Attachment 50 to

GNRO-2012/00039

Enercon. 2011b.
Evaluation of Potential Air Emissions from Coal and Natural Gas Fired

ENERCON	CALCULATION COVER SHEET	CALC NO. ENTGGG084-CALC-004
		REV. 0
		PAGE NO. 1 of 18

TITLE	Evaluation of Potential Air Emissions from Coal and Natural Gas Fired Power Generation Alternatives for Grand Gulf Nuclear Station, Unit 1 License Renewal Environmental Report	Client: Entergy Nuclear, Inc.
		Project: ENTGGG084

ITEM	COVER SHEET ITEMS	YES	NO
1	Does this calculation contain any open assumptions that require confirmation? (If **YES**, Identify the assumptions)		X
2	Does this calculation serve as an "Alternate Calculation"? (If **YES**, Identify the design verified calculation.) **Design Verified Calculation No.**		X
3	Does this calculation Supersede an existing Calculation? (If **YES**, identify the superseded calculation.) **Superseded Calculation No.**		X

Scope of Revision:

Initial issue.

Revision Impact on Results:

N/A

Study Calculation ☐ Final Calculation ☒

Safety Related ☐ Non-Safety Related ☒

(Print Name And Sign)

Originator: James A. Thomas	**Date: 4/06/2011**
Reviewer: Michelle Barnett	**Date: 4/27/2011**
Approver: Chris Byerman	**Date: 5/12/2011**

ENERCON	CALCULATION REVISION STATUS SHEET	CALC. NO. ENTGGG084-CALC-004 REV. 0 PAGE NO. 2 of 18

CALCULATION REVISION STATUS

REVISION	DATE	DESCRIPTION
0		Initial Issue

PAGE REVISION STATUS

PAGE NO.	REVISION	PAGE NO.	REVISION
1 – 18	0		

ATTACHMENT REVISION STATUS

ATTACHMENT NO.	PAGE NO.	REVISION NO.

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Calculation Design Verification Plan:

Calculation inputs of approximate air emissions characteristics, emissions removal rates, and waste generation for coal fired electric power generation and natural gas fired electric power generation shall be verified by checking the documented input with the source references. Equations used are applicable based on references cited. Check the validity of the references for their intended use. All assumptions shall be evaluated and verified to determine if they are based on sound emissions calculation principles and practices. Calculation results shall be verified by checks of all equations for each type of fuel source (coal and natural gas). Verify the methodology, results and conclusions.

(Print Name and Sign for Approval – mark "N/A" if not required)

Approver: Chris Byerman	**Date:**

Calculation Verification Summary:

Calculation inputs, assumptions, methodology, results, and conclusions of Revision 0 are evaluated/verified and were found to be acceptable. All comments have been incorporated.

Based on the above summary, the calculation is determined to be acceptable.

(Print Name and Sign)

Design Verifier: Michelle Barnett	**Date: 4/27/2011**
Others:	**Date:**

ENERCON	CALCULATION REVIEW CHECKLIST	CALC. NO. ENTGGG084-CALC-004 REV. 0 PAGE NO. 4 of 18

Item	Cover Sheet Items	Yes	No	N/A
1	Design Inputs - Were the design inputs correctly selected, referenced latest revision, consistent with the design basis and incorporated in the calculation?	☐	☐	☒
2	Assumptions – Were the assumptions reasonable and adequately described, justified and/or verified, and documented?	☒	☐	☐
3	Quality Assurance – Were the appropriate QA classification and requirements assigned to the calculation?	☐	☐	☒
4	Codes, Standard and Regulatory Requirements – Were the applicable codes, standards, and regulatory requirements, including issue and addenda, properly identified and their requirements satisfied?	☒	☐	☐
5	Construction and Operating Experience – Has applicable construction and operating experience been considered?	☐	☐	☒
6	Interfaces – Have the design interface requirements been satisfied, including interactions with other calculations?	☐	☐	☒
7	Methods – Was the calculation methodology appropriate and properly applied to satisfy the calculation objective?	☒	☐	☐
8	Design Outputs – Was the conclusion of the calculation clearly stated, did it correspond directly with the objectives and are the results reasonable compared to the inputs?	☒	☐	☐
9	Radiation Exposure – Has the calculation properly considered radiation exposure to the public and plant personnel?	☐	☐	☒
10	Acceptance Criteria – Are the acceptance criteria incorporated in the calculation sufficient to allow verification that the design requirements have been satisfactorily accomplished?	☐	☐	☒
11	Computer Software – Is a computer program or software used, and if so, are the requirements of CSP 3.02 met?	☐	☐	☒

