Results Of Modeling A Proposed CFB Combustor Project At An Existing Power Plant

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ABSTRACT

Oak Ridge National Laboratory (ORNL) staff performed air dispersion modeling to evaluate the potential environmental impacts associated with constructing and operating a new circulating fluidized bed (CFB) combustor at the site of a utility's existing power plant. The proposed project, which would receive cost-shared funding under the U.S. Department of Energy's (DOE's) Clean Coal Technology Program, would use coal and petroleum coke to generate nearly 300 MW of electricity by repowering an existing steam turbine (Unit 2) that has been out of service. In addition, without cost-shared funding from DOE, the utility plans to build an identical CFB combustor to repower a second, currently operating steam turbine (Unit 1). A third unit (Unit 3) would continue to operate using natural gas and fuel oil without equipment modification. The utility's management has established a target of a 10% reduction in annual stack emissions of each of 3 pollutants [sulfur dioxide (SO_2), oxides of nitrogen (NO_x), and particulate matter (PM-10)] from the 3-unit station, as compared to emissions during a recent 2-year operating period of the 2-unit station.

ORNL staff used the ISCST3 air dispersion model[1] to estimate maximum increases in ground-level concentrations of SO_2, nitrogen dioxide (NO_2), and PM-10 as a result of the proposed project alone (Unit 2) and for both repowered units. Predicted concentrations were compared with Prevention of Significant Deterioration (PSD) increments. Cumulative air quality impacts were evaluated by modeling regional sources along with both repowered units. Predicted concentrations were compared with national and state ambient air quality standards.

INTRODUCTION

New emissions of air pollutants would occur primarily from the 495-ft twin-flued CFB combustor stack. Table 1 summarizes annual emissions and maximum potential hourly emissions of SO_2, NO_x, and PM-10 from the existing and proposed units at the power plant. Specifically, Table 1 compares existing air emissions from Units 1 and 3 with emissions expected during the transition period after the Unit 2 repowering and emissions expected after the Unit 1 repowering. Although the capacity factor for the repowered Units 1 and 2 would be 90%, Table 1 uses a 100% capacity factor as an upper bound that matches the PSD air permit application.

Table 1. Comparison of existing air emissions with emissions expected during the transition period after the Unit 2 repowering and emissions expected after the Unit 1 repowering

Operating units	Fuel	Generating capacity (MW)	Capacity factor[a] (%)	Sulfur dioxide (SO_2)		Oxides of nitrogen (NO_x)		Particulate matter (PM-10)	
				tons/year	lb/hour[b]	tons/year	lb/hour[b]	tons/year	lb/hour[b]
Existing emissions									
Unit 1	Oil and gas	297.5	39	5,528[c]	5,479	1,716[c]	1,231	394[c]	346
Unit 3	Oil and gas	564	34	8,121[c]	9,965	2,284[c]	1,510	585[c]	629
Station total		861.5		13,649[c]	15,444	4,000[c]	2,741	979[c]	975
Expected emissions during the transition period after the Unit 2 repowering[d]									
Unit 1	Oil and gas	297.5	30	522	397[e]	1,046[f]	1,231	244[f]	346
Repowered Unit 2	Coal and coke	297.5	100[g]	1,833	419	1,100	251	135	31
Unit 3	Oil and gas	564	34	9,929[f]	9,965	1,454[f]	1,510	503[f]	629
Station total		1,159		12,284	10,781	3,600	2,992	882	1,006
Expected emissions after the Unit 1 repowering[h]									
Repowered Unit 1	Coal and coke	297.5	100[g]	1,833	419	1,100	251	135	31
Repowered Unit 2	Coal and coke	297.5	100[g]	1,833	419	1,100	251	135	31
Unit 3	Oil and gas	564	42	8,618[f]	9,965	1,400[f]	1,510	612[f]	629
Station total		1,159		12,284	10,803	3,600	2,012	882	691

[a]Capacity factor is the ratio of the energy generated during a period of time (12 months in this table) to the energy that would be produced if the equipment operated at its maximum power during that entire period.

[b]Maximum hourly emissions, based on using 100% fuel oil for the existing units (nearly independent of fuel type for the repowered units because emissions controls would be adjusted based on fuel type).

[c]Average of the 1994 and 1995 estimated actual values.

[d]Based on the expected schedule, the transition period would span from March 15, 2002, until March 15, 2003; the repowered Unit 2 would be brought online on March 15, 2002, and the existing Unit 1 would be taken offline on September 15, 2002, to complete the construction required for its repowering.

