arapahoe 4 with the calcium-based DSI system operating. Table 7 lists the air toxics that were sampled during the calcium-based DSI testing. Table 8 compares the target air toxics measured during each of the four test series. This report presents baseline dioxin data and air toxics data for the calcium-based DSI system. Refer to the other three environmental monitoring reports for more information on the other tests conducted.

Trace Metals	Arsenic	Lead
	Cadmium	Molybdenum
	Copper	Phosphorous
	Mercury	Beryllium
	Selenium	Cobalt
	Calcium	Manganese
	Barium	Nickel
	Chromium	Vanadium
	Calcium	Sodium
Anions [1]	Chloride	Sulfate
	Fluoride	

1. Elemental precursors of these anions measured in the fuel (Cl, F, S).

Table 7: Target Compounds for Calcium-Based DSI System

Sampling of the baseline dioxins was conducted on October 11, 12, and 13, 1993. The air toxics tests for the calcium-based DSI system were conducted on October 19 and 20, 1993. No sampling occurred during sootblowing operations.

Target Compounds		Test Period					
		Low-NOx Combustion	SNCR		Calcium-Based DSI		Sodium-Based DSI
			Baseline [3]	SNCR	Baseline	Sodium	
Trace Metals		X		X		X	X
Acid-Forming Anions		X		X		X	X
Volatile Organic Compounds	Benzene/toluene	X	X				
	Formaldehyde	X					
Semi-Volatile Organic Compounds	PAH	X					
	PCDD/PCDF [1]		X[2]		X		
Solid Particulate		X		X		X	X
Radio Nuclides		X					
Trace Metals Speciation	Total/hexavalent chromium		X				
	Mercury		X				
Nitrogen Compounds		X		X			
HHV, Ultimate/ Proximate Analysis		X	X	X	X	X	X
Loss-On-Ignition		X		X		X	X

1. Polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF).
2. Due to anomalous contamination of native 2,3,7,8,PCDD/PCDF isomers in the method blanks, samples, and archived resin, the results of these tests are invalid and were repeated during the calcium-based DSI test period.
3. Some baseline tests were repeated in the SNCR test period.

Table 8: Target Compounds

PSCC contracted with Carnot, Inc. of Tustin, California to complete the air toxics work at Arapahoe Unit 4. Fossil Energy Research Corp. of Laguna Hills, California provided some assistance at the site and with data collection. Table 9 lists the laboratories used to analyze the collected samples.

Analysis	Laboratory	Location
Solid particulate	Carnot, Inc	Tustin, CA
Chloride and sulfate (as necessary for confirmation)	Carnot, Inc	Tustin, CA
Acid-forming anions	Curtis and Tompkins	Berkeley, CA
Trace metals	Curtis and Tompkins	Berkeley, CA
Semi-volatile organic compounds	Zenon Environmental Laboratories	Burlington, Ontario, Canada
LOI for ash	Commercial Testing and Engineering	Denver, CO
Trace metals and anions analysis of fuel and ash	Curtis and Tompkins	Berkeley, CA
Coal preparation and ultimate analysis, including anions	Commercial Testing and Engineering	Denver, CO
Neutron activation analysis	Massachusetts Institute of Technology	Cambridge, MA
Coal preparation	A. J. Edmonds	Long Beach, CA
Ash preparation and anion analysis	Commercial Testing and Engineering	Denver, CO
Ash preparation	Carnot	Tustin, CA

Table 9: Laboratories for Air Toxics Analyses

The Environmental Monitoring Plan (EMP) addendum for air toxics includes details on the method used to determine the total mass flow of the air toxics. In addition to the measured concentrations of the air toxics in the sample, mass flows of the solid and gas are required. Table 10 lists the mass flowrates for the flue gas and the solids used to determine the mass flow of the toxics. The actual flue-gas flowrate is used for each of the trace metal, particulate matter, and anion tests. The flue-gas flowrates for the VOC and cyanide tests were from the major test conducted concurrently. The existing plant equipment was used to measure the coal flow. The measured particulate loading and flue-gas flowrate was used to calculate the flowrate of the fly ash and the stack ash. The coal input and the fly ash flowrates were used to calculate the bottom ash flowrate.

Stream	Test	Location	Test 1	Test 2	Test 3
Flue Gas Flow Rate (DSCFM)	Trace Metals	Inlet	271,100	279,700	276,300
		Outlet	279,200	288,700	279,700
	Particulate Matter	Inlet	252,500	263,000	272,700
		Outlet	260,000	268,900	275,900
	Anions	Inlet	252,500	263,000	272,700
		Outlet	260,000	268,900	275,900
	Dioxins and Furans	Inlet	232,600	199,100	225,200
		Outlet	234,900	204,700	206,900
Coal Flow (lb/h)			101,800	105,400	104,300
Fly Ash Flow (lb/h)			8,359	8,351	7,474
Bottom Ash Flow (lb/h)			3,638	3,889	4,593
Total Ash Flow (lb/h)			11,997	12,240	12,067
Stack Ash Flow (lb/h)			4.2	1.6	1.4

Table 10: Stream Mass Flow Data

Table 11 lists the average operating conditions of Arapahoe Unit 4 during the calcium and baseline air toxics testing. All three baseline dioxin tests were conducted at 75 Mwe. A problem occurred on the first day of testing that limited load to 75MWe. The problem was corrected the following day but the remaining tests were conducted at the same load to provide three replicate tests. Figure 1 shows a simplified diagram of the unit and shows the five different sample locations. Gaseous samples were obtained at the inlet and the outlet of the FFDC. Solid samples of unpulverized coal, bottom ash, and fly ash were also obtained. This section lists the results of the air toxics testing. For details on the methods used for sampling, analysis, and quality assurance, see the *Environmental Monitoring Plan Addendum for Air Toxics Monitoring,* dated July 1993.

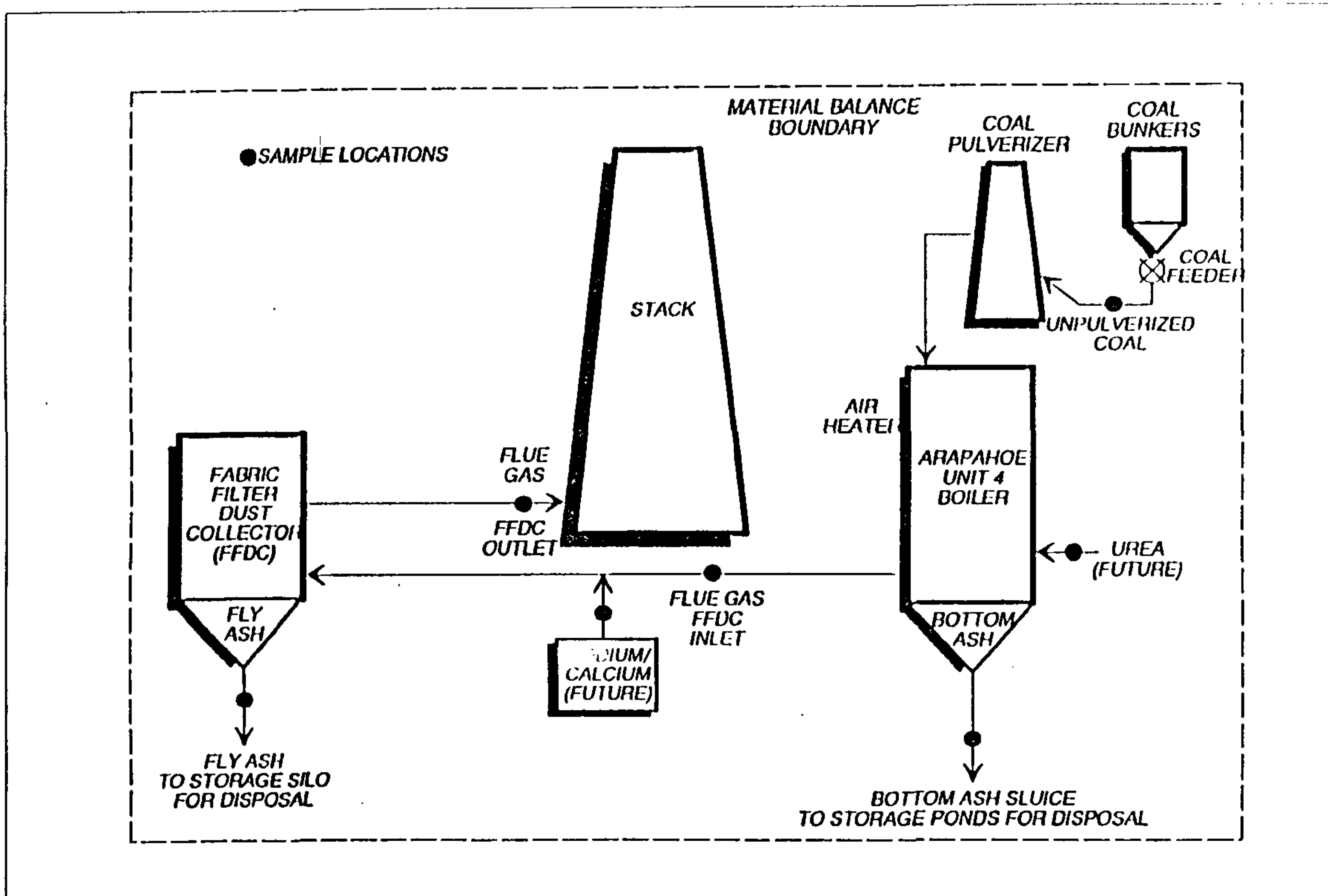

Figure 1: Sampling Locations

Property		Baseline Dioxins			Calcium-Based DSI Air Toxics		
		1	2	3	1	2	3
Unit load (MW, net) [3]		76	75	75	112	112	112
Input	Air (lb/h)	753,000	705,000	716,000	976,000	995,000	1,028,000
	Coal (lb/h)	67,600	68,900	72,200	101,800	105,400	104,300
Steam flow (lb/h)		638,000	632,000	630,000	959,000	966,000	966,000
DSI	Injection rate (lb/min)	--	--	--	51.5	52.4	51.7
	Ca/S	--	--	--	2.06	2.07	2.10
	Sorbent feeder output (A/B) [4]	--	--	--	56%/68%	57%/69%	56%/68%
	Humidification water (gpm)	--	--	--	70.9	66.8	72.8
FFDC outlet	$\%O_2$[1], dry	7.70%	7.24%	7.34%	6.11%	6.25%	6.32%
	CO (ppmd) [2]	14.0	19.2	13.2	71.7	231	212
	NO (ppmd) [2]	216	194	196	225	221	225
	SO_2 (ppmd) [2]	308	308	307	280	283	262

1. From Carnot's portable O_2 that sampled at each sample point.
2. From a single point Altech CEM system located in the FFDC outlet duct.
3. The "B" ID fan was off line for the first baseline test. To maintain consistent operating conditions, the remaining tests were operated at 75 MW.
4. Indicates level of operation of "A" and "B" DSI feed systems.

Table 11: Average Operating Conditions and Continuous Emissions Data

Table 12 lists the methods used during this sampling program that differ from the EMP.

A. Uncertainty Analysis

In the tables that follow, a value for uncertainty expressed as a percentage is provided for all data. The calculation method used is based upon ANSI/ASME PTC 19.1-1985, "Measurement of Uncertainty." The uncertainty is based on a 95% confidence interval for the mass emissions for the target species but is expressed as a percentage so that it may be applied to other units. A very important part of the method is assigning an estimated bias error for the major

Species		EMP Specified Method	Method Used
FFDC Inlet	Arsenic	EPA SW 846-7060 (GFAA)	EPA SW 846-6010 (ICP)
	Cadmium	EPA SW 846-7131 (ICP)	EPA SW 846-6010 (ICP)
	Chromium	EPA SW 846-7191 (GFAA)	EPA SW 846-6010 (ICP)
FFDC Outlet	Arsenic	EPA SW 846-7060 (GFAA)	EPA SW 846-6010 (ICP)
	Cadmium	EPA SW 846-7131 (ICP)	EPA SW 846-6010 (ICP)
	Chromium	EPA SW 846-7191 (GFAA)	EPA SW 846-6010 (ICP)
Fuel	Arsenic	EPA SW 846-7060 (GFAA)	INAA
	Barium	EPA SW 846-6010 (ICP)	EPA SW 846-6010 (ICP with EPA3050 digestion)
	Chlorine	ASTM D-4208 & ISP	INAA
	Sulfate	EPA SW 846-300-IC	ASTM D4239 & LECO SC-132
	Cadmium	EPA SW 846-7131 (ICP)	INAA
	Mercury	EPA SW 846-7470 (CVAA)	INAA
	Selenium	EPA SW 846-7740 (GFAA)	INAA
	Chromium	EPA SW 846-7191 (GFAA)	EPA SW846-6010 (ICP-AES)
	Lead	EPA SW 846-7421 (GFAA)	EPA SW846-7420 (GFAA)
	Calcium	EPA SW 846-6010 (ICP)	EPA SW 846-6010 (ICP with EPA3050 digestion)
	Sodium	EPA SW 846-6010 (ICP)	EPA SW 846-6010 (ICP with EPA3050 digestion)
	Manganese	EPA SW 846-6010 (ICP)	INAA
	Vanadium	EPA SW 846-6010 (ICP)	INAA
Flyash/ Bottom Ash	Barium	EPA SW 846-6010 (ICP)	EPA SW 846-7060 ICP-AES
	Beryllium	EPA SW 846-6010 (ICP)	EPA SW 846-7060 ICP-AES
	Cadmium	EPA SW 846-6010 (ICP)	EPA SW 846-7060 ICP-AES
	Chromium	EPA SW 846-6010 (ICP)	EPA SW 846-7060 ICP-AES
	Cobalt	EPA SW 846-6010 (ICP)	EPA SW 846-7060 ICP-AES
	Copper	EPA SW 846-6010 (ICP)	EPA SW 846-7060 ICP-AES
	Manganese	EPA SW 846-6010 (ICP)	EPA SW 846-7060 ICP-AES
	Mercury	EPA SW 846-7470 CVAA	EPA SW 846-7471 ICP-AES
	Molybdenum	EPA SW 846-6010 (ICP)	EPA SW 846-7060 ICP-AES
	Nickel	EPA SW 846-6010 (ICP)	EPA SW 846-7060 ICP-AES
	Phosphorus	EPA SW 846-6010 (ICP)	EPA SW 846-7060 ICP-AES
	Vanadium	EPA SW 846-6010 (ICP)	EPA SW 846-7060
	Calcium	EPA SW 846-6010 (ICP)	EPA SW 846-7060 (ICP with EPA3050 digestion)
	Sodium	EPA SW 846-6010 (ICP)	EPA SW 846-7471 (ICP with EPA3050 digestion)
	Fluoride	EPA 300.0(IC)	EPA 340.2 (ISE)
	Sulfate	EPA 300.0(IC)	ASTM D4239 & LECO SC-132

Table 12: Test Methods Different from EMP (TBD)

variables. The value presented represents only an approximation of the uncertainty as not all bias errors may be estimated. The uncertainty is also not a measure of long-term trace-species emissions for this boiler, but only the uncertainty for the specific test period. It was assumed that the samples are a normal population distribution. Table 13 summarizes the bias values used to determine uncertainties.

Location	Particle Collection [1]	Flowrate [2]	Fuel Flowrate [3]	Fly Ash Flowrate [4]	Bottom Ash Flow Rate [4]
Inlet	15%	0%	0%	15%	15%
Outlet	0%	0%	N/A	N/A	N/A

1. Bias based on difference between pitot and heat rate flowrates.
2. No bias estimated as measured inlet measured outlet, and calculated flow agreed within +-5%
3. No bias estimated as calculated flue gas flow agreed with measured outlet flow.
4. Bias equals the inlet particle collection bias.

Table 13: *Summary of Bias Values Used for Uncertainty Calculations*

B. Treatment of Non-Detectable Measurements

Many of the target species for which a measurement was attempted were not found using the specified sampling and analytical techniques. If a measurement for a target species was not found, the value that could have been measured (i.e. the detection limit) if the trace emissions were present are reported. The "non-detects" are shown as less than the detection limit. The difficulty occurs when averaging various samples of which some or all of the measurements are below the detection limit. The following summarizes the two cases:

- **All values below detection limit:** The arithmetic average of the detection limit is shown with a "<" sign to indicate that the trace species is less than the reported average detection limit. For example, if a species was not found and the method provided a detection limit of 0.45, the values is reported as <0.45.

- **Some, but not all, values below detection limit:** The value of all measurements above the detection limit are averaged with one-half of the detection limit. For example, if three measurements of 10, 8, and < 6 are found, the average would be (10+8+6/2)/3 or 7. Note that no " < " sign is used in these reported averages even though some of the values are below the detection limit. If the average calculated with this method is less than the greatest detection limit; the largest detection limit is reported and a " < " symbol is used. For example, if values of 6, < 4, and < 2 were reported, the average would be reported as < 4 and not (6+4/2+2/2)/3 or 3.

C. Treatment of Blank Values

Three different types of blanks were used as part of the air toxics testing quality assurance (QA) program. The QA program included field blanks, reagent blanks, and laboratory preparation blanks.

Field blanks are samples obtained by assembling a complete sample train at the test site using the same procedures as when obtaining the actual sample. The sample train is then leak checked and disassembled to recover and analyze the sample. Field blanks are not used to "correct" the data generally but are used to provide an indication of the quality of the sample.

Reagent blanks consist of samples of the reagent and/or filters that are collected at the site. Analysis of these samples show if any of the results were caused by existing levels of the trace species in the material used to collect or recover the sample. If measurable values of the trace species are found, the data is usually corrected by subtracting the value measured in the reagent.

Laboratory reagent blanks consist of samples of the chemicals used during the measurement analysis. If measurable values of the trace species are found, the data is usually corrected by subtracting the value measured in the reagent. Any measurable values in the laboratory reagent may be caused by initial trace species in the chemicals or by the analytical procedures.

In the tables that follow the value of the field blank is shown for reference, but none of the data has been changed due to these measurements. If a measurement has a value near the field blank measurement, there may be some question as to the accuracy of the data and the reported value may NOT be source related. A separate column lists a blank correction percentage for all trace species that were corrected due to either a reagent or laboratory reagent blank. This is an average percentage calculated as follows:

$$\%\,blank\ correct = \frac{\sum\left(\frac{blank\ value}{sample\ value}\right)}{number\ of\ samples}\ \text{æ}\ 100$$

For example, if three samples contained 10, 5, and 4 mg/kg of a trace species and the reagent blank was 2 mg/kg, the blank correction would be:

$$blank\ correction = \left(\frac{2}{10} + \frac{2}{5} + \frac{2}{4}\right)\ \text{æ}\ \frac{100}{3} = 37\%$$

Thus, on average, the actual value measured was 37% higher than the value reported in the table. If the blank correction is reported as 0%, no blank correction was calculated and the reported value was the measured value. Note that in most cases a high blank correction value does not mean that the data is inaccurate. If a sample was contaminated with a trace species due to a filter, and the filter was analyzed and the data corrected, it is likely that the data is meaningful.

D. Gaseous Species Monitoring

This section reports the trace metal, acid-forming anion, and FFDC efficiency from the air toxics testing of the calcium-based DSI system. In addition, it reports the furan and dioxin data from the baseline tests.

Trace Metals

Table 14 lists the gaseous trace metal emissions for the calcium-based DSI test period. Although calcium and sodium are neither trace metals or air toxics, Table 14 also lists their results. At the FFDC inlet, all 15 trace metals, calcium, and sodium were reported above their detection limits.

Previous air toxics test series at Arapahoe reported a wide unexplained variation of barium, calcium, and sodium in various solid streams between different test methods. Curtis and Tompkins, the laboratory completing the analysis, investigated and discovered a problem with the ASTM D3683 ashing/acid digestion method of sample preparation. Coal samples were prepared according to ASTM D3683 and also EPA method 3050. The EPA method does not require ashing or digestion using HF acid. A comparison of the data with the two different digestion methods for both the calcium and sodium injection program compared to INAA is shown in Table 15. This data suggests that ASTM D3683 (that uses HF acid digestion) may have a significant low bias. The EPA 3050 method provides better precision between replicates and better accuracy when compared to INAA which does not require sample digestion.

Trace Metals	FFDC Inlet							FFDC Outlet						
	Test 1	Test 2	Test 3	Avg.	Uncert.	Field Blank	Blank Correct [1]	Test 1	Test 2	Test 3	Avg.	Uncert.	Field Blank	Blank Correct [1]
	μg/Nm³				%	μg/Nm³	%	μg/Nm³				%	μg/Nm³	%
Arsenic [3]	27	28	19	25	50	0.14	1.4L	0.070	0.24	<0.070	0.12	239	0.074	39L
Barium [2,3,6]	16	353	730	542	443	0.80	0.3R	1.7	1.7	0.14	1.2	190	0.14	50R
Beryllium	10	15	11	12	52	<0.035	0.0	<0.027	<0.027	<0.028	<0.027	29	<0.027	0.0
Cadmium	5.0	4.8	5.2	5.0	17	<0.089	0.0	<0.070	0.48	<0.070	0.18	349	<0.069	0.0
Chromium [3]	62	95	81	80	55	0.26	1.5R	0.14	0.14	0.68	0.32	244	0.14	75R
Cobalt	43	90	70	68	88	<0.35	0.0	<0.27	<0.27	<0.28	<0.27	29	<0.27	0.0
Copper	632	322	234	396	132	1.0	0.2R	0.70	0.53	0.33	0.52	89	0.12	47R
Lead	27	103	79	70	139	0.083	0.4R	0.29	1.1	0.05	0.48	288	0.079	42R
Manganese	146	125	140	137	25	0.18	0.2R	1.2	0.21	0.84	0.74	163	0.14	26R
Mercury	4.4	5.0	3.4	4.3	50	0.12	0.0	0.33	0.19	0.27	0.26	63	0.31	0.0
Molybdenum [3]	21	43	34	33	83	3.2	15.9R	0.27	0.27	0.28	0.27	4.2	0.27	79R
Nickel [3]	36	22	17	25	100	0.77	4.1R	0.27	0.27	0.28	0.27	4.2	0.27	42R
Selenium [4]	50	103	64	72	96	<0.89	0.0	<0.070	0.11	<0.070	<0.070	88	<0.069	0.0
Phosphorus	20,300	16,100	12,500	16,300	62	<8.9	0.02L	<1.4	<1.4	<1.4	<1.4	29	3.6	0.0
Vanadium	190	319	232	247	68	<0.18	0.0	<0.14	<0.14	<0.14	<0.14	29	<0.14	0.0
Calcium [2,5,6]	1,170	<90	1,960	1,560	320	8.9	2R	143	151	102	132	50	8.9	14R
Sodium [3,5,6]	4,920	2,570	2,380	3,290	108	8.9	2R	7.5	34	7.0	16	237	27	75R

Note: "<" indicates that the quantity measured was less than the detection limit thus the detection limit is shown

1. "R" indicates reagent blank correction. "L" indicates laboratory blank correction.
2. *Tests Ba #1-Out* and Ca #2-In not included in averages.
3. Subtracting reagent blank lowered result below the detection for Ar #1-Out; Ba #3-Out; Cr #1-, 2-Out; Mb #1-, 2-, 3-Out; Ni #1-, 2-, 3-Out; and Na 3-Out.
4. Average calculated by dividing non-detects *in half was less than highest non-detect, so highest non-detect* used for average.
5. Results included, even though neither trace metals nor air toxics.
6. Values for these metals at the FFDC inlet are reported but believed to be invalid due to a problem with sample preparation (see text).

Table 14: Trace Metal Emission Results for Calcium-Based DSI System

	Reagent	D3683 mg/Kg	E3050 mg/Kg	INAA mg/Kg
Barium	sodium	5,976	24,390	33,122
	calcium	6,670	17,447	28,925
Calcium	sodium	122,740	213,404	NP
	calcium	78,917	204,879	NP
Sodium	sodium	14,843	64,322	105,096
	calcium	31,849	27,423	46,099

Table 15: Comparison of Alternate Digestion Methods with INAA

EPA method 29, multi-metals method, also uses HF acid for digestion of solid matter collected in the sample train. Due to the potential negative bias that may be caused with HF acid, all data collected for barium, calcium, and sodium from the solid samples using Method 29 are believed invalid and are presented for information only. Table 16 compares the inlet fuel levels to the values measured at the FFDC inlet determined from the Method 29 test using HF digestion. Note the very large discrepancy in the inlet values. It is believed that the fuel values are more accurate and that the FFDC inlet values for the three elements presented are invalid. They are shown in this table only to note the large variation that was believed due to the HF digestion techniques. Note that the inlet values are based on a large amount of particulate matter that is present at the FFDC inlet. Due to the very low particulate at the FFDC outlet, the possible interference with HF digestion is not believed to significantly affect the outlet data. While the fly ash and coal samples could be re-analyzed after the discovery of the possible HF interference, it was not possible to re-analyze the Method 29 train.

	Fuel lb/10^{12} Btu	FFDC Inlet lb/10^{12} Btu	Percent Difference
barium	17,400	431	3,937%
calcium	205,000	1,240	16,432%
sodium	27,400	2,580	962%

Table 16: Comparison of fuel vs FFDC Inlet Measurements

Uncertainties for copper, lead, and nickel were 100% and greater. The wide spread between the replicate tests caused the high uncertainty for these three elements. A review of the data logs and sample methods did not reveal any errors that could explain the differences.

The FFDC outlet trace metal emissions were very low with many at or near their detection limit. The high uncertainty values are due mainly to a wide variation of replicate tests. Due to the very low measured emissions, the reagent or laboratory blank corrections were also relatively high for many elements.

Anions

Anions were measured from both the front (solid/liquid phase) and the back-half (gaseous phase) of each particulate train. As expected, the majority of all anions occur in the gaseous phase. Results of the testing are presented in Table 17.

At the FFDC inlet, the sample-train measured 465 ppm of gaseous sulfate and the CEM measured 460 ppm of SO_2. The gaseous fraction represents SO_2 plus any SO_3 in the vapor phase. The sample-train measured 3 ppm of solid-phase sulfate at the FFDC inlet, representing sulfuric acid mist and solid-phase sulfate present at the 250°F filter temperature. At the FFDC outlet, the sample-train measured 287 ppm of gaseous sulfate and the CEM measured 275 ppm of SO_2.

Acid Forming Anions		FFDC Inlet							FFDC Outlet						
		Test 1	Test 2	Test 3	Avg.	Uncert.	Field Blank	Blank Correct	Test 1	Test 2	Test 3	Avg.	Uncert.	Field Blank	Blank Correct
		ppmw				%	ppmw	%	ppmw				%	ppmw	%
Chlorine (Cl^-)	Total	0.59	0.75	0.64	0.66	36	N/A		0.25	0.32	0.30	0.29	33	N/A	
	Gaseous	0.56	0.72	0.61	0.63				0.24	0.30	0.29	0.28			
	Solid	0.035	0.034	0.031	0.033			0	<0.017	0.020	0.012	<0.017			0
Fluorine (F^-)	Total	8.5	11	11	10	38	N/A		0.12	0.58	<0.06	0.24	293	N/A	
	Gaseous	8.2	10	11	9.6				0.09	0.54	<0.06	0.22			
	Solid	0.23	0.50	0.35	0.36			0	0.034	0.039	0.019	0.031			0
Sulfate (SO_4^{-2})	Total	455	477	474	469	17	N/A		302	297	262	287	15	N/A	
	Gaseous	452	474	470	465				302	297	262	287			
	Solid	2.9	3.1	3.3	3.1			1R	0.068	0.015	0.019	0.034			32R

1. "<" indicates that the quantity measured was less than the detection limit thus the detection limit is shown.
2. "R" indicates reagent blank correction. "L" indicates laboratory blank correction.
3. Solid fraction consists of filter and front-half rinse.
4. Gaseous fraction consists of bicarbonate/carbonate and 3% peroxide rinses.