COMMENTS:

	Print Name and Sign	
Reviewer: Michelle Barnett		**Date: 4/27/2011**
Others:		**Date:**

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1.0 PURPOSE

Supercritical Coal-Fired Power Plant

Entergy has chosen to evaluate the construction of three 538 gross MWe supercritical coal-fired plants using a closed-cycle cooling system with cooling towers at an alternate site in Mississippi rather than at the Grand Gulf Nuclear Station (GGNS) with an operating life of 40 years. The air emissions and waste generated from emissions control equipment are to be determined to evaluate the environmental impacts associated with operating a supercritical coal-fired plant. A supercritical coal-fired plant emits oxides of sulfur (SOx), nitrogen oxides (NOx), particulate matter, and carbon monoxide, all of which are regulated pollutants. However, Entergy has assumed a plant design that would minimize air emissions through a combination of boiler technology and post-combustion pollutant removal. Carbon dioxide (CO_2) is also emitted, but control technologies are not yet established.

The purpose of the following analyses is to provide an estimate of annual air emissions and air emissions control waste generation from supercritical coal-fired power generation.

Natural Gas-Fired Power Generation

Entergy has chosen to evaluate the construction of three 528 MWe natural gas-fired plants using a closed-cycle cooling system with cooling towers at the GGNS site, with an operating life of 40 years. Entergy has assumed that the plants would use combined-cycle turbines and used site-specific input as appropriate. The air emissions and waste generated from emissions control equipment are to be determined to evaluate the environmental impacts associated with operating a combined-cycle turbine plant. A combined-cycle natural gas-fired plant emits oxides of sulfur (SOx), nitrogen oxides (NOx), particulate matter, and carbon monoxide, all of which are regulated pollutants. However, Entergy has assumed a plant design that would minimize air emissions through a combination of boiler technology and post-combustion pollutant removal. Carbon dioxide (CO_2) is also emitted from natural gas-fired generation, but similar to coal, control technologies are not yet established.

The calculations are based on U.S. Department of Energy (DOE) information for the most recent use of coal and natural gas consumed for electric power generation in Mississippi, and U.S. Environmental Protection Agency (EPA) air emissions and emissions removal information from Air Pollutant Emission Factors.Vol.1, Stationary Point Sources and Area Sources.

2.0 SUMMARY OF RESULTS AND CONCLUSIONS

Supercritical Coal-Fired Power Plant

A supercritical coal-fired plant emits oxides of sulfur (SOx), nitrogen oxides (NOx), particulate matter, and carbon monoxide all of which are regulated pollutants. However, a plant design has been assumed that would minimize air emissions through a combination of boiler technology and post-combustion pollutant removal. Tables 1 and

Table 2 present the basic supercritical coal-fired alternative emission control characteristics and emission estimates. Emission control technology and percent control assumptions were based on alternatives that the EPA has identified as being available for minimizing emissions [EPA 1998]. Although the EPA regulations have not been finalized for carbon dioxide, carbon dioxide emissions are also estimated.

