LG&E/KU – Mill Creek Station

Phase II Air Quality Control Study

Chimney Alternatives

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Revision B – Issued For Client Review

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1.0 Introduction

Three chimneys currently exist at the Mill Creek Station: a common chimney with separate flues serving Units 1 and 2, and unit-specific chimneys serving Units 3 and 4, respectively. All three chimneys are currently in operation and are located downstream of the wet scrubbers at the units they serve.

Significant additional or replacement AQC equipment is proposed to be added to the units upstream of the chimneys. The intent of this report is to investigate the most cost effective means of discharging treated exhaust gas at each of the units and to describe the resulting recommended chimney arrangement.

2.0 System Evaluations and Recommendations

To establish a basis for evaluating the chimneys at Mill Creek, the AQC technology recommendations for the four Mill Creek units can be summarized as follows.

- Unit 1 and Unit 2 – add pulse jet fabric filters (PJFFs), replacement ID fans, and selective catalytic reduction (SCRs) to the AQC process, remove but not replace existing electrostatic precipitators (ESPs) and booster fans, and refurbish the existing wet flue gas scrubbers for reuse. This description is typical for both Unit 1 and Unit 2.
- Unit 3 – add a new PJFF downstream of the existing SCR and ESP (which remain in operation), add new booster fans, and divert the exhaust to the existing Unit 4 wet flue gas scrubber, refurbished for reuse. The existing Unit 3 scrubber is to be demolished to make room for the new PJFF.
- Unit 4 – add a new PJFF downstream of the existing SCR and ESP (which remain in operation), new booster fans, and a new wet flue gas desulfurization (WFGD) module to be located south of Unit 4.

Evaluation of the existing chimneys and recommendations with regard to their reuse or replacements will be based on the above equipment recommendations. It should be noted that B&V did not complete an onsite detailed inspection of the existing chimneys. The recommendations and alternatives described herein are based on the overall assumption that the existing chimneys remain structurally and functionally sound with no major defects requiring significant repair or replacement.

2.1 Unit 1 and Unit 2 Common Chimney

The existing Unit 1 / Unit 2 chimney consists of a common reinforced concrete shell supporting two independent and dedicated exhaust flues, one per unit, constructed of carbon steel lined with nickel alloy C-276 (UNS N10276). Each exhaust flue is 15’-6” interior diameter at discharge elevation. The flues extend to approximately 600 feet above surrounding grade and the shell is penetrated by two breeching openings, one for the exhaust duct from each unit’s wet scrubber.

The alloy flue liner is necessary due to the extremely corrosive conditions downstream of a wet flue gas scrubber. No physical inspection was completed as part of this study, but the alloy is an accepted and commonly-used liner material for this type of application and LG&E/KU have not indicated any reason to suspect problems with continuing to direct Unit 1 and Unit 2 exhaust gas to the existing chimney.

The Phase II AQC Study recommendations summarized in Section 2.0 would result in minor changes in the temperature, chemical aggressiveness, and total volume

flow of the exhaust gases reaching the existing chimney. Moreover, no significant changes are proposed in the ductwork downstream of the existing wet scrubbers at Units 1 and 2, resulting in no expected change in the loads imposed on the chimney shell or the breeching penetrating the shell. As a practical matter, the existing chimney is optimally located for exhausting treated exhaust duct from the two existing scrubbers. There is no easily-adaptable location in the immediate Unit 1/Unit 2 area for a new chimney or chimneys as long as the existing scrubbers continue to be used.

Based on the above evaluation, it is recommended that the existing common Unit 1 / Unit 2 chimney be used as is when the respective AQC systems are upgraded.

It should be noted that chimney flue diameters and discharge elevations would remain unchanged. However, any affects on flue gas velocity and temperature due to the new equipment must be reflected in the air permitting process.