[e]Derived by calculating the maximum hourly emissions from Unit 1 that would result in maximum downwind concentrations less than all ambient air quality standards; a blend of natural gas and fuel oil with an SO_2 emission rate averaging no more than 0.143 lb/MBtu would be required.

[f]Derived by calculating the maximum annual emissions from Unit 3 or Units 1 and 3 that would achieve a 10% reduction in annual stack emissions from the power plant compared to existing emissions (based on the average of the 1994 and 1995 estimated actual values).

[g]Although the capacity factor is expected to be 90%, this comparison uses a 100% capacity factor as an upper bound that matches the air permit application.

[h]Starting on March 15, 2003, based on the expected schedule.

The table shows that the repowering of Unit 2 and a corresponding reallocation of emissions among the three units would meet the utility management's target of a 10% reduction in annual emissions of each pollutant (SO_2, NO_x, and PM-10) from the three units collectively while at the same time increasing the station's total generating capacity. Repowering Unit 1 would allow that unit to operate a greater percentage of the time and consequently increase the total annual energy output of the station while maintaining the overall 10% reduction in annual SO_2, NO_x, and PM-10 emissions. Annual emissions from Units 1 and 3 (during the transition period after the Unit 2 repowering) and from Unit 3 (after the Unit 1 repowering) would be adjusted by using different blends of natural gas and fuel oil to meet the overall 10% reduction. Thus, the relationship between annual emissions and capacity factor is not proportional. For example, as indicated in the table, annual SO_2 emissions from Unit 3 would decrease after the Unit 1 repowering from 9,929 to 8,618 tons per year because more natural gas and less fuel oil would be used, even though the capacity factor would increase from 34% to 42%.

Compared with existing emissions, the combination of repowering both units would also reduce maximum potential hourly emissions from the three units collectively. Maximum hourly SO_2 emissions would decrease by 30% after the Unit 2 repowering and would remain essentially unchanged from that lower level after the Unit 1 repowering. This reduction results from a commitment by the utility to use a blend of natural gas and fuel oil with an SO_2 emission rate averaging no more than 0.143 lb/MBtu (effectively, a blend with a sulfur content averaging no more than 0.13%) to decrease hourly SO_2 emissions from Unit 1 by nearly 93% during the transition period. Maximum hourly emissions of NO_x and PM-10 would increase somewhat after Unit 2 is repowered because emissions from Units 1 and 3 would remain the same while emissions from Unit 2 would be added. Emissions would then decrease after the Unit 1 repowering; the net result compared to existing maximum hourly emissions at the power plant would be a decrease of 27% in NO_x emissions and 29% in PM-10 emissions.

In addition to the emissions summarized in Table 1, relatively small amounts of pollutants would be emitted from the 75-ft stacks serving the proposed limestone dryers. Maximum potential hourly emissions of NO_x from those stacks would be about 1% of NO_x emissions from the repowered Unit 2; hourly emissions of SO_2 and PM-10 would be even smaller percentages compared to Unit 2. Emissions from the dryers were conservatively assumed to be at their maximum hourly rate during the transition period after the Unit 2 repowering and to continue at that rate after the Unit 1 repowering.

Although emissions of SO_2, NO_x, and PM-10 from the power plant would decrease as a result of the repowering actions, the redistribution of pollutants in the atmosphere is a complex process that could result in increased ground-level concentrations at some locations and for some averaging periods. On any particular day, concentrations could be increased at some locations and decreased at others; at any particular location, concentrations could be increased on some days and reduced on others. Because emissions from the proposed limestone dryers would occur close to ground level, as compared with emissions from the boiler stacks, concentrations of pollutants emitted from the dryer stacks would be expected to increase near the site boundary; these increases would be greatest for NO_2 because NO_x emissions from the dryer stacks exceed those of other pollutants. Thus, concentrations could be increased slightly near the site boundary while decreased at other locations.

The following analysis first evaluates the changes in ambient air concentrations of pollutants expected to result from changes in stack emissions associated with the repowering actions (PSD section); then the analysis examines potential cumulative air quality impacts from the proposed facility and from other regional sources [National Ambient Air Quality Standards (NAAQS) section].

PREVENTION OF SIGNIFICANT DETERIORATION ANALYSIS

PSD increments are established to restrict the deterioration of air quality that could result from new pollutant sources (40 CFR Part 51.166). PSD increments are used in this analysis as standards by which to measure the significance of the changes in ambient air concentrations. The distance from the power plant to the two nearest PSD Class I areas ranges between 30 and 63 miles. All other areas are designated as Class II.