Table 1

Supercritical Coal-Fired Alternative Emission Control Characteristics

Characteristic	Basis
Total size = 1,614 MWe ISO rating gross/ 1,524 MWe ISO rating net[a]	Size set to gas-fired alternative. Chosen as comparable to GGNS unit.
Unit size = 538 MWe ISO rating gross / 508 MWe ISO rating net[a]	Based on approximately 6 percent onsite power usage
Number of units = 3	
Boiler type = pulverized coal, tangentially fired, dry-bottom, NSPS	Minimizes nitrogen oxide emissions [EPA 1998, Table 1.1-3]
Fuel type = combination bituminous, subbituminous, lignite	Typical for coal used in Mississippi [DOE 2010a, Table 4]
Fuel heating value = 8,541 Btu/lb	2009 value for coal used in Mississippi [DOE 2010a, Table 15]
Fuel ash content by weight = 11.27%	2009 value for coal used in Mississippi [DOE 2010a, Table 15]
Fuel sulfur content by weight = 0.53%	2009 value for coal used in Mississippi [DOE 2010a, Table 15]
Uncontrolled SOx emission = 38S Uncontrolled NO_x emission = 10 lb/ton Uncontrolled CO emission = 0.5 lb/ton	Typical for pulverized coal, tangentially fired, dry-bottom, NSPS [EPA 1998, Table 1.1-3]
Heat rate = 10,414 Btu/kWh	Average operating heat rate for coal [DOE 2011, Table 5.3]
Capacity factor = 0.85	Typical for newer large coal-fired units
NO_x control = low NO_x burners, overfire air and selective catalytic reduction (95% reduction)	Best available and widely demonstrated for minimizing NOx emissions [EPA 1998, Table 1.1-2]
Particulate Material, filterable (PMf) = 10 lb/ton of ash Particulate Material (less than 10 microns) PM_{10} = 2.3 lb/ton of ash	Typical for pulverized coal, tangentially fired, dry-bottom, [EPA 1998, Table 1.1-4]
Particulate control = fabric filters (baghouse - 99.8% removal efficiency)	Best available for minimizing particulate emissions [EPA 1998, pp. 1.1-6 and 1.1-7; Table 1.1-6]
SO_x control = Wet scrubber – lime (95% removal efficiency)	Best available for minimizing SOx emissions [EPA 1998, Table 1.1-1]
CO_2 emission - average of bituminous and lignite coal = 210 lb/MMBtu	Based on DOE 2010b
Btu = British thermal unit ISO rating = International Standards Organization rating at standard atmospheric conditions of 59°F, 60% relative humidity, and 14.696 pounds of atmospheric pressure per square inch	

kWh = kilowatt-hour
NSPS = New Source Performance Standard
lb = pound
MW = megawatt
NOx = nitrogen oxides
SOx = oxides of sulfur

a. The difference between "net" and "gross" is electricity consumed by auxiliary equipment and environmental control devices [DOE 2002, page 109].

Table 2

Air Emissions from Supercritical Coal-Fired Alternative

Annual coal consumption	7,326,650 tons of coal per year
SO_x	3,689 tons SO_x per year
NO_x	1,832 tons NO_x per year
CO	1,832 tons CO per year
PM_f	826 tons PM_f per year
PM_{10}	190 tons PM_{10} per year
CO_2	13,141,153 tons CO_2 per year (assuming 210 lb/CO_2/MMBtu)

SO_x = oxides of sulfur
NO_x = nitrogen oxides
CO = carbon monoxide
PM_f = filterable particulate matter
PM_{10} = particulates having diameter less than 10 microns
CO_2 = carbon dioxide

Table 3
Solid Waste from Coal-Fired Alternative

Annual SO_x generated [a]	77,542 tons of SO_x per year
Annual SO_x removed	73,665 tons of SO_x per year
Annual ash generated	824,062 tons of ash per year
Annual lime consumption [b]	67,864 tons of CaO per year
Calcium sulfate [c]	197,666 tons of $CaSO_4 \cdot 2H_2O$ per year
Annual scrubber waste [d]	201,059 tons of scrubber waste per year
Total volume of scrubber waste [e]	111,082,320 ft^3 of scrubber waste
Total volume of ash [f]	659,249,600 ft^3 of ash
Total volume of solid waste	770,331,920 ft^3 of solid waste
Waste pile area (acres)	589 acres of solid waste 30 feet high

Based on annual coal consumption of 7,326,650 tons per year (Table 2)
a. Calculations assume 100% combustion of coal.
b. Lime consumption is based on total SO_2 generated.
c. Calcium sulfate generation is based on total SO_2 removed.
d. Total scrubber waste includes scrubbing media carryover
e. Density of $CaSO_4 \cdot 2H_2O$ is 144.8 lb/ft^3.
f. Density of coal bottom ash is 100 lb/ft^3 [FHA 2000].
S = sulfur
SO_2 = sulfur dioxide
SO_x = oxides of sulfur
CaO = calcium oxide (lime)
$CaSO_4 \cdot 2H_2O$ = calcium sulfate dehydrate

Combined-Cycle Natural-Gas Power Plant

Table 3 presents the basic gas-fired alternative characteristics and Table 4 presents emission estimates. Emission control technology and percent control assumptions were based on alternatives that the EPA has identified as being available for minimizing emissions [EPA 2000].