Table 17: Acid-Forming Anion Emission Results for Calcium-Based DSI System

Baseline Dioxin and Furan Emissions

Table 18 lists the gaseous polychlorinated dibenzo-P-dioxin (PCDD) and polychlorinated dibenzofuran (PCDF) emissions at the FFDC inlet and outlet. Note that sampling and analysis techniques were optimized to lower detection limits to an average 10 times lower than that of normal dioxin and furan tests.

All dioxins and furans were measured near or below their detection limits. At the FFDC outlet, OCDD and 23478 PeCDF were the only individual isomers detected in all three samples. However, these isomers were also detected in the field blank, so their detected levels may not be entirely source related.

In Table 18, the column headed by "EPA Equiv." lists the EPA toxic equivalent for each specie. These values can be used for comparing risk and are used in the establishment of emission limits for municipal solid waste (MSW) incinerators. These equivalent values were calculated by multiplying the average actual emission of a specie by its EPA risk factor.

The total emissions of EPA equivalent toxics at the FFDC inlet was 0.0015 ng/Nm ^{3} and consisted of 0.0008 ng/Nm ^{3} of detected species and 0.0007 ng/Nm ^{3} of nondetects. Thus, 47% of the total EPA equivalent at the inlet of the FFDC was due to nondetects. The total emissions of EPA equivalent toxics at the FFDC outlet was 0.0014 ng/Nm ^{3} and consisted of 0.0003 ng/Nm ^{3} of detected species and 0.0012 ng/Nm ^{3} of nondetects. Thus, the nondetects at the outlet relate to 86% of the total EPA equivalent toxics. For comparison, well controlled MSW incinerators typically have on the order of 1 ng/Nm ^{3} of equivalent toxic emissions, three orders of magnitude higher than Arapahoe Unit 4.

PCDD/PCDF	FFDC Inlet							FFDC Outlet						
	Test 1	Test 2	Test 3	Avg.	Uncert.	Field Blank	EPA Equiv.	Test 1	Test 2	Test 3	Avg.	Uncert.	Field Blank	EPA Equiv.
	ng/Nm ^{3}				%	ng/Nm ^{3}		ng/Nm ^{3}				%	ng/Nm ^{3}	
2378-TCDD [1,2]	<0.0006	0.0006	0.0006	0.0005	95	<0.0006	0.0005	0.0006	<0.0004	<0.0005	<0.0005	74	<0.0005	0.0005
12378 PeCDD [1]	<0.0006	0.0002	<0.0004	<0.0006	78	<0.0006	0.0003	<0.0007	<0.0005	<0.0005	<0.0005	48	<0.0005	0.0003
123478 HxCDD [2]	<0.0007	0.0007	0.0007	0.0006	88	<0.0008	0.0001	0.0007	<0.0007	0.0006	0.0006	90	<0.0012	0.0001
123678 HxCDD [1]	<0.0004	0.0002	<0.0003	<0.0004	48	<0.0005	0.0000	<0.0004	<0.0004	<0.0002	<0.0003	83	<0.0007	0.0000
123789 HxCDD	<0.0006	<0.0002	<0.0004	<0.0004	108	<0.0007	0.0000	<0.0006	<0.0006	<0.0003	<0.0005	88	<0.0010	0.0000
1234678 HpCDD [1,2]	<0.0008	0.0004	0.0004	0.0004	43	<0.0008	0.0000	0.0010	<0.0006	<0.0004	<0.0006	136	<0.0005	0.0000
OCDD	<0.0011	0.0037	0.0020	0.0021	191	0.0036	0.0000	0.0042	0.0012	0.0008	0.0021	225	0.0010	0.0000
2378 TCDF	<0.0020	<0.0011	<0.0013	<0.0014	91	<0.0018	0.0001	<0.0022	<0.0018	<0.0018	<0.0020	36	<0.0011	0.0002
12378 PeCDF [1]	<0.0005	<0.0002	0.0002	<0.0005	92	<0.0005	0.0000	<0.0004	<0.0002	<0.0001	<0.0002	127	<0.0003	0.0000
23478 PeCDF	0.0005	0.0004	0.0004	0.0004	42	<0.0005	0.0002	0.0005	0.0004	0.0004	0.0004	62	0.0004	0.0002
123478 HxCDF [1]	<0.0006	<0.0002	<0.0004	<0.0004	126	<0.0004	0.0000	0.0004	<0.0004	<0.0002	<0.0004	75	<0.0004	0.0000
123678 HxCDF	<0.0004	<0.0002	<0.0003	<0.0003	89	<0.0002	0.0000	<0.0003	<0.0003	<0.0001	<0.0002	104	<0.0004	0.0000
234678 HxCDF	<0.0007	<0.0003	<0.0004	<0.0005	101	<0.0004	0.0000	<0.0004	<0.0004	<0.0002	<0.0003	96	<0.0004	0.0000
123789 HxCDF	<0.0007	<0.0004	<0.0004	<0.0005	107	<0.0004	0.0001	<0.0004	<0.0005	<0.0002	<0.0004	95	<0.0005	0.0000
1234678 HpCDF	<0.0004	<0.0003	<0.0003	<0.0004	45	<0.0007	0.0000	<0.0005	<0.0003	<0.0002	<0.0004	106	<0.0004	0.0000
1234789 HpCDF	<0.0006	<0.0005	<0.0005	<0.0005	44	<0.0010	0.0000	<0.0008	<0.0005	<0.0004	<0.0005	103	<0.0006	0.0000
OCDF	<0.0006	<0.0004	<0.0006	<0.0005	51	<0.0010	0.0000	<0.0006	<0.0008	<0.0005	<0.0006	67	<0.0006	0.0000
Total TCDD [1,2]	<0.0006	0.0006	0.0006	0.0005	95	<0.0006	--	0.0006	<0.0004	<0.0005	<0.0005	74	<0.0005	--
Total PeCDD [1]	<0.0006	0.0002	<0.0005	<0.0006	79	<0.0006	--	<0.0007	<0.0005	<0.0005	<0.0006	50	<0.0005	--
Total HxCDD	<0.0005	0.0008	0.0005	0.0005	132	<0.0006	--	0.0009	<0.0005	0.0004	0.0005	167	<0.0009	--
Total HpCDD [1,2]	<0.0008	0.0004	0.0004	0.0004	43	<0.0008	--	0.0010	<0.0006	<0.0005	<0.0006	119	<0.0005	--
Total TCDF	0.0019	0.0023	0.0028	0.0023	41	0.0019	--	0.0019	0.0016	0.0015	0.0017	26	0.0014	--
Total PeCDF	0.0011	0.0007	0.0014	0.0011	80	<0.0005	--	0.0011	0.0007	0.0007	0.0008	68	0.0004	--
Total HxCDF [1]	<0.0006	0.0003	<0.0004	<0.0006	69	<0.0006	--	0.0004	<0.0004	<0.0004	<0.0004	28	<0.0004	--
Total HpCDF	<0.0005	<0.0004	<0.0004	<0.0004	41	<0.0008	--	<0.0006	<0.0004	<0.0004	<0.0005	73	<0.0005	--
Total	0.0119	0.0144	0.0137	0.0133	27	--	0.0015 [3]	0.0185	0.0104	0.0093	0.0127	100	--	0.0014 [3]

"<"indicates detection limit and that species was not detected.

1. By convention, the calculated mean cannot be smaller than *the largest detection limit value*. When this happens, the mean is reported as not detected below highest detection limit.
2. Detection limits varied by sample, a straight average with non-detects divided by two was taken, highest non-detect rule was deemed inappropriate.
3. Total EPA toxic equivalent (2, 3, 7, 8, TCDD Equivalent)

Table 18: Baseline Polychlorinated Dibenzo-P-Dioxin (PCDD) and Polychlorinated Dibenzofuran (PCDF) Emissions

FFDC Efficiency

Table 19 shows the FFDC removal efficiency for trace metals, anions, calcium, and sodium. The FFDC did not affect flue gas concentrations of PCDDs or PCDFs. The FFDC averaged 98.6% removal efficiency for trace metals and 99.95% for particulates.

The FFDC's removal efficiency for mercury was 93.7%, significantly higher than was obtained in previous testing without calcium injection with humidification. Fly ash unburned carbon during this testing averaged 11.21%. Water was also injected into the flue gas to improve calcium utilization. The water injection cooled the flue gas to approximately 150°F. It is believed that the combination of low flue gas temperature and high unburned carbon in the fly ash allowed the higher than expected mercury removal.

As was discussed in the trace metals section, sodium, calcium, and barium are believed to be severely biased low. Thus the data for these three elements is presented for informational purposes but the relative numbers are considered invalid.

The combination of the FFDC with calcium injection with humidification obtained significant removal of the acid-forming anions. Removal of both chloride and fluoride were 55.1% and 97.5% respectively. The removals are comparable to previous testing with urea injection but are significantly higher than the original baseline which were 10% for chloride and 20% for fluorides. SO_2 removal during the test was approximately 37% due to the calcium and humidification system.

Species		Inlet	Outlet	FFDC Removal
Trace Metals		lb/10^{12} Btu	lb/10^{12} Btu	%
Arsenic		20	0.09	99.5
Barium [2]		431	0.94	99.8
Beryllium		9.5	<0.02	>99.8
Cadmium		3.9	0.15	96.2
Chromium		63	0.26	99.6
Cobalt		53	<0.22	>99.6
Copper		310	0.42	99.9
Lead		55	0.38	99.3
Manganese		108	0.59	99.4
Mercury		3.4	0.21	93.7
Molybdenum		26	0.22	99.1
Nickel		19	0.22	98.9
Selenium		57	<0.06	>99.9
Phosphorus		12,800	<1.1	>99.99
Vanadium		194	<0.11	>99.9
Calcium [1,2]		1,240	106	91.4
Sodium [1,2]		2,580	13	99.5
Average		--	--	**98.6**
Total Particulate		4.27 lb/MMBtu	0.0021 lb/MMBtu	99.95%
Acid-Forming Anions		lb/10^{12} Btu	lb/10^{12} Btu	%
Chloride (Cl)	Solid	41	<21	>48.9
	Gas	784	353	54.9
	Total	825	371	55.1
Fluoride (F)	Solid	241	21	91.3
	Gas	6,460	150	97.7
	Total	6,700	167	97.5
Sulfate	Solid	10,600	115	98.9
	Gas	$1.57(10^6)$	$9.89(10^5)$	37.1
	Total	$1.58(10^6)$	$9.90(10^5)$	37.5

NOTES:

"<" indicates that the quantity measured was less than the detection limit; thus the detection limit is shown.

">" indicates that the percentage removal is based on a detection limit so the expected minimum removal rate.

1. Included even though neither trace metals or air toxics.
2. Values for these metals are reported but are believed invalid due to a problem with sample preparation. (see text)

Table 19: FFDC Removal Efficiency (Calcium-Based DSI Test Period)

E. Solids Stream Monitoring

Calcium-Based Sorbent Analysis

Table 20 lists the trace metal and anion analysis results for the calcium-based sorbent (calcium hydroxide) and humidification water. Although calcium and sodium are neither trace metals nor air toxics, Table 20 also lists them.

The humidification water contained negligible amounts of trace metals but significant amounts of calcium, sodium, and acid-forming anions. The total mass input of air toxics due to the sorbent and water added to the process was insignificant in comparison to the amounts in the coal. Notable exceptions were molybdenum and chloride. The sorbent water contained 41% of the total mass input of molybdenum and 46% of the input chlorides. Other air toxics that were input due to the sorbent and water were much lower and ranged from 0 to 10% of those input from other sources on a mass basis.

Element	Calcium Sorbent		Sorbent H_2O
	Test 22	Blank Correct	
	mg/kg	%	µg/L
Arsenic	<1.2	0	<5.0
Barium	9.0	0	34
Beryllium	<0.49	0	<2.0
Cadmium	<1.2	0	<5.0
Chromium [1]	5.1	0	<10
Cobalt	<4.9	0	<20
Copper	5.3	0	<5.0
Lead	<0.73	0	<3.0
Manganese [1]	45	22.4	<10
Mercury	<0.091	0	<0.20
Molybdenum	6.2	0	25
Nickel [1]	5.3	0	<20
Selenium	<61	0	<250
Phosphorous	195	0	<100
Vanadium	7.9	0	<10
Calcium	NP	0	27,000
Sodium	NP	0	17,000
Chloride	<5.0	0	22,973
Fluoride	34	0	960
Sulfate	170	0	104,350

1. Prep blank levels were higher than the sample values, so the samples were not blank corrected.

Table 20: Air Toxics Analysis of Hydrated Lime

Coal Analysis

Previous air toxics testing at Arapahoe has shown the importance of obtaining representative solid samples. This is a difficult task due to the scale and current equipment. Coal sample procedures were modified and the ASTM D2234 collection method was followed more closely during the sodium- and calcium-based DSI test periods than during the low-NO_x combustion and SNCR test periods. In addition, the ASTM D2013 preparation method was followed during the sodium- and calcium-based DSI test periods. For barium, lead, calcium, and sodium, EPA Method 3050 was used for coal digestion instead of ASTM D3683.

For many trace metal data points, there were two or three sets of results. On average, there were three sets of data with some having as many as six sets. For example, one point had results from:

- Curtis & Tompkins analysis using conventional digestion.
- Curtis & Tompkins analysis using EPA 3050 digestion.
- Standard Laboratory's analysis.
- Curtis & Tompkins triplicate analysis using conventional digestion.
- Curtis & Tompkins triplicate analysis using EPA 3050 digestion.
- INAA.

Except for a few cases, the results from these different sources did not agree. Ideally, if the data for one element from one set was consistent with expected levels and other process streams, then the data for elements within the same data set processed by the same lab and method would also be consistent. Unfortunately, a common bias for a data set could not be found. Therefore, the use of a particular data set depended solely on its agreement with levels determined in other input and output streams from the same test program.

For the low-NO_x combustion and SNCR test periods, INAA was selected as the analytical technique most likely to produce representative data sets for arsenic, barium, mercury, selenium, and chloride because INAA:

- Could achieve lower detection limits for arsenic, mercury, selenium, and chloride.
- Results for barium agreed with USGS and Cyprus Yampa Valley coal data. ICP-AES results were biased low.

Since INAA is not a proven analytical technique for trace metal analysis of coal, it was not chosen to analyze an element unless there was a clear technical justification to discard the conventional data.

For the coal samples from the sodium- and calcium-based DSI test periods, INAA was the only technique used to analyze arsenic, mercury, selenium, and chloride. With the use of EPA 3050 digestion technique for barium, the ICP-AES analysis results for barium are no longer severely biased and are now consistent with expected levels. For sodium-based DSI test, the conventional analytical results for cadmium, chromium, manganese, and vanadium were considered as qualitative and discarded.

Table 21 lists the analysis of the coal for trace metals and acid-forming anions. Although calcium and sodium are neither trace metals nor air toxics, Table 21 also lists them. All trace metals were detected in each replicate. Most elements show relatively good precision (uncertainty less than 100%). A single high nickel reading caused uncertainty of 120%. While high the nickel readings are in the range expected for this coal.

Trace Metals	Base Test Method						INAA					
	Test 1	Test 2	Test 3	Avg.	Uncert.	Blank Correct	Test 1	Test 2	Test 3	Avg.	Uncert.	Blank Correct
	mg/kg				%		mg/kg				%	
Arsenic [2]	NP	NP	NP	NP	NP	0	0.54	0.48	0.51	0.51	14	0
Barium [1]	30	173	174	192	42	0	285	347	325	319	25	0
Beryllium	0.37	0.28	0.41	0.35	46	0						
Cadmium [2,3]	0.12	<0.10	<0.12	<0.11	--	0	0.05	0.08	0.047	0.048	86	0
Chromium	2.6	1.9	2.9	2.5	52	0	1.7	1.6	2.1	1.8	39	0
Cobalt	1.3	0.8	1.0	1.0	60	0	0.81	0.91	0.82	0.85	17	0
Copper	5.2	3.4	4.5	4.4	53	0						
Lead [1]	3.4	3.1	3.8	3.4	24	0						
Manganese	14	11	23	16	104	0	6.7	7.8	8.4	7.6	28	
Mercury [2]	NP	NP	NP	NP	NP	0	0.024	0.035	0.030	0.030	46	0
Molybdenum	0.52	0.32	0.42	0.42	60	0	0.9	0.8	0.9	0.9	14	0
Nickel	2.4	0.9	1.4	1.6	120	0						
Selenium [2]	NP	NP	NP	NP	NP	0	1.29	1.37	1.14	1.27	22	0
Phosphorus	450	338	376	388	37	0						
Vanadium	7.5	4.5	6.7	6.2	63	0	5.9	4.7	7.2	5.9	51	
Calcium [1,4]	2,390	2,280	2,110	2,260	16	0						
Sodium [1,4]	432	265	211	302	95	0	496	475	554	508	20	0
Anions	mg/kg				%		mg/kg				%	
Chloride (Cl⁻)[2]	--	--	--	--	--	0	13	25	19	19	78	0
Fluorine (F⁻)	80	70	70	73	20	0						
Sulfate	17,400	18,000	17,100	17,500	16	0						

"<" indicates that the quantity measured was less than the detection limit thus the detection limit is shown.

"NP" indicates not performed.

All values are reported on an as-received basis for the coal.

1. Analysis performed after an EPA 3050 digestion (acid only).
2. INAA results were used for these trace species rather than the base method.
3. Cadmium average less than highest nondetect and reported as such.
4. Included even though neither are trace metals or air toxics.

Table 21: Trace Metals Analysis of Coal

Fly Ash

Table 22 lists the results for the fly ash and bottom ash from the calcium-based DSI test period. Although calcium and sodium are neither trace metals nor air toxics, Table 22 also lists them. Cadmium is the only element reported below its detection limit. The results for barium, calcium, and sodium from Test-1 were not used in the average. The combination of EPA 3050 digestion and ICP-AES analysis is used only for these three elements, therefore a problem with the digestion or ICP analysis may have affected these results. The conventional digestion of the sodium sample for Test-1 also yielded a value an order of magnitude higher than the other samples. This suggests that EPA 3050 digestion failed to dissolve the entire samples of barium and calcium and that the sodium sample was contaminated. Test-3 for sodium appears to be negatively biased when compared with output stream levels.

Matrix effects and certain digestion techniques make the analysis of selenium very difficult. Selenium is by far the most problematic of potential air toxics elements to analyze. With the discovery that hydrofluoric (HF) acid was interfering with GFAA, ash samples were re-analyzed using EPA 3050 digestion. This method eliminated the need for diluting the ash samples to minimize interference as well as most of the questionable results and high detection limits. However, the ash results for selenium obtained with EPA 3050 digestion from the sodium- and calcium-based DSI test periods are not consistent with expected levels. Despite high detection limits and poor precision, the conventional ash results for selenium agree, on average, with expected values and are used in the mass balance.

Bottom Ash

Overall, sample preparation does not appear to have biased the results of the bottom ash. The average results for arsenic, cadmium, mercury, and molybdenum were below the detection limit. Except for selenium and sodium, the replicates show good agreement. As with the fly ash, the conventional digestion methods used to analyze selenium often produce spurious data points. Also, since bottom ash levels of sulfate contribute less than 1% of the total sulfate stream, the spread in the sulfate results is considered negligible.

	Bottom Ash/Sluice Water [7]						Fly Ash					
	Test 1	Test 2	Test 3	Avg.	Uncert.	Blank Correct	Test 1	Test 2	Test 3	Avg.	Uncert.	Blank Correct
Trace Metals	mg/kg				%		mg/kg				%	
Arsenic	<1.2	<1.3	<1.2	<1.2	40	0	5.9	3.7	3.3	4.3	84	0
Barium [1]	900	1,100	1,000	1,000	29	0	580	1,100	990	1,045	31	0
Beryllium	3.9	3.6	3.8	3.8	27	0	3.7	2.9	2.7	3.1	37	0
Cadmium [4]	<1.1	<1.1	<1.1	<1.1	40	0	<1.1	<1.3	<1.4	<1.3	41	0
Chromium	23	20	23	22	27	0	27	20	20	22	50	0
Cobalt	15	14	16	15	29	0	16	14	13	14	27	0
Copper [5]	120	47	49	72	91	0	42	47	43	44	20	0
Lead	23	22	21	22	28	0	45	29	30	35	68	0
Manganese	100	83	180	121	111	0	150	96	100	115	68	0
Mercury	<0.020	<0.020	<0.020	<0.020	44	0	0.15	0.32	0.27	0.25	91	0
Molybdenum [4]	4.5	<4.3	<3.9	<4.3	37	0	4.6	7.8	7.5	6.6	70	0
Nickel	15	13	19	16	44	0	17	16	10	14	69	0
Selenium [3]	<11	23	<9.7	11	233	0	18	<13	7.8	11	148	0
Phosphorus	5,100	5,900	5,900	5,630	27	0	3,900	4,600	4,300	4,270	22	0
Vanadium	49	50	54	51	28	0	57	46	45	49	31	0
Calcium [1,6]	19,700	23,700	21,400	21,600	28		22,000	160,000	150,000	155,500	26	
Sodium [1,6]	1,320	1,370	1,310	1,340	33		63,000	2,600	1,700	2,150	27	
Acid-Forming Anions	mg/kg				%		mg/kg				%	
Chloride as Cl^-	240	262	214	238	29	0	120	82	72	91	72	0
Fluoride as F^- [2]	6.9	6.2	5.1	6.1	34	0	1,100	73	72	1,100	N/A	0
Sulfate	186	260	1,680	710	297	0	66,500	49,400	59,900	58,600	33	0

"<" indicates that the quantity measured was less than the detection limit; thus the detection limit is shown.

1. Replicates for #1-Fly Ash for Ba, Ca, and S not used in average, since not consistent with expected values.
2. Fl results for #2- and #3-Fly Ash not used in average because of incomplete water extraction.
3. Since detection limits varied by sample, highest non-detect not used for average.
4. Highest non-detect used for bottom ash average.
5. #1-Bottom Ash was higher than fuel input and not used in average.
6. Included even though neither are trace metals nor air toxics.
7. Trace metals results from bottom ash solid fraction only. For anions, Ca, and Na, solid and liquid fractions analyzed separately and combined proportionately by weight after sluice water blank corrections

Table 22: Air Toxics Analysis of Ash for Calcium-Based DSI

F. Mass Balance Results

Mass balances are an important quality check on toxics emissions data. Using different sample and analytical techniques to measure toxics in both gaseous and solid forms is difficult. Mass balances provide a quick means for determining how well various analytical methods agree. The low absolute quantities of the measured materials, however, makes the occurrence of a 100% mass balance very unlikely.

There are three major sources of potential error in the mass balance: operating conditions, analytical difficulties, and sample collection and handling. Since Arapahoe Unit 4 operated at or near steady-state conditions and the daily tests show that the same coal was fired throughout the tests, operating conditions are not likely to contribute any significant sources of error. Analytical difficulties usually only affect the results of individual replicates or species, so they are considered with each species. Normally, analytical difficulties outweigh sampling problems. On a utility coal-fired unit, however, obtaining representative samples from process streams flowing at thousands of pounds per hour adds a major source of potential error. It should also be noted that uncertainties only represent consistency, not accuracy.

In addition, recent findings from other Department of Energy (DOE) sponsored programs indicate that the sample digestion methods of EPA Method 29 are not effective for large quantities of ash and introduce a 20 to 60% negative bias. The difficulty of finding a correct digestion method and the need for different digestion methods for different elements casts doubt on the validity of the sample preparation procedures of both EPA Method 29 and the ASTM methods which use only one digestion method for all elements.

Only compounds dependent on the fuel inputs can be balanced. Since semi-volatile organic compounds depend on combustion parameters, they cannot be balanced. The boiler/FFDC mass balance uses the coal and calcium-based sorbent as its inputs and the bottom ash, fly ash, and FFDC outlet as its outputs. The boiler mass balance uses the coal for its only input and the FFDC inlet and the bottom ash as its outputs. For the sorbent results, nondetects are treated as zeroes if the detection limit is greater than 25% of the fuel input (selenium, for instance) or if the element is not expected to exist in the sorbent (arsenic and mercury, for example).

Table 23 shows the mass balance results for the calcium-based DSI test period. Based on fuel-input and fly ash levels, the FFDC results for mercury appear to be positively biased. For the boiler/FFDC balance, most species were in the range of 69 to 130%, except for barium, cobalt, and phosphorous. The following may have affected the results for these elements:

- Since the fuel input for barium is considered accurate, the barium levels in the ash are considered negatively biased by 30 to 40%.
- The fuel input for cobalt appears to be biased low.
- Since previous tests produced good closure for phosphorous, the phosphorous levels in the sorbent may be biased low. The phosphorous levels in the bottom ash, however, are higher than those in previous tests, so these values may also be causing the poor closure results.

Species	Inputs		Intermediate	Outputs			Mass Balance	
	Fuel	DSI[1] (Calcium)	FFDC Inlet	Bottom Ash	Fly Ash	FFDC Outlet	Boiler/ FFDC [2]	Boiler [2]
Trace Metals	lb/10^{12} Btu		lb/10^{12} Btu	lb/10^{12} Btu			%	
Arsenic [3]	47	<3.4	20	<4.4	30	0.093	75	52
Barium	17,400	26	NV	3,580	7,300	0.94	62	--
Beryllium	32	<1.4	9.5	13	22	<0.022	105	72
Cadmium [3]	5.4	<3.4	3.9	<3.9	<8.8	0.15	--	72
Chromium	224	14	63	79	157	0.26	99	63
Cobalt	93	<14	53	54	101	<0.22	144	115
Copper	396	14	310	172	308	0.42	117	122
Lead	310	<2.1	55	79	244	0.38	104	43
Manganese	1,450	123	108	448	812	0.59	80	38
Mercury [3]	2.7	<0.25	3.4	<0.072	1.7	0.21	74	128
Molybdenum	38	18	26	<15	46	0.22	110	108
Nickel	141	15	19	57	102	0.22	102	54
Selenium [3]	115	<174	57	38	77	<0.057	100	83
Phosphorus	35,200	532	12,800	20,300	29,800	<1.1	140	94
Vanadium	565	22	194	183	346	<0.11	90	67
Average Metals							**100**	**79**
Calcium [4]	205,000	1.47(10^6)	NV	77,300	1.08(10^6)	106	69	--
Sodium	27,400	522	NV	4,780	15,000	13	71	--
Acid-Forming Anions	lb/10^{12} Btu		lb/10^{12} Btu	lb/10^{12} Btu			%	
Chloride (Cl^-)[3]	1,720	712	825	848	645	371	77	98
Fluoride (F^-)	6,650	122	6,700	21	7,680	167	116	101
Sulfate	1.59(10^6)	3,670	1.58(10^6)	2,790	410,000	990,000	88	100
Average Anions							**94**	**100**

"<" indicates that the quantity measured was less than the detection limit; thus the detection limit is shown.

"NP" indicates not performed. "NV" indicates not valid.

1. Sorbent input stream includes trace metal and anion levels in both the calcium sorbent and the sorbent water.
2. Boiler/FFDC mass balance calculated using: (outlet + fly ash + bottom ash)/(fuel + sorbent). Boiler mass balance calculated using: (inlet + bottom ash)/fuel.
3. Fuel concentrations from INAA.
4. Calcium sorbent flow rate as {(weight% of Ca) * (Ca flow rate) * (10^6)} + (sorbent H_2O flow rate).

Table 23: Mass Balance Results for Calcium-Based DSI Test Period

G. Summary of Test Results

Table 24 summarizes the fuel input, FFDC inlet, and FFDC outlet results for each of the test periods. Yampa coal was fired at Arapahoe Unit 4 for low-NO_x combustion, SNCR, and sodium-based DSI test periods. For the calcium-based DSI test period, Edna coal was fired at Arapahoe Unit 4. It is not clear whether the significantly higher values for many trace metals in the coal tested during the sodium- and calcium-based DSI test periods is due to more representative techniques or the coal matrix. The higher levels in the FFDC of these trace metals, however, indicates that changes in the coal matrix caused the higher levels in the fuel input.