The ISCST3 atmospheric dispersion model[1] was used to estimate maximum increases in ground-level concentrations of SO_2, NO_2, and PM-10 that would occur at any location as a result of emissions from the CFB combustor and limestone dryers for the Unit 2 repowering. Five years of hourly meteorological surface data from a nearby National Weather Service station, in conjunction with upper-air data from a more distant National Weather Service station were used. Maximum potential hourly emissions and a 100% capacity factor were used in the modeling. All NO_x emissions were conservatively assumed to be in the form of NO_2 for comparison with the NO_2 increment. Concentrations were modeled at 352 locations (receptors) along or outside the property boundary at distances of up to 6 miles from the proposed CFB combustor stack. For short-term averaging periods, PSD regulations allow for one anomalous exceedance of an increment per year (40 CFR Part 51.166); therefore, the highest modeled short-term concentrations at each receptor location for each year were excluded, and the highest remaining values for all 5 years modeled were included in the analysis.

Results for the repowered Unit 2 indicate that maximum modeled increases are always less than 15% of their corresponding Class II increments (Table 2). Maximum concentrations generally occur at locations along, or very close to, the site boundary, often within 0.6 mile of the proposed CFB combustor stack. Because the nearest PSD Class I areas are more than 30 miles from the proposed facility, pollutant concentrations estimated by the ISCST3 air dispersion model for those locations would be overly conservative. Dispersion of pollutants at such distances would reduce atmospheric concentrations to only a small fraction of the maximum modeled increases near the site. Because these maximum modeled increases are about equal to (for short-term SO_2 and annual NO_2 concentrations) or less than PSD Class I increments at the locations of their maximum impact near the power plant, the increases in pollutant concentrations at the nearest PSD Class I areas would be expected to be only small fractions of the corresponding Class I increments.

Table 2. Prevention of Significant Deterioration (PSD) impact analysis for the proposed project (repowered Unit 2) and repowered Unit 1

Pollutant[a]	Averaging period	PSD Class II increment[b] ($\mu g/m^3$)	Repowered Unit 2		Both repowered units	
			Modeled increase ($\mu g/m^3$)	Percentage of PSD Class II increment	Modeled increase ($\mu g/m^3$)	Percentage of PSD Class II increment
SO_2	3-hour[c]	512	27	5	30	6
	24-hour[c]	91	6	7	6	7
	Annual[d]	20	0.4	2	0.3	2
NO_2	Annual[d]	25	3	12	3	12
PM-10	24-hour[c]	30	0.7	2	0.7	2
	Annual[d]	17	0.06	< 1	0.06	< 1

[a]SO_2 = sulfur dioxide; NO_2 = nitrogen dioxide; PM-10 = particulate matter less than 10 μm in ***aerodynamic*** diameter.

[b]PSD increments are standards established in accordance with the Clean Air Act provisions to limit the degradation of ambient air quality in areas in attainment of the National Ambient Air Quality Standards.

[c]For averaging periods less than 1 year, one exceedance per year is allowed (40 CFR Part 51.166); therefore, the highest modeled concentration for each year has been excluded, and the highest of the remaining concentrations over the 5-year period is given.

[d]The maximum modeled annual concentration is used.

The combination of both repowered units would result in emissions from the new 495-ft twin-flued stack that would be twice those considered in the analysis of the repowered Unit 2 alone. However, emissions from the stacks serving the proposed limestone dryers were assumed to be at their maximum value for the repowered Unit 2 alone and were not increased in the analysis of both repowered units. Furthermore, the elimination of emissions from the existing 250-ft stack serving Unit 1 would more than compensate for the added emissions. Compared to existing plantwide emissions, a net decrease in maximum hourly emissions of SO_2, NO_x, and PM-10 would result from the addition of the repowered Unit 2 and the limestone dryers and the replacement of the existing Unit 1 with the repowered Unit 1 (Table 1). Therefore, a decrease in ground-level concentrations of these pollutants would be expected most of the time at most locations in the surrounding area.