Table 4

Gas-Fired Alternative Emission Control Characteristics

Characteristic	Basis
Total size = 1,584 MWe ISO rating gross/ 1,524 MWe ISO rating net[a]	Manufacturer's standard size gas-fired combined cycle plant
Individual unit size = 528 MWe ISO rating gross/ 508 MWe ISO rating net[a]	Based on approximately 4 percent onsite power usage
Number of units = 3	
Fuel type = natural gas	
Fuel heating value = 1,025 Btu/ft^3	2009 value for gas used in Mississippi [DOE 2011, Table 3.7]
Fuel sulfur content = 0.0034 lb/MMBtu	Used when sulfur content is not available [EPA 2000, Table 3.1-2a]
NOx control = selective catalytic reduction (SCR) with steam/water injection	Best available for minimizing NOx emissions [EPA 2000, Table 3.1]
Fuel NOx content = 0.099 lb/MMBtu	Natural gas-fired turbine, Lean-premix [EPA 2000, Table 3.1-1]
Fuel CO content = 0.015 lb/MMBtu	Natural gas-fired turbine, Lean-premix [EPA 2000, Table 3.1-1]
CO_2 emission rate – gas turbine, lean premix = 117 lb/MMBtu	[DOE 2010b]
Heat rate = 7,543 Btu/kWh	Typical for combined cycle gas-fired turbines [DOE 2011, Table 5.4]
Uncontrolled filterable particulates = 0.0019 lb/MMBtu	[EPA 2000, Table 3.1-2a]
Uncontrolled total particulate matter = 0.0066 lb/MMBtu	[EPA 2000, Table 3.1-2a]
Capacity factor = 0.85	Typical for large gas-fired base load units.

Btu = British thermal unit
ft3 = cubic foot
ISO rating = International Standards Organization rating at standard atmospheric conditions of 59°F, 60% relative humidity, and 14.696 pounds of atmospheric pressure per square inch
kWh = kilowatt-hour
MM = million
MW = megawatt
NOx = nitrogen oxides
SCR = selective catalytic reduction

Table 5
Air Emissions from Gas-Fired Alternative

Annual gas consumption	86,795,748,246 ft^3 per year
Annual Btu input	88,965,642 MMBtu per year
SO_x	151 tons SO_x per year
NO_x	4,404 tons NO_x per year
CO	667 tons CO per year
PM_f	85 tons filterable particulate matter per year
PM_T	294 tons total particulate matter per year
CO_2	5,204,490 tons CO_2 per year (assuming 117 lb CO_2/MMBtu)

SO_x = oxides of sulfur
NO_x = nitrogen oxides
CO = carbon monoxide
PM_f = total filterable particulates
PM_T = total particulates
CO_2 = carbon dioxide

3.0 REFERENCES

DOE (United States Department of Energy). 2002. Energy Information Administration, "Electric Power Annual 2000, Volume II," DOE/EIA-0348(00)/2. November 2002.

DOE (United States Department of Energy). 2010a. Cost and Quality of Fuels for Electric Plants 2009, DOE/EIA-0191(2010). December 2010.

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DOE (United States Department of Energy). 2011. Electric Power Annual 2009, DOE/EIA-0348 (2009). January 2011.

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Bituminous and Subbituminous Coal Combustion. AP-42. September 1998. Accessed at http://www.epa.gov/ttn/ chief/ap42/ch01/final/c01s01.pdf.

EPA (United States Environmental Protection Agency). 2000. Air Pollutant Emission Factors.Vol.1, Stationary Point Sources and Area Sources, Section 3.1, Stationary Gas Turbines for Electricity Generation, AP-42. April 2000. Accessed at http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s01.pdf.