The increase of the trace metal levels in the FFDC inlet are consistent with the fuel input levels. However, if the FFDC inlet is considered as a point of uncontrolled emissions, the emissions levels are consistently in the same range.

Improved FFDC removal efficiency with sorbent injection may account for the lower levels of chromium, copper, manganese, nickel, and vanadium in the sodium- and calcium-based DSI test periods. Both sodium and calcium injection before the FFDC significantly reduced the FFDC outlet levels of phosphorous, chloride, fluoride, and sulfate. The lower levels of arsenic, mercury, and selenium suggest that calcium injection removes these elements more effectively than sodium injection.

Parameter	Fuel Input				FFDC Inlet				FFDC Outlet			
	Low-NO_x Combustion	SNCR	DSI (Sodium)	DSI (Calcium)	Low-NO_x Combustion	SNCR	DSI (Sodium)	DSI (Calcium	Low-NO_x Combustion	SNCR	DSI (Sodium)	DSI (Calcium)
	lb/10^{12} Btu				lb/10^{12} Btu				lb/10^{12} Btu			
Arsenic	43	56	62	47	23	13	30	20	0.75	0.15	0.47	0.093
Barium	37,600	29,700	24,400	17,400	234	192	189	431	1.1	1.1	2.5	0.94
Beryllium	20	48	34	32	9.0	7.5	9.0	9.5	<0.021	<0.023	<0.023	<0.022
Cadmium	<4.5	<5.3	3.5	5.4	2.3	2.0	3.6	3.9	0.12	<0.066	<0.058	0.15
Chromium	97	125	272	224	50	51	135	63	0.66	0.30	0.15	0.26
Cobalt	84	114	122	93	30	26	43	53	<0.21	<0.23	<0.23	<0.22
Copper	241	324	568	396	169	206	245	310	1.1	1.3	0.59	0.42
Lead	185	195	358	310	64	46	80	55	0.44	0.40	0.36	0.38
Manganese	379	458	2,340	1,450	195	88	113	108	1.0	0.89	0.29	0.59
Mercury	1.9	1.7	4.6	2.7	1.3	1.9	1.2	3.4	<0.29	0.41	0.41	0.21
Molybdenum	9.0	44	45	38	10	12	32	26	0.17	0.27	0.23	0.22
Nickel	53.5	88	175	141	30	29	62	19	1.5	0.45	0.23	0.22
Selenium	73	127	47	115	22	12	<66	57	0.36	<0.064	0.36	<0.057
Phosphorous	36,700	27,700	48,500	35,200	14,300	9,300	11,600	12,800	6.7	4.6	1.5	<1.1
Vanadium	266	379	779	565	135	120	178	194	0.24	0.29	0.13	<0.11
Calcium	NP	185,000	213,000	205,000	NP	880	192	1,240	NP	29	33	106
Sodium	NP	29,300	64,300	27,400	NP	2,700	1,750	2,580	NP	367	112	13
Chloride	2,000	1,400	1,370	1,720	795	1,010	864	825	626	719	811	371
Fluoride	7,600	7,400	9,140	6,650	4,780	5,780	7,670	6,700	4,290	4,810	1140	167
Sulfate	1.18(10^6)	1.15(10^6)	1.17(10^6)	1.59(10^6)	10.6(10^6)	9.88(10^5)	1.14(10^6)	1.58(10^6)	9.83(10^5)	1.17(10^6)	3.69(10^5)	9.9(10^5)
Cyanide	N/A	N/A	N/A	N/A	<8	<12	NP	NP	<7	<9	NP	NP
Ammonia	N/A	N/A	N/A	N/A	<100	12,000	NP	NP	N/A	7,000	NP	NP

"<" indicates that the quantity measured was less than the detection limit thus the detection limit is shown.
"NP" indicates test not performed.

Table 24: Summary of Fuel Input, FFDC Inlet, and FFDC Outlet Levels

Table 25 compares the trace metal levels in the output streams as a percentage of the fuel input. A larger distribution of the trace metals in the bottom ash improved the mass balances for the sodium- and calcium-based DSI test periods. The bottom ash levels for the SNCR test period appear negatively biased by 15% of fuel input. For the low-NO_x combustion test period, the bottom ash levels appear negatively biased by 20% of fuel input and the fly ash levels appear negatively biased by 15% of fuel input. The use of the same collection methods for all four test periods suggests that the closer adherence to ASTM preparation methods during the sodium- and calcium-based DSI test periods improved the trace metal results. Also, the use of more representative sampling techniques for fly ash during these test periods appears to have reduced the occurrence of poor trace metal results seen during the low-NO_x combustion test period.

Test Period	Output Stream (% of Fuel Input[1])			Total (% Closure)
	Bottom Ash	Fly Ash	FFDC Outlet	
Low-NO_x Combustion[2]	9	53	2	64
SNCR	14	67	2	83
DSI (Sodium)	28	63	1	92
DSI (Calcium)	31	68	1	100

1. Fuel input for sodium- and calcium-based DSI test periods include the sorbent injection streams.
2. The fuel result for molybdenum appears to be severely biased low. The percentages for the low-NO_x combustion test period are based on an average of the molybdenum levels in the fuels from the SNCR and sodium-based DSI test periods.

Table 25: Distribution of Trace Metals Across Output Streams

Appendix I

ECONOMIC SAMPLE CALCULATIONS AND ASSUMPTIONS

DETAILED CAPITAL AND OPERATION AND MAINTENANCE ESTIMATED COSTS

1.0 Sample Economic Calculations

1.1 TOTAL CAPITAL REQUIREMENNT

Eqn. 1–1: Preproduction Costs

$$\begin{aligned} \textit{Preproduction costs} &= \textit{total O+M costs} \times \textit{length of startup} \\ &= \frac{\$1.126\ (10^6)}{yr} \times 2\ \textit{weeks startup} \times \frac{yr}{52\ weeks} \\ &= \$0.043\ (10^6) \end{aligned}$$

Eqn. 1–2: Inventory Capital

$$\begin{aligned} \textit{Inventory capital} &= \frac{\textit{total variable operating cost} \times 60\ days}{365\ days} \\ &= \frac{\$1.025\ (10^6)}{yr} \times 60\ days \times \frac{yr}{365\ days} \\ &= \$0.169\ (10^6) \end{aligned}$$

Eqn. 1–3: Cost of Constrution Downtime

$$\begin{aligned} \textit{Cost of downtime} &= \textit{downtime} \times \textit{capacity factor} \times \textit{replacement cost} \times \textit{power rating} \\ &= 2\ days \times 0.65 \times \frac{\$0.05}{kWh} \times \frac{24\ h}{day} \times 100\ MWe \times \frac{10^3\ kW}{MWe} \\ &= \$0.156\ (10^6) \end{aligned}$$

1.2 Operating and Maintenance Costs

Eqn. 1–4: Operating Labor

$$\textit{Operating labor} = \frac{2\ \textit{operator-h}}{\textit{day}} \times \frac{\$23.00}{\textit{operator-h}} \times \frac{365\ \textit{days}}{\textit{yr}}$$

$$= 0.017\ \frac{\$(10^6)}{\textit{yr}}$$

Eqn. 1–5: Maintenance Labor

$$\textit{Maintenance labor} = \textit{maintenance percentage} \times \textit{total installed equipment cost} \times 40\%$$

$$= 4\% \times \frac{\$1.76\ (10^6)}{\textit{yr}} \times 40\%$$

$$= 0.028\ \frac{\$(10^6)}{\textit{yr}}$$

Eqn. 1–6: Maintenance Materials

$$\textit{Maintenace material} = \textit{maintenance percentage} \times \textit{total installed equipment cost} \times 60\%$$

$$= 4\% \times \frac{\$1.76\ (10^6)}{\textit{yr}} \times 60\%$$

$$= 0.042\ \frac{\$(10^6)}{\textit{yr}}$$

Eqn. 1–7: Reagent Cost (Sodium Sesquicarbonate)

$$\textit{Reagent cost} = \textit{injection rate} \times \textit{reagent cost} \times \textit{capacity factor}$$

$$= \frac{1.723\ \textit{tons reagent}}{h} \times \frac{\$60.00}{\textit{ton reagent}} \times \frac{24\ h}{\textit{day}} \times \frac{365\ \textit{days}}{\textit{yr}} \times 0.65$$

$$= 0.589\ \frac{\$(10^6)}{\textit{yr}}$$

Eqn. 1−8: Reagent Freight

$$\textit{Reagent freight cost} = \textit{injection rate} \times \textit{freight cost} \times \textit{capacity factor}$$
$$= \frac{1.723 \textit{ tons reagent}}{h} \times \frac{\$33.00}{\textit{ton reagent}} \times \frac{24\ h}{day} \times \frac{365\ days}{yr} \times 0.65$$
$$= 0.324\ \frac{\$\left(10^6\right)}{yr}$$

Eqn. 1−9: Auxilliary Power

$$\textit{Auxilliary power cost} = \textit{power rate} \times \textit{power cost} \times \textit{capacity factor}$$
$$= \frac{72.5\ kWh}{h} \times \frac{\$0.05}{kWh} \times \frac{24\ h}{day} \times \frac{365\ days}{yr} \times 0.65$$
$$= 0.021\ \frac{\$\ \left(10^6\right)}{yr}$$

Eqn. 1−10: Annual Waste Disposal Cost (Dry Solids Trucked to Landfill)

$$\textit{Annual waste disposal cost} = \textit{injection rate} \times \textit{disposal cost} \times \textit{capacity factor}$$
$$= \frac{1.723 \textit{ tons waste}}{h} \times \frac{\$9.29}{\textit{ton waste}} \times \frac{24\ h}{day} \times \frac{365\ days}{yr} \times 0.65$$
$$= 0.091\ \frac{\$\left(10^6\right)}{yr}$$

1.3 SUMMARY OF PERFORMANCE AND COST DATA

1.3.1 Power Plant Attributes

Eqn. 1−11: Power Produced

$$\textit{Power produced} = \textit{plant capacity} \times \textit{capacity factor} \times \frac{24\ h}{day} \times \frac{365\ days}{yr}$$
$$= 100\ MWe \times \frac{1{,}000\ kW}{MWe} \times 0.65 \times \frac{24\ h}{day} \times \frac{365\ days}{yr}$$
$$= 0.569\ \frac{\left(10^9\right) kWh}{yr}$$

Eqn. 1 – 12: Coal Feed

$$Coal\ feed = \frac{94{,}184\ lb\ coal}{h} \times \frac{24\ h}{day} \times \frac{365\ days}{yr} \times 0.65 \times \frac{ton}{2{,}000\ lb}$$

$$= 0.268\ \frac{(10^6)\ tons\ coal}{yr}$$

Eqn. 1 – 13: SO_2 Removed

$$SO_2\ removed = (uncontrolled\ SO_2\ emissions - controlled\ SO_2\ emissions) \times capacity\ factor$$

$$= \frac{748 - 224\ lb\ SO_2}{h} \times \frac{24\ h}{day} \times \frac{365\ days}{yr} \times 0.65 \times \frac{ton}{2{,}000\ lb}$$

$$= 1{,}490\ \frac{tons\ SO_2}{yr}$$

1.3.2 Levelized Cost of Power

Eqn. 1 – 14: Levelized Capital Charge (mills/kWh)

$$Levelized\ capital\ charge = \frac{total\ capital \times levelization\ factor}{net\ power\ produced}$$

$$= \frac{\$2.586\ (10^6) \times 0.160}{\frac{0.569\ (10^9)\ kWh}{yr}} \times \frac{10^3\ mills}{\$}$$

$$= 0.727\ \frac{mills}{kWh}$$

Eqn. 1 – 15: Levelized Fixed O&M Cost (mills/kWh)

$$Levelized\ fixed\ O{+}M\ cost = \frac{fixed\ O{+}M\ cost \times levelization\ factor}{net\ power\ produced}$$

$$= \frac{\$0.101\ (10^6)}{yr} \times 1.314 \times \frac{yr}{0.569\ (10^9)\ kWh} \times \frac{10^3\ mills}{\$}$$

$$= 0.233\ \frac{mills}{kWh}$$

Eqn. 1-16: Levelized Variable O&M Cost (mills/kWh)

$$\text{Levelized variable } O{+}M \text{ cost} = \frac{\text{variable } O{+}M \text{ cost} \times \text{levelization factor}}{\text{net power produced}}$$

$$= \frac{\$1.025\ (10^6)}{yr} \times 1.314 \times \frac{yr}{0.569\ (10^9)\ kWh} \times \frac{10^3\ mills}{\$}$$

$$= 2.367\ \frac{mills}{kWh}$$

Eqn. 1-17: Levelized Capital Charge (\$/ton SO_2 removed)

$$\text{Levelized capital charge} = \frac{\text{total capital requirement} \times \text{levelization factor}}{SO_2 \text{ removed}}$$

$$= \frac{\$2.586\ (10^6) \times 0.160}{\dfrac{1{,}490\ tons\ SO_2}{yr}}$$

$$= 278\ \frac{\$}{ton\ SO_2\ removed}$$

Eqn. 1-18: Levelized Fixed O&M Cost (\$/ton SO_2 removed)

$$\text{Levelized fixed } O{+}M \text{ cost} = \frac{\text{fixed } O{+}M \text{ cost} \times \text{levelization factor}}{tons\ SO_2\ removed}$$

$$= \frac{\$0.101\ (10^6)}{yr} \times 1.314 \times \frac{yr}{1{,}490\ tons\ SO_2\ removed}$$

$$= 89\ \frac{\$}{tons\ SO_2\ removed}$$

Eqn. 1-19: Levelized Variable O&M Cost (\$/ton SO_2 removed)

$$\text{Levelized variable } O{+}M \text{ cost} = \frac{\text{variable } O{+}M \text{ cost} \times \text{levelization factor}}{tons\ SO_2\ removed}$$

$$= \frac{\$1.025\ (10^6)}{yr} \times 1.314 \times \frac{yr}{1{,}490\ tons\ SO_2\ removed}$$

$$= 904\ \frac{\$}{tons\ SO_2\ removed}$$

INTEGRATED DRY NOx/SO2 EMISSIONS CONTROL SYSTEM

FINAL REPORT, VOLUME 2: PROJECT PERFORMANCE AND ECONOMICS

Appendix I-1

Summary of Inputs and Results

Input Data

NOTE: Do not change input data cell locations unless all affected files are in memory.

	Coal 1	Coal 2	Coal 3
Sulfur Content	0.40%	1.20%	2.63%
Heat Content (Btu/lb)	11,050	7,080	10,300
Ash Content	9.6%	10.4%	10.8%
Na2O Content	0.63%	1.05%	3.40%
Unit Data			
Base Unit Size (MWe)	100		
Unit Sizes (MWe)	50	100	300
Unit heatrate (Btu/Net-kWh)	10,542		
Capacity Factors	10%	30%	65%
Economic Data			
Study Year	1994		
Inflation Rate	4%		
General Facilities Rate	0%		
Engineering & Home Office Rate	10%		

DOE Specified Costs

Replacement Power Cost ($/kWh)	$0.05
Labor ($/operator-h)	$23.00
Ash disposal ($/ton)	$9.29
Limestone ($/ton)	$15.00
Condensate ($/10^3 gal)	$0.77
Raw Water ($/10^3 gal)	$0.60
Cooling Water ($/10^3 gal)	$0.16
LP Steam, 0-70 psi ($/10^3 lb)	$2.85
MP Steam, 70-250 psi ($/10^3 lb)	$3.50
HP Steam, >250 psi ($/10^3 lb)	$5.30
Ammonia ($/dry ton)	$150.00

PSCo Assigned Costs

Freight ($/ton-mi)	$0.08
Sodium Bicarbonate ($/ton)	$140.00
Sodium Sesquicarbonate ($/ton)	$65.00
Hydrated Lime ($/ton)	$62.00
Blowdown Water ($/10^3 gal)	$0.00
Dry Urea Cost ($/ton)	$180.00

DOE Levelization Factors

Capital Factor (current $)	0.160
Capital Factor (constant $)	0.124
O&M Factor (current $)	1.314
O&M Factor (constant $)	1.000
Plant life (yr)	15

Coal Notes

Coal-1 is Yampa coal reported in PDR.
Coal-2 is lignite from S. Hallsville, TX (B&W Steam, p. 8-9)
Coal-3 is Delta #6 coal reported in proposal.

NOx Data

Base SNCR & SCR NOx (lb/MMBtu)	0.4		
Base LNB/OFA NOx (lb/MMBtu)	1.15		
SNCR & SCR NOx (lb/MMBtu)	0.4	0.9	1.15
LNB/OFA NOx (lb/MMBtu)	0.9	1.15	1.4
LNB/OFA Base Removal Rate	65%		
SNCR Base NOx Removal Rate	40%		
SCR Base NOx Removal Rate	80%		
SNCR Removal Rates	30%	40%	50%
SCR Removal Rates	50%	65%	80%
LNB/OFA Removal Rates	50%	65%	80%
Integrated NOx Removal Rate	79%		

Base SO2 Removal Rates

Economizer Injection	15%
Humidification	30%
Sodium	70%
LSFO	90%

SO2 Removal Rates

Economizer Inj	15%	20%	30%
Humidification	15%	30%	50%
Sodium Bi & Sesqui	30%	50%	70%
LSFO	50%	70%	90%

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DOE Retrofit Factors

New	0.0
Free access	0.02
Some limits	0.10
Limited space	0.25
Severe limits	1.00

DOE Process Contingency

New concept	70%
Bench scale	50%
Pilot plant	25%
Full-size data	15%
Commercial	5%

DOE Project Contingency

Simplified	40%
Preliminary	25%
Detailed	15%
Finalized	5%

DOE Maintenance Factors

Corrosive/abrasive	6.0
Solids-hi pres/temp	5.0%
Solids-lo pres/temp	4.0%
Liquids & gases	2.0%
Utilities	1.0%

^^^^^^^^^^ ^^^^^^^^^^ ^^^^^^^^^^

Revised: 12/16/94
By: T.J. Hanley

Sulfur Content & Base NOx

Sulfur Content	0.4%	1.2%	2.6%	0.40%	1.20%	2.63%	0.40%	1.20%	2.63%	0.40%	1.20%	2.63%
	Current Dollars						Constant Dollars					
	$/ton			mills/kWh			$/ton			mills/kWh		
Econ Inj(15%)	$4,247	$2,936	$2,855	2.13	6.89	10.09	$3,251	$2,240	$2,178	1.63	5.25	7.69
Humid(30%)	$2,917	$1,081	$933	2.92	5.07	6.59	$2,237	$827	$713	2.24	3.88	5.04
Bicarb(70%)	$1,460	$1,111	$1,079	3.41	12.16	17.79	$1,115	$846	$822	2.61	9.26	13.55
Sesqui(70%)	$1,412	$1,064	$1,032	3.30	11.64	17.02	$1,079	$811	$786	2.52	8.87	12.96
LSFO(90%)	$4,369	$1,033	$735	13.13	14.53	15.58	$3,362	$794	$565	10.10	11.17	11.98
	Total Capital Required ($10^6)											
Econ Inj(15%)	$2.39	$3.45	$4.62									
Humid(30%)	$4.27	$5.11	$6.14									
Bicarb(70%)	$2.52	$2.66	$2.76									
Sesqui(70%)	$2.51	$2.65	$2.74									
LSFO(90%)	$28.31	$29.98	$31.60									

Base NOx (lb/MMBtu)	0.4	0.9	1.15	1.4	0.4	0.9	1.15	1.4
	$/ton (current dollars)				mills/kWh (current dollars)			
LNB/OFA (65%)	N/A	$1,234	$966	$793	N/A	3.81	3.81	3.81
SNCR (40%)	$2,906	$1,838	$1,655	N/A	2.45	3.49	4.01	N/A
SCR (80%)	$3,736	$1,803	$1,514	N/A	6.30	6.84	7.34	N/A
	Total Capital Required ($10^6)							
LNB/OFA (65%)	N/A	$12.87	$12.87	$12.87				
SNCR (40%)	$4.13	$4.15	$4.15	N/A				
SCR (80%)	$11.06	$11.38	$11.78	N/A				

Unit Size

SO2 Systems	50 MWe	100 MWe	300 MWe	50 MWe	100 MWe	300 MWe	50 MWe	100 MWe	300 MWe	50 MWe	100 MWe	300 MWe
	CURRENT DOLLARS						CONSTANT DOLLARS					
		$/ton			mill/kWh			$/ton			mill/kWh	
Econ Inj(15%)	$5,291	$4,247	$3,432	2.65	2.13	1.72	$4,055	$3,251	$2,623	2.03	1.63	1.31
Humid(30%)	$4,023	$2,917	$1,557	4.03	2.92	1.56	$3,089	$2,237	$1,195	3.09	2.24	1.20
Bicarb(70%)	$1,748	$1,460	$1,253	4.08	3.41	2.93	$1,337	$1,115	$956	3.12	2.61	2.23
Sesqui(70%)	$1,656	$1,390	$1,198	3.87	3.25	2.80	$1,267	$1,062	$914	2.96	2.48	2.14
LSFO(90%)	$5,292	$4,369	$2,770	15.90	13.13	8.33	$4,071	$3,362	$2,134	12.23	10.10	6.41

	Total Capital Required ($10^6)		
Econ Inj(15%)	$1.80	$2.39	$4.36
Humid(30%)	$3.50	$4.27	$7.39
Bicarb(70%)	$2.03	$2.52	$4.50
Sesqui(70%)	$2.03	$2.51	$4.47
LSFO(90%)	$16.51	$28.31	$58.86

NOx Systems	50 MWe	100 MWe	300 MWe	50 MWe	100 MWe	300 MWe	50 MWe	100 MWe	300 MWe	50 MWe	100 MWe	300 MWe
	CURRENT DOLLARS						CONSTANT DOLLARS					
		$/ton			mills/kWh			$/ton			mills/kWh	
LNB/OFA (65%)	$1,337	$966	$658	5.27	3.81	2.59	$1,035	$748	$510	4.08	2.95	2.01
SNCR (40%)	$3,879	$2,891	$1,861	3.27	2.44	1.57	$2,981	$2,219	$1,426	2.51	1.87	1.20
SCR (80%)	$4,408	$3,721	$2,577	7.44	6.28	4.35	$3,388	$2,857	$1,978	5.72	4.82	3.34

	Total Capital Required ($10^6)			
LNB/OFA (65%)	$8.84	$12.87	$26.60	1.15 lb/MMBtu
SNCR (40%)	$3.19	$4.13	$6.44	0.40 lb/MMBtu
SCR (80%)	$7.18	$11.05	$22.20	0.40 lb/MMBtu

Integrated Systems	50 MWe	100 MWe	300 MWe	50 MWe	100 MWe	300 MWe	50 MWe	100 MWe	300 MWe	
	CURRENT DOLLARS									
		$/ton			mills/kWh		Total Capital Required ($10^6)			
SNCR & DSI	$2,313	$1,839	$1,414	34.82	15.09	9.62	$5.22	$6.65	$10.94	0.40 lb NOx/MMBtu NOx=40%, SO2=70%
Integrated	$1,746	$1,339	$987	12.43	9.53	7.03	$14.06	$19.52	$37.55	1.15 lb NOx/MMBtu SO2=70%, NOx=79%
SCR & LSFO	$4,974	$4,136	$2,701	23.34	19.40	12.67	$23.70	$39.37	$81.06	0.40 lb NOx/MMBtu NOx=80%, SO2=90%

Capacity Factor

SO2 Systems	CURRENT DOLLARS 10%	30%	65%	10%	30%	65%	CONSTANT DOLLARS 10%	30%	65%	10%	30%	65%
		$/ton			mills/kWh			$/ton			mills/kWh	
Econ Inj(15%)	$12,108	$5,914	$4,247	6.06	2.96	2.13	$9,308	$4,535	$3,251	4.66	2.27	1.63
Humid(30%)	$11,606	$4,760	$2,917	11.63	4.77	2.92	$8,935	$3,658	$2,237	8.95	3.66	2.24
Bicarb(70%)	$3,570	$1,907	$1,460	8.34	4.46	3.41	$2,741	$1,460	$1,115	6.41	3.41	2.61
Sesqui(70%)	$3,522	$1,859	$1,412	8.23	4.35	3.30	$2,704	$1,424	$1,079	6.32	3.33	2.52
LSFO(90%)	$25,768	$8,908	$4,369	77.44	26.77	13.13	$19,848	$6,859	$3,362	59.65	20.61	10.10

	Total Capital Required ($10^6)		
Econ Inj(15%)	$1.83	$2.03	$2.39
Humid(30%)	$4.05	$4.13	$4.27
Bicarb(70%)	$2.21	$2.32	$2.52
Sesqui(70%)	$2.21	$2.32	$2.51
LSFO(90%)	$28.02	$28.13	$28.31

NOx Systems	CURRENT DOLLARS 10%	30%	65%	10%	30%	65%	CONSTANT DOLLARS 10%	30%	65%	10%	30%	65%
		Current $/ton			Current mills/kWh			$/ton			mills/kWh	
LNB/OFA (65%)	$12,108	$5,914	$4,247	17.98	6.81	3.81	$3,533	$1,339	$748	13.92	5.27	2.95
SNCR (40%)	$11,002	$4,839	$2,996	9.28	4.08	2.53	$8,482	$3,723	$2,300	7.15	3.14	1.94
SCR (80%)	$19,687	$7,107	$3,721	33.21	11.99	6.28	$15,134	$5,461	$2,857	25.53	9.21	4.82

	Total Capital Required ($10^6)		
LNB/OFA (65%)	$9.17	$10.52	$12.87
SNCR (40%)	$3.59	$4.06	$4.40
SCR (80%)	$10.05	$10.42	$11.05

Integrated Systems	CURRENT DOLLARS 10%	30%	65%	10%	30%	65%	Total Capital Required 10%	30%	65%	
		$/ton			mills/kWh			($10^6)		
SNCR & DSI	$5,540	$2,685	$1,867	7.36	5.85	4.50	$5.80	$6.38	$6.92	0.40 lb NOx/MMBtu NOx=40%, SO2=70%
Integrated	$4,889	$2,119	$1,352	34.82	15.09	9.62	$14.97	$16.90	$19.79	1.15 lb NOx/MMBtu SO2=70%, NOx=79%
SCR & LSFO	$23,582	$8,261	$4,136	110.64	38.76	19.40	$38.08	$38.55	$39.37	0.40 lb NOx/MMBtu NOx=80%, SO2=90%

SO2 Removal Rate

	$/ton (current dollars) 15%	20%	30%	50%	70%	90%
Econ Inj	$4,247	$3,815	$3,448	N/A	N/A	N/A
Humid	$4,110	N/A	$2,924	$2,385	N/A	N/A
Bicarb	N/A	N/A	$1,749	$1,551	$1,460	N/A
Sesqui	N/A	N/A	$1,472	$1,285	$1,412	N/A
LSFO	N/A	N/A	N/A	$7,111	$5,227	$4,370

	mills/kWh (current dollars) 15%	20%	30%	50%	70%	90%
Econ Inj	2.13	2.55	3.45	N/A	N/A	N/A
Humid	2.74	N/A	2.93	3.19	N/A	N/A
Bicarb	N/A	N/A	1.75	2.59	3.41	N/A
Sesqui	N/A	N/A	1.47	2.14	3.30	N/A
LSFO	N/A	N/A	N/A	11.87	12.22	13.13

	Total Capital Required ($10^6) 15%	20%	30%	50%	70%	90%
Econ Inj	$2.39	$2.44	$2.72	N/A	N/A	N/A
Humid	$4.26	N/A	$4.29	$4.52	N/A	N/A
Bicarb	N/A	N/A	$2.08	$2.32	$2.52	N/A
Sesqui	N/A	N/A	$2.06	$2.28	$2.51	N/A
LSFO	N/A	N/A	N/A	$25.20	$25.98	$28.31

