

**CLASS II AIR QUALITY PERMIT APPLICATION
BORAL KIRKLAND MINE**

Submitted to:
Arizona Department of Environmental Quality
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1.0 INTRODUCTION

Boral Materials, LLC (Boral) is submitting this permit application to the Arizona Department of Environmental Quality (ADEQ) for a Class II Air Quality Control Permit. Boral is proposing to construct and operate a non-metallic mineral processing mill and supporting equipment to mine and process natural pozzolan at the Kirkland Mine Site located in Kirkland Valley within Yavapai County, Arizona. The proposed project will mine and process up to 750,000 tons of natural pozzolan per year. Previous discussions and correspondence with the ADEQ for this project indicated the general permit for crushing and screening was applicable and would be used for this project. Recently, ADEQ has reevaluated the proposed project and decided that a Class II individual permit would be more appropriate for the proposed operations. This application is being submitted to satisfy the request of ADEQ for a Class II permit.

This application contains the technical report, which forms the basis for this application for a Class II Air Quality Control Permit. Section 1.0 is the introduction. Section 2.0 provides a description of the proposed project. Section 3.0 contains the calculations of the potential to emit for the proposed project and provides an analysis of the predicted impacts resulting from the project. Section 4.0 provides a summary of regulatory applicability. The completed Standard Permit Application Form and Certification of Truth, Accuracy and Completeness are included in Appendix 1. Appendix 2 contains the emissions calculations and summary of emissions for the proposed project along with an equipment list of associated applicable equipment for the project. Appendix 3 provides site maps and a process flow diagram showing the proposed equipment for the project. Appendix 4 contains supporting documents and studies used to support the analysis in the permit application.

Boral understands once ADEQ has completed a draft permit, that there will be a 30-day public comment period. Boral is requesting that a public hearing also be scheduled during the 30-day public comment period to allow interested parties to provide comments during this time.

2.0 PROJECT DESCRIPTION

The Kirkland Mine is located in the Kirkland Valley near Skull Valley, Arizona. The site address for the project is 7855 S. Iron Springs Road Skull Valley, Arizona 86338. A vicinity map and overview map of the proposed site operations are provided in Appendix 3. The proposed project will mine and process up to 750,000 tons of high quality natural pozzolan per year for use as Supplementary Cementitious Materials (SCM's) in ready-mix concrete as well as other potential uses. SCM's are added to concrete mixtures for various reasons including improving durability, decreasing permeability, mitigating alkali reactivity, and improving the overall properties of hardened concrete through hydraulic or pozzolanic activity. The need for these materials is growing increasingly due to the decrease in fly ash supply from coal fired power plants, historically used as SCM's in concrete. The proposed mining activities will occur on approximately 88 acres of land administered by the BLM.

Portions of the project area have been heavily disturbed by historical mining activities. Mining has been conducted at this location since the late 1800s. Per the Arizona Department of Mines and Mineral Resources website, the area has been known variously throughout its history as the Arizona Tufa ("Magic Mountain") Property, Rynearson Quarry, Kirkland Tuff Quarry, Maverick Mine, Kitty Litter Mine, and Capital Quarry. In 1958, the Rynearson family leased the quarry to Capital Quarries to provide dimensioned stone for construction of the Arizona State Capital Building; it is estimated that the builders may have used up to 1,000 tons during this operation. In 1979, Kitty Litter Mine began shipping oil absorbent material from the mine that was producing approximately 1,200 tons of tuff per month. The mine was closed in 1985 and the equipment was removed. Kirkland Mining Company completed the NEPA process with the BLM for the proposed project in 2018, and a signed decision notice was issued by BLM on December 3, 2018 allowing for the mining operations to proceed.

The proposed mining activities will occur on approximately 88 acres of land administered by the BLM. Mineral processing will occur on privately held lands located adjacent to the mine site. Mined material will be loaded into haul trucks and transported to adjacent private lands for processing. Mining will be conducted using conventional heavy equipment (dozer and/or excavator). No drilling or blasting is anticipated for the proposed project. A maximum annual production of 750,000 tons is expected for the project.

Mined material will be stored adjacent to operations within a covered storage building enclosed on 3 sides. Material will be fed with a front end loader into a feeder / breaker which will break larger sized material down into smaller chunks necessary for further processing. This activity will

be conducted under cover within a building enclosed on 3 sides. Emissions from the breaker will be controlled by a dust collector. Material exiting the breaker will be fed to a grinding mill rated at 100 tons per hour. The mill will further grind material down to finished product specs. Hot air will be injected into the grinding process to dry material during grinding. This hot gas will be generated using a propane fired hot gas generator rated at 16.379 MW per hour. The ground pozzolanic material will be carried by the hot gas inlet air to a product recovery baghouse, where the pozzolan material will be recovered from the stream. The balance of the air will pass through a fan and directed either to the stack (for moisture removal) or the hot gas generator for reuse in the process. Finished product will be stored in one of two 5,000 ton storage silos. Material from the silos will be loaded into trucks and transported off-site to other storage locations and customers. A site plan for the proposed mill operations and process flow diagram are provided in Appendix 3.

Particulate matter emissions from supporting processes, product transfer and storage bins will be controlled by dust collection systems. Fugitive emissions can occur from quarry truck loading, unloading, plant feed, unpaved roads, and paved roads. Emissions from unpaved roads will be controlled by regular wetting of the road surfaces with a water truck. Additional emissions of CO, NO_x, SO₂, and VOC's will result from propane combustion as part of the drying process within the mill. The proposed burner for the dryer process is equipped with a low NO_x burner. The process design utilizes flue gas recirculation. As part of the design 50% of flow and associated heat is recirculated back to the burner to maintain heat and reduce fuel consumption. Emissions of CO and NO_x are further reduced in the drying process from the flue gas recirculation process design. It is estimated based on studies that NO_x and CO are further reduced up to 65% based on flue gas recirculation studies.

3.0 EMISSION CALCULATIONS

This section describes and summarizes the calculations for potential to emit (PTE), and the resulting potential emissions, along with a summary of the predicted impacts from the proposed project. The complete emissions calculation details for the proposed emission sources and complete list of applicable equipment are provided in Appendix 2. Supporting data and information used in the analysis is provided in Appendix 4.

3.1 Emissions Summary

Emissions calculations of particulate matter from the proposed project are based on manufacturers rated proposed design flow rate and emissions grain loading or emissions guarantee. Based on the proposed design and bag technology particle size distribution, most particulate matter emissions will be smaller than 2.5 microns. The operating schedule for the proposed source is conservatively estimated at 8760 hours per year for purposes of calculating PTE. Fugitive emissions of particulate matter are calculated based on the maximum potential operating scenario for the mill operating at 100 tons per hour or 876,000 tons per year.

Emissions of NO_x, CO and SO₂ resulting from the drying process are based on the manufacturer specifications for the low NO_x burner proposed for the process. Additional emissions reductions for NO_x and CO are based the design of the drying process which utilizes flue gas recirculation to return approximately 50% of the heat within the system back to the burner. Flue gas recirculation is part of the design, the mill process cannot operate without this loop. The recirculation loop is a function of the process and cannot be modified or bypassed during processing. This process has shown to reduce emissions of NO_x and CO up to 65% from this type of combustion process. The proposed burner is larger than studies which have shown this reduction of NO_x and CO, but the principles remain the same irrespective of the size. Flue Gas Recirculation reduces the heat requirement (less fuel) and places the system into a reducing atmosphere where there is less oxygen to react with the nitrogen at high temperatures. These reductions are based on thermodynamic principles which remain the same regardless of the size of the burner. Studies showing the reduction in CO and NO_x were done using a propane-butane blend. The proposed plant will burn pure propane, which is the hottest, cleanest fuel that can be used which is comprised of long carbon chains and very low impurities. Use of pure propane instead of propane-butane blend does not change the principals which result in NO_x and CO emissions reductions when utilizing flue-gas recirculation in the design. Based on this analysis and design principles, the proposed reductions in CO and NO_x where conservatively assumed at 50%, lower than the expected 65% reduction shown from studies.