However, pollutant concentrations would not decrease for all averaging times at all locations; maximum ground-level concentrations at some locations could increase because the characteristics and location of the proposed new stack would be different from those of the stack currently serving Unit 1. For example, the presence of a scrubber would result in a lower exit temperature for the exhaust gas from the new stack. This would tend to decrease the buoyancy of the exhaust gas, lower the height of the pollutant plume, decrease the vertical and horizontal spread of the plume, and increase ground-level concentrations. On the other hand, exhaust gas from the repowered Units 1 and 2 operating simultaneously would be emitted from adjacent flues, which increase the initial upward momentum and buoyancy of the exhaust gas. This larger initial lift would result in a greater plume height, a greater vertical and horizontal spread of the plume, and lower ground-level concentrations than would occur otherwise. The net result would be a complex redistribution of pollutant concentrations near the power plant. The net impacts could be positive or negative on any particular day at any particular location.

The existing Unit 2 that would be repowered was run with negative emissions in ISCST3 to take credit for the elimination of its emissions from an existing 250-ft stack, while simultaneously running both repowered units with positive emissions from the new 495-ft twin-flued stack. Maximum modeled increases in ground-level concentrations for both repowered units together are very similar to those for repowered Unit 2 alone. Maximum increases are always less than 15% of their corresponding Class II increments (Table 2). This result is largely attributable to the dominance of the proposed limestone dryer stacks in determining maximum concentrations. Although emissions from the limestone dryer stacks would be less than 1% of emissions from the proposed twin-flued CFB combustor stack, the maximum modeled concentrations of the former are comparable to, and frequently larger than, maximum concentrations of the latter. Because the dryer stacks would only be 75 ft tall, they would be subject to strong aerodynamic effects from surrounding structures. Under frequently occurring meteorological conditions (e.g., neutral atmospheric stability and moderate or high wind speeds), these effects could cause maximum impacts from the dryer stacks, which would occur about 500 ft from their source, to be larger than maximum impacts from the CFB combustor stack, which would occur several miles from their source.

Because the nearest PSD Class I areas are more than 30 miles away, pollutants from the power plant would be well mixed in the atmosphere, and stack characteristics would have little effect on ground-level pollutant concentrations in these areas. Therefore, a net decrease in pollutant emissions following

the repowering of both units (Table 1) would be expected to improve air quality, albeit by a very small amount, at the nearest PSD Class I areas.

The foregoing discussion of air quality impacts has focused primarily on maximum degradation. Improvements would also be expected to result from the decrease in air emissions that would accompany the repowered units (Table 1). Maximum modeled improvements in air quality were obtained by simultaneously modeling the emissions from the proposed CFB combustor stack and limestone dryer stacks with the elimination of emissions from the stack currently serving the existing Unit 1. Maximum improvements in air quality would occur at different times, and typically at different places, than would maximum degradations. Modeled maximum improvements and degradations are compared in Table 3. The improvements would generally be much greater than the degradations, reflecting primarily the net emissions decrease.

Table 3. Maximum improvements and maximum degradations in air quality that were modeled to result from repowering both units

Pollutant[a]	Averaging period	Maximum improvement ($\mu g/m^3$)	Maximum degradation[b] ($\mu g/m^3$)
SO_2	3-hour[c]	157	30
	24-hour[c]	42	6
	Annual[d]	3	< 1
NO_2	Annual[d]	1	3
PM-10	24-hour[c]	3	< 1
	Annual[d]	< 1	< 1

[a]SO_2 = sulfur dioxide; NO_2 = nitrogen dioxide; PM-10 = particulate matter less than 10 μm in aerodynamic diameter.

[b]Same as the modeled increase shown in Table 2 resulting from repowering both units.

[c]For averaging periods less than 1 year, one exceedance per year is allowed (40 CFR Part 51.166); therefore, the highest modeled concentration for each year has been excluded, and the highest of the remaining concentrations over the 5-year period is given.

[d]The maximum modeled annual concentration is used.

NATIONAL AMBIENT AIR QUALITY STANDARDS ANALYSIS

Potential cumulative air quality impacts of SO_2, NO_x, and PM-10 emissions from the proposed facility and from other regional sources were evaluated by estimating maximum increases in ground-level concentrations using the ISCST3 air dispersion model[1] with the same meteorological input data discussed earlier. Modeling included sources within 30 miles of the power plant that were expected to

contribute to cumulative impacts. Maximum modeled concentrations during the 5-year period were added to the corresponding monitored background concentrations, and the totals are compared to NAAQS or state standards in Table 4.