NOx REMOVAL RATES

	$/ton (current dollars) 30%	40%	50%	65%	80%
LNB/OFA(1.15)	N/A	N/A	$1,256	$966	$785
SNCR(0.40)	$4,673	$2,891	$1,909	N/A	N/A
SCR(0.40)	N/A	N/A	$5,460	$4,548	$4,106

	mills/kWh (current dollars) 30%	40%	50%	65%	80%
LNB/OFA(1.15)	N/A	N/A	3.81	3.81	3.81
SNCR(0.40)	2.96	2.44	2.01	N/A	N/A
SCR(0.40)	N/A	N/A	5.76	6.23	6.93

	Total Capital Requirement ($10^6) 30%	40%	50%	65%	80%
LNB/OFA(1.15)	N/A	N/A	$12.87	$12.87	$12.87
SNCR(0.40)	$6.36	$4.13	$2.18	N/A	N/A
SCR(0.40)	N/A	N/A	$10.55	$11.05	$11.81

	0.4	
	0.4	
1.15	0.4	0.4
1.15		0.4
1.15		0.4

SO2 REMOVAL SYSTEMS

	Sulfur Content			Unit Size			Capacity Factor			SO2 Removal Rate		
	0.40%	1.20%	2.63%	50 MWe	100 MWe	300 MWe	10%	30%	65%			
Econ Inj										15%	20%	30%
Tot Cap Required ($10^6)	$2.39	$3.45	$4.62	$1.80	$2.39	$4.36	$1.83	$2.03	$2.39	$2.39	$2.44	$2.72
Total Current (mills/kWh)	2.13	6.89	10.09	2.65	2.13	1.72	6.06	2.96	2.13	2.13	2.55	3.45
Total Constant (mills/kWh)	1.63	5.25	7.69	2.03	1.63	1.31	4.66	2.27	1.63	1.63	1.95	2.64
Total Current ($/ton)	$4,247	$2,936	$2,855	$5,291	$4,247	$3,432	$12,108	$5,914	$4,247	$4,247	$3,815	$3,448
Total Constant ($/ton)	$3,251	$2,240	$2,178	$4,055	$3,251	$2,623	$9,308	$4,535	$3,251	$3,251	$2,918	$2,634
Humidification										15%	30%	50%
Tot Cap Required ($10^6)	$4.27	$5.11	$6.14	$3.50	$4.27	$7.39	$4.05	$4.13	$4.27	$4.26	$4.29	$4.52
Total Current (mills/kWh)	2.92	5.07	6.59	4.03	2.92	1.56	11.63	4.77	2.92	2.74	2.93	3.19
Total Constant (mills/kWh)	2.24	3.88	5.04	3.09	2.24	1.20	8.95	3.66	2.24	2.11	2.25	2.44
Total Current ($/ton)	$2,917	$1,081	$933	$4,023	$2,917	$1,557	$11,606	$4,760	$2,917	$4,110	$2,924	$2,385
Total Constant ($/ton)	$2,237	$827	$713	$3,089	$2,237	$1,195	$8,935	$3,658	$2,237	$3,153	$2,242	$1,828
Bicarbonate										30%	50%	70%
Tot Cap Required ($10^6)	$2.52	$2.66	$2.76	$2.03	$2.52	$4.50	$2.21	$2.32	$2.52	$2.08	$2.32	$2.52
Total Current (mills/kWh)	3.41	12.16	17.79	4.08	3.41	2.93	8.34	4.46	3.41	1.75	2.59	3.41
Total Constant (mills/kWh)	2.61	9.26	13.55	3.12	2.61	2.23	6.41	3.41	2.61	1.34	1.98	2.61
Total Current ($/ton)	$1,460	$1,111	$1,079	$1,748	$1,460	$1,253	$3,570	$1,907	$1,460	$1,749	$1,551	$1,460
Total Constant ($/ton)	$1,115	$846	$822	$1,337	$1,115	$956	$2,741	$1,460	$1,115	$1,339	$1,186	$1,115
Sesquicarbonate										30%	50%	70%
Total Capital Required ($10^6)	$2.51	$2.65	$2.74	$2.03	$2.51	$4.47	$2.21	$2.32	$2.51	$2.06	$2.28	$2.51
Total Current (mills/kWh)	3.30	11.64	17.02	3.87	3.25	2.80	8.23	4.35	3.30	1.47	2.14	3.30
Total Constant (mills/kWh)	2.52	8.87	12.96	2.96	2.48	2.14	6.32	3.33	2.52	1.13	1.64	2.52
Total Current ($/ton)	$1,412	$1,064	$1,032	$1,656	$1,390	$1,198	$3,522	$1,859	$1,412	$1,472	$1,285	$1,412
Total Constant ($/ton)	$1,079	$811	$786	$1,267	$1,062	$914	$2,704	$1,424	$1,079	$1,128	$983	$1,079
LSFO										50%	70%	90%
Total Capital Required ($10^6)	$28.31	$29.98	$31.60	$16.51	$28.31	$58.86	$28.02	$28.13	$28.31	$25.20	$25.98	$28.31
Total Current (mills/kWh)	13.13	14.53	15.58	15.90	13.13	8.33	77.44	26.77	13.13	11.87	12.22	13.13
Total Constant (mills/kWh)	10.10	11.17	11.98	12.23	10.10	6.41	59.65	20.61	10.10	9.13	9.40	10.10
Total Current ($/ton)	$4,369	$1,033	$735	$5,292	$4,369	$2,770	$25,768	$8,908	$4,369	$7,111	$5,227	$4,370
Total Constant ($/ton)	$3,362	$794	$565	$4,071	$3,362	$2,134	$19,848	$6,859	$3,362	$5,471	$4,021	$3,362

NOx and INTEGRATED SYSTEMS

		Inlet NOx (lb/MMBtu)		Unit Size (MWe)			Capacity Factor			NOx Removal Rate		
LNB/OFA	0.9 lb/MMBtu	1.15	1.40	50 MWe	100 MWe	300 MWe	10%	30%	65%	50%	65%	80%
Total Capital Required ($10^6)	$12.87	$12.87	$12.87	$8.84	$12.87	$26.60	$9.17	$10.52	$12.87	$12.87	$12.87	$12.87
Total Current (mills/kWh)	3.81	3.81	3.81	5.27	3.81	2.59	17.98	6.81	3.81	3.81	3.81	3.81
Total Constant (mills/kWh)	2.95	2.95	2.95	4.08	2.95	2.01	13.92	5.27	2.95	2.95	2.95	2.95
Total Current ($/ton)	$1,234	$966	$793	$1,337	$966	$658	$4,564	$1,729	$966	$1,256	$966	$785
Total Constant ($/ton)	$956	$748	$614	$1,035	$748	$510	$3,533	$1,339	$748	$972	$748	$608
SNCR	0.4 lb/MMBtu	0.90	1.15	50 MWe	100 MWe	300 MWe	10%	30%	65%	30%	40%	50%
Total Capital Required ($10^6)	$4.13	$4.15	$4.15	$3.19	$4.13	$6.44	$3.59	$4.06	$4.40	$6.36	$4.13	$2.18
Total Current (mills/kWh)	2.45	3.49	4.01	3.27	2.44	1.57	9.28	4.08	2.53	2.96	2.44	2.01
Total Constant (mills/kWh)	1.88	2.67	3.07	2.51	1.87	1.20	7.15	3.14	1.94	2.27	1.87	1.54
Total Current ($/ton)	$2,906	$1,838	$1,655	$3,879	$2,891	$1,861	$11,002	$4,839	$2,996	$4,673	$2,891	$1,909
Total Constant ($/ton)	$2,231	$1,408	$1,266	$2,981	$2,219	$1,426	$8,482	$3,723	$2,300	$3,596	$2,219	$1,461
SCR	0.4 lb/MMBtu	0.9	1.15	50 MWe	100 MWe	300 MWe	10%	30%	65%	50%	65%	80%
Total Capital Required ($10^6)	$11.06	$11.38	$11.78	$7.18	$11.05	$22.20	$10.05	$10.42	$11.05	$10.55	$11.05	$11.81
Total Current (mills/kWh)	6.30	6.84	7.34	7.44	6.28	4.35	33.21	11.99	6.28	5.76	6.23	6.93
Total Constant (mills/kWh)	4.84	5.25	5.63	5.72	4.82	3.34	25.53	9.21	4.82	4.42	4.79	5.32
Total Current ($/ton)	$3,736	$1,803	$1,514	$4,408	$3,721	$2,577	$19,687	$7,107	$3,721	$5,460	$4,548	$4,106
Total Constant ($/ton)	$2,869	$1,384	$1,162	$3,388	$2,857	$1,978	$15,134	$5,461	$2,857	$4,195	$3,492	$3,152
INTEGRATED SYSTEMS												
SNCR & DSI	0.4 lb/MMBtu			50 MWe	100 MWe	300 MWe	10%	30%	65%			
Total Capital Required ($10^6)	$6.65			$5.22	$6.65	$10.94	$5.80	$6.38	$6.92			
Total Current (mills/kWh)	15.09			34.82	15.09	9.62	7.36	5.85	4.50			
Total Constant (mills/kWh)	11.63			26.88	11.63	7.40	5.64	4.48	3.44			
Total Current ($/ton)	$1,839			$2,313	$1,839	$1,414	$5,540	$2,685	$1,867			
Total Constant ($/ton)	$1,591			$1,851	$1,591	$1,338	$3,725	$2,084	$1,610			
Integrated	0.4 lb/MMBtu			50 MWe	100 MWe	300 MWe	10%	30%	65%			
Total Capital Required ($10^6)	$19.52			$14.06	$19.52	$37.55	$14.97	$16.90	$19.79			
Total Current (mills/kWh)	9.53			12.43	9.53	7.03	34.82	15.09	9.62			
Total Constant (mills/kWh)	7.33			9.57	7.33	5.40	26.88	11.63	7.40			
Total Current ($/ton)	$1,339			$1,746	$1,339	$987	$4,889	$2,119	$1,352			
Total Constant ($/ton)	$1,104			$1,368	$1,104	$869	$3,487	$1,628	$1,113			
SCR & LSFO	0.4 lb/MMBtu			50 MWe	100 MWe	300 MWe	10%	30%	65%			
Total Capital Required ($10^6)	$39.37			$23.70	$39.37	$81.06	$38.08	$38.55	$39.37			
Total Current (mills/kWh)	19.40			23.34	19.40	12.67	110.64	38.76	19.40			
Total Constant (mills/kWh)	14.92			17.95	14.92	9.75	85.17	29.82	14.92			
Total Current ($/ton)	$4,136			$4,974	$4,136	$2,701	$23,582	$8,261	$4,136			
Total Constant ($/ton)	$2,712			$3,085	$2,712	$1,877	$13,937	$5,093	$2,712			

INTEGRATED DRY NOx/SO2 EMISSIONS CONTROL SYSTEM

FINAL REPORT, VOLUME 2: PROJECT PERFORMANCE AND ECONOMICS

Appendix I-2

Economizer Injection of Hydrated Lime

	SULFUR CONTENT			UNIT SIZE			CAPACITY FACTOR			SO2 REMOVAL		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	15%	20%	30%
Coal Specfications												
Avg Sulfur Content	0.40%	1.20%	2.63%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%
Heat Content (Btu/lb)	11,050	7,080	10,300	11,050	11,050	11,050	11,050	11,050	11,050	11,050	11,050	11,050
Ash Content	9.60%	10.40%	10.80%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%
Unit and Operating Specifications												
Unit Heatrate (Btu/NkWh)	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542
Unit Size (MWe)	100	100	100	50	100	300	100	100	100	100	100	100
Capacity Factor	65%	65%	65%	65%	65%	65%	10%	30%	65%	65%	65%	65%
SO2 Removal Required	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	20%	30%
Reagent Specifications												
NSR	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.7	4.0
Utilization	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
lb Ca(OH)2/lb reagent	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%
Inerts	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%
Reagent Flowrate												
Max Coal Flow (tons/h)	48	74	51	24	48	143	48	48	48	48	48	48
S02 In Duct (lb/h)	668	3,127	4,711	334	668	2,003	668	668	668	668	668	668
S02 to be Removed (lb/h)	100	469	707	50	100	301	100	100	100	100	134	200
Reagent Flowrate (lb/h)	1,718	8,043	12,117	859	1,718	5,153	1,718	1,718	1,718	1,718	2,290	3,436
Reagent Flowrate (tons/h)	0.859	4.022	6.059	0.429	0.859	2.577	0.859	0.859	0.859	0.859	1.145	1.718
Ash Reaction Data (Assume all unreacted Ca(OH)2 converts to CaCO3)												
Unreacted Ca(OH)2 (lb/h)	1,429	6,689	10,076	714	1,429	4,286	1,429	1,429	1,429	1,429	1,905	2,857
Ca(OH)2 Conversion to CaCO3	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
CaSO3 Formation	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
CaSO4 Formation	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Ash Disposal Flowrate												
Ca(OH)2 in Ash (lb/h)	0	0	0	0	0	0	0	0	0	0	0	0
CaCO3 (lb/h)	1,930	9,039	13,617	965	1,930	5,791	1,930	1,930	1,930	1,930	2,574	3,861
CaSO3 (lb/h)	162	761	1,146	81	162	487	162	162	162	162	217	325
CaSO4 (lb/h)	0	0	0	0	0	0	0	0	0	0	0	0
Inerts (lb/h)	174	812	1,224	87	174	521	174	174	174	174	231	347
Total Added Waste (lb/h)	2,266	10,612	15,986	1,133	2,266	6,799	2,266	2,266	2,266	2,266	3,022	4,533
Total Added Waste (tons/h)	1.13	5.31	7.99	0.57	1.13	3.40	1.13	1.13	1.13	1.13	1.51	2.27

Molecular Weights

MW Ca (lb/mole)	40	MW CaCO3 (lb/mole)	100	MW CaSO4*2H2O	172	Revised:	12/02/94
MW CaO (lb/mole)	56	MW CaSO3 (lb/mole)	120	MW SO2 (lb/mole)	64	By:	TJ Hanley
MW Ca(OH)2	74	MW CaSO4 (lb/mole)	136				

TOTAL CAPITAL RESULTS	Sulfur Content			Unit Size			Capacity Factor			SO2 Removal Rate		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	15%	20%	30%
Year Installed	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991
Year of Study	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994
Subtotal Install-1991 ($/kW)	$12.03	$16.72	$23.09	$20.43	$12.03	$5.57	$12.03	$12.03	$12.03	$12.03	$12.16	$13.64
Inflation Rate	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Subtotal Install-1994 ($/kW)	$13.53	$18.81	$25.98	$22.98	$13.53	$6.27	$13.53	$13.53	$13.53	$13.53	$13.68	$15.34
Subtotal Install-1994 ($10^6)	*$1.35*	*$1.88*	*$2.60*	*$1.15*	*$1.35*	*$1.88*	*$1.35*	*$1.35*	*$1.35*	*$1.35*	*$1.37*	*$1.53*
Retrofit Factor	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Retrofit Cost ($10^6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Process Contingency Factor	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Proc Contingency Cost ($10^6)	$0.135	$0.188	$0.260	$0.115	$0.135	$0.188	$0.135	$0.135	$0.135	$0.135	$0.137	$0.153
Total Install Equip ($10^6)	$1.49	$2.07	$2.86	$1.26	$1.49	$2.07	$1.49	$1.49	$1.49	$1.49	$1.50	$1.69
Tot. Process Capital ($10^6)	$1.49	$2.07	$2.86	$1.26	$1.49	$2.07	$1.49	$1.49	$1.49	$1.49	$1.50	$1.69
General Facilities Rate	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Gen Facilities Cost ($10^6)	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Engr & Home Office Rate	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Engr & Home Office ($10^6)	$0.149	$0.207	$0.286	$0.126	$0.149	$0.207	$0.149	$0.149	$0.149	$0.149	$0.150	$0.169
Project Contingency Rate	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Proj Contingency Cost ($10^6)	$0.082	$0.114	$0.157	$0.070	$0.082	$0.114	$0.082	$0.082	$0.082	$0.082	$0.083	$0.093
Total Plant Cost ($10^6)	$1.72	$2.39	$3.30	$1.46	$1.72	$2.39	$1.72	$1.72	$1.72	$1.72	$1.74	$1.95
AFDC rate (<1 year)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AFDC Cost ($10^6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total Plant Invest ($10^6)	$1.72	$2.39	$3.30	$1.46	$1.72	$2.39	$1.72	$1.72	$1.72	$1.72	$1.74	$1.95
Royalty Rate	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Royalty Cost ($10^6)	$0.0086	$0.0119	$0.0165	$0.0073	$0.0086	$0.0119	$0.0086	$0.0086	$0.0086	$0.0086	$0.0087	$0.0097
Startup Time (weeks)	2	2	2	2	2	2	2	2	2	2	2	2
Preproduction Costs ($10^6)	$0.024	$0.099	$0.146	$0.014	$0.024	$0.065	$0.007	$0.013	$0.024	$0.024	$0.031	$0.045
Inventory Capital ($10^6)	$0.087	$0.405	$0.610	$0.044	$0.087	$0.259	$0.013	$0.040	$0.087	$0.087	$0.116	$0.174
Initial Catalyst ($10^6)	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Subtotal Capital ($10^6)	$1.84	$2.90	$4.07	$1.52	$1.84	$2.73	$1.75	$1.78	$1.84	$1.84	$1.89	$2.18
Construction Downtime (days)	7	7	7	7	7	7	7	7	7	7	7	7
Replacement Power Cost ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Construction Downtime ($10^6)	$0.55	$0.55	$0.55	$0.27	$0.55	$1.64	$0.08	$0.25	$0.55	$0.55	$0.55	$0.55
Total Capital Required ($10^6)	$2.39	$3.45	$4.62	$1.80	$2.39	$4.36	$1.83	$2.03	$2.39	$2.39	$2.44	$2.72

O&M COST RESULTS ($10^6/yr)	Sulfur Content			Unit Size			Capacity Factor			SO2 Removal Rate		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	15%	20%	30%
Annual Fixed O&M Costs												
Labor ($/operator-h)	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00
Labor (operator-h/day)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Operating Labor ($10^6/yr)	$0.025	$0.025	$0.025	$0.025	$0.025	$0.025	$0.025	$0.025	$0.025	$0.025	$0.025	$0.025
Total Install Equip ($10^6)	$1.49	$1.49	$1.49	$1.26	$1.49	$2.07	$1.49	$1.49	$1.49	$1.49	$1.50	$1.69
Maintenance Factor	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
Maintenance Labor ($10^6/yr)	$0.024	$0.024	$0.024	$0.020	$0.024	$0.033	$0.024	$0.024	$0.024	$0.024	$0.024	$0.027
Maintenance Mat'l ($10^6/yr)	$0.036	$0.036	$0.036	$0.030	$0.036	$0.050	$0.036	$0.036	$0.036	$0.036	$0.036	$0.040
Admin/Support Labor ($10^6/yr)	$0.015	$0.015	$0.015	$0.014	$0.015	$0.017	$0.015	$0.015	$0.015	$0.015	$0.015	$0.016
Total Fixed O&M ($10^6/yr)	$0.0994	$0.0994	$0.0994	$0.0894	$0.0994	$0.1254	$0.0994	$0.0994	$0.0994	$0.0994	$0.1001	$0.1083
Annual Variable O&M Costs												
Annual Reagent Cost												
Hydrated Lime Use (tons/yr)	4,891	22,899	34,498	2,445	4,891	14,672	752	2,257	4,891	4,891	6,521	9,781
Hydrated Lime Cost ($/ton)	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00
Hydrated Lime Cost ($10^6/yr)	$0.303	$1.420	$2.139	$0.152	$0.303	$0.910	$0.047	$0.140	$0.303	$0.303	$0.404	$0.606
Annual Ash Disposal Cost												
Freight Cost ($/ton-mile)	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08
Freight Distance (mi)	413	413	413	413	413	413	413	413	413	413	413	413
Reagent Freight ($/ton)	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04
Reagent Freight ($/yr)	$0.162	$0.757	$1.140	$0.081	$0.162	$0.485	$0.025	$0.075	$0.162	$0.162	$0.215	$0.323
Annual Auxiliary Power Cost												
Aux Power (kW/MWe)	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501
Auxiliary Power (kWh/h)	25	25	25	13	25	75	25	25	25	25	25	25
Auxiliary Power ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Auxiliary Power ($10^6/yr)	$0.007	$0.007	$0.007	$0.004	$0.007	$0.003	$0.001	$0.003	$0.007	$0.007	$0.007	$0.007
Annual Ash Disposal Cost												
Ash Disposal ($/ton)	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29
Total Added Waste (tons/yr)	6,452	30,211	45,513	3,226	6,452	19,357	993	2,978	6,452	6,452	8,603	12,905
Ash Disposal ($10^6/yr)	$0.0599	$0.2807	$0.4228	$0.0300	$0.0599	$0.1798	$0.0092	$0.0277	$0.0599	$0.0599	$0.0799	$0.1199
Total Variable ($10^6/yr)	$0.53	$2.46	$3.71	$0.27	$0.53	$1.58	$0.08	$0.25	$0.53	$0.53	$0.71	$1.06
Total O&M ($10^6/yr)	$0.63	$2.56	$3.81	$0.36	$0.63	$1.70	$0.18	$0.34	$0.63	$0.63	$0.81	$1.16

LEVELIZED COSTS	Sulfur Content			Unit Size			Capacity Factor			SO2 Removal Rate		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	15%	20%	30%
Tot Cap Required ($10^6)	$2.39	$3.45	$4.62	$1.80	$2.39	$4.36	$1.83	$2.03	$2.39	$2.39	$2.44	$2.72
Fixed O&M ($10^6/yr)	$0.099	$0.099	$0.099	$0.089	$0.099	$0.125	$0.099	$0.099	$0.099	$0.099	$0.100	$0.108
Variable O&M ($10^6/yr)	$0.532	$2.464	$3.709	$0.266	$0.532	$1.578	$0.082	$0.245	$0.532	$0.532	$0.707	$1.057
POWER PRODUCED (10^9 kWh/yr)	0.569	0.569	0.569	0.285	0.569	1.708	0.088	0.263	0.569	0.569	0.569	0.569
SO2 REMOVED (tons/yr)	285	1,335	2,012	143	285	856	44	132	285	285	380	570
Levelized Cost Per Power Produced (Current Dollars)												
Level Cap Chg (mills/kWh)	0.670	0.970	1.298	1.010	0.670	0.409	3.346	1.238	0.670	0.670	0.685	0.765
Level Fixed O&M (mills/kWh)	0.229	0.229	0.229	0.412	0.229	0.096	1.491	0.497	0.229	0.229	0.231	0.250
Level Variable O&M (mills/kWh)	1.23	5.69	8.56	1.23	1.23	1.21	1.23	1.23	1.23	1.23	1.63	2.44
Total Current (mills/kWh)	2.13	6.89	10.09	2.65	2.13	1.72	6.06	2.96	2.13	2.13	2.55	3.45
Levelized Cost Per Power Produced (Constant Dollars)												
Level Cap Chg (mills/kWh)	0.519	0.752	1.006	0.783	0.519	0.317	2.593	0.959	0.519	0.519	0.531	0.593
Level Fixed O&M (mills/kWh)	0.175	0.175	0.175	0.314	0.175	0.073	1.135	0.378	0.175	0.175	0.176	0.190
Level Variable O&M (mills/kWh)	0.93	4.33	6.51	0.93	0.93	0.92	0.93	0.93	0.93	0.93	1.24	1.86
Total Constant (mills/kWh)	1.63	5.25	7.69	2.03	1.63	1.31	4.66	2.27	1.63	1.63	1.95	2.64
Levelized Cost Per Ton Pollutant Removed (Current Dollars)												
Level Cap Chg ($/ton)	$1,338	$413	$367	$2,017	$1,338	$816	$6,680	$2,471	$1,338	$1,338	$1,026	$764
Level Fixed O&M ($/ton)	$458	$98	$65	$824	$458	$193	$2,977	$992	$458	$458	$346	$250
Level Variable O&M ($/ton)	$2,451	$2,425	$2,422	$2,451	$2,451	$2,423	$2,451	$2,451	$2,451	$2,451	$2,442	$2,434
Total Current ($/ton)	$4,247	$2,936	$2,855	$5,291	$4,247	$3,432	$12,108	$5,914	$4,247	$4,247	$3,815	$3,448
Total w/o Downtime ($/ton)	$3,940	$2,871	$2,811	$4,985	$3,940	$3,125	$11,801	$5,608	$3,940	$3,940	$3,585	$3,294
Levelized Cost Per Ton Pollutant Removed (Constant Dollars)												
Level Cap Chg ($/ton)	$1,037	$320	$285	$1,563	$1,037	$632	$5,177	$1,915	$1,037	$1,037	$795	$592
Level Fixed O&M ($/ton)	$349	$74	$49	$627	$349	$147	$2,266	$755	$349	$349	$263	$190
Level Variable O&M ($/ton)	$1,865	$1,845	$1,844	$1,865	$1,865	$1,844	$1,865	$1,865	$1,865	$1,865	$1,859	$1,852
Total Constant ($/ton)	$3,251	$2,240	$2,178	$4,055	$3,251	$2,623	$9,308	$4,535	$3,251	$3,251	$2,918	$2,634
Total w/o downtime ($/ton)	$3,013	$2,190	$2,144	$3,818	$3,013	$2,386	$9,070	$4,298	$3,013	$3,013	$2,739	$2,516

Levelization Factors (Plant life =15yr)	
Level Cap Factor (current)	0.160
Level Cap Factor (constant)	0.124
Level O&M Factor (current)	1.314
Level O&M Factor (constant)	1.000

INTEGRATED DRY NOx/SO2 EMISSIONS CONTROL SYSTEM

FINAL REPORT, VOLUME 2: PROJECT PERFORMANCE AND ECONOMICS

Appendix I-3

Humidification System

	SULFUR CONTENT 0.40%	1.20%	2.63%	UNIT SIZE 50	100	300	CAPACITY FACTOR 10%	30%	65%	SO2 REMOVAL 20%	30%	40%
Coal Specifications												
Avg Sulfur Content	0.40%	1.20%	2.63%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%
Heat Content (Btu/lb)	11,050	7,080	10,300	11,050	11,050	11,050	11,050	11,050	11,050	11,050	11,050	11,050
Ash Content	9.60%	10.40%	10.80%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%
Unit and Operating Specifications												
Unit Heatrate (Btu/NkWh)	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542
Unit Size (MWe)	100	100	100	50	100	300	100	100	100	100	100	100
Capacity Factor	65%	65%	65%	65%	65%	65%	10%	30%	65%	65%	65%	65%
SO2 Removal Required	30%	30%	30%	30%	30%	30%	30%	30%	30%	20%	30%	40%
Reagent Specifications												
NSR	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.3	2.0	2.7
Utilization	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%
lb Ca(OH)2/lb reagent	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%	89.9%
Inerts	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%	10.1%
Reagent Flowrate												
Max Coal Flow (tons/h)	48	74	51	24	48	143	48	48	48	48	48	48
S02 In Duct (lb/h)	668	3,127	4,711	334	668	2,003	668	668	668	668	668	668
S02 to be Removed (lb/h)	200	938	1,413	100	200	601	200	200	200	134	200	267
Reagent Flowrate (lb/h)	1,718	8,043	12,117	859	1,718	5,153	1,718	1,718	1,718	1,145	1,718	2,290
Ash Reaction Data *(Assume all unreacted Ca(OH)2 converts to CaCO3)*												
Unreacted Ca(OH)2 (lb/h)	1,313	6,146	9,259	656	1,313	3,938	1,313	1,313	1,313	875	1,313	1,750
Ca(OH)2 Conversion to CaCO3	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
CaSO3*1/2H2O Formation	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%
CaSO4*2H2O Formation	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%
Ash Disposal Flowrate												
Ca(OH)2 in Ash (lb/h)	0	0	0	0	0	0	0	0	0	0	0	0
CaCO3 (lb/h)	1,774	8,306	12,513	887	1,774	5,322	1,774	1,774	1,774	1,183	1,774	2,365
CaSO3*1/2H2O (lb/h)	140	654	985	70	140	419	140	140	140	93	140	186
CaSO4*2H2O (lb/h)	323	1,513	2,279	162	323	969	323	323	323	215	323	431
Inerts (lb/h)	174	812	1,224	87	174	521	174	174	174	116	174	231
Total Added Waste (lb/h)	2,410	11,285	17,001	1,205	2,410	7,230	2,410	2,410	2,410	1,607	2,410	3,214