2.2 Unit 3 Chimney

As part of the AQC upgrade recommended for Unit 3, exhaust from Unit 3 will be diverted to the existing Unit 4 wet scrubber. The Unit 4 scrubber would be refurbished for continued use and would become a permanent part of the Unit 3 AQC equipment train. The Unit 4 scrubber currently discharges to the adjacent Unit 4 chimney via existing ductwork. The close proximity and existing ductwork make reuse of the Unit 4 chimney for discharge of Unit 3 exhaust a natural preference. Diverting the treated Unit 3 exhaust gas from the Unit 4 scrubber outlet back to the existing Unit 3 chimney would require extensive additional ductwork, increased friction losses through the added duct (causing up-sizing of the planned booster fans), and increased congestion in an area already crowded with existing and proposed new equipment. If the existing Unit 4 chimney is determined acceptable to discharge the Unit 3 exhaust gas, reusing the Unit 4 chimney is the recommended choice over reusing the Unit 3 chimney.

The Unit 4 chimney consists of a reinforced concrete shell supporting a single 19’-6” inside diameter exhaust flue constructed of carbon steel with a nickel alloy C-276 lining. The flue extends to approximately 600 feet above surrounding grade and the shell is penetrated by a single breeching opening for the combined exhaust from both “trains” of the Unit 4 wet scrubber.

As with the Unit 1 / Unit 2 chimney, the alloy flue liner was provided to withstand the extremely corrosive conditions downstream of the wet scrubber. Alloy C-276 is an accepted and commonly-used liner material for the conditions expected in this application and, although no physical inspection was completed as part of this study, LG&E/KU have not indicated there is any reason to suspect problems with the condition of the existing chimney.

Because the Unit 4 chimney was designed for a unit larger than Unit 3, the inside diameter of the flue is larger than that in the existing Unit 3 chimney. The larger diameter flue will result in lower discharge velocities, assuming maximum Unit 3 flow remains relatively constant. The design exhaust gas flow reaching the Unit 4 chimney from Unit 3 is 1,348,885 ACFM. Based on the 19'-6" diameter of the flue, the average maximum velocity through the flue will be approximately 75 ft/sec.

The critical velocity for a liner material is a balance between sufficient velocity to ensure adequate dispersion as the gas is discharged from the top and a maximum velocity that prevents "stripping" of acidic condensate droplets from the liner surface and their carryover into the gas being discharged from the chimney. Relatively smooth liner surfaces like that of the alloy liner are less prone to being stripped of condensate by the gas stream than are rougher-surfaced brick and mortar liners. Thus higher velocities are normally allowed where smooth-surfaced liners are installed. There is no regulated or code-required range of velocities for exhaust gas in a chimney flue, but industry sources recommend the maximum gas velocity in a C-276 material-lined flue at 65 to 70 ft/sec. The calculated velocity of Unit 3 exhaust gas through the Unit 4 flue thus slightly exceeds the industry recommendations. However, this calculated velocity is less than that currently experienced through the existing smaller diameter Unit 3 chimney. Diverting the Unit 3 exhaust to the Unit 4 chimney would be expected to slightly lessen the potential of acid carryover, if any, from the Unit 3 chimney under current conditions.

Accordingly, the Unit 4 chimney is deemed fully acceptable as a discharge point for Unit 3 exhaust. Liner materials are appropriate for the conditions expected, maximum velocities are near optimum to prevent acid carryover, yet the exit velocity is only slightly reduced from that in the existing Unit 3 chimney.

Based on the above, it is recommended that the existing Unit 4 chimney be reused as is for the discharge of treated exhaust from Unit 3. Although some repair of the existing ductwork between scrubber and chimney may be required, any such work would be far less expensive and schedule-critical than adding the new duct required to reuse the Unit 3 chimney. Due to the marginal usefulness of the location currently occupied by the Unit 3 chimney and the cost required to demolish it, it is further recommended that the existing Unit 3 chimney be bypassed and abandoned in place. Due to the larger diameter of the Unit 4 chimney, as well as potential impacts to the exhaust flow velocity and temperature resulting from upstream additions and modifications, the affects of the new stack must be included in the air permitting process. Also, any existing duct and flue liquid collection system must be evaluated for any additional removal rate due to a slower flue velocity.

2.3 Unit 4 Chimney

Due to the recommended reuse of the existing Unit 4 chimney for Unit 3, Unit 4 is left without a dedicated chimney. LG&E/KU is left with two potential alternatives: re-direct Unit 4 exhaust gas to the existing Unit 3 chimney or construct a new chimney specifically for Unit 4.