In addition, based on lab analysis low levels of metals which are listed as Hazardous Air Pollutants (HAPS) may be present in the particulate emissions which naturally occur in natural pozzolan

material being mined. Analysis was conducted for metals in 2019 on two different samples. Of the metals tested, only four federally listed HAPs were found to be present in natural pozzolan from the site, which include arsenic, chromium, nickel, and lead. The emissions from these HAPS were conservatively estimated as the percent of each HAP potentially present in the particulate matter emissions from process sources based on the highest value detected from the laboratory analysis conducted on natural pozzolan from the mine.

Table 1 summarizes the potential point source emissions from the proposed project. Proposed emissions are below the significance thresholds for each applicable pollutant. Table 2 provides a summary of additional potential fugitive emissions resulting from the proposed project. Table 3 provides an estimate of potential HAPs that may be present from both point and fugitive process source particulate matter emissions.

Table 1 – Point Source Emissions Summary

Pollutant	Potential Emissions (tpy)	Permit Exemption Threshold (tpy)	Significant Threshold (tpy)
PM ¹	4.89	N/A	25
PM ₁₀ ¹	4.89	7.5	15
PM _{2.5} ¹	4.89	5	10
NO _x ²	19.80	20	40
SO ₂ ²	0.99	20	40
CO ²	4.95	50	100
VOC ³	2.68	20	40

¹Emissions calculations for PM, PM₁₀ and PM_{2.5} are based upon proposed manufacturer guaranteed flow rate and bag emissions guarantee for proposed dust collectors.

²NO_x, CO and SO₂ based on manufacturer emissions specifications for low NO_x burner.

Additional reduction in CO and NO_x of 50% used for flue gas recirculation based on design studies.

³Emissions of VOC's based on AP-42 Table 1.5-1.

Table 2 – Fugitive Emissions Summary

Source ID	PM Potential Emissions (tpy)	PM₁₀ Potential Emissions (tpy)	PM_{2.5} Potential Emissions (tpy)
Quarry Loader	0.94	0.56	0.06
Plant Loader	1.21	0.72	0.07
Haul Truck	5.56	3.30	0.33
Pozzolan Trucks	3.39	1.55	0.38
Truck Loading	0.08	0.04	0.01
Truck Unloading	0.08	0.04	0.01
Feed Hopper	0.08	0.04	0.01
Storage Pile	1.53	0.77	0.77
Total	12.88	7.01	1.62

Table 3 – HAP Emissions Summary

Pollutant	Highest Lab Result (mg/Kg)	Present in Natural Pozzolan (%)	Potential Emissions (tpy)
Arsenic	1.1	0.011%	0.002
Chromium	9.94	0.099%	0.018
Nickel	4.55	0.046%	0.008
Lead	9.3	0.093%	0.017

¹Emissions based on percent of HAP present from lab analysis in total process particulate emissions.

3.2 Impacts Analysis

As seen in Table 1 above and discussed in Section 3.1, the proposed project results in point source emissions which are below the minor NSR and significant regulatory thresholds. At the request of ADEQ, Boral is fully assessing impacts from the proposed project by conducting an air impact analysis using regulatory air models. The impact analysis will include analysis of both point source and fugitive source emissions that may result from the project. The supporting model and impacts will be presented to ADEQ during the permit development phase to fully assess and ensure that the

project impacts will be below ambient air quality standards. As part of the modeling analysis, additional modeling may be performed to assess impacts for voluntary emissions limits higher than potential emissions to ensure enforceable emissions will not impact human health and the environment. Boral may elect to assess impacts from point source emissions up to 90% of the significant level as proposed emission limits within the permit as follows:

Table 4 – Proposed Modeling Limits

Pollutant	Point Source Potential Emissions (tpy)	Potential Enforceable Permit Limit (tpy)	Significant Threshold (tpy)
PM ₁₀ ¹	4.89	13.5	15
PM _{2.5} ¹	4.89	9.0	10
NO _x ²	19.80	36.0	40
SO ₂ ²	0.99	36.0	40
CO ²	4.95	90.0	100
VOC ³	2.68	36.0	40

While the potential to emit does not trigger minor NSR, in addition to air quality impact modeling, the following assessment of Reasonably Available Control Technology (RACT) is being provided to show the facility design and proposed control measures meet or exceed RACT. All sources of process emissions from the feed breaker at the start of the process through load out of final product will be controlled by the product recovery baghouse and associated bin vent and process dust collectors at each applicable emission point location. These dust collectors will utilize the latest design and bag technology for each process. All manufacturer guaranteed emissions from these sources are below the Federal Standards under NSPS Subpart OOO for controlled source emissions. These controls therefore meet or exceed RACT for the mill and supporting processes and storage of pozzolan.

The proposed burner utilizes propane for the combustion process. Propane is considered a clean burning fuel in combustion processes. The burner design utilizes low NO_x technology to further reduce NO_x emissions. The process is also designed to recirculate flue gas back to the burner. Flue gas recirculation keeps heat within the system, reducing the amount of fuel required to dry the material during the grinding process. Flue gas recirculation has shown through studies to reduce NO_x and CO emissions from the combustion process up to 65% when compared to systems which

do not use flue gas recirculation. Both low NO_x burners and flue gas recirculation design have been determined to meet or exceed RACT for combustion processes.

Unpaved roads will be controlled by regular watering with a water truck. ADEQ has already assessed and determined the use of water to be considered RACT for controlled emissions from unpaved roads. The plant ingress, egress and loadout operations area will be paved. Paving of this area provides additional control of fugitive emissions compared with unpaved roads and is therefore considered to meet or exceed RACT for the truck loadout process. The plant feed storage pile, and rock breaker feed hopper which feeds the mill will be located in covered storage enclosed on three sides. Average material moisture is estimated to be 18% from mined natural pozzolan. The high moisture content and covered storage will reduce fugitive emissions from wind erosion and the plant feed process. This control measure is considered to meet RACT to control emissions from the proposed plant feed process and material storage pile.

The proposed facility design and operations meet or exceed RACT, and an impacts analysis will be conducted to ensure the proposed project impacts will be below the NAAQS for all applicable pollutants. Based on this analysis the proposed project does not pose a risk to human health and the environment.

4.0 REGULATORY APPLICABILITY

4.1 AAC Title 18, Chapter 2

The proposed permit is not a major source of emissions. The proposed potential to emit is not significant as defined under R-18-2 101. As such, the requirements under A.A.C. Title 18, Chapter 2 Article 4 are not applicable.

The proposed permit revision will not result in significant emissions of any regulated HAP. As such, the requirements covered under A.A.C. Title 18, Chapter 2 Article 17 are not applicable.

A.A.C. Title 18, Chapter 2 Article 9 incorporates by reference the requirements under 40 CFR Part 60 New Source Performance Standards (NSPS) of which R-18-2-109.71 corresponding to Subpart OOO, Standards of Performance for Nonmetallic Mineral Processing Plants are applicable to the proposed project. These requirements pertaining to the proposed project are outlined in the following section.

The proposed grinding mill utilizes a propane burner to dry material during the grinding process. This drying activity is not subject to any federal standards of performance under Article 9 or 11. NSPS Subpart UUU - Standards of Performance for Calciners and Dryers in Mineral Industries has been discussed and reviewed with the agency and has been determined to not be applicable. The facility does not meet the definition of a mineral processing plant under this rule because natural pozzolan at the site does not have greater than 50% of any minerals covered under the rule present and does not meet the standard of a lightweight aggregate as determined by applicable ASTM standards. In addition, this subpart is not applicable to grinding equipment that also dries the process material under the applicability section. A review of Subpart Dc - Standards of Performance for Small Industrial-Commercial-Institutional Steam Generating Units was also performed and determined not to be applicable. The facility does not meet the definition of a steam generating unit under the rule because it does not produce steam or heat water of any transfer medium as part of the process. In addition, heat input to steam generating units is not applicable to recirculated flue gases under § 60.41c definitions. The standards of performance for unclassified sources under R-18-2-730 are applicable as well as any applicable enforceable emissions limitations or operational requirements deemed necessary to ensure compliance under R-18-2-306.A.2.