Molecular Weights

MW Ca (lb/mole)	40	MW CaSO3 (lb/mole)	120	MW SO2 (lb/mole)	64
MW Ca(OH)2	74	MW CaSO3*1/2 H2O	129	MW CaSO4*2H2O	172
MW CaCO3 (lb/mole)	100	MW CaSO4 (lb/mole)	136	H2O Density (lb/gal)	8.333646

Revised: 12/02/94
By: TJ Hanley

TOTAL CAPITAL RESULTS	Sulfur Content			Unit Size			Capacity Factor			SO2 Removal Rate		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	20%	30%	40%
Year Installed	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991
Year of Study	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994
DSI Install-1991 ($/kw)	$12.03	$16.72	$23.09	$20.43	$12.03	$5.57	$12.03	$12.03	$12.03	$12.03	$12.16	$13.64
Humid Install-1991 ($/kw)	$15.81	$15.81	$15.81	$26.32	$15.81	$10.07	$15.81	$15.81	$15.81	$15.81	$15.81	$15.81
Inflation Rate	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
DSI+Humid Install-1991 ($/kw)	$31.31	$36.59	$43.76	$52.59	$31.31	$17.59	$31.31	$31.31	$31.31	$31.31	$31.46	$33.12
DSI+Humid Install-1994 ($10^6)	$3.13	$3.66	$4.38	$2.63	$3.13	$5.28	$3.13	$3.13	$3.13	$3.13	$3.15	$3.31
Retrofit Factor	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Retrofit Cost ($10^6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Process Contingency Factor	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Proc Contingency Cost ($10^6)	$0.313	$0.366	$0.438	$0.263	$0.313	$0.528	$0.313	$0.313	$0.313	$0.313	$0.315	$0.331
Total Install Equip ($10^6)	$3.44	$4.02	$4.81	$2.89	$3.44	$5.81	$3.44	$3.44	$3.44	$3.44	$3.46	$3.64
Tot. Process Capital ($10^6)	$3.44	$4.02	$4.81	$2.89	$3.44	$5.81	$3.44	$3.44	$3.44	$3.44	$3.46	$3.64
General Facilities Rate	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Gen Facilities Cost ($10^6)	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Engr & Home Office Rate	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Engr & Home Office ($10^6)	$0.344	$0.402	$0.481	$0.289	$0.344	$0.581	$0.344	$0.344	$0.344	$0.344	$0.346	$0.364
Project Contingency Rate	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Proj Contingency Cost ($10^6)	$0.189	$0.221	$0.265	$0.159	$0.189	$0.319	$0.189	$0.189	$0.189	$0.189	$0.190	$0.200
Total Plant Cost ($10^6)	$3.98	$4.65	$5.56	$3.34	$3.98	$6.71	$3.98	$3.98	$3.98	$3.98	$4.00	$4.21
AFDC rate (<1 year)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AFDC Cost ($10^6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total Plant Invest ($10^6)	$3.98	$4.65	$5.56	$3.34	$3.98	$6.71	$3.98	$3.98	$3.98	$3.98	$4.00	$4.21
Royalty Rate	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Royalty Cost ($10^6)	$0.0199	$0.0232	$0.0278	$0.0167	$0.0199	$0.0335	$0.0199	$0.0199	$0.0199	$0.0199	$0.0200	$0.0210
Startup Time (weeks)	2	2	2	2	2	2	2	2	2	2	2	2
Preproduction Costs ($10^6)	$0.029	$0.061	$0.081	$0.017	$0.029	$0.043	$0.011	$0.017	$0.029	$0.026	$0.029	$0.032
Inventory Capital ($10^6)	$0.090	$0.226	$0.314	$0.045	$0.090	$0.136	$0.014	$0.042	$0.090	$0.078	$0.090	$0.102
Initial Catalyst ($10^6)	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Subtotal Capital ($10^6)	$4.12	$4.96	$5.98	$3.42	$4.12	$6.92	$4.02	$4.06	$4.12	$4.10	$4.14	$4.36
Construction Downtime (days)	2	2	2	2	2	2	2	2	2	2	2	2
Replacement Power Cost ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Construction Downtime ($10^6)	$0.16	$0.16	$0.16	$0.08	$0.16	$0.47	$0.02	$0.07	$0.16	$0.16	$0.16	$0.16
Total Capital Required ($10^6)	$4.27	$5.11	$6.14	$3.50	$4.27	$7.39	$4.05	$4.13	$4.27	$4.26	$4.29	$4.52

Annual Fixed O&M Costs												
Labor ($/operator-h)	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00
DSI Labor (operator-h/day)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Humid Labor (operator-h/day)	1	1	1	1	1	1	1	1	1	1	1	1
Operating Labor ($10^6/yr)	$0.034	$0.034	$0.034	$0.034	$0.034	$0.034	$0.034	$0.034	$0.034	$0.034	$0.034	$0.034
Total Install Equip ($10^6)	$3.44	$3.44	$3.44	$2.89	$3.44	$5.81	$3.44	$3.44	$3.44	$3.44	$3.46	$3.64
Maintenance Factor	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
Maintenance Labor ($10^6/yr)	$0.055	$0.055	$0.055	$0.046	$0.055	$0.093	$0.055	$0.055	$0.055	$0.055	$0.055	$0.058
Maintenance Matl ($10^6/yr)	$0.083	$0.083	$0.083	$0.069	$0.083	$0.139	$0.083	$0.083	$0.083	$0.083	$0.083	$0.087
Admin/Support Labor ($10^6/yr)	$0.027	$0.027	$0.027	$0.024	$0.027	$0.038	$0.027	$0.027	$0.027	$0.027	$0.027	$0.028
Total Fixed O&M ($10^6/yr)	$0.20	$0.20	$0.20	$0.17	$0.20	$0.30	$0.20	$0.20	$0.20	$0.20	$0.20	$0.21
Annual Variable O&M Costs												
Annual Reagent Cost												
Hydrated Lime Use (tons/yr)	4,891	22,899	34,498	2,445	4,891	14,672	752	2,257	4,891	3,260	4,891	6,521
Hydrated Lime Cost ($/ton)	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00	$62.00
Hydrated Lime Cost ($/yr)	$0.303	$1.420	$2.139	$0.152	$0.303	$0.910	$0.047	$0.140	$0.303	$0.202	$0.303	$0.404
Freight Cost ($/ton-mile)	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08
Freight Distance (mi)	413	413	413	413	413	413	413	413	413	413	413	413
Reagent Freight ($/ton)	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00	$33.00
Reagent Freight ($/yr)	$0.161	$0.756	$1.138	$0.081	$0.161	$0.484	$0.025	$0.074	$0.161	$0.108	$0.161	$0.215
Annual Water and Auxiliary Power Costs												
H2O Use (gal/h/MWe)	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
H2O Use (10^3 gal/h)	0.049	0.049	0.049	0.025	0.049	0.147	0.049	0.049	0.049	0.049	0.049	0.049
Raw H2O Cost ($/10^3 gal)	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60
Annual H2O Cost ($10^6/yr)	$0.00017	$0.00017	$0.00017	$0.00008	$0.00017	$0.00050	$0.00003	$0.00008	$0.00017	$0.00017	$0.00017	$0.00017
DSI Aux Power Use (kW/MWe)	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501	0.2501
Humid Aux Power Use (kW/MWe)	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09
Total Aux Power (kWh/h)	1,134	1,134	1,134	567	1,134	3,402	1,134	1,134	1,134	1,134	1,134	1,134
Aux Power Cost ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Aux Power Cost ($10^6/yr)	$0.323	$0.323	$0.323	$0.161	$0.323	$0.149	$0.050	$0.149	$0.323	$0.323	$0.323	$0.323
Annual Ash Disposal Cost												
Ash Disposal ($/ton)	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29
Total Added Ash (tons/yr)	6,862	32,128	48,401	3,431	6,862	20,585	1,056	3,167	6,862	4,574	6,862	9,149
Ash Disposal ($10^6/yr)	$0.0637	$0.2985	$0.4496	$0.0319	$0.0637	$0.1912	$0.0098	$0.0294	$0.0637	$0.0425	$0.0637	$0.0850
Total Variable ($10^6/yr)	$0.548	$1.38	$1.91	$0.27	$0.55	$0.82	$0.08	$0.25	$0.55	$0.47	$0.55	$0.62
Total O&M ($10^6/yr)	$0.75	$1.57	$2.11	$0.45	$0.75	$1.13	$0.28	$0.45	$0.75	$0.67	$0.75	$0.83

	0.40%	1.20%	2.63%	50	100	300	10.00%	30.00%	65.00%	20.00%	30.00%	40.00%
Tot Cap Required ($10^6)	$4.27	$5.11	$6.14	$3.50	$4.27	$7.39	$4.05	$4.13	$4.27	$4.26	$4.29	$4.52
Fixed O&M ($10^6/yr)	$0.198	$0.198	$0.198	$0.173	$0.198	$0.304	$0.198	$0.198	$0.198	$0.198	$0.199	$0.207
Variable O&M ($10^6/yr)	$0.548	$1.377	$1.911	$0.274	$0.548	$0.824	$0.084	$0.253	$0.548	$0.473	$0.548	$0.623
Power Produced (10^9 kWh/yr)	0.569	0.569	0.569	0.285	0.569	1.708	0.088	0.263	0.569	0.569	0.569	0.569
SO2 Removed (tons/yr)	570	2,671	4,023	285	570	1,711	88	263	570	380	570	761
Levelized Cost Per Power Produced (Current Dollars)												
Level Cap Chg (mills/kWh)	1.201	1.437	1.725	1.966	1.201	0.692	7.392	2.514	1.201	1.196	1.206	1.270
Level Fixed O&M (mills/kWh)	0.457	0.457	0.457	0.800	0.457	0.234	2.969	0.990	0.457	0.457	0.459	0.477
Level Variable O&M (mills/kWh)	1.26	3.18	4.41	1.26	1.26	0.63	1.26	1.26	1.26	1.09	1.26	1.44
Total Current (mills/kWh)	2.92	5.07	6.59	4.03	2.92	1.56	11.63	4.77	2.92	2.74	2.93	3.19
Levelized Cost Per Power Produced (Constant Dollars)												
Level Cap Chg (mills/kWh)	0.931	1.114	1.337	1.523	0.931	0.536	5.728	1.948	0.931	0.927	0.935	0.984
Level Fixed O&M (mills/kWh)	0.348	0.348	0.348	0.609	0.348	0.178	2.260	0.753	0.348	0.348	0.349	0.363
Level Variable O&M (mills/kWh)	0.96	2.42	3.36	0.96	0.96	0.48	0.96	0.96	0.96	0.83	0.96	1.09
Total Constant (mills/kWh)	2.24	3.88	5.04	3.09	2.24	1.20	8.95	3.66	2.24	2.11	2.25	2.44
Levelized Cost Per Ton Pollutant Removed (Current Dollars)												
Level Cap Chg ($/ton)	$1,199	$306	$244	$1,962	$1,199	$691	$7,379	$2,510	$1,199	$1,792	$1,204	$951
Level Fixed O&M ($/ton)	$456	$97	$65	$798	$456	$233	$2,964	$988	$456	$684	$458	$357
Level Variable O&M ($/ton)	$1,263	$677	$624	$1,262	$1,262	$633	$1,262	$1,262	$1,262	$1,634	$1,262	$1,076
Total Current ($/ton)	$2,917	$1,081	$933	$4,023	$2,917	$1,557	$11,606	$4,760	$2,917	$4,110	$2,924	$2,385
Total w/o downtime ($/ton)	$2,874	$1,072	$927	$3,979	$2,873	$1,513	$11,562	$4,716	$2,873	$4,044	$2,880	$2,352
Levelized Cost Per Ton Pollutant Removed (Constant Dollars)												
Level Cap Chg ($/ton)	$929	$237	$189	$1,521	$929	$535	$5,719	$1,945	$929	$1,388	$933	$737
Level Fixed O&M ($/ton)	$347	$74	$49	$607	$347	$178	$2,256	$752	$347	$521	$348	$272
Level Variable O&M ($/ton)	$961	$516	$475	$961	$961	$482	$961	$961	$961	$1,244	$961	$819
Total Constant ($/ton)	$2,237	$827	$713	$3,089	$2,237	$1,195	$8,935	$3,658	$2,237	$3,153	$2,242	$1,828
Total w/o downtime ($/ton)	$2,203	$820	$709	$3,055	$2,203	$1,161	$8,901	$3,624	$2,203	$3,102	$2,208	$1,803

Levelization Factors (Plant life = 15yr)	
Level Cap Factor (current)	0.160
Level Cap Factor (constant)	0.124
Level O&M Factor (current)	1.314
Level O&M Factor (constant)	1.000

Humidification Capital Costs for year:		Arapahoe 4			Unit Size (MWe)					
1991	Unit Cost	No.	Factor	Cost	No.	Factor	50	No.	Factor	300
Humidification lances	$13,600	14	1	$190,400	7	1	$95,200	20	1.5	$408,000
Water pump	$3,115	1	1	$3,115	1	0.8	$2,492	1	2	$6,230
Atomization air compressor	$80,560	2	1	$161,120	2	0.8	$128,896	6	1	$483,360
Shield air fan	$2,321	1	1	$2,321	1	0.8	$1,857	1	2	$4,642
Other equipment	$424,050	1	1	$424,050	1	0.9	$381,645	1	2	$848,100
Total procurement				$781,006			$610,090			$1,750,332
Total design/engineering	$330,000	1	1	$330,000	1	1	$330,000	1	1	$330,000
Total installation	$470,000	1	1	$470,000	1	0.8	$376,000	1	2	$940,000
Total capital cost	N/A			$1,581,006			$1,316,090			$3,020,332
$/kW	**N/A**			**$15.81**			**$26.32**			**$10.07**

INTEGRATED DRY NOx/SO2 EMISSIONS CONTROL SYSTEM

FINAL REPORT, VOLUME 2: PROJECT PERFORMANCE AND ECONOMICS

Appendix I-4

Sodium Bicarbonate Dry Sorbent Injection

Bicarbonate SO2 Removal	SULFUR CONTENT			UNIT SIZE			CAPACITY FACTOR			SO2 REMOVAL		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	30%	50%	70%
Coal Data												
Avg Sulfur Content	0.40%	1.20%	2.63%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%
Heat Content (Btu/lb)	11,050	7,080	10,300	11,050	11,050	11,050	11,050	11,050	11,050	11,050	11,050	11,050
Ash Content	9.60%	10.40%	10.80%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%
Na2O in Ash	0.63%	1.05%	3.40%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%
Operating Specifications												
Unit Heatrate (Btu/NkWh)	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542
Unit Size (MWe)	100	100	100	50	100	300	100	100	100	100	100	100
Capacity Factor	65%	65%	65%	65%	65%	65%	10%	30%	65%	65%	65%	65%
SO2 Removal Required	70%	70%	70%	70%	70%	70%	70%	70%	70%	30%	50%	70%
NSR	*1.10*	*1.10*	*1.10*	*1.10*	*1.10*	*1.10*	1.10	1.10	1.10	0.40	0.75	1.10
Utilization	64%	64%	64%	64%	64%	64%	64%	64%	64%	75%	67%	64%
Reagent Specifications												
Na Content (lb Na/lb reagent)	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.272
Na2SO4 Formation Rate	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%
Na2SO3 Formation Rate	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
NaHCO3 Content	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%
Na2CO3 Content	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Inert Content	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Reagent Flowrate												
Max Coal Flow (tons/h)	48	74	51	24	48	143	48	48	48	48	48	48
S02 In Duct (lb/h)	668	3,127	4,711	334	668	2,003	668	668	668	668	668	668
S02 to be Removed (lb/h)	467	2,189	3,297	234	467	1,402	467	467	467	200	334	467
Reagent Flowrate (lb/h)	*1,941*	*9,089*	*13,692*	*971*	*1,941*	*5,823*	1,941	1,941	1,941	706	1,324	1,941
Reagent Flowrate (ton/h)	0.971	4.544	6.846	0.485	0.971	2.912	0.971	0.971	0.971	0.353	0.662	0.971
Ash Disposal												
Ash Formation (lb/h)	9,159	15,485	11,054	4,579	9,159	27,476	9,159	9,159	9,159	9,159	9,159	9,159
Unreacted reagent (lb/h)	706	3,305	4,979	353	706	2,118	706	706	706	176	441	706
Na2SO4 (lb/h)	1,045	4,893	7,372	523	1,045	3,135	1,045	1,045	1,045	448	746	1,045
Na2SO3 (lb/h)	116	544	819	58	116	348	116	116	116	50	83	116
NaHCO3 (lb/h)	702	3,289	4,954	351	702	2,107	702	702	702	176	439	702
Na2CO3 (lb/h)	0	0	0	0	0	0	0	0	0	0	0	0
Inerts (lb/h)	*10*	*45*	*68*	5	10	29	10	10	10	4	7	10
Total Added Ash (lb/h)	2,579	12,076	18,192	1,290	2,579	7,737	2,579	2,579	2,579	853	1,716	2,579
Total Added Ash (ton/h)	1.29	6.04	9.10	0.645	1.29	3.87	1.29	1.29	1.29	0.427	0.858	1.29

Sodium bicarbonate data from reagent data reported in PDR.
Revised: 12/15/94
By: TJ Hanley

Bicarbonate SO2 Removal	SULFUR CONTENT			UNIT SIZE			CAPACITY FACTOR			SO2 REMOVAL		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	30%	50%	70%
Coal Data												
Avg Sulfur Content	0.40%	1.20%	2.63%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%
Heat Content (Btu/lb)	11,050	7,080	10,300	11,050	11,050	11,050	11,050	11,050	11,050	11,050	11,050	11,050
Ash Content	9.60%	10.40%	10.80%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%
Na2O in Ash	0.63%	1.05%	3.40%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%
Operating Specifications												
Unit Heatrate (Btu/NkWh)	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542
Unit Size (MWe)	100	100	100	50	100	300	100	100	100	100	100	100
Capacity Factor	65%	65%	65%	65%	65%	65%	10%	30%	65%	65%	65%	65%
SO2 Removal Required	70%	70%	70%	70%	70%	70%	70%	70%	70%	30%	50%	70%
NSR	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	0.40	0.75	1.10
Utilization	64%	64%	64%	64%	64%	64%	64%	64%	64%	75%	67%	64%
Reagent Specifications												
Na Content (lb Na/lb reagent)	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.272
Na2SO4 Formation Rate	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%
Na2SO3 Formation Rate	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
NaHCO3 Content	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%
Na2CO3 Content	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Inert Content	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Reagent Flowrate												
Max Coal Flow (tons/h)	48	74	51	24	48	143	48	48	48	48	48	48
S02 in Duct (lb/h)	668	3,127	4,711	334	668	2,003	668	668	668	668	668	668
S02 to be Removed (lb/h)	467	2,189	3,297	234	467	1,402	467	467	467	200	334	467
Reagent Flowrate (lb/h)	1,941	9,089	13,692	971	1,941	5,823	1,941	1,941	1,941	706	1,324	1,941
Reagent Flowrate (ton/h)	0.971	4.544	6.846	0.485	0.971	2.912	0.971	0.971	0.971	0.353	0.662	0.971
Ash Disposal												
Ash Formation (lb/h)	9,159	15,485	11,054	4,579	9,159	27,476	9,159	9,159	9,159	9,159	9,159	9,159
Unreacted reagent (lb/h)	706	3,305	4,979	353	706	2,118	706	706	706	176	441	706
Na2SO4 (lb/h)	1,045	4,893	7,372	523	1,045	3,135	1,045	1,045	1,045	448	746	1,045
Na2SO3 (lb/h)	116	544	819	58	116	348	116	116	116	50	83	116
NaHCO3 (lb/h)	702	3,289	4,954	351	702	2,107	702	702	702	176	439	702
Na2CO3 (lb/h)	0	0	0	0	0	0	0	0	0	0	0	0
Inerts (lb/h)	10	45	68	5	10	29	10	10	10	4	7	10
Total Added Ash (lb/h)	2,579	12,076	18,192	1,290	2,579	7,737	2,579	2,579	2,579	853	1,716	2,579
Total Added Ash (ton/h)	1.29	6.04	9.10	0.645	1.29	3.87	1.29	1.29	1.29	0.427	0.858	1.29

Sodium bicarbonate data from reagent data reported in PDR.

Revised: 12/15/94

By: TJ Hanley

BICARBONATE TOTAL CAPITAL

	Sulfur Content			Unit Size			Capacity Factor			SO2 Removal Rate		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	30%	50%	70%
Install Year	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991
Study Year	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994
Inflation Rate	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Subtotal Install-1991 ($/kW)	$14.95	$23.69	$32.55	$25.69	$14.95	$7.90	$14.95	$14.95	$14.95	$12.82	$14.03	$14.95
Subtotal Install-1994 ($10^6)	$1.68	$2.66	$3.66	$1.44	$1.68	$2.66	$1.68	$1.68	$1.68	$1.44	$1.58	$1.68
Retrofit Factor	0	0	0	0	0	0	0	0	0	0	0	0
Retrofit Cost ($10^6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Process Contingency Factor	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Proc Contingency Cost ($10^6)	$0.168	$0.168	$0.168	$0.144	$0.168	$0.266	$0.168	$0.168	$0.168	$0.144	$0.158	$0.168
Total Install Equip ($10^6)	$1.85	$1.85	$1.85	$1.59	$1.85	$2.93	$1.85	$1.85	$1.85	$1.59	$1.74	$1.85
Tot. Process Capital ($10^6)	$1.85	$1.85	$1.85	$1.59	$1.85	$2.93	$1.85	$1.85	$1.85	$1.59	$1.74	$1.85
General Facilities Rate	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Gen Facilities Cost ($10^6)	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Engr & Home Office Rate	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Engr & Home Office ($10^6)	$0.185	$0.185	$0.185	$0.159	$0.185	$0.293	$0.185	$0.185	$0.185	$0.159	$0.174	$0.185
Project Contingency Rate	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Proj Contingency Cost ($10^6)	$0.102	$0.102	$0.102	$0.087	$0.102	$0.161	$0.102	$0.102	$0.102	$0.087	$0.095	$0.102
Total Plant Cost ($10^6)	$2.14	$2.14	$2.14	$1.84	$2.14	$3.39	$2.14	$2.14	$2.14	$1.83	$2.00	$2.14
AFDC rate	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AFDC Cost ($10^6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total Plant Invest ($10^6)	$2.14	$2.14	$2.14	$1.84	$2.14	$3.39	$2.14	$2.14	$2.14	$1.83	$2.00	$2.14
Royalty Rate	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Royalty Cost ($10^6)	$0.01	$0.01	$0.01	$0.01	$0.01	$0.02	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01
Startup Time (weeks)	2	2	2	2	2	2	2	2	2	2	2	2
Preproduction Costs ($10^6)	$0.045	$0.190	$0.284	$0.025	$0.045	$0.125	$0.011	$0.023	$0.045	$0.019	$0.032	$0.045
Inventory Capital ($10^6)	$0.172	$0.172	$0.172	$0.086	$0.172	$0.507	$0.026	$0.079	$0.172	$0.064	$0.118	$0.172
Initial Catalyst ($10^6)	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Subtotal Capital ($10^6)	$2.36	$2.51	$2.60	$1.96	$2.36	$4.03	$2.18	$2.25	$2.36	$1.93	$2.17	$2.36
Construction Downtime (days)	2	2	2	2	2	2	2	2	2	2	2	2
Replacement Power Cost ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Construction Downtime ($10^6)	$0.16	$0.16	$0.16	$0.08	$0.16	$0.47	$0.02	$0.07	$0.16	$0.16	$0.16	$0.16
Total Capital Required ($10^6)	$2.52	$2.66	$2.76	$2.03	$2.52	$4.50	$2.21	$2.32	$2.52	$2.08	$2.32	$2.52

BICARBONATE O&M COSTS	Sulfur Content			Unit Size			Capacity Factor			SO2 Removal Rate		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	30%	50%	70%
Fixed O&M Costs												
Labor ($/op-h)	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23 00	$23.00	$23.00
Labor (operator-h/day)	4	4	4	4	4	4	4	4	4	4	4	4
Operating Labor ($10^6/yr)	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336
Total Install Equip ($10^6)	$1.85	$1.85	$1.85	$1.59	$1.85	$2.93	$1.85	$1.85	$1.85	$1.59	$1.74	$1.85
Maintenance Factor	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Maintenance Labor ($10^6/yr)	$0.0296	$0.0296	$0.0296	$0.0254	$0.0296	$0.0469	$0.0296	$0.0296	$0.0296	$0.0254	$0.0278	$0.0296
Maintenance Matl ($10^6/yr)	$0.0444	$0.0444	$0.0444	$0.0381	$0.0444	$0.0703	$0.0444	$0.0444	$0.0444	$0.0381	$0.0417	$0.0444
Admin/Support Labor ($10^6/yr)	$0.0190	$0.0190	$0.0190	$0.0177	$0.0190	$0.0241	$0.0190	$0.0190	$0.0190	$0.0177	$0.0184	$0.0190
Total Fixed O&M ($10^6/yr)	$0.127	$0.127	$0.127	$0.115	$0.127	$0.175	$0.127	$0.127	$0.127	$0.115	$0.121	$0.127
Variable O&M Costs												
Reagent Cost												
Na Bicarbonate Use (tons/yr)	5,526	25,876	38,982	2,763	5,526	16,579	850	2,551	5,526	2,010	3,768	5,526
Na Bicarbonate Cost ($/ton)	$140.00	$140.00	$140.00	$140.00	$140.00	$140.00	$140.00	$140.00	$140.00	$140.00	$140.00	$140.00
Na Bicarbonate Cost ($10^6/yr)	$0.77	$3.62	$5.46	$0.39	$0.77	$2.32	$0.12	$0.36	$0.77	$0.28	$0.53	$0.77
Reagent Freight Cost												
Freight Cost ($/ton-mile)	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08
Freight Distance (mi)	413	413	413	413	413	413	413	413	413	413	413	413
Reagent Freight ($/ton)	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04
Reagent Freight ($10^6/yr)	$0.18	$0.85	$1.29	$0.09	$0.18	$0.55	$0.03	$0.08	$0.18	$0.07	$0.12	$0.18
Auxiliary Electric Power												
Auxiliary Power (kW/MWe)	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725
Auxiliary Power (kWh/h)	72.5	72.5	72.5	36.25	72.5	217.5	72.5	72.5	72.5	72.5	72.5	72.5
Auxiliary Power ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Auxiliary Power ($10^6/yr)	$0.0206	$0.0206	$0.0206	$0.0103	$0.0206	$0.0095	$0.0032	$0.0095	$0.0206	$0.0206	$0.0206	$0.0206
Ash Disposal Cost												
Ash Disposal ($/ton)	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29
Ash Disposal (tons/yr)	7,343	34,380	51,793	3,671	7,343	22,028	1,130	3,389	7,343	2,429	4,886	7,343
Added Disposal Cost ($10^6/yr)	$0.068	$0.319	$0.481	$0.034	$0.068	$0.205	$0.010	$0.031	$0.068	$0.023	$0.045	$0.068
Total Variable ($10^6/yr)	$1.045	$4 818	$7.247	$0.523	$1.045	$3.083	$0.161	$0.482	$1.045	$0.391	$0.718	$1.045
Total O&M ($10^6/yr)	$1.172	$4.94	$7.37	$0.64	$1.17	$3.26	$0.29	$0.61	$1.17	$0.51	$0.84	$1.17