The new AQC train proposed for Unit 4 is to be located either south of the Unit 4 powerblock on an east-west axis extending towards the river or south of the Unit 4 ESP on a north-south access extending towards the fly ash handling facility, depending on the results of other studies currently in progress. In either arrangement, the discharge flange on the new WFGD will be located a considerable distance (a minimum of 800 feet) from the location of the Unit 3 chimney. In addition, the majority of the new equipment installed, plus significant existing equipment, would lie in the way of any ductwork routed back to the Unit 3 chimney. Physically connecting the outlet of the new Unit 4 WFGD to the inlet of the existing Unit 3 chimney presents severe constructability and significant cost considerations.

The flue in the existing Unit 3 chimney is 18'-0", inside diameter. The design exhaust gas flow expected from Unit 4 is 1,641,798 ACFM. If the flow from Unit 4 were directed to the Unit 3 chimney, the average maximum velocity through the flue will be approximately 92 ft/sec. This velocity far exceeds the industry-recommend maximum gas velocity of 70 ft/sec in a C-276 material-lined flue and would likely result in significant acid carryover into the discharged exhaust gas. Reuse of the existing Unit 3 chimney for Unit 4 is not viable from either a design or a construction viewpoint. It should also be noted that any ductwork downstream of the new Unit 4 WFGD absorber must be designed for extremely corrosive conditions. The cost of the alloy or FRP ductwork required makes limiting the ductwork length between WFGD and chimney very desirable.

Accordingly, a new chimney will be required for the new Unit 4 AQC train. The new chimney will be located downstream of a WFGD system and will thus be subject to extremely corrosive conditions. A "wet" chimney is required, usually consisting of a reinforced concrete shell protecting and supporting a chemically-resistant flue actually carrying the wet and acidic exhaust stream.

Several materials are suitable for use as a liner material in a wet chimney, each with its own advantages and disadvantages. Flues constructed of fire brick and acid-resistant mortar were the norm for many years. However, because of its relatively rough interior surface (increasing potential of carryover), high labor cost to construct, low seismic resistance, and high repair and maintenance record, brick and mortar flues are

seldom specified any longer in the United States. Use of this type of flue for Mill Creek Unit 4 is not recommended.

Resin-lined carbon steel and borosilicate block-lined carbon steel are also suitable for the expected environment. However, the relatively low longevity and high repair costs of the resin liner make it a poor choice for a large chimney subject to constant operation. The borosilicate block (often known as Pennguard block after a primary manufacturer) is, similar to acid brick and mortar, relatively expensive to install and is somewhat brittle and susceptible to erosion and damage. For that reason, borosilicate block is used more often as a re-liner for existing chimneys than as the original liner material for a new chimney in the U.S. Neither resin nor borosilicate block liners are recommended for Mill Creek Unit 4.

The two liner materials used most often in the United States for large wet chimneys in the last 15 to 20 years are fiberglass-reinforced plastic (FRP) and C-276 alloy, either as a full-thickness flue material or as a cladding on carbon steel (known as "wallpapering"). The FRP liner material consists of fiberglass strands combined with a high temperature, flame retardant resin that is generally immune to the corrosive conditions in the flue gas. It has an excellent operating record in the U.S. and, usually prefabricated in sections onsite, is relatively quick to install and less expensive than other materials. One significant concern with FRP is its flammability. The fire-retardant resins will burn under the right conditions, although a "FR" FRP liner material has been developed with additional chemicals mixed with the resins to improve the fire rating on the finished liner. Moreover, a fire upstream of FRP liners could cause serious over-temperature damage to the lining. A flue gas quench system is mandatory to protect the liner from high flue temperatures. Some owners do not specify FRP liners due to requirements by their insurance carriers because of fire and high heat concerns.

Alloy C-276 also has an excellent service record as a liner material over the last 20 years. It is highly resistant to the corrosive environment, has superior internal strength, is non-combustible, and is relatively easy to install. However, the nickel alloy material is expensive, and its price volatility over the last 10 years has been extreme, making it an uncertain choice on which to budget large construction projects. To minimize the material costs, a flue of solid C-276 material is often rejected in favor of a carbon steel flue with a thin lining of C-276 material welded to the interior. This "wallpapered" flue is still, depending on market conditions, usually more expensive than an FRP flue and is substantially more dependent on the quality of installation than a solid C-276 flue. Failures of the welds attaching the thin wallpaper to the carbon steel flue result in leaks and exposure of the underlying carbon steel to the corrosive environment in the chimney.