FHA (Federal Highway Administration). 2000. User Guidelines for Waste and Byproduct Materials in Pavement Construction, Coal Bottom Ash/Boiler Slag. Accessed at http://tfhrc.gov/hnr20/recycle/waste/cbabs1.htm.

4.0 ASSUMPTIONS/DESIGN INPUTS

4.1 SUPERCRITICAL COAL-FIRED EMISSIONS ESTIMATES

Based on input from Entergy, the net MWe size of the supercritical coal-fired plant to be evaluated is 1,524 MWe. It is assumed that the plant would be built in Mississippi, and would use coal typical of that currently used for electricity generation in Mississippi. However, since bituminous and lignite coal is used almost equally, the average input values for the type of coal, fuel heating value, ash content, and sulfur content are used (see Table 1) for Mississippi coal listed in the most recent DOE reference available [DOE 2011]. Assumptions for gaseous effluents are as follows:

- Plant generating size is 1,524 MWe net ISO
- Plant would use pulverized coal, tangentially fired, dry-bottom, required to meet New Source Performance Standards;
- Fuel type might be either bituminous, subbituminous, or lignite, since all of these are used in Mississippi based on DOE report;
- Average heating value for coal used Mississippi is 8,541 Btu/lb [DOE 2010, Table 15];
- Average sulfur content by weight for coal used in Mississippi is 0.53% [DOE 2010, Table 15]
- Average ash content by weight for coal used in Mississippi is 11.27 percent [DOE 2010, Table 15]
- Average heat rate for coal is 10,414 Btu/kWh [DOE 2011, Table 5.3];
- Capacity factor for supercritical coal-fired baseload plant is 0.85;
- SO_x emission factor is based on use of bituminous coal use, since the EPA emissions factors are given only for bituminous and sub-bituminous coal; bituminous coal is more representative than sub-bituminous based on use in Mississippi; for pulverized coal, tangentially fired, bituminuous coal use, meeting NSPS standards SO_x is 38S lb/ton [EPA 1998, Table 1.1-3];
- Molecular weight of Sulfur is 32.1; molecular weight of SO_2 is 64.1 (sulfur = 32.1 and oxygen = 16)
- Uncontrolled NO_x emission is based on use of bituminous coal use, since the EPA emissions factors are given only for bituminous and sub-bituminous coal; bituminous coal is more representative than sub-bituminous based on use in Mississippi; 10 lb/ton [EPA 1998, Table 1.1-3];

- Uncontrolled CO emission is based on use of bituminous coal use, since the EPA emissions factors are given only for bituminous and sub-bituminous coal; bituminous coal is more representative than sub-bituminous based on use in Mississippi; 0.5 lb/ton [EPA 1998, Table 1.1-3];
- CO_2 emission based on average of bituminous (205 lb/MMBtu) and lignite coal (215 lb/MMBtu) is 210 lb/MMBtu [DOE 2010b];
- Uncontrolled filterable particulate material (PM_f) emission is based on use of bituminous coal use, since the EPA emissions factors are given only for bituminous and sub-bituminous coal; bituminous coal is more representative than sub-bituminous based on use in Mississippi; 10 lb/ton [EPA 1998, Table 1.1-4];
- Uncontrolled filterable particulate material less than or equal to 10 microns emission is based on use of bituminous coal use, since the EPA emissions factors are given only for bituminous and sub-bituminous coal; bituminous coal is more representative than sub-bituminous based on use in Mississippi; 2.3 lb/ton [EPA 1998, Table 1.1-4];
- After combustion, 95% of NO_x would be removed based on low NO_x burner, overfire air, and selective catalytic reduction [EPA 1998, Table 1.1-2];
- After combustion, 95% of SO_x would be removed based on wet scrubbing with lime [EPA 1998, Table 1.1-1];
- After combustion, 99.8% of ash would be removed based on baghouse removal efficiency and disposed of at either an onsite or offsite landfill [EPA 1998, Section 1.4.1.1 and Table 1.1-6]
- ISO rating = International Standards Organization rating at standard atmospheric conditions of 59°F, 60% relative humidity, and 14.696 pounds of atmospheric pressure per square inch