The modeling of existing nearby sources assures inclusion of their effects on air quality near the site of the proposed project; these effects may not be fully represented at the nearest monitoring location because the instrument may be located relatively far from the power plant. Addingmonitored background concentrations to the modeling results assures inclusion of contributions from sources that were not modeled (e.g., natural sources, vehicles, and utilities or industrial sources that were not modeled because of their small size and/or large distance from the proposed facility). Adding modeled and monitored concentrations is conservative because it "double counts" any modeled effects that are included in the monitoring data.

Results of modeling regional sources, including the existing Units 1 and 3 and the repowered Unit 2 during the transition period, indicate no exceedances of national or state ambient air quality standards (Table 4). However, the 24-hour average SO_2 concentration would be 97% of the corresponding state standard, and all SO_2 concentrations would increase appreciably compared with the ambient background concentrations. Particularly for the short-term concentrations, these large values result from aerodynamic downwash effects caused by the proposed 200-ft tall combustor structure that would induce downward motion on the exhaust gas emitted from the 250-ft stack serving the existing Unit 1 and the 350-ft stack serving the existing Unit 3. Downwash leads to substantial, localized increases in ground-level concentrations near the site boundary compared with concentrations that would result from an identical situation without downwash. Interestingly, because the downwash would be affecting existing units, the U.S. Environmental Protection Agency does not require modeling in the PSD analysis of the change in ground-level concentrations caused by downwash from the proposed structure. Exhaust gas from the proposed 495-ft CFB combustor stack would not be subjected to substantial downwash because the stack is taller.

Results of modeling regional sources, including the existing Unit 3 and both repowered units, indicate that maximum concentrations are always less than corresponding concentrations during the transition period. For example, the 24-hour average SO_2 concentration is 91% of the state standard, compared to the 97% obtained previously. This decrease is attributable to several factors. First, the repowered Unit 1 would emit pollutants through a 495-ft stack rather than the 250-ft stack serving the existing Unit 1. The taller stack would allow more dilution of the pollutant plume before it reaches ground level. Second, elimination of emissions from the existing shorter stack would be augmented by the corresponding elimination of aerodynamic downwash affecting those emissions. Third, although the Unit 1 repowering would increase the maximum potential hourly emissions from the twin-flued 495-ft stack by a factor of two, the exhaust gas would be emitted from adjacent flues, which would add buoyancy and upward momentum to the plume, so that ground-level concentrations of pollutants emitted from that stack alone would increase by much less than a factor of two. Finally, compared to the transition period after the Unit 2 repowering, the Unit 1 repowering would be accompanied by appreciable reductions in maximum hourly emissions of NO_x and PM-10; maximum hourly emissions of SO_2 would remain almost the same (Table 1). The net effect would be that expected maximum

Table 4. Ambient air quality standards impact analysis for combined effects of regional sources, including the existing Units 1 and 3 and the repowered Unit 2

Pollutant[a]	Averaging period	Standard[b] ($\mu g/m^3$)	Modeled concentration[c] ($\mu g/m^3$)	Ambient background concentration ($\mu g/m^3$)	Total impact[d] ($\mu g/m^3$)	Total impact as a percentage of standard
SO_2	3-hour	1,300	478	236	714	55
	24-hour	260	199	52	251	97
	Annual	60	18	8	26	43
NO_2	Annual	100	6	30	36	36
PM-10	24-hour	150	26	66	92	61
	Annual	50	2	28	30	60

[a]SO_2 = sulfur dioxide; NO_2 = nitrogen dioxide; PM-10 = particulate matter less than 10 μm in aerodynamic diameter.

[b]National Ambient Air Quality Standards (NAAQS) except for annual and 24-hour averages of SO_2. The NAAQS are established in accordance with the Clean Air Act to protect public health and welfare with an adequate margin of safety. States may establish standards more stringent than NAAQS.

[c]Maximum modeled concentration from regional sources, including the existing Units 1 and 3 and the repowered Unit 2.

[d]The sum of the modeled concentration and the ambient background concentration.

ground-level concentrations would decrease appreciably for NO_2 and PM-10 and would decrease slightly for SO_2 compared with the modeling performed for the transition period.

REFERENCE

1. U.S. Environmental Protection Agency, *User's Guide for the Industrial Source Complex (ISC3) Dispersion Models*, EPA-454/B-95-003, Research Triangle Park, N.C., 1995.

KEY WORDS

Air dispersion model
Air emissions
Sulfur dioxide
Oxides of nitrogen
Particulate matter
Concentrations
Prevention of significant deterioration
National ambient air quality standards
Environmental impacts
Circulating fluidized bed
Power plant
Repowering