Additional fugitive emissions resulting from areas not otherwise classified including open areas, roads, storage piles and material handling activities associated with the process are subject to the

opacity emission standards under R-18-2-614. Reasonable precautions to prevent excessive fugitive dust from these sources are covered under R-18-2-604 through R-18-2-607. Additional opacity emissions standards for applicable mobile sources, off-road machinery and roadway and site cleaning machinery are covered under R-18-2-801, R-18-2-802 and R-18-2-804, respectively. Associated monitoring, recordkeeping and reporting requirements deemed necessary to ensure compliance with these standards are covered under R-18-2-306 permit contents.

4.2 40 CFR Part 60 Subpart OOO

The proposed Boral facility is a fixed non-metallic mineral processing plant as defined under 40 CFR 60.671, and therefore is subject to the provisions of Subpart OOO of 40 CFR Part 60, Standards of Performance for Non Metallic Mineral Processing Plants as well as applicable general provisions under 40 CFR Part 60 Subpart A. The provisions of Subpart OOO are applicable to the following affected facilities in fixed (greater than 25 tons per hour) or portable (greater than 150 tons per hour) nonmetallic mineral processing plants: each crusher, grinding mill, screening operation, bucket elevator, belt conveyor, bagging operation, storage bin, enclosed truck or railcar loading station. The associated affected sources for the Boral process include all processes from the rock breaker through the mill and loadout of material into trucks. Mining, loading, unloading, material storage, and fugitive emissions from paved and unpaved roads as well as the drying process within the grinding system are not covered under Subpart OOO and thus not subject to these standards of performance.

APPENDIX 1

Standard Permit Application Form and Certification of Truth, Accuracy
and Completeness

APPENDIX 2

Emission Calculations Tables and Equipment List

**EMISSIONS SUMMARY
BORAL KIRKLAND MINE**

POINT SOURCE EMISSIONS							
Source ID	PM	PM₁₀	PM_{2.5}	CO	NO_x	SO₂	VOC
1651-BF01	4.44	4.44	4.44	4.95	19.80	0.99	2.68
1621-DE01	0.025	0.025	0.024	-	-	-	-
1621-DE02	0.002	0.002	0.002	-	-	-	-
BF-5066	0.006	0.006	0.006	-	-	-	-
CF-5260	0.203	0.203	0.203	-	-	-	-
CF-5360	0.203	0.203	0.203	-	-	-	-
BF-5251	0.006	0.006	0.006	-	-	-	-
BF-5351	0.006	0.006	0.006	-	-	-	-
BF-5041	0.002	0.002	0.002	-	-	-	-
TOTALS	4.89	4.89	4.89	4.95	19.80	0.99	2.68

FUGITIVE SOURCE EMISSIONS							
Source ID	PM	PM₁₀	PM_{2.5}	CO	NO_x	SO₂	VOC
Quarry Loader	0.94	0.56	0.06	-	-	-	-
Plant Loader	1.21	0.72	0.07	-	-	-	-
Haul Truck	5.56	3.30	0.33	-	-	-	-
Pozzolan Trucks	3.39	1.55	0.38	-	-	-	-
Truck Loading	0.08	0.04	0.01	-	-	-	-
Truck Unloading	0.08	0.04	0.01	-	-	-	-
Feed Hopper	0.08	0.04	0.01	-	-	-	-
Storage Pile	1.53	0.77	0.77	-	-	-	-
TOTALS	12.88	7.01	1.62	0.00	0.00	0.00	0.00

**PARTICULATE MATTER EMISSION ESTIMATION
BORAL KIRKLAND MINE POINT SOURCE EMISSIONS MILL PRODUCT RECOVERY BAGHOUSE**

Point Emission Sources		Estimated Vent Air Moisture	Stack Nominal Air Flow from Control Device	PM ₁₀ Controlled Emission Factor	Controlled Emission Rates						Stack Temp
Equipment ID Number	Description	%	Nm ³ /hr	mg/Nm ³ ¹	PM (max. lb/hr)	PM (tpy)	PM ₁₀ (max. lb/hr)	PM ₁₀ (tpy)	PM _{2.5} (max. lb/hr)	PM _{2.5} (tpy)	K
1651-BF01	Product Recovery Baghouse	16.8	80,800	10	1.01	4.44	1.01	4.44	1.01	4.44	370
				TOTALS	1.01	4.44	1.01	4.44	1.01	4.44	

NOTES:

1 - The emission factors are from baghouse manufacturer specifications for bag emissions grain loading and particle sizes

Manufacturer Design Flow Rate	165,145	Nm ³ /hr
Process Design Flow Rate =	160,800	Nm ³ /hr
Process Design Outlet Stack Flow Rate =	80,800	Nm ³ /hr
Outlet Dust Concentration =	10	mg/Nm ³

Outlet Dust Concentration =	1.78	lb/hr
Process Design Stack Outlet Temperature =	369.75	K
Process Design Vent Air Moisture =	16.8	%

Corrected to standard conditions (sea level with 1,013 mbar and 293 K = 20 °C). Barometric pressure at Kirkland is 874.3 mbar (4025' elev.)

100% of Particulate emissions are assumed to be PM_{2.5} based on bag design particle size capture efficiency

**MILL DRYER EMISSIONS CALCULATIONS
BORAL KIRKLAND MINE**

<u>Low NOx Burner</u>	<u>Propane</u>	Quantity	<u>1</u>
		Hours per year ¹	<u>8760</u>
Power Rating	55.89	MM BTU	
Power Rating	16.38	MW	
Combustion Air Flow	20500.0	Nm ³ /hr	

Pollutant	Emission Factor ²	Emission Factor	Emissions	Emissions
	(mg/Nm ³)	(lb/Nm ³)	lb/hr	tons/yr
<i>PM</i> ₁₀	10.0	2.20E-05	0.45	1.98
<i>PM</i> _{2.5}	10.0	2.20E-05	0.45	1.98
CO ³	25.0	5.51E-05	1.13	4.95
NOx ³	100.0	2.20E-04	4.52	19.80
SO ₂	5.0	1.10E-05	0.23	0.99
Pollutant	Emission Factor ⁴	Emission Factor	Emissions	Emissions
	(lb/10 ³ gal)	(lb/MM BTU)	lb/hr	tons/yr
VOCs	1.00	1.09E-02	0.61	2.68

Note: Dryer emissions for *PM*₁₀ and *PM*_{2.5} are included in Product Recovery Baghouse Emissions Estimates

¹ Emissions based on potential estimated operating hours annually of 8760 hours

² Emission factors from propane burner manufacturer specifications

³ NOx and CO emissions estimate reduced by 50% due to plant design which uses flue gas recirculation

FLUE GAS RECIRCULATION FOR REDUCTION OF NITROGEN OXIDES (NOx) EMISSIONS IN INDUSTRIAL BOILERS

Experimental Investigation of Primary De-Nox Method Application Effects on NOx and CO Emissions

from a Small-Scale Furnace

Studies show significant reduction in NOx and CO by using flue gas recirculation

Boral design utilizes flue gas recirculation greater than 20% which study shows >50% reduction in NOx and CO

⁴ Emission factors taken from AP-42, Table 1.5-1, (Heat Content 91.5 x 10⁶ BTU/10³ gallon for propane)