4.2 COMBINED-CYCLE NATURAL GAS EMISSIONS

Based on input from Entergy, the net MWe size of the supercritical coal-fired plant to be evaluated is 1,524 MWe. It is assumed that the plant would be built in Mississippi, and would use natural gas. Assumptions for gaseous emissions are as follows:

- Plant generating size is 1,524 MWe net ISO
- Fuel type is natural gas;
- Average heating value for natural gas is 1,025 Btu/cubic foot [DOE 2011, Table 3.7];
- Fuel sulfur content - where sulfur content is not available – is 0.0034 lb/MMBtu [EPA 2000, Table 3.1-2a]
- Average heat rate for combined-cycle natural gas is 7,543 Btu/kWh [DOE 2011, Table 5.4];
- Capacity factor is assumed as a baseload plant is 0.85;
- NO_x emission factor based on gas turbine, lean premix is 0.099 lb/MMBtu [EPA 2000, Table 3.1];
- CO emission factor based on gas turbine, lean premix is 0.015 lb/MMBtu [EPA 2000, Table 3.1];
- CO_2 emission based on natural gas is 117 lb/MMBtu [DOE 2010b];

- Total Particulate Matter (PM) uncontrolled emissions from natural gas is 0.0066 lb/MMBtu [EPA 2000, Table 3.1-2a];

5.0 METHODOLOGY

ENERCON reviewed readily available emissions calculations to determine the annual emissions for supercritical coal-fired and combined-cycle natural gas-fired power plants used in previous Appendix E Applicant's Environmental Report for license renewal. Equations are as provided below.

6.0 CALCULATIONS

The following is an assessment of the annual emissions (and, for coal, emissions control waste generation) for a supercritical coal-fired power plant and a combined-cycle gas-fired power plant to be built in Mississippi, assuming the plants are constructed and the input parameters are as specified in Section 4.1 and 4.2, respectively. The calculations presented in the equations listed below were selected to provide the emissions quantities desired, and were selected as being used by the nuclear industry in other license renewal Environmental Report applications (see NPPD Cooper ER, and South Texas Project license renewal applications at the NRC website @ http://www.nrc.gov/reactors/operating/licensing/renewal/applications/south-texas-proj/south-texas-project-enviro.pdf)

Information presented in Section 4.1 was readily available for coal type, Btu per pound, sulfur content percent by weight, NO_x and CO for coal currently used in Mississippi. Emission factors were selected from EPA's AP-42 guidance to be representative of the type of coal most likely to be used in Mississippi (bituminous or lignite), based on current use cited by DOE, and to be representative of the most efficient type of coal plant that would minimize emissions.

Information presented in Section 4.2 was established from readily available information on natural gas, for Btu, sulfur content percent by weight, NO_x and CO for natural gas. Emission factors were selected from EPA's AP-42 guidance to be representative of the emissions representative of the most efficient type of natural gas plant that would minimize emissions, as further discussed in Section 4.2.