Both FRP and C-276 materials are relatively smooth and have similar critical velocities. Maximum industry-recommended critical velocity of exhaust flow through a C-276-lined flue is 70 ft/sec; for FRP, 65 ft/sec. For an estimated design exhaust flow of 1,641,798 acfm, the minimum recommended flue diameter for a C-276 flue is 22.3 ft; for an FRP flue, 23.2 ft. Based on the existing Unit 4 chimney, a flue discharge height of 600 feet above grade is assumed acceptable. The required height of the chimney would be confirmed as part of the air modeling and permitting process to take into account environmental considerations.

Although all three chimneys existing at Mill Creek have flues lined with C-276 material, the expected lower cost of the FRP liner makes it the recommended choice, assuming LG&E/KU requirements do not dictate otherwise. The new chimney for Ghent Station Unit 4 contains an FRP liner and it is thus assumed LG&E/KU has no inherent objection to FRP liners. The estimate completed as part of the Phase II Study includes the cost of a reinforced concrete chimney with a single 24-foot diameter FRP liner with a discharge elevation 600 feet above grade. The new chimney flue will be equipped with a liquid collection system to minimize carryover and avoid rain-out conditions around the new chimney. The design of the liquid collection system will be based on a flow modeling study made specifically for the flue diameter and exhaust conditions expected.

A new Unit 4 chimney will be built to support the new Unit 4 equipment. The affects of the new stack must be included in the air permitting process.

3.0 Summary

Based on the evaluations presented in Section 2, the following recommendations are made with regard to chimneys for the four units at Mill Creek Station:

- Unit 1 and Unit 2 – reuse as is the existing common chimney shell and two independent alloy-lined flues downstream of the existing wet scrubbers.
- Unit 3 – use as is the existing Unit 4 chimney downstream of the existing Unit 4 wet scrubber to discharge treated exhaust gases from Unit 3. The existing Unit 3 chimney is to be abandoned in place.
- Unit 4 – construct a new "wet" chimney consisting of a concrete shell housing a FRP liner to discharge treated exhaust gases from Unit 4. The new chimney is to be located directly downstream of the new Unit 4 WFGD.

A summary of the recommended chimney arrangements is included on Sketches A and B in Appendix A, the differences lying in the arrangement ultimately selected for the new Unit 4 equipment. Chimney design parameters based on the recommendations included in this study for each chimney are summarized in Table 3-1.

Table 3-1
Chimney Design Parameters

Parameters	Unit 1	Unit 2	Unit 3[1]	Unit 4[2]
Flue inside diameter at discharge, ft	15.5	15.5	19.5	24.0
Height of discharge above grade[3], ft	600	600	600	600
Calculated discharge flow[4], acfm	1,004,195	1,063,784	1,348,885	1,641,798
Calculated discharge velocity[5], ft/sec	88.7	94.0	75.3	60.5

Notes:
1. Unit 3 chimney is the existing Unit 4 chimney re-purposed to discharge treated exhaust gas from Unit 3. Existing Unit 3 chimney is to be bypassed and abandoned.
2. Unit 4 chimney is a new chimney with a FRP liner to be constructed as part of the Unit 4 AQC train.
3. Based on a discharge elevation of MSL +1060.0 and grade at MSL +460.0.
4. Discharge flows per Combustion & Mass Balance Calculations (SCAT runs), Version 3, dated 10/04/2010.
5. Industry-recommended discharge velocities for C-276 liners is 65-70 ft/sec, for FRP liners is 60-65 ft/sec.

Characteristics of exhaust flow exiting the chimneys as recommended above will differ from that currently occurring due to new or modified equipment being added

upstream, as well as reassignment of an existing chimney to a different unit and construction of a new chimney. Because of these changes in design conditions, the chimneys, existing or new, must be included in any air modeling to be completed as part of the permit process and permits procured accordingly.