**FUGITIVE PARTICULATE EMISSIONS QUARRY AND PLANT VEHICLE TRAFFIC
BORAL KIRKLAND MINE**

Quarry and Plant Vehicle Traffic													
Fugitive Emission Sources	Equipment Type	Gross Vehicle Weight (tons)	Annual VMT (miles/yr)	PM Emission Rate (lb/VMT)	PM ₁₀ Emission Rate (lb/VMT)	PM _{2.5} Emission Rate (lb/VMT)	Control Efficiency (%) *	Controlled Emission Rate (lb/VMT)	Controlled Emission Rate (lb/VMT)	Controlled Emission Rate (lb/VMT)	Estimated PM Emissions (tons)	Estimated PM ₁₀ Emissions (tons)	Estimated PM _{2.5} Emissions (tons)
Loaders													
QL	Quarry Loader	34	6227.34	3.01	1.79	0.18	90%	0.301	0.179	0.018	0.938	0.557	0.056
PL	Plant Loader	19	10379.15	2.34	1.39	0.14	90%	0.234	0.139	0.014	1.214	0.721	0.072
Unpaved Roads Haul to Plant													
HT	Haul Truck	50	30938.6	3.59	2.13	0.21	90%	0.359	0.213	0.021	5.559	3.302	0.330

*Control Efficiency of 90% taken from ADEQ CGP emissions calculations for regular road watering

For Unpaved Roads:

AP-42 13.2.2, Eqns 1a and 2 $E = (k(S/12)^a) \times (W/3)^b \times (365-p)/365$

WHERE:

E = site specific emission factor (lb/VMT)

k = particle size multiplier, Table 13.2.2-2

S = surface silt content = 4.3% (obtained from ADEQ CSGP)

W = fleet average vehicle weight for given service (tons)

a = empirical constant, Table 13.2.2-2

b = empirical constant, Table 13.2.2-2

P = 30, ave. days per year with precipitation greater than 0.01 inches, obtained from Figure 13.2.2-1

Constant / Variable	PM ₁₀	PM _{2.5}
k	1.5	0.15
a	0.9	0.9
b	0.45	0.45
P	30	30
S	4.8	4.8

Equipment

Wheel Loader w/6 cu-yd bucket - 34,039lbs empty weight + 8440lbs material = 42,479 lbs loaded

Wheel Loader w/10 cu-yd bucket – 60,142lbs empty weight + 14,067lbs material = 74,209 lbs loaded

Haul Truck w/31.4 cu-yd cap – 77,283lbs empty weight + 44,170 material = 121,453 lbs loaded

*Ceidars Report

	Mean Vehicle Weight	Emission Factor (lb/VMT)	PM *	PM ₁₀	PM _{2.5}
Quarry Loader	33.6	E =	3.013	1.790	0.179
Haul Truck	49.7	E =	3.593	2.134	0.213
Plant Loader	19.1	E =	2.339	1.389	0.139

VMT Trip Estimates per Hour

		Haul Truck	Quarry Loader	Plant Loader
Mill	tph	100	100	100
Equipment Capacity		22.1	7.0	4.2
No of trips per hour		5	14	24
Distance per round trip		0.78	0.05	0.05
VMT/hr		3.53	0.71	1.18

**FUGITIVE PARTICULATE EMISSIONS PLANT VEHICLE TRAFFIC
BORAL KIRKLAND MINE**

Quarry and Plant Vehicle Traffic													
Fugitive Emission Sources	Equipment Type	Gross Vehicle Weight (tons)	Annual VMT (miles/yr)	PM Emission Rate (lb/VMT)	PM ₁₀ Emission Rate (lb/VMT)	PM _{2.5} Emission Rate (lb/VMT)	Control Efficiency (%) *	Controlled Emission Rate (lb/VMT)	Controlled Emission Rate (lb/VMT)	Controlled Emission Rate (lb/VMT)	Estimated PM Emissions (tons)	Estimated PM ₁₀ Emissions (tons)	Estimated PM _{2.5} Emissions (tons)
Paved Roads Final Product Transfer Off-Site													
PT	Pozzolan Transport Trucks	28	5972.73	1.14	0.52	0.13	0%	1.136	0.519	0.127	3.394	1.551	0.381

For Paved Roads:

AP-42, 13.2.1, Eq 2. $E = (k * sL^{0.91} * W^{1.02}) * (1 - P/4N)$

WHERE:

E = site specific emission factor (lb/VMT)

k = particle size multiplier from Table 13.2-1.1 (lb/VMT)

sL = surface silt loading (10.1 g/m²), obtained from average of Concrete Batching and Quarry mean values in Table 13.2.1-3

W = fleet average vehicle weight (tons) - 40 ton loaded, 15 ton unloaded weight

P = ave. days per year with precipitation greater than 0.01 inches, obtained from Figure 13.2.2-1 30 days

N = number of days in the averaging period (365 days used for annual emissions)

Constant	PM ₁₀	PM _{2.5}
k	0.0022	0.00054

*Ceidars Report

	Gross Vehicle Weight	Emission Factor (lb/VMT)	PM *	PM ₁₀	PM _{2.5}
PT	27.5	E =	1.136	0.519	0.127

VMT Trip Estimates per Hour

Mill	tph	100
Truck Capacity		25.0
No of trips per hour		4
Distance per round trip		0.170
VMT/hr		0.68

**FUGITIVE PARTICULATE EMISSIONS MATERIAL LOADING AND UNLOADING
BORAL KIRKLAND MINE**

Loading and Unloading Operations										
Fugitive Emission Sources	Quarry Operations	Maximum Transfer Rate or Emissions Basis	Units	Annual Production (tons)	PM Emission Rate (lb/ton)	PM ₁₀ Emission Rate (lb/ton)	PM _{2.5} Emission Rate (lb/ton)	Estimated PM Emissions (tons)	Estimated PM ₁₀ Emissions (tons)	Estimated PM _{2.5} Emissions (tons) ²
TL	Truck Loading	100	tons/hr	876,000	1.85E-04	8.75E-05	1.33E-05	0.0811	0.0383	0.0058
TUL	Truck Unloading	100	tons/hr	876,000	1.85E-04	8.75E-05	1.33E-05	0.0811	0.0383	0.0058
FH	Feed Hopper	100	tons/hr	876,000	1.85E-04	8.75E-05	1.33E-05	0.0811	0.0383	0.0058

Note: **Batch Drop Operations and transfer operations to haul trucks, storage pile and feed hopper
Plant Maximum Production is 750,000 tons per year. Emissions based on maximum potential of 876,000 tons to be conservative.**

AP-42, 13.2.4.3 Predictive Emission Factor Equation

Assumptions

Wind speed, U 7.5 miles/hr Assumed from ADEQ CGP emissions calculations
 Moisture, M 18 % Mean Moisture of Mined Pozzolan based on analysis
 Emission factor
 $k*0.0032((U/5)^{1.3})/((M/2)^{1.4})$

Pollutant	k	U	M	Emission factor
				lb/ton
PM	0.74	7.5	18	1.85E-04
PM ₁₀	0.35	7.5	18	8.75E-05
PM _{2.5}	0.053	7.5	18	1.33E-05

**FUGITIVE PARTICULATE EMISSIONS MATERIAL STORAGE PILE
BORAL KIRKLAND MINE**

Storage Pile Emissions										
Fugitive Emission Sources	Quarry Operations	Maximum Transfer Rate or Emissions Basis	Units	PM Emission Rate (lb/hr-acre)	PM Emission Rate (lb/hr)	PM ₁₀ Emission Rate (lb/hr)	PM _{2.5} Emission Rate (lb/hr)	PTE PM Emissions (tons)	PTE PM ₁₀ Emissions (tons)	PTE PM _{2.5} Emissions (tons)
SP	Material Storage Pile	1	acres	0.3500	0.3500	0.1750	0.1750	1.53	0.77	0.77

Note: Storage Pile will be within building enclosed on 3 sides. Emissions are conservatively based on 1 acre outdoor storage

Storage Pile Emissions

USEPA, January 1989. Air/Superfund National Technical Guidance Study Series; Volume III –

Estimation of Air Emissions from Cleanup Activities at Superfund Sites, Interim final report EPA-450/1-89-003.