6.1 COAL EMISSIONS AND WASTE GENERATION EQUATIONS

Table 6
Air Emissions from Supercritical Coal-Fired Alternative

Parameter	Calculation	Result
Annual coal consumption	$3 \text{ units} \times \frac{538 \text{ MW}}{\text{unit}} \times \frac{10{,}414 \text{ Btu}}{\text{kW} \times \text{hr}} \times \frac{1{,}000 \text{ kW}}{\text{MW}} \times \frac{\text{lb}}{8{,}541 \text{ Btu}} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{365 \text{ day}}{\text{yr}} \times \frac{\text{ton}}{2{,}000 \text{ lb}} \times 0.85$	7,326,650 tons of coal per year
SO_x [a, b]	$\frac{7{,}326{,}650 \text{ tons}}{\text{yr}} \times \frac{0.53\% \times 38 \text{ lb}}{\text{ton}} \times \frac{\text{ton}}{2{,}000 \text{ lb}} \times (100 - 95)/100$	3,689 tons SO_x per year
NO_x [b, c]	$\frac{7{,}326{,}650 \text{ tons}}{\text{yr}} \times \frac{10 \text{ lb}}{\text{ton}} \times \frac{\text{ton}}{2{,}000 \text{ lb}} \times (100 - 95)/100$	1,832 tons NO_x per year
CO [b]	$\frac{7{,}326{,}650 \text{ tons}}{\text{yr}} \times \frac{0.5 \text{ lb}}{\text{ton}} \times \frac{\text{ton}}{2{,}000 \text{ lb}}$	1,832 tons CO per year
CO_2	$\frac{7{,}326{,}650 \text{ tons}}{\text{yr}} \times \frac{210 \text{ lb}}{\text{MMBtu}} \times \frac{\text{MMBtu}}{1{,}000{,}000 \text{ Btu}} \times \frac{8{,}541 \text{ Btu}}{\text{lb}}$	13,141,153 tons CO_2 per year
PM_f [d]	$\frac{7{,}326{,}650 \text{ tons}}{\text{yr}} \times \frac{11.27\% \times 10 \text{ lb}}{\text{ton}} \times \frac{\text{ton}}{2{,}000 \text{ lb}} \times (100 - 99.8)/100$	826 tons PM_f per year
PM_{10} [d]	$\frac{7{,}326{,}650 \text{ tons}}{\text{yr}} \times \frac{11.27\% \times 2.3 \text{ lb}}{\text{ton}} \times \frac{\text{ton}}{2{,}000 \text{ lb}} \times (100 - 99.8)/100$	190 tons PM_{10} per year

CO = carbon monoxide
NO_x = nitrogen oxides
PM_{10} = particulates having diameter less than 10 microns
SO_x = oxides of sulfur
TSP = total suspended particulates

a. EPA 1998, Table 1.1-1
b. EPA 1998, Table 1.1-3
c. EPA 1998, Table 1.1-2
d. EPA 1998, Table 1.1-4

Table 7
Solid Waste from Supercritical Coal-Fired Alternative

Parameter	Calculation	Result
Annual SO_x generated [a]	$\frac{7{,}326{,}650 \text{ tons Coal}}{\text{yr}} \times \frac{0.53 \text{ tons S}}{100 \text{ tons Coal}} \times \frac{64.1 \text{ tons } SO_2}{32.1 \text{ tons S}}$	77,542 tons of SO_x per year
Annual SO_x removed	$\frac{77{,}542 \text{ tons } SO_2}{\text{yr}} \times (95/100)$	73,665 tons of SO_x per year
Annual ash generated	$\frac{7{,}326{,}650 \text{ tons Coal}}{\text{yr}} \times \frac{11.27 \text{ tons ash}}{100 \text{ tons Coal}} \times (99.8/100)$	824,062 tons of ash per year
Annual lime consumption [b]	$\frac{77{,}542 \text{ tons } SO_2}{\text{yr}} \times \frac{56.1 \text{ tons CaO}}{64.1 \text{ tons } SO_2}$	67,864 tons of CaO per year
Calcium sulfate [c]	$\frac{73{,}665 \text{ tons } SO_2}{\text{yr}} \times \frac{172 \text{ tons } CaSO_4 \bullet 2H_2O}{64.1 \text{ tons } SO_2}$	197,666 tons of $CaSO_4 \cdot 2H_2O$ per year
Annual scrubber waste [d]	$\frac{67{,}864 \text{ tons CaO}}{\text{yr}} \times \frac{(100-95)}{100} + 197{,}666 \text{ tons } CaSO_4 \bullet 2H_2O$	201,059 tons of scrubber waste per year
Total volume of scrubber waste [e]	$\frac{201{,}059 \text{ tons}}{\text{yr}} \times 40 \text{ yr} \times \frac{2{,}000 \text{ lb}}{\text{ton}} \times \frac{\text{ft}^3}{144.8 \text{ lb}}$	111,082,320 ft^3 of scrubber waste
Total volume of ash [f]	$\frac{824{,}062 \text{ tons}}{\text{yr}} \times 40 \text{ yr} \times \frac{2{,}000 \text{ lb}}{\text{ton}} \times \frac{\text{ft}^3}{100 \text{ lb}}$	659,249,600 ft^3 of ash
Total volume of solid waste	111,082,320 ft^3 + 659,249,600 ft^3	770,331,920 ft^3 of solid waste
Waste pile area (acres)	$\frac{770{,}331{,}920 \text{ ft}^3}{30 \text{ ft}} \times \frac{\text{acre}}{43{,}560 \text{ ft}^2}$	589 acres of solid waste 30 feet high