BICARBONATE LEVELIZED COSTS	Sulfur Content			Unit Size			Capacity Factor			SO2 Removal Rate		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	30%	50%	70%
Tot Cap Required ($10^6)	$2.52	$2.66	$2.76	$2.03	$2.52	$4.50	$2.21	$2.32	$2.52	$2.08	$2.32	$2.52
Tot Cap Required ($/kW)	$25.20	$26.65	$27.58	$40.67	$25.20	$15.01	$22.09	$23.22	$25.20	$20.82	$23.21	$25.20
Fixed O&M ($10^6/yr)	$0.127	$0.127	$0.127	$0.115	$0.127	$0.175	$0.127	$0.127	$0.127	$0.115	$0.121	$0.127
Variable O&M ($10^6/yr)	$1.045	$4.818	$7.247	$0.523	$1.045	$3.083	$0.161	$0.482	$1.045	$0.391	$0.718	$1.045
POWER PRODUCED (10^9 kWh/yr)	0.569	0.569	0.569	0.285	0.569	1.708	0.088	0.263	0.569	0.569	0.569	0.569
SO2 REMOVED (tons/yr)	1,331	6,232	9,388	665	1,331	3,993	205	614	1,331	570	951	1,331
	Cost per Power Produced (Current Dollars)											
Level Cap Chg (mills/kWh)	0.708	0.749	0.775	1.143	0.708	0.422	4.034	1.414	0.708	0.585	0.652	0.708
Level Fixed O&M (mills/kWh)	0.292	0.292	0.292	0.530	0.292	0.135	1.898	0.633	0.292	0.265	0.280	0.292
Level Variable O&M (mills/kWh)	2.41	11.12	16.72	2.41	2.41	2.37	2.41	2.41	2.41	0.90	1.66	2.41
Total Current (mills/kWh)	3.41	12.16	17.79	4.08	3.41	2.93	8.34	4.46	3.41	1.75	2.59	3.41
	Cost per Power Produced (Constant Dollars)											
Level Cap Chg (mills/kWh)	0.549	0.580	0.601	0.886	0.549	0.327	3.126	1.095	0.549	0.453	0.506	0.549
Level Fixed O&M (mills/kWh)	0.222	0.222	0.222	0.403	0.222	0.102	1.444	0.481	0.222	0.202	0.213	0.222
Level Variable O&M (mills/kWh)	1.84	8.46	12.73	1.84	1.84	1.80	1.84	1.84	1.84	0.69	1.26	1.84
Total Constant (mills/kWh)	2.61	9.26	13.55	3.12	2.61	2.23	6.41	3.41	2.61	1.34	1.98	2.61
	Cost Per Ton Pollutant Removed (Current Dollars)											
Level Cap Chg ($/ton)	$303	$68	$47	$489	$303	$180	$1,726	$605	$303	$584	$391	$303
Level Fixed O&M ($/ton)	$125	$27	$18	$227	$125	$58	$812	$271	$125	$264	$168	$125
Level Variable O&M ($/ton)	$1,032	$1,016	$1,014	$1,032	$1,032	$1,015	$1,032	$1,032	$1,032	$901	$993	$1,032
Total Current ($/ton)	$1,460	$1,111	$1,079	$1,748	$1,460	$1,253	$3,570	$1,907	$1,460	$1,749	$1,551	$1,460
Total w/o downtime ($/ton)	$1,441	$1,107	$1,076	$1,729	$1,441	$1,234	$3,551	$1,889	$1,441	$1,705	$1,525	$1,441
	Cost Per Ton Pollutant Removed (Constant Dollars)											
Level Cap Chg ($/ton)	$235	$53	$36	$379	$235	$140	$1,337	$469	$235	$453	$303	$235
Level Fixed O&M ($/ton)	$95	$20	$13	$173	$95	$44	$618	$206	$95	$201	$128	$95
Level Variable O&M ($/ton)	$785	$773	$772	$785	$785	$772	$785	$785	$785	$685	$755	$785
Total Constant ($/ton)	$1,115	$846	$822	$1,337	$1,115	$956	$2,741	$1,460	$1,115	$1,339	$1,186	$1,115
Total w/o downtime ($/ton)	$1,101	$843	$820	$1,322	$1,101	$941	$2,726	$1,445	$1,101	$1,305	$1,165	$1,101

Levelization Factors	
Plant Life (yr)	15
Level Cap Factor (current)	0.160
Level Cap Factor (constant)	0.124
Level O&M Factor (current)	1.314
Level O&M Factor (constant)	1.000

Install Year= 1991

SODIUM CAPITAL COSTS	Arapahoe 4 (Base)				Sulfur Content					
Item	Unit Cost	No.	Factor	Cost	No.	Factor	1.20%	No.	Factor	2.63%
Reagent storage silos	$104,480	2	1	$208,960	3	1.2	$376,128	4	1.5	$626,880
Silo vent filters	$3,850	2	1	$7,700	3	1	$11,550	4	1	$15,400
Reagent screw feeders	$5,525	2	1	$11,050	3	1.2	$19,890	4	1.2	$26,520
Blower & heat exchanger	$13,104	2	1	$26,208	3	1	$39,312	4	1	$52,416
Pulverizers	$65,533	2	1	$131,066	3	1.2	$235,919	4	1.5	$393,198
Splitter Box	$7,616	2	1	$15,232	3	1	$22,848	4	1.1	$33,510
Rotary airlock	$9,340	2	1	$18,680	3	1	$28,020	4	1.1	$41,096
Other equipment	$335,950	1	1	$335,950	1	1.8	$604,710	1	2.2	$739,090
Total design/engineering	$199,000	1	1	$199,000	1	1.1	$218,900	1	1.5	$298,500
Total procurement	$545,398			$754,846			$1,338,377			$1,928,110
Total installation	$541,000	1	1	$541,000	1	1.5	$811,500	1	1.9	$1,027,900
Total Installed Cost				$1,494,846			$2,368,777			$3,254,510
$/kW =				$14.95			$23.69			$32.55

		SO2 Removal Rate						Unit Size			
Item	Item Cost	No.	Factor	30%	No.	Factor	50%	No.	Factor	50	300
Reagent storage silos	$104,480	2	0.7	$146,272	2	0.85	$177,616	2	0.8	$167,168	
Silo vent filters	$3,850	2	1	$7,700	2	1	$7,700	2	0.8	$6,160	(See 1.2%
Reagent screw feeders	$5,525	2	0.8	$8,840	2	1	$11,050	2	0.8	$8,840	sulfur coal data)
Blower & heat exchanger	$13,104	2	1	$26,208	2	1	$26,208	2	0.8	$20,966	
Pulverizers	$65,533	2	0.8	$104,853	2	1	$131,066	2	0.9	$117,959	
Splitter Box	$7,616	2	1	$15,232	2	1	$15,232	2	0.9	$13,709	
Rotary airlock	$9,340	2	1	$18,680	2	1	$18,680	2	0.8	$14,944	
Other equipment	$335,950	1	0.8	$268,760	1	0.9	$302,355	1	0.8	$268,760	
Total design/engineering	$199,000	1	1	$199,000	1	1	$199,000	1	0.9	$179,100	
Total procurement	$545,398			$596,545			$689,907			$618,507	
Total installation	$541,000	1	0.9	$486,900	1	0.95	$513,950	1	0.9	$486,900	
Total Installed Cost	$1,285,398			$1,282,445			$1,402,857			$1,284,507	$2,368,777
$/kW =				$12.82			$14.03			$25.69	$7.90

INTEGRATED DRY NOx/SO2 EMISSIONS CONTROL SYSTEM

FINAL REPORT, VOLUME 2: PROJECT PERFORMANCE AND ECONOMICS

Appendix I-5

Sodium Sesquicarbonate Dry Sorbent Injection

SESQUICARBONATE SO2 REMOVAL	SULFUR CONTENT			UNIT SIZE			CAPACITY FACTOR			SO2 REMOVAL		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	30%	50%	70%
Coal Data												
Avg Sulfur Content	0.40%	1.20%	2.63%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%
Heat Content (Btu/lb)	11,050	7,080	10,300	11,050	11,050	11,050	11,050	11,050	11,050	11,050	11,050	11,050
Ash Content	9.60%	10.40%	10.80%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%
Na2O in Ash	0.63%	1.05%	3.40%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%
Operating Data												
Unit Heatrate (Btu/NkWh)	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542
Unit Size (MWe)	100	100	100	50	100	300	100	100	100	100	100	100
Capacity Factor	65%	65%	65%	65%	65%	65%	10%	30%	65%	65%	65%	65%
SO2 Removal Required	70%	70%	70%	70%	70%	70%	70%	70%	70%	30%	50%	70%
NSR	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	0.5	1	1.9
Utilization	37%	37%	37%	37%	37%	37%	37%	37%	37%	60%	50%	37%
Reagent Specifications												
Na Content (lb Na/lb reagent)	0.298	0.298	0.298	0.298	0.298	0.298	0.298	0.298	0.298	0.298	0.298	0.298
Na2SO4 Formation Rate	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%
Na2SO3 Formation Rate	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
NaHCO3 Content	36.3%	36.3%	36.3%	36.3%	36.3%	36.3%	36.3%	36.3%	36.3%	36.3%	36.3%	36.3%
Na2CO3 Content	45.8%	45.8%	45.8%	45.8%	45.8%	45.8%	45.8%	45.8%	45.8%	45.8%	45.8%	45.8%
Inert Content	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%
Reagent Flowrate												
Max Coal Flow (tons/h)	48	74	51	24	48	143	48	48	48	48	48	48
S02 In Duct (lb/h)	668	3,127	4,711	334	668	2,003	668	668	668	668	668	668
S02 to be Removed (lb/h)	467	2,189	3,297	234	467	1,402	467	467	467	200	334	467
Reagent Flowrate (lb/h)	3,060	14,329	21,587	1,530	3,060	9,181	3,060	3,060	3,060	805	1,611	3,060
Ash Disposal Rate												
Ash Formation (lb/h)	9,159	15,485	11,054	4,579	9,159	27,476	9,159	9,159	9,159	9,159	9,159	9,159
Unreacted reagent (lb/h)	1,933	9,050	13,634	966	1,933	5,799	1,933	1,933	1,933	322	805	1,933
Na2SO4 (lb/h)	954	4,466	6,728	477	954	2,862	954	954	954	409	681	954
Na2SO3 (lb/h)	106	496	748	53	106	318	106	106	106	45	76	106
NaHCO3 (lb/h)	702	3,285	4,949	351	702	2,105	702	702	702	117	292	702
Na2CO3 (lb/h)	885	4,145	6,244	443	885	2,656	885	885	885	148	369	885
Inerts (lb/h)	70	330	497	35	70	211	70	70	70	19	37	70
Total Added Ash (lb/h)	4,650	21,772	32,800	2,325	4,650	13,950	4,650	4,650	4,650	1,059	2,261	4,650

Note. Sodium sesquicarbonate data from reagent data reported in PDR.
NASESQUI.WK3 Revised: 12/02/94
By: TJ Hanley

SESQUICARBONATE TOTAL CAPITAL	Sulfur Content			Unit Size			Capacity Factor			SO2 Removal Rate		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	30%	50%	70%
Install Year	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991
Study Year	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994
Inflation Rate	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Subtotal Install-1991 ($/kW)	$14.95	$23.69	$32.55	$25.69	$14.95	$7.90	$14.95	$14.95	$14.95	$12.82	$14.03	$14.95
Subtotal Install-1994 ($10^6)	$1.68	$2.66	$3.66	$1.44	$1.68	$2.66	$1.68	$1.68	$1.68	$1.44	$1.58	$1.68
Retrofit Factor	0	0	0	0	0	0	0	0	0	0	0	0
Retrofit Cost ($10^6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Process Contingency Factor	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Proc Contingency Cost ($10^6)	$0.168	$0.168	$0.168	$0.144	$0.168	$0.266	$0.168	$0.168	$0.168	$0.144	$0.158	$0.168
Total Install Equip ($10^6)	$1.85	$1.85	$1.85	$1.59	$1.85	$2.93	$1.85	$1.85	$1.85	$1.59	$1.74	$1.85
Tot. Process Capital ($10^6)	$1.85	$1.85	$1.85	$1.59	$1.85	$2.93	$1.85	$1.85	$1.85	$1.59	$1.74	$1.85
General Facilities Rate	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Gen Facilities Cost ($10^6)	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Engr & Home Office Rate	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Engr & Home Office ($10^6)	$0.185	$0.185	$0.185	$0.159	$0.185	$0.293	$0.185	$0.185	$0.185	$0.159	$0.174	$0.185
Project Contingency Rate	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Proj Contingency Cost ($10^6)	$0.102	$0.102	$0.102	$0.087	$0.102	$0.161	$0.102	$0.102	$0.102	$0.087	$0.095	$0.102
Total Plant Cost ($10^6)	$2.14	$2.14	$2.14	$1.84	$2.14	$3.39	$2.14	$2.14	$2.14	$1.83	$2.00	$2.14
AFDC rate (<1 yr)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AFDC Cost ($10^6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total Plant Invest ($10^6)	$2.14	$2.14	$2.14	$1.84	$2.14	$3.39	$2.14	$2.14	$2.14	$1.83	$2.00	$2.14
Royalty Rate	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Royalty Cost ($10^6)	$0.01	$0.01	$0.01	$0.01	$0.01	$0.02	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01
Startup Time (weeks)	2	2	2	2	2	2	2	2	2	2	2	2
Preproduction Costs ($10^6)	$0.043	$0.182	$0.271	$0.023	$0.042	$0.119	$0.011	$0.023	$0.043	$0.015	$0.025	$0.043
Inventory Capital ($10^6)	$0.164	$0.164	$0.164	$0.082	$0.164	$0.483	$0.025	$0.076	$0.164	$0.045	$0.087	$0.164
Initial Catalyst ($10^6)	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Subtotal Capital ($10^6)	$2.35	$2.49	$2.58	$1.95	$2.35	$4.00	$2.18	$2.25	$2.35	$1.90	$2.13	$2.35
Construction Downtime (days)	2	2	2	2	2	2	2	2	2	2	2	2
Replacement Power Cost ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Construction Downtime ($10^6)	$0.16	$0.16	$0.16	$0.08	$0.16	$0.47	$0.02	$0.07	$0.16	$0.16	$0.16	$0.16
Total Capital Required ($10^6)	$2.51	$2.65	$2.74	$2.03	$2.51	$4.47	$2.21	$2.32	$2.51	$2.06	$2.28	$2.51

SESQUICARBONATE O&M COSTS	Sulfur Content			Unit Size			Capacity Factor			SO2 Removal Rate		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	30%	50%	70%
ANNUAL FIXED O&M COSTS												
Labor ($/op-h)	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00
Labor (operator-h/day)	4	4	4	2	2	2	4	4	4	4	4	4
Operating Labor ($10^6/yr)	$0.0336	$0.0336	$0.0336	$0.0168	$0.0168	$0.0168	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336
Total Install Equip ($10^6)	$1.85	$1.85	$1.85	$1.59	$1.85	$2.93	$1.85	$1.85	$1.85	$1.59	$1.74	$1.85
Maintenance Factor	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Maintenance Labor ($10^6/yr)	$0.0296	$0.0296	$0.0296	$0.0254	$0.0296	$0.0469	$0.0296	$0.0296	$0.0296	$0.0254	$0.0278	$0.0296
Maintenance Matl ($10^6/yr)	$0.0444	$0.0444	$0.0444	$0.0381	$0.0444	$0.0703	$0.0444	$0.0444	$0.0444	$0.0381	$0.0417	$0.0444
Admin/Support Labor ($10^6/yr)	$0.0190	$0.0190	$0.0190	$0.0127	$0.0139	$0.0191	$0.0190	$0.0190	$0.0190	$0.0177	$0.0184	$0.0190
Total Fixed O&M ($10^6/yr)	$0.127	$0.127	$0.127	$0.093	$0.105	$0.153	$0.127	$0.127	$0.127	$0.115	$0.121	$0.127
ANNUAL VARIABLE O&M COSTS												
Annual Reagent Cost												
Sesquicarbonate Use (tons/yr)	8,713	40,795	61,459	4,356	8,713	26,139	1,340	4,021	8,713	2,293	4,586	8,713
Sesquicarbonate Cost ($/ton)	$65.00	$65.00	$65.00	$65.00	$65.00	$65.00	$65.00	$65.00	$65.00	$65.00	$65.00	$65.00
Sesquicarbonate Cost ($10^6/yr)	$0.57	$2.65	$3.99	$0.28	$0.57	$1.70	$0.09	$0.26	$0.57	$0.15	$0.30	$0.57
Freight Cost ($/ton-mile)	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08
Freight Distance (mi)	413	413	413	413	413	413	413	413	413	413	413	413
Reagent Freight ($/ton)	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04	$33.04
Reagent Freight ($10^6/yr)	$0.29	$1.35	$2.03	$0.14	$0.29	$0.86	$0.04	$0.13	$0.29	$0.08	$0.15	$0.29
Annual Auxillaiary Power Cost												
Aux Power (kW/MWe)	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725
Auxillary Power (kWh/h)	72.5	72.5	72.5	36.25	72.5	217.5	72.5	72.5	72.5	72.5	72.5	72.5
Auxillary Power ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Auxillary Power ($10^6/yr)	$0.0206	$0.0206	$0.0206	$0.0103	$0.0206	$0.0095	$0.0032	$0.0095	$0.0206	$0.0206	$0.0206	$0.0206
Annual Disposal Cost												
Ash Disposal (tons/yr)	13,239	61,985	93,381	6,619	13,239	39,716	2,037	6,110	13,239	3,016	6,436	13,239
Ash Disposal ($/ton)	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29
Added Disposal Cost ($/yr)	$0.123	$0.576	$0.868	$0.061	$0.123	$0.369	$0.019	$0.057	$0.123	$0.028	$0.060	$0.123
Total Variable ($10^6/yr)	$0.998	$4.596	$6.914	$0.499	$0.998	$2.941	$0.154	$0.461	$0.998	$0.273	$0.530	$0.998
Total O&M ($10^6/yr)	$1.124	$4.72	$7.04	$0.59	$1.10	$3.09	$0.28	$0.59	$1.12	$0.39	$0.65	$1.12

SESQUICARBONATE LEVELIZED COSTS	Sulfur Content			Unit Size			Capacity Factor			SO2 Removal Rate		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	30%	50%	70%
Economic Data												
Tot Cap Required ($10^6)	$2.51	$2.65	$2.74	$2.03	$2.51	$4.47	$2.21	$2.32	$2.51	$2.06	$2.28	$2.51
Fixed O&M ($10^6/yr)	$0.127	$0.127	$0.127	$0.093	$0.105	$0.153	$0.127	$0.127	$0.127	$0.115	$0.121	$0.127
Variable O&M ($10^6/yr)	$0.998	$4.596	$6.914	$0.499	$0.998	$2.941	$0.154	$0.461	$0.998	$0.273	$0.530	$0.998
POWER PRODUCED (10^9 kWh/yr)	0.569	0.569	0.569	0.285	0.569	1.708	0.088	0.263	0.569	0.569	0.569	0.569
SO2 REMOVED (tons/yr)	1,331	6,232	9,388	665	1,331	3,993	205	614	1,331	570	951	1,331
Levelized Cost Per Power Produced (Current Dollars)												
Level Cap Chg (mills/kWh)	0.705	0.744	0.769	1.140	0.705	0.419	4.031	1.411	0.705	0.578	0.642	0.705
Level Fixed O&M (mills/kWh)	0.292	0.292	0.292	0.429	0.242	0.118	1.898	0.633	0.292	0.265	0.280	0.292
Level Variable O&M (mills/kWh)	2.30	10.61	15.95	2.30	2.30	2.26	2.30	2.30	2.30	0.63	1.22	2.30
Total Current (mills/kWh)	3.30	11.64	17.02	3.87	3.25	2.80	8.23	4.35	3.30	1.47	2.14	3.30
Levelized Cost Per Power Produced (Constant Dollars)												
Level Cap Chg (mills/kWh)	0.547	0.577	0.596	0.883	0.546	0.325	3.124	1.093	0.547	0.448	0.497	0.547
Level Fixed O&M (mills/kWh)	0.222	0.222	0.222	0.327	0.164	0.090	1.444	0.481	0.222	0.202	0.213	0.222
Level Variable O&M (mills/kWh)	1.75	8.07	12.14	1.75	1.75	1.72	1.75	1.75	1.75	0.48	0.93	1.75
Total Constant (mills/kWh)	2.52	8.87	12.96	2.96	2.48	2.14	6.32	3.33	2.52	1.13	1.64	2.52
Levelized Cost Per Ton Pollutant Removed (Current Dollars)												
Level Cap Chg ($/ton)	$302	$68	$47	$488	$302	$179	$1,725	$604	$302	$577	$384	$302
Level Fixed O&M ($/ton)	$125	$27	$18	$184	$103	$50	$812	$271	$125	$264	$168	$125
Level Variable O&M ($/ton)	$985	$969	$968	$985	$985	$968	$985	$985	$985	$630	$733	$985
Total Current ($/ton)	$1,412	$1,064	$1,032	$1,656	$1,390	$1,198	$3,522	$1,859	$1,412	$1,472	$1,285	$1,412
Total w/o Downtime ($/ton)	$1,393	$1,060	$1,029	$1,638	$1,371	$1,179	$3,503	$1,841	$1,393	$1,428	$1,258	$1,393
Levelized Cost Per Ton Pollutant Removed (Constant Dollars)												
Level Cap Chg ($/ton)	$234	$53	$36	$378	$234	$139	$1,337	$468	$234	$447	$298	$234
Level Fixed O&M ($/ton)	$95	$20	$13	$140	$79	$38	$618	$206	$95	$201	$128	$95
Level Variable O&M ($/ton)	$750	$738	$736	$750	$750	$737	$750	$750	$750	$479	$558	$750
Total Constant ($/ton)	$1,079	$811	$786	$1,267	$1,062	$914	$2,704	$1,424	$1,079	$1,128	$983	$1,079
Total w/o Downtime ($/ton)	$1,064	$807	$784	$1,253	$1,048	$899	$2,690	$1,409	$1,064	$1,094	$963	$1,064

Levelization Factors (plant life=15 yr)	
Level Cap Factor (current)	0.160
Level Cap Factor (constant)	0.124
Level O&M Factor (current)	1.314
Level O&M Factor (constant)	1.000

INTEGRATED DRY NOx/SO2 EMISSIONS CONTROL SYSTEM

FINAL REPORT, VOLUME 2: PROJECT PERFORMANCE AND ECONOMICS

Appendix I-6

Limestone With Forced Oxidation Scrubbing

Scrubber (LSFO) SO2 Removal	SULFUR CONTENT			UNIT SIZE			CAPACITY FACTOR			SO2 REMOVAL		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	50%	70%	90%
Coal Data												
Avg Sulfur Content	0.40%	1.20%	2.63%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%
Heat Content (Btu/lb)	11,050	7,080	10,300	11,050	11,050	11,050	11,050	11,050	11,050	11,050	11,050	11,050
Ash Content	9.60%	10.40%	10.80%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%	9.60%
Operating Data												
Unit Heatrate (Btu/NkWh)	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542
Unit Size (MWe)	100	100	100	50	100	300	100	100	100	100	100	100
Capacity Factor	65%	65%	65%	65%	65%	65%	10%	30%	65%	65%	65%	65%
SO2 Removal Required	90%	90%	90%	90%	90%	90%	90%	90%	90%	50%	70%	90%
mole CaCO3/mole SO2 removed	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Utilization	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%
Purity (lb CaCO3/lb reagent)	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%
Reagent Flowrate												
Max Coal Flow (tons/h)	48	74	51	24	48	143	48	48	48	48	48	48
SO2 In Duct (lb/h)	668	3,127	4,711	334	668	2,003	668	668	668	668	668	668
SO2 to be Removed (lb/h)	601	2,814	4,240	301	601	1,803	601	601	601	334	467	601
CaCO3 Flowrate (lb/h)	1,033	4,837	7,287	517	1,033	3,099	1,033	1,033	1,033	574	803	1,033
Limestone Flowrate (lb/h)	1,099	5,146	7,752	549	1,099	3,297	1,099	1,099	1,099	611	855	1,099
Ash Flowrate												
Unreacted CaCO3 (lb/h)	94	440	662	47	94	282	94	94	94	52	73	94
CaSO4*2H2O (lb/h)	1,615	7,563	11,394	808	1,615	4,846	1,615	1,615	1,615	897	1,256	1,615
Inerts (lb/h)	66	309	465	33	66	198	66	66	66	56	78	100
Total Added Waste (lb/h)	1,775	8,312	12,521	888	1,775	5,325	1,775	1,775	1,775	1,005	1,407	1,809

Molecular Weights

MW Ca (lb/mole)	40	MW CaSO4*2H2O	172
MW CaCO3 (lb/mole)	100	MW SO2 (lb/mole)	64
MW CaSO4 (lb/mole)	136		

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By: TJ Hanley

TOTAL CAPITAL RESULTS	Sulfur Content			Unit Size			Capacity Factor			SO2 Removal Rate		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	50%	70%	90%
Year Installed	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994
Year of Study	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994
Subtotal Install-1994 ($/kW)	$180	$190	$200	$210	$180	$125	$180	$180	$180	$160	$165	$180
Inflation Rate	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Subtotal Install-1994 ($/kW)	$180	$190	$200	$210	$180	$125	$180	$180	$180	$160	$165	$180
Subtotal Install-1994 ($10^6)	$18.00	$19.00	$20.00	$10.50	$18.00	$37.50	$18.00	$18.00	$18.00	$16.00	$16.50	$18.00
Retrofit Factor	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%
Retrofit Cost ($10^6)	$2.16	$2.28	$2.40	$1.26	$2.16	$4.50	$2.16	$2.16	$2.16	$1.92	$1.98	$2.16
Process Contingency Factor	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Proc Contingency Cost ($10^6)	$0.360	$0.380	$0.400	$0.210	$0.360	$0.750	$0.360	$0.360	$0.360	$0.320	$0.330	$0.360
Total Install Equip ($10^6)	$20.52	$21.66	$22.80	$11.97	$20.52	$42.75	$20.52	$20.52	$20.52	$18.24	$18.81	$20.52
Tot. Process Capital ($10^6)	$20.52	$21.66	$22.80	$11.97	$20.52	$42.75	$20.52	$20.52	$20.52	$18.24	$18.81	$20.52
General Facilities Rate	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Gen Facilities Cost ($10^6)	$2.052	$2.166	$2.280	$1.197	$2.052	$4.275	$2.052	$2.052	$2.052	$1.824	$1.881	$2.052
Engr & Home Office Rate	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Engr & Home Office ($10^6)	$2.052	$2.166	$2.280	$1.197	$2.052	$4.275	$2.052	$2.052	$2.052	$1.824	$1.881	$2.052
Project Contingency Rate	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%
Proj Contingency Cost ($10^6)	$2.955	$3.119	$3.283	$1.724	$2.955	$6.156	$2.955	$2.955	$2.955	$2.627	$2.709	$2.955
Total Plant Cost ($10^6)	$27.58	$29.11	$30.64	$16.09	$27.58	$57.46	$27.58	$27.58	$27.58	$24.51	$25.28	$27.58
AFDC rate (<1 year)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AFDC Cost ($10^6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total Plant Invest ($10^6)	$27.58	$29.11	$30.64	$16.09	$27.58	$57.46	$27.58	$27.58	$27.58	$24.51	$25.28	$27.58
Royalty Rate	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Royalty Cost ($10^6)	$0.14	$0.15	$0.15	$0.08	$0.14	$0.29	$0.14	$0.14	$0.14	$0.12	$0.13	$0.14
Startup Time (weeks)	8	8	8	8	8	8	8	8	8	8	8	8
Preproduction Costs ($10^6)	$0.345	$0.407	$0.447	$0.221	$0.345	$0.562	$0.269	$0.297	$0.345	$0.319	$0.328	$0.345
Inventory Capital ($10^6)	$0.096	$0.162	$0.205	$0.048	$0.096	$0.090	$0.015	$0.044	$0.096	$0.088	$0.092	$0.096
Initial Catalyst ($10^6)	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Subtotal Capital ($10^6)	$28.16	$29.83	$31.45	$16.44	$28.16	$58.40	$28.00	$28.06	$28.16	$25.04	$25.83	$28.16
Construction Downtime (days)	2	2	2	2	2	2	2	2	2	2	2	2
Replacement Power Cost ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Construction Downtime ($10^6)	$0.16	$0.16	$0.16	$0.08	$0.16	$0.47	$0.02	$0.07	$0.16	$0.16	$0.16	$0.16
Total Capital Required ($10^6)	$28.31	$29.98	$31.60	$16.51	$28.31	$58.86	$28.02	$28.13	$28.31	$25.20	$25.98	$28.31