TSP (lb/year/acre of surface) = 1.7 (s/1.5) (365 [(365-p)/235]) (f/15)

where: s = silt content of material (weight %)

p = number of days per year with at least 0.01 inch of precipitation

f = percentage of time unobstructed wind speed is greater than 12 mph at mean pile height

s	Silt content quarry stone (various products)	3.9	AP-42 Table 13.2.4-1 (estimated)
p	No. of days with 0.01 inch of precipitation per year	30	AP-42 Figure 13.2.2-1
f	% of time unobstructed wind speed exceeds 5.4 m/sec (12 mph)	20	Assumed from ADEQ CGP Emissions Calculations

	PM		PM ₁₀ (50% of PM)	PM _{2.5} (Same as PM ₁₀)
Storage piles (Acres)	PM Emissions Lb/hr-acre	PM Emissions lb/hr	PM ₁₀ Emissions lb/hr	PM _{2.5} Emissions lb/hr
1	0.3500	0.3500	0.1750	0.1750

$$PM = 1.7 * (s/1.5) * [(365-p)/235] * (f/15)$$

PM emission factor = 8.4011 lb/day-acre

**PARTICULATE MATTER EMISSION ESTIMATION
BORAL KIRKLAND MINE POINT SOURCE EMISSIONS**

Point Emission Sources		Control Device Nominal Air Flow	PM ₁₀ Controlled Emission Factor	Controlled Emission Rates					
Equipment ID Number	Description	CFM	gr/dscf ^{1,2}	PM (max. lb/hr)	PM (tpy)	PM ₁₀ (max. lb/hr)	PM ₁₀ (tpy)	PM _{2.5} (max. lb/hr)	PM _{2.5} (tpy)
1621-DE01 ¹	Mill Feed Breaker Discharge Baghouse	10,000	0.0000675	0.006	0.025	0.006	0.025	0.005	0.024
1621-DE02 ¹	Mill Feed to Rotary Valve Filter	900	0.0000675	0.001	0.002	0.001	0.002	0.000	0.002
BF-5066 ¹	Product Storage Transfer Baghouse	2,350	0.0000675	0.001	0.006	0.001	0.006	0.001	0.006
CF-5260 ²	Cartridge Filter Silo Loadout 1	1,800	0.003	0.046	0.203	0.046	0.203	0.046	0.203
CF-5360 ²	Cartridge Filter Silo Loadout 2	1,800	0.003	0.046	0.203	0.046	0.203	0.046	0.203
BF-5251 ¹	Storage Silo Bin Vent 1	2,350	0.0000675	0.001	0.006	0.001	0.006	0.001	0.006
BF-5351 ¹	Storage Silo Bin Vent 2	2,350	0.0000675	0.001	0.006	0.001	0.006	0.001	0.006
BF-5041 ¹	Off Spec Bin Vent	900	0.0000675	0.001	0.002	0.001	0.002	0.000	0.002
			TOTALS	0.10	0.45	0.10	0.45	0.10	0.45

NOTES:

1 - Emission factors based on manufacturer grain loading guarantee of 0.0000675 gr/dscf for PM and PM₁₀, and 0.0000638 for PM_{2.5}

2 - Emission factors based on manufacturer grain loading guarantee of 0.003 gr/dscf, 100% of emissions are PM_{2.5}

**EQUIPMENT LIST
BORAL KIRKLAND MINE**

EQUIPMENT ID / TAG	TYPE	DESCRIPTION	CAPACITY	MAKE & MODEL	MFR DATE
MILL FEED SYSTEM					
1621-FB01	HYDRAULIC CONVEYOR	FEEDER/BREAKER	125 TPH	Proprietary, TBD	2021
1621-BC01	BELT CONVEYOR	MILL FEED BELT CONVEYOR	150 TPH	Proprietary, TBD	2021
1621-BN01	BIN	MILL FEED METAL SEPARATOR BIN	-	Proprietary, TBD	2021
1621-DE02	BAGHOUSE	MILL FEED TO ROTARY VALVE FILTER	900 CFM	Proprietary, TBD	2021
1621-BN02	BIN	MILL FEED DIVERT BIN	-	Proprietary, TBD	2021
1621-DE01	BAGHOUSE	MILL FEED BAGHOUSE (FEEDER BREAKER DISCHARGE)	10,000 CFM	Proprietary, TBD	2021
1641-BC01	BELT CONVEYOR	MILL REJECTS BELT CONVEYOR	150 TPH	Proprietary, TBD	2021
1641-BN01	BIN	REJECT BIN	-	Proprietary, TBD	2021
MILL					
1631-RM01	VERTICAL MILL	MILL	100 TPH	Proprietary, TBD	2020
1651-CL01	HIGH EFFICIENCY	CLASSIFIER	100 TPH	Proprietary, TBD	2020
1661-HG01	PROPANE GAS BURNER	HOT GAS GENERATOR (Burner)	16.379 MW	Proprietary, TBD	2021
1651-BF01	BAGHOUSE	PRODUCT RECOVERY BAGHOUSE	158,916 ACFM	Proprietary, TBD	2020
1651-AS01	AIR SLIDE	AIR SLIDE PRODUCT RECOVERY BAGHOUSE	100 TPH	Proprietary, TBD	2021
1651-AS02	AIR SLIDE	AIR SLIDE PRODUCT RECOVERY BAGHOUSE	100 TPH	Proprietary, TBD	2021
1661DU03		Stack	80,800 Nm ³ /hr	Proprietary, TBD	2021
BALANCE OF PLANT					
AS-1001A	AIR SLIDE	MAIN COLLECTOR DISCHARGE AIRSLIDE 1	-	Proprietary, TBD	2021
AS-1001B	AIR SLIDE	MAIN COLLECTOR DISCHARGE AIRSLIDE 2	-	Proprietary, TBD	2021
AS-5045	AIR SLIDE	PRODUCT AIR SLIDE	100 TPH	Proprietary, TBD	2021
BE-5050	BUCKET ELEVATOR	PRODUCT STORAGE BUCKET ELEVATOR	150 TPH	Proprietary, TBD	2021
BF-5066	BAGHOUSE	PRODUCT STORAGE TRANSFER BAGHOUSE	2,350 CFM	Proprietary, TBD	2021
AS-5052	AIR SLIDE	PRODUCT STORAGE AIR SLIDE	100 TPH	Proprietary, TBD	2021
SI-5200	SILO	STORAGE SILO 1	5,000 TONS	Proprietary, TBD	2021
BF-5251	BAGHOUSE	STORAGE SILO BIN VENT 1	2,350 CFM	Proprietary, TBD	2021
CF-5260	FILTER	CARTRIDGE FILTER MODULE 1	1,800 CFM	Proprietary, TBD	2021
SP-5265	OTHER	TELESCOPING LOADOUT SPOUT 1	150 TPH	Proprietary, TBD	2021
Si-5300	SILO	STORAGE SILO 2	5,000 TONS	Proprietary, TBD	2021

EQUIPMENT ID / TAG	TYPE	DESCRIPTION	CAPACITY	MAKE & MODEL	MFR DATE
BF-5351	BAGHOUSE	STORAGE SILO BIN VENT 2	2,350 CFM	Proprietary, TBD	2021
CF-5360	FILTER	CARTRIDGE FILTER MODULE 2	1,800 CFM	Proprietary, TBD	2021
SP-5365	OTHER	TELESCOPING LOADOUT SPOUT 2	150 TPH	Proprietary, TBD	2021
AS-5015	AIR SLIDE	OFF-SPEC AIR SLIDE	100 TPH	Proprietary, TBD	2021
BE-5020	BUCKET ELEVATOR	OFF-SPEC BUCKET ELEVATOR	150 TPH	Proprietary, TBD	2021
BN-5000	BIN	OFF-SPEC BIN	60 TON	Proprietary, TBD	2021
BF-5041	BAGHOUSE	OFF-SPEC BIN VENT	900 CFM	Proprietary, TBD	2021
SC-5030	SCREW CONVEYOR	OFF-SPEC RECYCLE SCREW CONVEYOR	10 TPH	Proprietary, TBD	2021
UTILITIES					
TK-3201	TANK	GASOLINE STORAGE TANK 1,000 GAL.	1,000 GALLONS	Proprietary, TBD	2021
TK-3202	TANK	DIESEL STORAGE TANK 2,000 GAL.	2,000 GALLONS	Proprietary, TBD	2021
TK-3203	TANK	DIESEL STORAGE TANK 10,000 GAL.	10,000 GALLONS	Proprietary, TBD	2021
V-3301	PRESSURE VESSEL	PROPANE STORAGE TANK 30,000 GAL.	30,000 GALLONS	Proprietary, TBD	2021
V-3302	PRESSURE VESSEL	PROPANE STORAGE TANK 30,000 GAL.	30,000 GALLONS	Proprietary, TBD	2021
V-3303	PRESSURE VESSEL	PROPANE STORAGE TANK 30,000 GAL.	30,000 GALLONS	Proprietary, TBD	2021