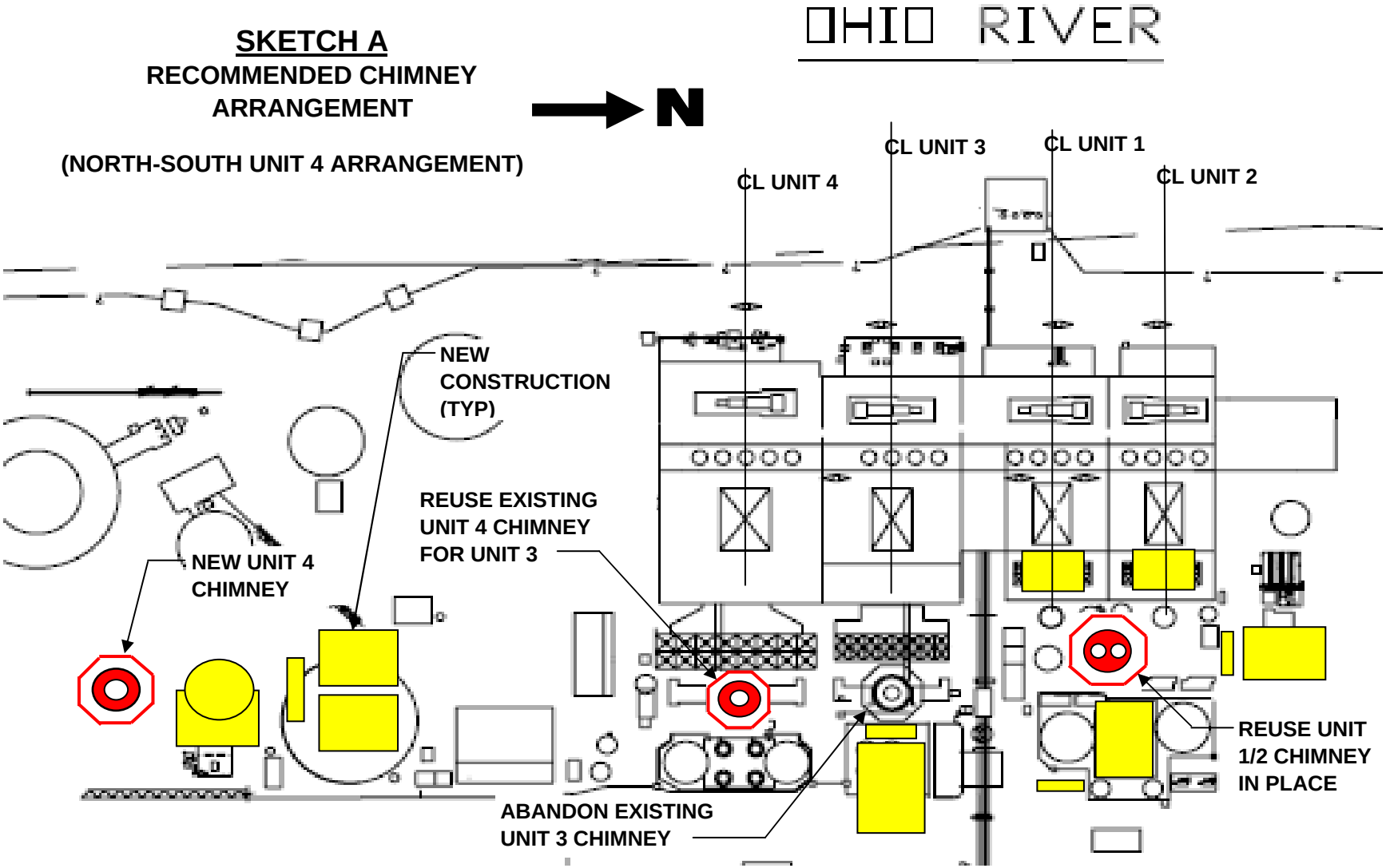
Appendix A
Recommended Chimney Arrangement Sketches

Sketch A

SKETCH A

RECOMMENDED CHIMNEY ARRANGEMENT

(NORTH-SOUTH UNIT 4 ARRANGEMENT)



Sketch B

SKETCH B

RECOMMENDED CHIMNEY ARRANGEMENT

(EAST-WEST UNIT 4 ARRANGEMENT)