Based on annual coal consumption of 7,326,650 tons per year

a. Calculations assume 100% combustion of coal and both gaseous and non-gaseous SO_x.
b. Lime consumption is based on total SO_2 generated.
c. Calcium sulfate generation is based on total SO_2 removed.
d. Total scrubber waste includes scrubbing media carryover
e. Density of $CaSO_4 \cdot 2H_2O$ is 144.8 lb/ft^3.
f. Density of coal bottom ash is 100 lb/ft^3 [FHA 2000].

S = sulfur (molecular weight = 32.1)
SO_2 = sulfur dioxide (molecular weight = 64.1)
SO_x = oxides of sulfur
CaO = calcium oxide (lime) (molecular weight = 56.1)
$CaSO_4 \cdot 2H_2O$ = calcium sulfate dehydrate

6.2 COMBINED-CYCLE GAS-FIRED POWER GENERATION EQUATIONS

Table 8
Air Emissions from Combined-Cycle Gas-Fired Alternative

Parameter	Calculation	Result
Annual gas consumption	$3x \frac{528\ \text{MW}}{\text{unit}} \times \frac{7{,}543\ \text{Btu}}{\text{kW} \times \text{hr}} \times \frac{1{,}000\ \text{kW}}{\text{MW}} \times 0.85 \times \frac{\text{ft}^3}{1{,}025\ \text{Btu}} \times \frac{24\ \text{hr}}{\text{day}} \times \frac{365\ \text{day}}{\text{yr}}$	86,795,748,246 ft^3 per year
Annual Btu input	$\frac{86{,}795{,}748{,}246\ \text{ft}^3}{\text{yr}} \times \frac{1{,}025\ \text{Btu}}{\text{ft}^3} \times \frac{\text{MMBtu}}{10^6\ \text{Btu}}$	88,965,642 MMBtu per year
SO_x [1]	$\frac{0.0034\ \text{lb}}{\text{MMBtu}} \times \frac{\text{ton}}{2{,}000\ \text{lb}} \times \frac{88{,}965{,}642\ \text{MMBtu}}{\text{yr}}$	151 tons SO_x per year
NO_x [2]	$\frac{0.099\ \text{lb}}{\text{MMBtu}} \times \frac{\text{ton}}{2{,}000\ \text{lb}} \times \frac{88{,}965{,}642\ \text{MMBtu}}{\text{yr}}$	4,404 tons NO_x per year
CO [2]	$\frac{0.015\ \text{lb}}{\text{MMBtu}} \times \frac{\text{ton}}{2{,}000\ \text{lb}} \times \frac{88{,}965{,}642\ \text{MMBtu}}{\text{yr}}$	667 tons CO per year
CO_2	$\frac{117\ \text{lb}}{\text{MMBtu}} \times \frac{\text{ton}}{2{,}000\ \text{lb}} \times \frac{88{,}965{,}642\ \text{MMBtu}}{\text{yr}}$	5,204,490 tons CO_2 per year
PM_f [1]	$\frac{0.0019\ \text{lb}}{\text{MMBtu}} \times \frac{\text{ton}}{2{,}000\ \text{lb}} \times \frac{88{,}965{,}642\ \text{MMBtu}}{\text{yr}}$	85 tons filterable particulate matter per year
PM_T [1]	$\frac{0.0066\ \text{lb}}{\text{MMBtu}} \times \frac{\text{ton}}{2{,}000\ \text{lb}} \times \frac{88{,}965{,}642\ \text{MMBtu}}{\text{yr}}$	294 tons total particulate matter per year

References: [1]. EPA 2000, Table 3.1-2a;
[2]. EPA 2000, Table 3.1-1

CO = carbon monoxide
NO_x = oxides of nitrogen
PM_{10} = particulates having diameter less than 10 microns
SO_x = oxides of sulfur
TSP = total suspended particulates