APPENDIX 3

Site Maps and Proposed Process Flow Diagrams

Figure 1

Vicinity Map



Skull Valley

Kirkland Mine

Wilhoit

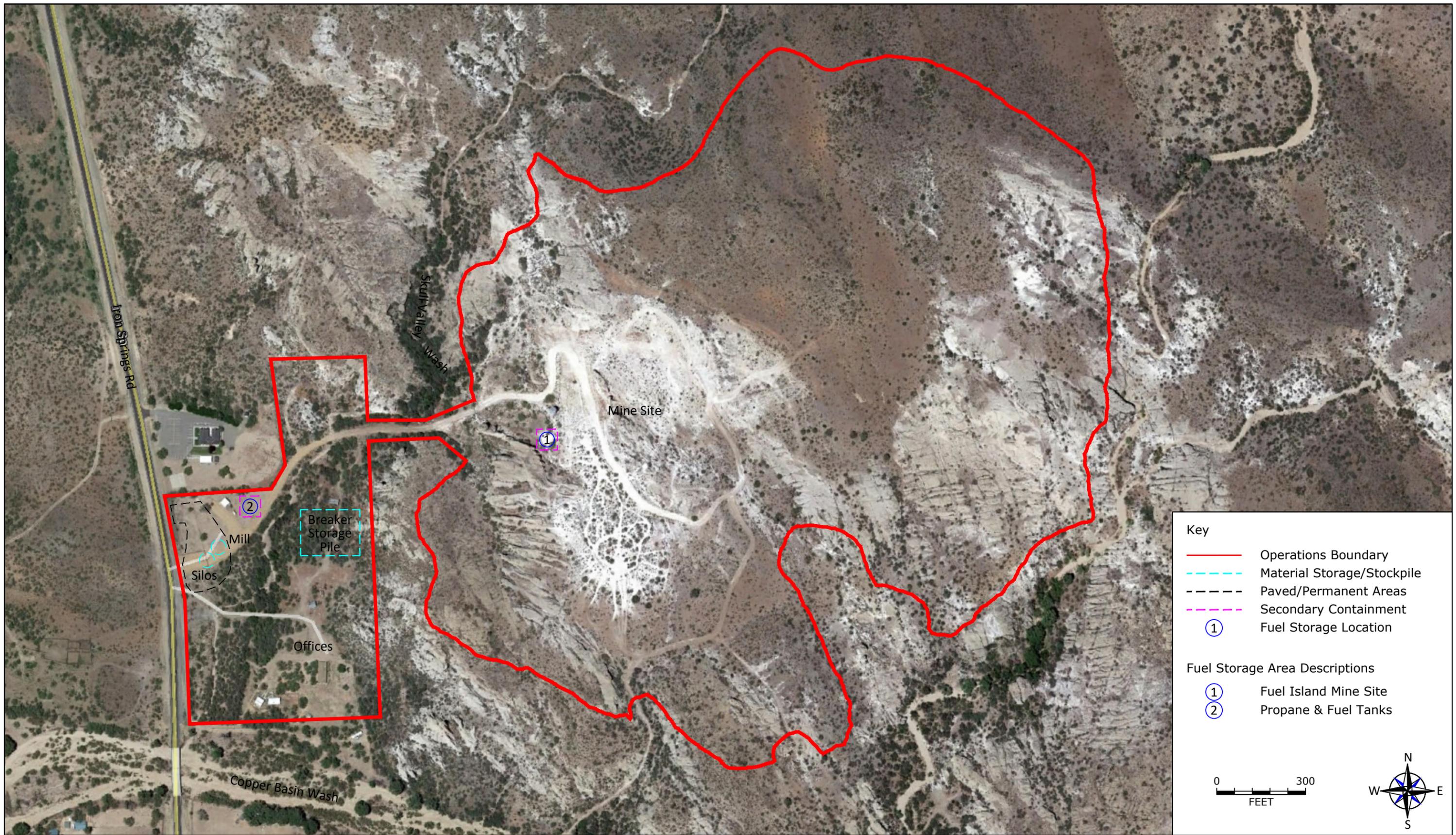
89

Google Earth

© 2021 Google

5 mi





Prepared For:

Prepared By:

Map Reference: Google Earth 6/11/2017



Class II Air Quality Control Permit Application
Boral Resources Kirkland Mine



Site Map Overview

Date: 04/15/2021

Figure: 2



BF-5251 Baghouse

BF-5351 Baghouse

BF-5066 Baghouse

CONCRETE VAULT
W/ MANHOLE
T/CONC. 4018.50

Employee entrance gate

1621-DE02
Baghouse

North entry gate

PLOT PLAN

Property Line ~300 feet north

Haul truck route ~
2,500 feet to mine

HIGH WATER
LEVEL EXISTING WASH
APPROX EL. 4011'-0"

RAW MATERIAL
BUILDING
FOUNDATION

Three sided
building open side

1621-DE21
Baghouse

BF-5041 Baghouse

1661-DU03 Main Stack

1651-BF01 Product
Recovery Baghouse

1661-HG01
Propane Burner

SEDIMENTATION
BASIN

FEEDER
BREAKER

53,673
GALLON WATER
TANK

PUMP
RAD

MAINTENANCE
BUILDING
FOUNDATION

PARKING

LAB

OFFICE/
BATH HOUSE
FOUNDATION

REJECT
BELT

MILL FEED
BELT

TANK #1

TANK #2

2"Ø STD WT
STEEL PIPE

4"Ø STD WT
STEEL PIPE

CRANE

(3) BURIED
24"Ø RCT

(2) BURIED
24"Ø RCT

RIGHT OF WAY

DWG No.
R200613- GA1-001

SCALE: NTS

DATE: 9/15/20

DESIGN BY: RAW

DRAWN BY: JKH/SDT

CHECKED BY: JKH

APPROVED BY: JKH

SHEET NO.

1

REVISION NO.

0

PROJECT NO.