O&M COST RESULTS ($10^6/yr)	Sulfur Content 0.40%	1.20%	2.63%	Unit Size 50	100	300	Capacity Factor 10%	30%	65%	SO2 Removal Rate 50%	70%	90%
ANNUAL FIXED O&M COSTS												
Labor ($/operator-h)	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00
Labor (operators/shift)	2.3	2.3	2.3	2.0	2.3	3.5	2.3	2.3	2.3	2.3	2.3	2.3
Labor (shifts/week)	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Operating Labor ($10^6/yr)	$0.464	$0.464	$0.464	$0.406	$0.464	$0.697	$0.464	$0.464	$0.464	$0.464	$0.464	$0.464
Total Install Equip ($10^6)	$20.5	$20.5	$20.5	$12.0	$20.5	$42.8	$20.5	$20.5	$20.5	$18.2	$18.8	$20.5
Maintenance Factor	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%
Maintenance Labor ($10^6/yr)	$0.378	$0.378	$0.378	$0.220	$0.378	$0.787	$0.378	$0.378	$0.378	$0.336	$0.346	$0.378
Maintenance Matl ($10^6/yr)	$0.566	$0.566	$0.566	$0.330	$0.566	$1.180	$0.566	$0.566	$0.566	$0.503	$0.519	$0.566
Admin/Support Labor ($10^6/yr)	*$0.253*	*$0.253*	*$0.253*	*$0.188*	*$0.253*	*$0.445*	$0.253	$0.253	$0.253	$0.240	$0.243	$0.253
Total Fixed O&M ($10^6/yr)	$1.66	$1.66	$1.66	$1.14	$1.66	$3.11	$1.66	$1.66	$1.66	$1.54	$1.57	$1.66
ANNUAL VARIABLE O&M COSTS												
Annual Reagent Cost												
Limestone Use (tons/yr)	3,129	14,650	22,070	1,564	3,129	9,386	481	1,444	3,129	1,738	2,433	3,129
Limestone Cost ($/ton)	$15.00	$15.00	$15.00	$15.00	$15.00	$15.00	$15.00	$15.00	$15.00	$15.00	$15.00	$15.00
Limestone Cost ($/yr)	$0.047	$0.220	$0.331	$0.023	$0.047	$0.141	$0.007	$0.022	$0.047	$0.026	$0.037	$0.047
Freight Cost ($/ton-mile)	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08
Freight Distance (mi)	250	250	250	250	250	250	250	250	250	250	250	250
Reagent Freight ($/ton)	$20.00	$20.00	$20.00	$20.00	$20.00	$20.00	$20.00	$20.00	$20.00	$20.00	$20.00	$20.00
Reagent Freight ($/yr)	$0.063	$0.293	$0.441	$0.031	$0.063	$0.188	$0.010	$0.029	$0.063	$0.035	$0.049	$0.063
Annual Auxilliary Power Cost												
Aux Power Use (kW/MWe)	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6
Auxillary Power Use (kWh/h)	1,657	1,657	1,657	828	1,657	4,970	1,657	1,657	1,657	1,657	1,657	1,657
Auxillary Power Cost ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Aux Power Cost ($10^6/yr)	*$0.472*	*$0.472*	*$0.472*	*$0.236*	*$0.472*	*$0.218*	*$0.073*	*$0.218*	*$0.472*	$0.472	$0.472	$0.472
Annual Water Cost												
Blowdown H2O (gpm/MWe)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Blowdown H2O (gal/min)	110	110	110	55	110	330	110	110	110	110	110	110
Blowdown H2O ($/10^3 gal)	*$0.00*	*$0.00*	*$0.00*	*$0.00*	*$0.00*	*$0.00*	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Blowdown H2O ($10^6/yr)	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000
Annual Disposal Cost												
Total Added Ash (tons/yr)	5,054	23,663	35,648	2,527	5,054	15,161	778	2,333	5,054	2,861	4,006	5,151
Ash Disposal Cost ($/ton)	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29	$9.29
Ash Disposal ($10^6/yr)	$0.0469	$0.2198	$0.3312	$0.0235	$0.0469	$0.1408	$0.0072	$0.0217	$0.0469	$0.0266	$0.0372	$0.0478
Total Variable ($10^6/yr)	$0.581	$0.984	$1.24	$0.29	$0.58	$0.55	$0.09	$0.27	$0.58	$0.53	$0.56	$0.58
Total O&M ($10^6/yr)	$2.24	$2.65	$2.90	$1.43	$2.24	$3.66	$1.75	$1.93	$2.24	$2.08	$2.13	$2.24

LEVELIZED COSTS	Sulfur Content			Unit Size			Capacity Factor			SO2 Removal Rate		
	0.40%	1.20%	2.63%	50	100	300	10%	30%	65%	50%	70%	90%
Tot Cap Required ($10^6)	$28.31	$29.98	$31.60	$16.51	$28.31	$58.86	$28.02	$28.13	$28.31	$25.20	$25.98	$28.31
Fixed O&M ($10^6/yr)	$1.661	$1.661	$1.661	$1.144	$1.661	$3.109	$1.661	$1.661	$1.661	$1.543	$1.572	$1.661
Variable O&M ($10^6/yr)	$0.581	$0.984	$1.244	$0.291	$0.581	$0.546	$0.089	$0.268	$0.581	$0.533	$0.558	$0.582
Power Produced (10^9 kWh/yr)	0.569	0.569	0.569	0.285	0.569	1.708	0.088	0.263	0.569	0.569	0.569	0.569
SO2 Removed (tons/yr)	1,711	8,012	12,070	856	1,711	5,133	263	790	1,711	951	1,331	1,711
Cost Per Power Produced (Current Dollars)												
Level Cap Chg (mills/kWh)	7.956	8.425	8.881	9.281	7.956	5.513	51.187	17.126	7.956	7.081	7.301	7.956
Level Fixed O&M (mills/kWh)	3.832	3.832	3.832	5.282	3.832	2.391	24.909	8.303	3.832	3.561	3.629	3.832
Level Variable O&M (mills/kWh)	1.34	2.27	2.87	1.34	1.34	0.42	1.34	1.34	1.34	1.23	1.29	1.34
Total Current (mills/kWh)	13.13	14.53	15.58	15.90	13.13	8.33	77.44	26.77	13.13	11.87	12.22	13.13
Cost Per Power Produced (Constant Dollars)												
Level Cap Chg (mills/kWh)	6.166	6.529	6.882	7.193	6.166	4.273	39.670	13.273	6.166	5.488	5.658	6.166
Level Fixed O&M (mills/kWh)	2.916	2.916	2.916	4.019	2.916	1.820	18.956	6.319	2.916	2.710	2.762	2.916
Level Variable O&M (mills/kWh)	1.02	1.73	2.19	1.02	1.02	0.32	1.02	1.02	1.02	0.94	0.98	1.02
Total Constant (mills/kWh)	10.10	11.17	11.98	12.23	10.10	6.41	59.65	20.61	10.10	9.13	9.40	10.10
Cost Per Ton SO2 Removed (Current Dollars)												
Level Cap Chg ($/ton)	$2,647	$599	$419	$3,088	$2,647	$1,835	$17,033	$5,699	$2,647	$4,241	$3,124	$2,647
Level Fixed O&M ($/ton)	$1,275	$272	$181	$1,757	$1,275	$796	$8,289	$2,763	$1,275	$2,133	$1,553	$1,275
Level Variable O&M ($/ton)	$446	$161	$135	$446	$446	$140	$446	$446	$446	$737	$550	$447
Total Current ($/ton)	$4,369	$1,033	$735	$5,292	$4,369	$2,770	$25,768	$8,908	$4,369	$7,111	$5,227	$4,370
Total w/o downtime ($/ton)	$4,354	$1,029	$733	$5,278	$4,354	$2,756	$25,753	$8,893	$4,354	$7,085	$5,208	$4,355
Cost Per Ton SO2 Removed (Constant Dollars)												
Level Cap Chg ($/ton)	$2,052	$464	$325	$2,393	$2,052	$1,422	$13,200	$4,417	$2,052	$3,287	$2,421	$2,052
Level Fixed O&M ($/ton)	$970	$207	$138	$1,337	$970	$606	$6,308	$2,103	$970	$1,623	$1,182	$970
Level Variable O&M ($/ton)	$340	$123	$103	$340	$340	$106	$340	$340	$340	$561	$419	$340
Total Constant ($/ton)	$3,362	$794	$565	$4,071	$3,362	$2,134	$19,848	$6,859	$3,362	$5,471	$4,021	$3,362
Total w/o downtime ($/ton)	$3,351	$792	$564	$4,059	$3,351	$2,123	$19,837	$6,848	$3,351	$5,451	$4,007	$3,351

Levelization Factors (Plant life = 15 yr)	
Level Cap Factor (current)	0.160
Level Cap Factor (constant)	0.124
Level O&M Factor (current)	1.314
Level O&M Factor (constant)	1.000

INTEGRATED DRY NOx/SO2 EMISSIONS CONTROL SYSTEM

FINAL REPORT, VOLUME 2: PROJECT PERFORMANCE AND ECONOMICS

Appendix I-7

Low-NOx Combustion System

B/OFA CAPITAL COSTS   Install year= 1991

Item	A4 Unit Cost	No.	Factor	50	No.	Factor	100	No.	Factor	300
						Unit Size				
Burners	$42,900	6	1	$257,400	12	1	$514,800	24	1	$1,029,600
Ignitors	$3,100	6	1	$18,600	12	1	$37,200	24	1	$74,400
IR Scanner	$3,400	6	1	$20,400	12	1	$40,800	24	1	$81,600
UV Scanner	$3,400	6	1	$20,400	12	1	$40,800	24	1	$81,600
Sliding disk actuator	$2,000	6	1	$12,000	12	1	$24,000	24	1	$48,000
OFA damper actuator	$6,200	2	1	$12,400	2	1	$12,400	2	1	$12,400
OFA Port	$12,100	4	1	$48,400	6	1	$72,600	10	1	$121,000
Other equipment	$1,217,400	1	0.8	$973,920	1	1	$1,217,400	1	2	$2,434,800
Total Procurement	N/A			$1,363,520			$1,960,000			$3,883,400
Total design/engineering	$1,053,000	1	0.9	$947,700	1	1	$1,053,000	1	1.1	$1,158,300
Total installation	$2,903,000	1	0.8	$2,322,400	1	1	$2,903,000	1	1.5	$4,354,500
Total capital cost	N/A	1	1	$4,633,620	1	1	$5,916,000	1	1	$9,396,200
$/kW	N/A			$92.67			$59.16			$31.32

INTEGRATED DRY NOx/SO2 EMISSIONS CONTROL SYSTEM

FINAL REPORT, VOLUME 2: PROJECT PERFORMANCE AND ECONOMICS

Appendix I-8

Selective Non-Catalytic Reduction

SNCR NOx REMOVAL

	Inlet NOx (lb/MMBtu)			UNIT SIZE			CAPACITY FACTOR			NOx REMOVAL		
	0.40	0.90	1.15	50	100	300	10%	30%	65%	30%	40%	50%
Unit Specifications												
Unit Heatrate (Btu/NkWh)	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542
Unit Size (MWe)	100	100	100	50	100	300	100	100	100	100	100	100
Capacity Factor	65%	65%	65%	65%	65%	65%	10%	30%	65%	65%	65%	65%
Inlet NOx												
NOx before SNCR (lb/MMBtu)	0.4	0.9	1.15	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
NOx before SNCR (lb/h)	422	949	1,212	211	422	1,265	422	422	422	422	422	422
NOx before SNCR (mole/h)	14.1	31.6	40.4	7.0	14.1	42.2	14.1	14.1	14.1	14.1	14.1	14.1
NOx Removal Required by SNCR (Assume all NOx is NO.)												
SNCR NOx Removal Required	40%	40%	40%	40%	40%	40%	40%	40%	40%	30%	40%	50%
NSR	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.6	0.8	1
Utilization	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
NO to be Removed (lb/h)	169	380	485	84	169	506	169	169	169	127	169	211
NO to be Removed (mole/h)	5.62	12.65	16.16	2.81	5.62	16.87	5.62	5.62	5.62	4.22	5.62	7.03
SNCR Injection Flowrates												
lb H2O/lb soln	84.6%	84.6%	84.6%	84.6%	84.6%	84.6%	84.6%	84.6%	84.6%	84.6%	84.6%	84.6%
lb Urea/lb soln	15.4%	15.4%	15.4%	15.4%	15.4%	15.4%	15.4%	15.4%	15.4%	15.4%	15.4%	15.4%
Urea Flowrate (mole/h)	11.2	25.3	32.3	5.6	11.2	33.7	11.2	11.2	11.2	8.4	11.2	14 1
Urea Flowrate (lb/h)	675	1,518	1,940	337	675	2,024	675	675	675	506	675	843
H2O Flowrate (lb/h)	3,706	9,857	12,596	2,191	4,381	13,143	4,381	4,381	4,381	3,286	4,381	5,476

MOLECULAR WEIGHTS	
MW Nitrogen (lb/mole)	14.0067
MW NO (lb/mole)	30
MW (NH2)2CO	60
Water Density (lb/gal)	8.3

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By: TJ Hanley

SNCR TOTAL CAPITAL RESULTS	Inlet NOx (lb/MMBtu)			Unit Size			Capacity Factor			NOx Removal Rate		
	0.40	0.90	1.15	50	100	300	10%	30%	65%	30%	40%	50%
Install Year	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991	1991
Study Year	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994
Inflation Rate	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Subtotal Install-1991 ($/kW)	$24.28	$26.17	$26.17	$39.92	$24.28	$10.60	$24.28	$26.17	$26.17	$39.92	$24.28	$10.60
Subtotal Install-1994 ($10^6)	$2.73	$2.94	$2.94	$2.25	$2.73	$3.58	$2.73	$2.94	$2.94	$4.49	$2.73	$1.19
Retrofit Factor	0	0	0	0	0	0	0	0	0	0	0	0
Retrofit Cost ($10^6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Process Contingency Factor	*10%*	*10%*	*10%*	*10%*	*10%*	*10%*	*10%*	*10%*	*10%*	*10%*	*10%*	*10%*
Proc Contingency Cost ($10^6)	$0.273	$0.273	$0.273	$0.225	$0.273	$0.358	$0.273	$0.294	$0.294	$0.449	$0.273	$0.119
Total Install Equip ($10^6)	$3.00	$3.00	$3.00	$2.47	$3.00	$3.94	$3.00	$3.24	$3.24	$4.94	$3.00	$1.31
Tot. Process Capital ($10^6)	$3.00	$3.00	$3.00	$2.47	$3.00	$3.94	$3.00	$3.24	$3.24	$4.94	$3.00	$1.31
General Facilities Rate	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Gen Facilities Cost ($10^6)	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Engr & Home Office Rate	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Engr & Home Office ($10^6)	$0.300	$0.300	$0.300	$0.247	$0.300	$0.394	$0.300	$0.324	$0.324	$0.494	$0.300	$0.131
Project Contingency Rate	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Proj Contingency Cost ($10^6)	$0.165	$0.165	$0.165	$0.136	$0.165	$0.216	$0.165	$0.178	$0.178	$0.272	$0.165	$0.072
Total Plant Cost ($10^6)	$3.47	$3.47	$3.47	$2.85	$3.47	$4.55	$3.47	$3.74	$3.74	$5.71	$3.47	$1.52
AFDC rate (<1 year)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AFDC Cost ($10^6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total Plant Invest ($10^6)	$3.47	$3.47	$3.47	$2.85	$3.47	$4.55	$3.47	$3.74	$3.74	$5.71	$3.47	$1.52
Royalty Rate	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Royalty Cost ($10^6)	$0.02	$0.02	$0.02	$0.01	$0.02	$0.02	$0.02	$0.02	$0.02	$0.03	$0.02	$0.01
Startup Time (weeks)	2	2	2	2	2	2	2	2	2	2	2	2
Preproduction Costs ($10^6)	$0.022	$0.039	$0.047	$0.012	$0.021	$0.048	$0.007	$0.012	$0.022	$0.019	$0.021	$0.023
Inventory Capital ($10^6)	$0.074	$0.074	$0.074	$0.036	$0.073	$0.185	$0.012	$0.034	$0.073	$0.058	$0.073	$0.088
Initial Catalyst ($10^6)	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Subtotal Capital ($10^6)	$3.58	$3.60	$3.61	$2.92	$3.58	$4.80	$3.51	$3.81	$3.85	$5.81	$3.58	$1.63
Construction Downtime (days)	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*
Replacement Power Cost ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Construction Downtime ($10^6)	$0.55	$0.55	$0.55	$0.27	$0.55	$1.64	$0.08	$0.25	$0.55	$0.55	$0.55	$0.55
Total Capital Required ($10^6)	$4.13	$4.15	$4.15	$3.19	$4.13	$6.44	$3.59	$4.06	$4.40	$6.36	$4.13	$2.18

SNCR O&M COST RESULTS	Inlet NOx (lb/MMBtu) 0.40	0.90	1.15	Unit Size 50	100	300	Capacity Factor 10%	30%	65%	NOx Removal Rate 30%	40%	50%
Fixed O&M Costs												
Labor ($/op-h)	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00
Labor (operator-h/day)	4	4	4	4	4	4	4	4	4	4	4	4
Operating Labor ($10^6/yr)	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336
Total Install Equip ($10^6)	$3.00	$3.00	$3.00	$2.47	$3.00	$3.94	$3.00	$3.24	$3.24	$4.94	$3.00	$1.31
Maintenance Factor	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Maintenance Labor ($10^6/yr)	$0.0240	$0.0240	$0.0240	$0.0198	$0.0240	$0.0315	$0.0240	$0.0259	$0.0259	$0.0395	$0.0240	$0.0105
Maintenance Matl ($10^6/yr)	$0.0361	$0.0361	$0.0361	$0.0296	$0.0361	$0.0472	$0.0361	$0.0389	$0.0389	$0.0593	$0.0361	$0.0157
Admin/Support Labor ($10^6/yr)	$0.0173	$0.0173	$0.0173	$0.0160	$0.0173	$0.0195	$0.0173	$0.0178	$0.0178	$0.0219	$0.0173	$0.0132
Total Fixed O&M ($10^6/yr)	$0.111	$0.111	$0.111	$0.099	$0.111	$0.132	$0.111	$0.116	$0.116	$0.154	$0.111	$0.073
Variable O&M Costs												
Urea Cost												
Dry Urea Use (tons/yr)	1,921	4,322	5,522	960	1,921	5,763	296	887	1,921	1,441	1,921	2,401
Dry Urea Cost ($/ton)	$180.00	$180.00	$180.00	$180.00	$180.00	$180.00	$180.00	$180.00	$180.00	$180.00	$180.00	$180.00
Dry Urea Cost ($10^/yr)	$0.35	$0.78	$0.99	$0.17	$0.35	$1.04	$0.05	$0.16	$0.35	$0.26	$0.35	$0.43
Urea Delivery Cost												
Urea Concentration (wt%)	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
Dilute Urea Use (tons/yr)	2,744	6,174	7,889	1,372	2,744	8,232	422	1,266	2,744	2,058	2,744	3,430
Freight Distance (mi)	90	90	90	90	90	90	90	90	90	90	90	90
Freight Cost ($/ton-mile)	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08
Dilute Urea Freight ($10^6/ton)	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20
Dilute Urea Freight ($/yr)	$0.0198	$0.0311	$0.0398	$0.0069	$0.0138	$0.0415	$0.0021	$0.0064	$0.0138	$0.0104	$0.0138	$0.0173
Auxiliary Power Cost												
Aux Power Use (kWh/MWe)	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83
Aux Power Use (kWh/h)	283	283	283	142	283	849	283	283	283	283	283	283
Aux Power Cost ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Aux Power Cost ($10^6/yr)	$0.0806	$0.0806	$0.0806	$0.0403	$0.0806	$0.0372	$0.0124	$0.0372	$0.0806	$0.0806	$0.0806	$0.0806
Water Cost												
Water Use (10^3 gal/h)	0.447	1.188	1.518	0.264	0.528	1.584	0.528	0.528	0.528	0.396	0.528	0.660
Water Cost ($/10^3 gal)	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60	$0.60
Water Cost ($10^6/yr)	$0.0023	$0.0062	$0.0080	$0.0014	$0.0028	$0.0083	$0.0028	$0.0028	$0.0028	$0.0021	$0.0028	$0.0035
Total Variable ($10^6/yr)	$0.448	$0.896	$1.122	$0.221	$0.443	$1.124	$0.070	$0.206	$0.443	$0.352	$0.443	$0.534
Total O&M ($10^6/yr)	$0.559	$1.01	$1.23	$0.32	$0.55	$1.26	$0.18	$0.32	$0.56	$0.51	$0.55	$0.61

SNCR LEVELIZED COSTS	Inlet NOx (lb/MMBtu)			Unit Size			Capacity Factor			NOx Removal Rate		
	0.40	0.90	1.15	50	100	300	10%	30%	65%	30%	40%	50%
Economic Data												
Tot Cap Required ($10^6)	$4.13	$4.15	$4.15	$3.19	$4.13	$6.44	$3.59	$4.06	$4.40	$6.36	$4.13	$2.18
Fixed O&M ($10^6/yr)	$0.111	$0.111	$0.111	$0.099	$0.111	$0.132	$0.111	$0.116	$0.116	$0.154	$0.111	$0.073
Variable O&M ($10^6/yr)	$0.448	$0.896	$1.122	$0.221	$0.443	$1.124	$0.070	$0.206	$0.443	$0.352	$0 443	$0.534
POWER PRODUCED (10^9 kWh/yr)	0.569	0.569	0.569	0.285	0.569	1.708	0.088	0.263	0.569	0.569	0.569	0.569
NOx REMOVED (tons/yr)	480	1,080	1,381	240	480	1,441	74	222	480	360	480	600
Cost Per kW (Current Dollars)												
Level Cap Chg (mills/kWh)	1.160	1.165	1.167	1.792	1.160	0.603	6.557	2.470	1.236	1.786	1.160	0.613
Level Fixed O&M (mills/kWh)	0.256	0.256	0.256	0.457	0 256	0.101	1.664	0.581	0.268	0.356	0.256	0.169
Level Variable O&M (mills/kWh)	1.03	2.07	2.59	1.02	1.02	0.86	1.06	1.03	1.02	0.81	1.02	1.23
Total Current (mills/kWh)	2.45	3.49	4.01	3.27	2.44	1.57	9.28	4.08	2.53	2.96	2.44	2.01
Cost Per kW (Constant Dollars)												
Level Cap Chg (mills/kWh)	0.899	0.903	0.905	1.389	0.899	0.467	5.082	1.915	0.958	1.384	0.899	0.475
Level Fixed O&M (mills/kWh)	0.195	0.195	0.195	0.348	0.195	0.077	1.267	0.442	0.204	0.271	0.195	0.128
Level Variable O&M (mills/kWh)	0.79	1.57	1.97	0.78	0.78	0.66	0.80	0.78	0.78	0.62	0.78	0.94
Total Constant (mills/kWh)	1.88	2.67	3.07	2.51	1.87	1.20	7.15	3.14	1.94	2.27	1.87	1.54
Cost Per Ton Pollutant Removed (Current Dollars)												
Level Cap Chg ($/ton)	$1,376	$614	$481	$2,125	$1,375	$715	$7,775	$2,929	$1,466	$2,824	$1,375	$581
Level Fixed O&M ($/ton)	$304	$135	$106	$542	$304	$120	$1,973	$689	$318	$563	$304	$160
Level Variable O&M ($/ton)	$1,227	$1,089	$1,068	$1,212	$1,212	$1,025	$1,254	$1,221	$1,212	$1,285	$1,212	$1,168
Total Current ($/ton)	$2,906	$1,838	$1,655	$3,879	$2,891	$1,861	$11,002	$4,839	$2,996	$4,673	$2,891	$1,909
Total w/ downtime ($/ton)	$2,724	$1,758	$1,592	$3,697	$2,709	$1,679	$10,820	$4,657	$2,814	$4,430	$2,709	$1,763
Cost Per Ton Pollutant Removed (Constant Dollars)												
Level Cap Chg ($/ton)	$1,066	$476	$373	$1,647	$1,066	$554	$6,026	$2,270	$1,136	$2,189	$1,066	$450
Level Fixed O&M ($/ton)	$231	$103	$80	$412	$231	$91	$1,502	$524	$242	$428	$231	$122
Level Variable O&M ($/ton)	$934	$829	$813	$922	$922	$780	$954	$929	$922	$978	$922	$889
Total Constant ($/ton)	$2,231	$1,408	$1,266	$2,981	$2,219	$1,426	$8,482	$3,723	$2,300	$3,596	$2,219	$1,461
Total w/ downtime ($/ton)	$2,090	$1,345	$1,217	$2,840	$2,078	$1,285	$8,341	$3,583	$2,159	$3,408	$2,078	$1,348

Levelization Factors (Plant life = 15 yr)	
Level Cap Factor (current)	0.160
Level Cap Factor (constant)	0.124
Level O&M Factor (current)	1.314
Level O&M Factor (constant)	1.000

SNCR Capital Costs		Arapahoe 4			NOx (lb/MMBtu)					
Item	Unit Cost	No.	Factor	0.40	No.	Factor	0.90	No.	Factor	1.15
Urea storage tank		2	1	$0	2	1	$0	2	1	$0
Urea circulation pump		2	1	$0	2	1	$0	2	1	$0
Urea heater		2	1	$0	2	1	$0	2	1	$0
Urea filter		2	1	$0	2	1	$0	2	1	$0
Urea injection pump		2	1	$0	2	1	$0	2	1	$0
Atomization compressor		1	1	$0	1	1	$0	1	1	$0
Quench vessel		1	1	$0	1	1	$0	1	1	$0
Purge fan		2	1	$0	2	1	$0	2	1	$0
Water softener skid		1	1	$0	1	1	$0	1	1	$0
Injection lances (level 1)		10	1	$0	10	1	$0	10	1	$0
Injection lances (level 2)		10	1	$0	10	1	$0	10	1	$0
NH3 conversion system	$136,828	0	1	$0	0	1	$0	0	1	$0
Other equipment	$1,181,172	1	1	$1,181,172	1	1.1	$1,299,289	1	1.1	$1,299,289
Total design/engineering	$536,000	1	1	$536,000	1	1	$536,000	1	1	$536,000
Total procurement	$1,318,000			$1,181,172			$1,299,289			$1,299,289
Total installation	$711,000	1	1	$711,000	1	1.1	$782,100	1	1.1	$782,100
Total Installed Cost				$2,428,172			$2,617,389			$2,617,389
$/kW =				$24.28			$26.17			$26.17

SNCR Capital Costs	A4	Unit Size (MWe)					
Item	Unit Cost	No.	Factor	50	No.	Factor	300
Urea storage tank		2	1	$0	2	1	$0
Urea circulation pump		2	1	$0	2	1	$0
Urea heater		2	1	$0	2	1	$0
Urea filter		2	1	$0	2	1	$0
Urea injection pump		2	1	$0	2	1	$0
Atomization compressor		1	1	$0	1	1	$0
Quench vessel		1	1	$0	1	1	$0
Purge fan		2	1	$0	2	1	$0
Water softener skid		1	1	$0	1	1	$0
Injection lances (level 1)		10	1	$0	10	1	$0
Injection lances (level 2)		10	1	$0	10	1	$0
NH3 conversion system	$136,828	0	1	$0	0	1	$0
Other equipment	$1,181,172	1	0.8	$944,938	1	1.5	$1,417,406
Total design/engineering	$536,000	1	0.9	$482,400	1	1.3	$696,800
Total procurement	$1,318,000			$944,938			$1,417,406
Total installation	$711,000	1	0.8	$568,800	1	1.5	$1,066,500
Total Installed Cost				$1,996,138			$3,180,706
$/kW =				$39.92			$10.60