XXXXXX

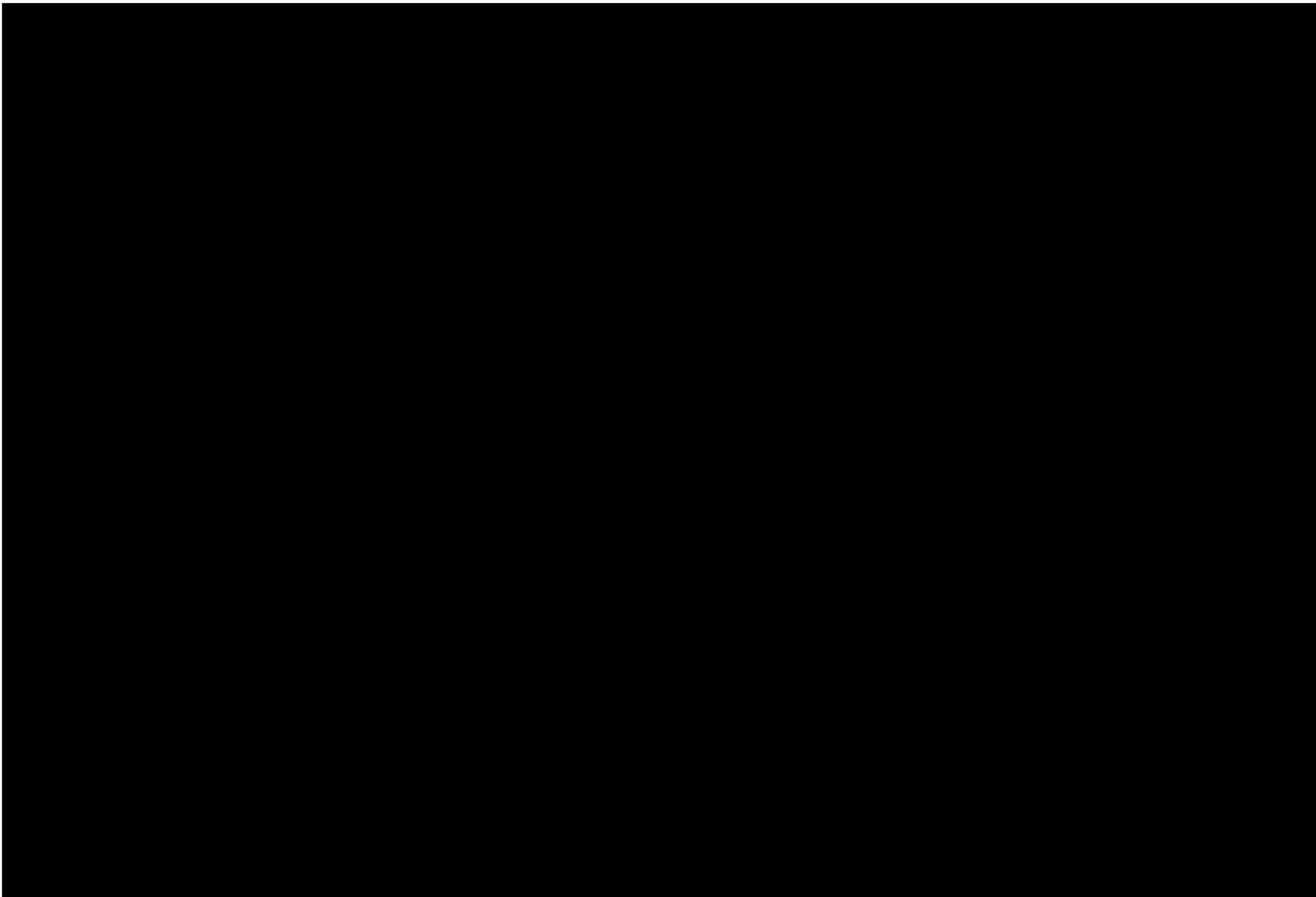
**BORAL
RESOURCES**

BORAL RESOURCES
200 MANSELL COURT EAST
SUITE 305
ROSWELL, GA 30076
(770) 645-4500
www.flyash.com

KIRKLAND POZZOLAN MINE
FIGURE 3
PLOT PLAN
KIRKLAND, AZ

REV	REVISION DESCRIPTION	DATE	BY	REV	REVISION DESCRIPTION	DATE	BY
0	RELEASED FOR CONSTRUCTION	4/13/21	JKH				

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APPENDIX 4

Supporting Documentation

AAF Filter 4200006

EFFICIENCY Certificate

██████████ 90595 / ARIZONA PUZZOLANA

AAF Dust Collector EFFICIENCY STATEMENT :

CASE - 1 :

GAS FLOW (Standard Cond. - 0°C / 1013 mbar / 0% humid.)	Nm ³ /h	165.145
GAS FLOW (Actual Cond. - 95°C / 835,3 mbar / 1% humid.)	Am ³ /h	270.000
DUST (GROSS) at Filter INLET : (Mill production)	T/h	90,7
	mg/h	90.700.000.000
	mg/Nm ³	549.214
DUST SIZE at Filter INLET :	microns	32
DUST at Filter OUTLET :	mg/Nm ³	10
DUST KEPT inside the Fiilter :	mg/Nm ³	549.204
EFICCIENCY :	%	99,9982

CASE - 2 :

GAS FLOW (Standard Cond. - 0°C / 1013 mbar / 0% humid.)	Nm ³ /h	152.912
GAS FLOW (Actual Cond. - 95°C / 835,3 mbar / 1% humid.)	Am ³ /h	250.000
DUST (GROSS) at Filter INLET : (Mill production)	T/h	77,1
	mg/h	77.100.000.000
	mg/Nm ³	504.212
DUST SIZE at Filter INLET :	microns	32
DUST at Filter OUTLET :	mg/Nm ³	10
DUST KEPT inside the Fiilter :	mg/Nm ³	504.202
EFICCIENCY :	%	99,9980