"No." = quantity
"Factor" = Scaling factor

INTEGRATED DRY NOx/SO2 EMISSIONS CONTROL SYSTEM

FINAL REPORT, VOLUME 2: PROJECT PERFORMANCE AND ECONOMICS

Appendix I-9

Selective Catalytic Reduction

SCR NOx REMOVAL

	Inlet NOx (lb/MMBtu)			UNIT SIZE			CAPACITY FACTOR			NOx REMOVAL		
	0.40	0.90	1.15	50	100	300	10%	30%	65%	50%	65%	80%
Unit Specifications												
Unit Heatrate (Btu/NkWh)	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542	10,542
Unit Size (MWe)	100	100	100	50	100	300	100	100	100	100	100	100
Capacity Factor	65%	65%	65%	65%	65%	65%	10%	30%	65%	65%	65%	65%
Base NOx												
NOx before SCR (lb/MMBtu)	0.4	0.9	1.15	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
NOx before SCR (lb/h)	422	949	1,212	211	422	1,265	422	422	422	422	422	422
NOx before SCR (mole/h)	14.1	31.6	40.4	7.0	14.1	42.2	14.1	14.1	14.1	14.1	14.1	14.1
NOx Removal Required by SNCR (Assume all NOx is NO.)												
SCR NOx Removal Required	80%	80%	80%	80%	80%	80%	80%	80%	80%	50%	65%	80%
mole NH3/mole NOx removed	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14
NSR	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.57	0.74	0.91
Utilization	87.7%	87.7%	87.7%	87.7%	87.7%	87.7%	87.7%	87.7%	87.7%	87.7%	87.7%	87.7%
NO to be Removed (lb/h)	337	759	970	169	337	1,012	337	337	337	211	274	337
NO to be Removed (mole/h)	11.24	25.30	32.33	5.62	11.24	33.73	11.24	11.24	11.24	7.03	9.14	11.24
NH3 Injection Flowrates												
lb NH3/lb soln	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
NH3 Flowrate (mole/h)	12.8	28.8	36.9	6.4	12.8	38.5	12.8	12.8	12.8	8.0	10.4	12.8
NH3 Flowrate (lb/h)	218	491	627	109	218	654	218	218	218	136	177	218

MOLECULAR WEIGHTS	
MW Nitrogen (lb/mole)	14.0067
MW NO (lb/mole)	30
MW (NH2)2CO	60
NH3	17.0067
NH4OH	35.0067
Water Density (lb/gal)	8.3

Notes

Assume all NOx is NO.
The higher the inlet NOx, the lower the space velocity.
Space velocity = scfh of flue gas/ft^3 of catalyst

System Specifications

Hot-side, high-dust
NH3 slip = 5 PPM

Revised: 12/02/94
By: TJ Hanley

SCR TOTAL CAPITAL RESULTS	Inlet NOx (lb/MMBtu)			Unit Size			Capacity Factor			NOx Removal Rate		
	0.40	0.90	1.15	50	100	300	10%	30%	65%	50%	65%	80%
Install Year	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994
Study Year	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994
Inflation Rate	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Subtotal Install-1994 ($/kW)	$42	$43	$48	$62	$42	$22	$42	$42	$42	$42	$42	$42
Subtotal Install-1994 ($10^6)	$4.15	$4.33	$4.83	$3.08	$4.15	$6.45	$4.15	$4.15	$4.15	$4.15	$4.15	$4.15
Retrofit Factor	0.10	0.10	0.10	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.10	0.10
Retrofit Cost ($10^6)	$0.42	$0.42	$0.42	$0.31	$0.42	$0.00	$0.42	$0.42	$0.42	$0.42	$0.42	$0.42
Process Contingency Factor	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Proc Contingency Cost ($10^6)	$0.623	$0.623	$0.623	$0.461	$0.623	$0.968	$0.623	$0.623	$0.623	$0.623	$0.623	$0.623
Total Install Equip ($10^6)	$5.19	$5.37	$5.87	$3.84	$5.19	$7.42	$5.19	$5.19	$5.19	$5.19	$5.19	$5.19
Tot. Process Capital ($10^6)	$5.19	$5.37	$5.87	$3.84	$5.19	$7.42	$5.19	$5.19	$5.19	$5.19	$5.19	$5.19
General Facilities Rate	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Gen Facilities Cost ($10^6)	$0.259	$0.269	$0.294	$0.192	$0.259	$0.371	$0.259	$0.259	$0.259	$0.259	$0.259	$0.259
Engr & Home Office Rate	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Engr & Home Office ($10^6)	$0.519	$0.537	$0.587	$0.384	$0.519	$0.742	$0.519	$0.519	$0.519	$0.519	$0.519	$0.519
Project Contingency Rate	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Proj Contingency Cost ($10^6)	$0.895	$0.926	$1.013	$0.663	$0.895	$1.280	$0.895	$0.895	$0.895	$0.895	$0.895	$0.895
Total Plant Cost ($10^6)	$6.86	$7.10	$7.76	$5.08	$6.86	$9.81	$6.86	$6.86	$6.86	$6.86	$6.86	$6.86
AFDC rate (=1 year)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AFDC Cost ($10^6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total Plant Invest ($10^6)	$6.86	$7.10	$7.76	$5.08	$6.86	$9.81	$6.86	$6.86	$6.86	$6.86	$6.86	$6.86
Royalty Rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Royalty Cost ($10^6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Startup Time (weeks)	2	2	2	2	2	2	2	2	2	2	2	2
Preproduction Costs ($10^6)	$0.053	$0.061	$0.067	$0.028	$0.053	$0.113	$0.038	$0.043	$0.053	$0.047	$0.052	$0.060
Inventory Capital ($10^6)	$0.201	$0.201	$0.201	$0.100	$0.199	$0.450	$0.136	$0.159	$0.199	$0.173	$0.196	$0.231
Initial Catalyst ($10^6)	$2.850	$3.167	$3.563	$1.425	$2.850	$8.550	$2.850	$2.850	$2.850	$2.375	$2.850	$3.563
Subtotal Capital ($10^6)	$9.96	$10.53	$11.60	$6.64	$9.96	$18.92	$9.88	$9.91	$9.96	$9.45	$9.96	$10.71
Construction Downtime (days)	14	14	14	14	14	14	14	14	14	14	14	14
Replacement Power Cost ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Construction Downtime ($10^6)	$1.09	$1.09	$1.09	$0.55	$1.09	$3.28	$0.17	$0.50	$1.09	$1.09	$1.09	$1.09
Total Capital Required ($10^6)	$11.06	$11.62	$12.69	$7.18	$11.05	$22.20	$10.05	$10.42	$11.05	$10.55	$11.05	$11.81

SCR O&M COST RESULTS	Inlet NOx (lb/MMBtu)			Unit Size			Capacity Factor			NOx Removal Rate		
	0.40	0.90	1.15	50	100	300	10%	30%	65%	50%	65%	80%
Fixed O&M Costs												
Labor ($/op-h)	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00	$23.00
Labor (operator-h/day)	4	4	4	4	4	4	4	4	4	4	4	4
Operating Labor ($10^6/yr)	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336	$0.0336
Total Install Equip ($10^6)	$5.19	$5.19	$5.19	$3.84	$5.19	$7.42	$5.19	$5.19	$5.19	$5.19	$5.19	$5.19
Maintenance Factor	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Maintenance Labor ($10^6/yr)	$0.0415	$0.0415	$0.0415	$0.0308	$0.0415	$0.0593	$0.0415	$0.0415	$0.0415	$0.0415	$0.0415	$0.0415
Maintenance Matl ($10^6/yr)	$0.0623	$0.0623	$0.0623	$0.0461	$0.0623	$0.0890	$0.0623	$0.0623	$0.0623	$0.0623	$0.0623	$0.0623
Admin/Support Labor ($10^6/yr)	$0.0225	$0.0225	$0.0225	$0.0193	$0.0225	$0.0279	$0.0225	$0.0225	$0.0225	$0.0225	$0.0225	$0.0225
Total Fixed O&M ($10^6/yr)	$0.160	$0.160	$0.160	$0.130	$0.160	$0.210	$0.160	$0.160	$0.160	$0.160	$0.160	$0.160
Variable O&M Costs												
NH3 Cost												
NH3 Use (dry tons/yr)	621	1,397	1,784	310	621	1,862	95	286	621	388	504	621
NH3 Cost ($/dry ton)	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00
NH3 Cost ($10^/yr)	$0.093	$0.209	$0.268	$0.047	$0.093	$0.279	$0.014	$0.043	$0.093	$0.058	$0.076	$0.093
NH3 Concentration (wt%)	29.4%	29.4%	29.4%	29.4%	29.4%	29.4%	29.4%	29.4%	29.4%	29.4%	29.4%	29.4%
Dilute NH3 Use (tons/yr)	2,111	4,750	6,070	1,056	2,111	6,333	325	974	2,111	1,319	1,715	2,111
Freight Distance (mi)	90	90	90	90	90	90	90	90	90	90	90	90
Freight Cost ($/ton-mile)	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08
NH3 Freight ($10^6/ton)	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20
NH3 Freight ($10^6/yr)	$0.0152	$0.0101	$0.0128	$0.0022	$0.0045	$0.0134	$0.0007	$0.0021	$0.0045	$0.0028	$0.0036	$0.0045
Catalyst Cost												
Catalyst Life (yr)	3	3	3	3	3	3	3	3	3	3	3	3
No. of replacements in 15 yrs	4	4	4	4	4	4	4	4	4	4	4	4
Catalyst Cost ($/ft^3)	$475	$475	$475	$475	$475	$475	$475	$475	$475	$475	$475	$475
Flue Gas Flowrate (scfm/MWe)	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Space Velocity (h^-1)	2,500	2,250	2,000	2,500	2,500	2,500	2,500	2,500	2,500	3,000	2,500	2,000
Catalyst Reqd (ft^3)	6,000	6,667	7,500	3,000	6,000	18,000	6,000	6,000	6,000	5,000	6,000	7,500
Catalyst Cost ($10^6/replace)	$2.85	$3.17	$3.56	$1.43	$2.85	$8.55	$2.85	$2.85	$2.85	$2.38	$2.85	$3.56
Annual Cost ($10^6/yr)	$0.760	$0.844	$0.950	$0.380	$0.760	$2.280	$0.760	$0.760	$0.760	$0.633	$0.760	$0.950
Auxillary Power Cost												
Aux Power Use (kWh/MWe)	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Aux Power Use (kWh/h)	1,250	1,250	1,250	625	1,250	3,750	1,250	1,250	1,250	1,250	1,250	1,250
Aux Power Cost ($/kWh)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Aux Power Cost ($10^6/yr)	$0.3559	$0.3559	$0.3559	$0.1779	$0.3559	$0.1643	$0.0548	$0.1643	$0.3559	$0.3559	$0.3559	$0.3559
Total Variable ($10^6/yr)	$1.224	$1.420	$1.586	$0.607	$1.213	$2.737	$0.830	$0.969	$1.213	$1.050	$1.195	$1.403
Total O&M ($10^6/yr)	$1.384	$1.58	$1.75	$0.74	$1.37	$2.95	$0.99	$1.13	$1.37	$1.21	$1.36	$1.56

SCR LEVELIZED COSTS	Inlet NOx (lb/MMBtu)			Unit Size			Capacity Factor			NOx Removal Rate		
	0.40	0.90	1.15	50	100	300	10%	30%	65%	50%	65%	80%
Economic Data												
Tot Cap Required ($10^6)	$11.06	$11.62	$12.69	$7.18	$11.05	$22.20	$10.05	$10.42	$11.05	$10.55	$11.05	$11.81
Fixed O&M ($10^6/yr)	$0.160	$0.160	$0.160	$0.130	$0.160	$0.210	$0.160	$0.160	$0.160	$0.160	$0.160	$0.160
Variable O&M ($10^6/yr)	$1.224	$1.420	$1.586	$0.607	$1.213	$2.737	$0.830	$0.969	$1.213	$1.050	$1.195	$1.403
POWER PRODUCED (10^9 kWh/yr)	0.569	0.569	0.569	0.285	0.569	1.708	0.088	0.263	0.569	0.569	0.569	0.569
NOx REMOVED (tons/yr)	960	2,161	2,761	480	960	2,881	148	443	960	600	780	960
Cost Per kW (Current Dollars)												
Level Cap Chg (mills/kWh)	3.107	3.266	3.565	4.036	3.106	2.079	18.362	6.342	3.106	2.964	3.105	3.317
Level Fixed O&M (mills/kWh)	0.369	0.369	0.369	0.599	0.369	0.161	2.398	0.799	0.369	0.369	0.369	0.369
Level Variable O&M (mills/kWh)	2.83	3.28	3.66	2.80	2.80	2.11	12.45	4.85	2.80	2.42	2.76	3.24
Total Current (mills/kWh)	6.30	6.91	7.59	7.44	6.28	4.35	33.21	11.99	6.28	5.76	6.23	6.93
Cost Per kW (Constant Dollars)												
Level Cap Chg (mills/kWh)	2.408	2.531	2.763	3.128	2.407	1.611	14.230	4.915	2.407	2.297	2.407	2.571
Level Fixed O&M (mills/kWh)	0.281	0.281	0.281	0.456	0.281	0.123	1.825	0.608	0.281	0.281	0.281	0.281
Level Variable O&M (mills/kWh)	2.15	2.49	2.79	2.13	2.13	1.60	9.47	3.69	2.13	1.84	2.10	2.46
Total Constant (mills/kWh)	4.84	5.31	5.83	5.72	4.82	3.34	25.53	9.21	4.82	4.42	4.79	5.32
Cost Per Ton Pollutant Removed (Current Dollars)												
Level Cap Chg ($/ton)	$1,842	$861	$735	$2,393	$1,842	$1,233	$10,886	$3,760	$1,842	$2,811	$2,266	$1,967
Level Fixed O&M ($/ton)	$219	$97	$76	$355	$219	$96	$1,422	$474	$219	$350	$269	$219
Level Variable O&M ($/ton)	$1,675	$863	$755	$1,660	$1,660	$1,248	$7,379	$2,873	$1,660	$2,299	$2,012	$1,920
Total Current ($/ton)	$3,736	$1,821	$1,566	$4,408	$3,721	$2,577	$19,687	$7,107	$3,721	$5,460	$4,548	$4,106
Total w/ downtime ($/ton)	$3,554	$1,740	$1,503	$4,226	$3,539	$2,395	$19,505	$6,925	$3,539	$5,169	$4,324	$3,924
Cost Per Ton Pollutant Removed (Constant Dollars)												
Level Cap Chg ($/ton)	$1,428	$667	$570	$1,855	$1,427	$955	$8,437	$2,914	$1,427	$2,179	$1,756	$1,524
Level Fixed O&M ($/ton)	$166	$74	$58	$270	$166	$73	$1,082	$361	$166	$266	$205	$166
Level Variable O&M ($/ton)	$1,275	$657	$575	$1,263	$1,263	$950	$5,616	$2,187	$1,263	$1,750	$1,532	$1,461
Total Constant ($/ton)	$2,869	$1,398	$1,202	$3,388	$2,857	$1,978	$15,134	$5,461	$2,857	$4,195	$3,492	$3,152
Total w/ downtime ($/ton)	$2,728	$1,335	$1,153	$3,247	$2,716	$1,837	$14,993	$5,320	$2,716	$3,969	$3,319	$3,011

Levelization Factors

Level Cap Factor (current)	0.160	Plant Life (yr)	15
Level Cap Factor (constant)	0.124		
Level O&M Factor (current)	1.314		
Level O&M Factor (constant)	1.000		

INTEGRATED DRY NOx/SO2 EMISSIONS CONTROL SYSTEM

FINAL REPORT, VOLUME 2: PROJECT PERFORMANCE AND ECONOMICS

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Integrated System

INTEGRATED LEVELIZED COSTS

Cost Per Power Produced	LNB/OFA, SNCR, & DSI Unit Size (MWe) 50	100	300	Capacity Factor 10%	30%	65%	SNCR & DSI Unit Size 50	100	300	Capacity Factor 10%	30%	65%
Total Capital Required for Integrated System												
LNB/OFA Capital Reqd ($10^6)	$8.84	$12.9	$26.60	$9.17	$10.52	$12.87	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
SNCR Capital Reqd ($10^6)	$3.19	$4.13	$6.44	$3.59	$4.06	$4.40	$3.19	$4.13	$6.44	$3.59	$4.06	$4.40
DSI Capital Reqd ($10^6)	$2.03	$2.52	$4.50	$2.21	$2.32	$2.52	$2.03	$2.52	$4.50	$2.21	$2.32	$2.52
Total Capital Reqd ($10^6)	$14.06	$19.5	$37.55	$14.97	$16.90	$19.79	$5.22	$6.65	$10.94	$5.80	$6.38	$6.92
Fixed O&M Cost for Integrated System												
LNB/OFA Fixed O&M ($10^6/yr)	$0.0229	$0.0293	$0.0465	$0.0293	$0.0293	$0.0293	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000
SNCR Fixed O&M ($10^6/yr)	$0.0990	$0.111	$0.132	$0.111	$0.116	$0.116	$0.0990	$0.1110	$0.1318	$0.1110	$0.1162	$0.1162
DSI Fixed O&M ($10^6/yr)	$0.115	$0.127	$0.175	$0.127	$0.127	$0.127	$0.1149	$0.1265	$0.1750	$0.1265	$0.1265	$0.1265
Total Fixed O&M ($10^6/yr)	$0.237	$0.267	$0.353	$0.267	$0.272	$0.272	$0.214	$0.237	$0.307	$0.237	$0.243	$0.243
Variable O&M Cost for Integrated System												
LNB/OFA Variable O&M ($10^6/yr)	$0.00034	$0.00034	$0.00034	$0.00017	$0.00034	$0.00102	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
SNCR Variable O&M ($10^6/yr)	$0.221	$0.443	$1.124	$0.070	$0.206	$0.443	$0.221	$0.443	$1.124	$0.070	$0.206	$0.443
DSI Variable O&M ($10^6/yr)	$0.523	$1.045	$3.083	$0.161	$0.482	$1.045	$0.523	$1.045	$3.083	$0.161	$0.482	$1.045
Total Variable O&M ($10^6/yr)	$0.744	$1.49	$4.21	$0.23	$0.69	$1.49	$0.74	$1.49	$4.21	$0.23	$0.69	$1.49
Power Produced (10^9 kWh/yr)	0.285	0.569	1.708	0.088	0.263	0.569	0.285	0.569	1.708	0.088	0.263	0.569
Levelized Cost Per Power Produced (Current Dollars)												
Level Cap Chg (mills/kWh)	7.90	5.48	3.52	27.34	10.29	5.56	2.93	1.87	1.02	10.59	3.88	1.94
Level Fixed O&M (mills/kWh)	1.09	0.62	0.27	4.00	1.36	0.63	0.99	0.55	0.24	3.56	1.21	0.56
Level Variable O&M (mills/kWh)	3.44	3.43	3.24	3.47	3.44	3.44	3.43	3.43	3.24	3.47	3.44	3.43
Total Current (mills/kWh)	12.43	9.53	7.03	34.82	15.09	9.62	7.36	5.85	4.50	17.62	8.54	5.94
Levelized Cost Per Power Produced (Constant Dollars)												
Level Cap Chg (mills/kWh)	6.13	4.25	2.73	21.19	7.97	4.31	2.27	1.45	0.79	8.21	3.01	1.51
Level Fixed O&M (mills/kWh)	0.83	0.47	0.21	3.05	1.04	0.48	0.75	0.42	0.18	2.71	0.92	0.43
Level Variable O&M (mills/kWh)	2.61	2.61	2.46	2.64	2.62	2.62	2.61	2.61	2.46	2.64	2.62	2.61
Total Constant (mills/kWh)	9.57	7.33	5.40	26.88	11.63	7.40	5.64	4.48	3.44	13.56	6.55	4.55

Revised: 12/15/94 By: TJ Hanley

Levelized Cost Per Ton Removed

	LNB/OFA, SNCR, & DSI						SNCR & DSI					
	Unit Size (MWe)			Capacity Factor			Unit Size			Capacity Factor		
	50	100	300	10%	30%	65%	50	100	300	10%	30%	65%
SO2 & NOx Removal Rates												
LNB/OFA NOx Removal Rate	65%	65%	65%	65%	65%	65%	0%	0%	0%	0%	0%	0%
SNCR NOx Removal Rate	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%
Overall NOx Removal Rate	79%	79%	79%	79%	79%	79%	40%	40%	40%	40%	40%	40%
SO2 Removal Rate	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
Total Pollutants Removed												
SO2 Removed (tons/yr)	665	1,331	3,993	205	614	1,331	665	1,331	3,993	205	614	1,331
LNB/OFA NOx Removed (tons/yr)	1,122	2,243	6,730	345	1,035	2,243	0	0	0	0	0	0
SNCR NOx Removed (tons/yr)	240	480	1,441	74	222	480	240	480	1,441	74	222	480
Total NOx Removed (tons/yr)	1,362	2,724	8,171	419	1,257	2,724	240	480	1,441	74	222	480
Total NOx/SO2 Removed (tons/yr)	2,027	4,055	12,164	624	1,871	4,055	906	1,811	5,433	279	836	1,811
Levelized Cost Per Ton Pollutant Removed (Current Dollars)												
Level Cap Chg ($/ton)	$1,110	$770	$494	$3,840	$1,445	$781	$923	$587	$322	$3,330	$1,221	$611
Level Fixed O&M ($/ton)	$153	$86	$38	$562	$191	$88	$310	$172	$74	$1,120	$382	$176
Level Variable O&M ($/ton)	$482	$482	$455	$488	$484	$483	$1,080	$1,080	$1,018	$1,091	$1,082	$1,080
Total Current ($/ton)	$1,746	$1,339	$987	$4,889	$2,119	$1,352	$2,313	$1,839	$1,414	$5,540	$2,685	$1,867
Total w/o downtime ($/ton)	$1,020	$803	$609	$2,509	$1,192	$816	$2,251	$1,777	$1,352	$5,478	$2,623	$1,805
Levelized Cost Per Ton Pollutant Removed (Constant Dollars)												
Level Cap Chg ($/ton)	$860	$597	$383	$2,976	$1,120	$605	$715	$455	$250	$2,581	$946	$474
Level Fixed O&M ($/ton)	$117	$66	$29	$428	$145	$67	$236	$131	$56	$852	$290	$134
Level Variable O&M ($/ton)	$367	$367	$346	$371	$368	$367	$822	$822	$774	$830	$823	$822
Total Constant ($/ton)	$1,344	$1,030	$758	$3,775	$1,633	$1,040	$1,773	$1,408	$1,081	$4,263	$2,060	$1,429
Total w/o Downtime ($/ton)	$782	$615	$465	$1,930	$915	$624	$1,725	$1,360	$1,032	$4,215	$2,012	$1,381

Levelization Factors

Level Cap Factor (current)	0.160
Level Cap Factor (constant)	0.124
Level O&M Factor (current)	1.314
Level O&M Factor (constant)	1.000

INTEGRATED DRY NOx/SO2 EMISSIONS CONTROL SYSTEM

FINAL REPORT, VOLUME 2: PROJECT PERFORMANCE AND ECONOMICS

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Limestone Forced Oxidation Scrubbing with Selective Catalytic Reduction

SCR & LSFO LEVELIZED COSTS | LSFO & SCR

Cost Per Power Produced	Unit Size (MWe)			Capacity Factor		
	50	100	300	10%	30%	65%
Total Capital Required for LSFO & SCR						
SCR Capital Reqd ($10^6)	$7.18	$11.05	$22.20	$10.05	$10.42	$11.05
LSFO Capital Reqd ($10^6)	$16.51	$28.31	$58.86	$28.02	$28.13	$28.31
Total Capital Reqd ($10^6)	$23.70	$39.37	$81.06	$38.08	$38.55	$39.37
Fixed O&M Cost for LSFO & SCR						
SCR Fixed O&M ($10^6/yr)	$0.130	$0.160	$0.210	$0.160	$0.160	$0.160
LSFO Fixed O&M ($10^6/yr)	$1.144	$1.661	$3.109	$1.661	$1.661	$1.661
Total Fixed O&M ($10^6/yr)	$1.274	$1.820	$3.319	$1.820	$1.820	$1.820
Variable O&M Cost for LSFO & SCR						
SCR Variable O&M ($10^6/yr)	$0.607	$1.213	$2.737	$0.830	$0.969	$1.213
LSFO Variable O&M ($10^6/yr)	$0.291	$0.581	$0.546	$0.089	$0.268	$0.581
Total Variable O&M ($10^6/yr)	$0.90	$1.79	$3.28	$0.92	$1.24	$1.79
Power Produced (10^9 kWh/yr)	0.285	0.569	1.708	0.088	0.263	0.569
Levelized Cost Per Power Produced (Current Dollars)						
Level Cap Chg (mills/kWh)	13.32	11.06	7.59	69.55	23.47	11.06
Level Fixed O&M (mills/kWh)	5.88	4.20	2.55	27.31	9.10	4.20
Level Variable O&M (mills/kWh)	4.14	4.14	2.53	13.79	6.19	4.14
Total Current (mills/kWh)	23.34	19.40	12.67	110.64	38.76	19.40
Levelized Cost Per Power Produced (Constant Dollars)						
Level Cap Chg (mills/kWh)	10.32	8.57	5.88	53.90	18.19	8.57
Level Fixed O&M (mills/kWh)	4.48	3.20	1.94	20.78	6.93	3.20
Level Variable O&M (mills/kWh)	3.15	3.15	1.92	10.49	4.71	3.15
Total Constant (mills/kWh)	17.95	14.92	9.75	85.17	29.82	14.92

Levelized Cost Per Ton Removed				SCR & LSFO		
	Unit Size (MWe)				Capacity Factor	
	50	100	300	10%	30%	65%
	SO2 & NOx Removal Rates					
SCR NOx Removal Rate	80%	80%	80%	80%	80%	80%
SO2 Removal Rate	90%	90%	90%	90%	90%	90%
	Total Pollutants Removed					
SO2 Removed (tons/yr)	856	1,711	5,133	263	790	1,711
NOx Removed (tons/yr)	480	960	2,881	148	443	960
Total NOx/SO2 Removed (tons/yr)	1,336	2,672	8,015	411	1,233	2,672
	Levelized Cost Per Ton Pollutant Removed (Current Dollars)					
Level Cap Chg ($/ton)	$2,838	$2,358	$1,618	$14,823	$5,002	$2,358
Level Fixed O&M ($/ton)	$1,253	$895	$544	$5,820	$1,940	$895
Level Variable O&M ($/ton)	$883	$883	$538	$2,939	$1,319	$883
Total Current ($/ton)	$4,974	$4,136	$2,701	$23,582	$8,261	$4,136
Total w/o downtime ($/ton)	$4,900	$4,061	$2,626	$23,507	$8,186	$4,061
	Levelized Cost Per Ton Pollutant Removed (Constant Dollars)					
Level Cap Chg ($/ton)	$2,200	$1,827	$1,254	$11,488	$3,876	$1,827
Level Fixed O&M ($/ton)	$213	$213	$213	$213	$213	$213
Level Variable O&M ($/ton)	$672	$672	$410	$2,236	$1,004	$672
Total Constant ($/ton)	$3,085	$2,712	$1,877	$13,937	$5,093	$2,712
Total w/o Downtime ($/ton)	$3,027	$2,654	$1,819	$13,879	$5,035	$2,654

Levelization Factors	
Level Cap Factor (current)	0.160
Level Cap Factor (constant)	0.124
Level O&M Factor (current)	1.314
Level O&M Factor (constant)	1.000

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By: TJ Hanley