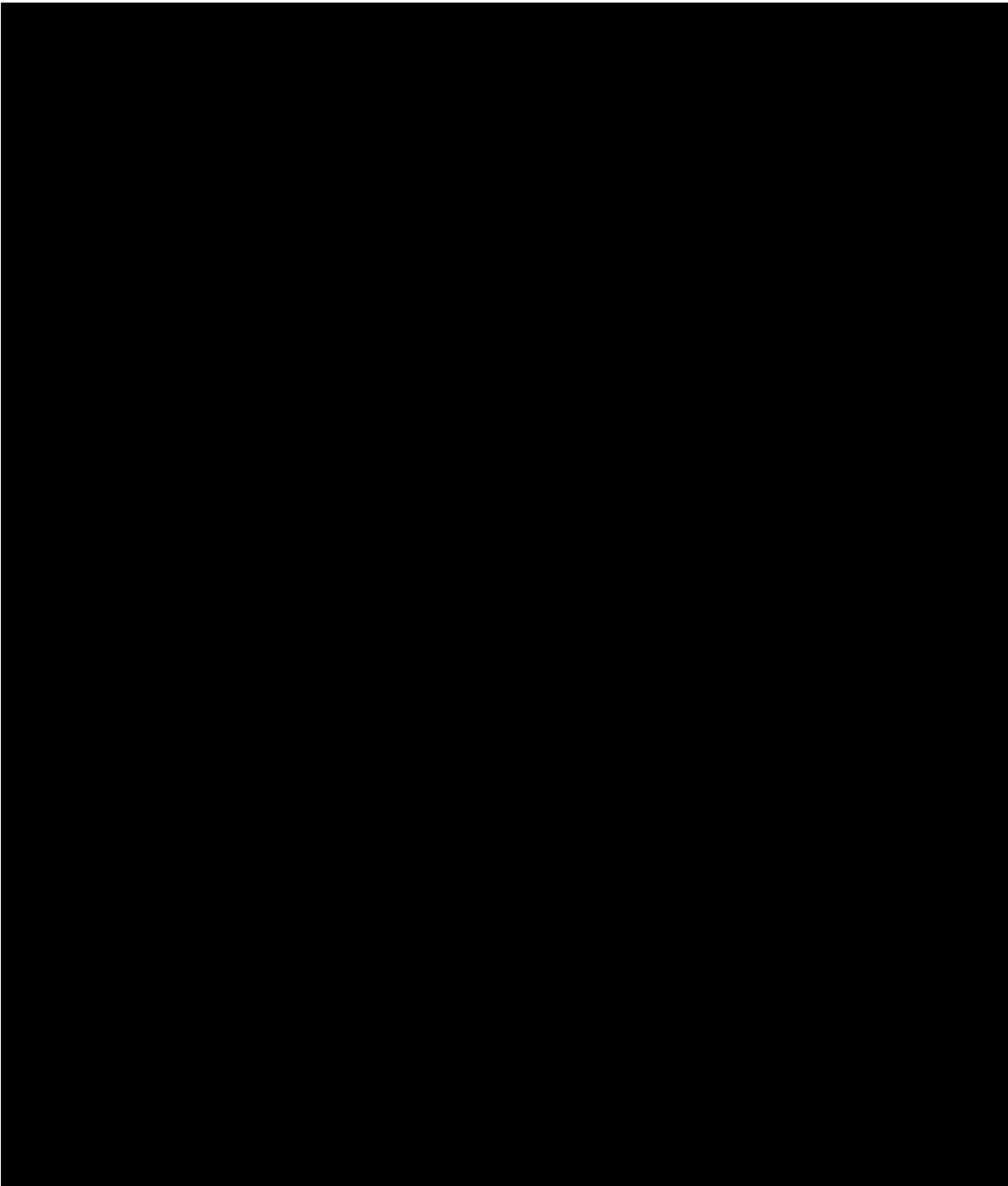
**EPA-ETV EFFICIENCY
275 Degree F**

VERIFICATION PARAMETERS	SB Non-Woven Spun Bond	SB-TX High Efficiency ePTFE Membrane
PM 2.5 Emissions (gr/dscf)	<0.0000638	<0.0000073*
Projected Efficiency	>99.99362 %	>99.99927 %
Total Mass Emissions (gr/dscf)	<0.0000675	<0.0000073*
Projected Efficiency	>99.99325 %	>99.99927 %

The testing laboratory and RTI have said that they cannot state emission efficiency accurately below .00001667gr/dscf. If the emissions measured is less than .00001667 gr/dscf it will be stated as less than.

<http://www.epa.gov/etv/pubs/600etv08039vr.pdf>

<http://www.epa.gov/etv/pubs/600etv11016vr.pdf>



FLUE GAS RECIRCULATION FOR REDUCTION OF NITROGEN OXIDES (NO_x) EMISSIONS IN INDUSTRIAL BOILERS



Revision Date: 4/04
Process Code: Navy/Marines: SER-010-03, SER-010-04; Air Force: FA03; Army N/A
Usage List: Navy: High; Marines: High; Army: High; Air Force: High
Alternative For: Normal combustion practices
Compliance Impact: Medium
Applicable EPCRA Targeted Constituents and CAS Numbers: N/A

Overview:

Flue gas recirculation (FGR) significantly reduces nitrogen oxides (NO_x) emissions (up to 60 percent) in industrial boilers by recirculating a portion of the boiler flue gas (up to 20 percent) into the main combustion chamber. This process reduces the peak combustion temperature and lowers the percentage of oxygen in the combustion air/flue gas mixture; thus retarding the formation of NO_x caused by high flame temperatures (thermal NO_x).

Nitrogen oxides (NO_x) emissions are a significant pervasive pollutant that causes a wide variety of diseases, contributes to ozone and smog formation, causes 20 to 30 percent of acid rain, and is the basis for visibility problems because of the formation of aerosols. Thermal NO_x is produced from the oxidation of nitrogen (N₂) at temperatures above 1500°F. Thermal NO_x is the primary source of NO_x formation from natural gas and distillate oils because these fuels are generally lower or devoid of nitrogen. Fuel NO_x, on the other hand, results from oxidation of nitrogen organically bound in the fuel. Therefore, FGR is not very effective on boilers that use fuels containing large amounts of fuel bound nitrogen.

Department of Defense installations have large numbers of single burner water tube and fire tube package boilers that supply steam and hot water to the installation. These boilers range in size from 0.4 million British thermal units per hour (MMBtu/hr) to 250 MMBtu/hr. The majority of these boilers are old, less than 50 MMBtu/hr, package boilers that lack any pollution control devices. This equipment is the major source of nitrogen oxide (NO_x) emissions at most military installations.

To modify an existing boiler, ducting must be run from the stack to the boiler air supply fan. Space limitations can make routing new ductwork difficult and costly. More powerful fans, oxygen monitors, and air flow controllers are usually required.

Compliance Benefit:

The use of FGR decreases the amount of NO_x formation at the facility and therefore may help facilities meet state air pollution control requirements (**40 CFR 52**). Additionally, this technology may help facilities meet the standards of performance for industrial-commercial-institutional steam generating units in **40 CFR 60**. A decrease in a facility's NO_x emissions may decrease the possibility that a facility will meet the NO_x emission threshold for an air permit under **40 CFR 70 and 71**.

The compliance benefits listed here are only meant to be used as general guidelines and are not meant to be strictly interpreted. Actual compliance benefits will vary depending on the factors involved, e.g., the amount of workload involved.

**Materials
Compatibility:**

FGR can almost always be used safely and effectively with existing burner hardware. FGR works particularly well with boilers which use clean fuels (e.g., natural gas, kerosene, and distillate oils). Any change in boiler configuration or operation should be checked to ensure that no flame impingement or other adverse change in operation occurs.

Safety and Health:

No significant changes in safety or health issues should result from the installation and implementation of FGR. Consult your local industrial health specialist, your local health and safety personnel, and the appropriate material safety data sheet (MSDS) prior to implementing this technology.

Benefits:

- Typically costs less to implement than low NOx burners, if installing as separate unit.
- Satisfies (in most situations) state NOx Reasonably Available Control Technology (RACT) regulations or other NOx emissions requirements.
- Provides potential for emission reduction credits Provides potential for increased boiler flexibility.
- If part of an integral system, may reduce energy and space requirements.

Disadvantages:

- May cause space limitations for recirculation ducts, fans, and additional air ports if FGR is installed separately.
- May require additional energy to run the recirculation fans if FGR is installed separately.
- Oxygen concentration must remain above 17 percent.
- Requires additional controls and instruments to control air flow over the desired operating range.

Economic Analysis:

Two 8.37 MM Btu/hr package #2 oil fired boilers at the Naval Consolidated Brig Marine Corps Air Station (MCAS) were retrofitted with a new FGR system and low-NOx burners, resulting in average NOx emissions of 130 parts per million (ppm) or 0.16 lb/MMBtu at full load when burning #2 oil. No adverse combustion conditions or boiler operating problems were encountered. However, the boiler efficiency dropped from 92 percent to about 89.5 percent due to the conversion to natural gas from #2 fuel oil. The cost attributed to retrofitting one boiler with ductwork, controls, and an uprated fan motor was \$20,000 (1992 dollars).

Each boiler has its own unique operating characteristics. Boilers of the same size and same equipment may have different operating requirements and combustion properties. Each boiler should be economically evaluated for FGR on an individual basis.

The \$20,000 cost included substantial effort on pre- and post-retrofit testing of NOx emissions and combustion conditions and the purchase and installation of oxygen (O₂) and carbon monoxide (CO) instrumentation. Additional operation and maintenance (O&M) costs associated with the system are expected to be minimal. If the FGR is installed as an integral system, built into the boiler front; maintenance costs may be significantly reduced. The dampers and the ductwork provided should present no additional operating costs and require only minimal maintenance. Any instrumentation and controls supplied will require the usual periodic calibration and repair associated with those devices. The annual

operating cost for maintenance will probably be decreased because of the increased reliability of the new equipment. Fuel costs increased due to the drop in efficiency by $(((92-89.5)/92) \times \text{fuel use of } 159,350 \text{ gallons})$ or 4330 gallons or about \$4,330. Fuel consumption increased due to reduction in efficiency; however, fuel costs were reduced as natural gas prices were lower.

Implementation of a FGR system is not likely to result in an economic benefit, indeed it is typically very expensive. However, if regulations change or there is a need to obtain NOx reductions, it is among the first alternatives that should be considered as it is often cheaper than many other alternatives.

Economic Analysis Summary:

- Annual Savings for FGR System: -\$4,330
- Capital Cost for Equipment/Process: \$20,000
- Payback Period for Investment in Equipment/Process: N/A

Note: With an integral system, maintenance savings may result in a less than 5 year payback, based on fuel cost estimates.

NSN/MSDS: None identified.

Approving Authority: Appropriate authority for making process changes should always be sought and obtained prior to procuring or implementing any of the technology identified herein.

Points of Contact: [For more information](#)

Vendors: This is not meant to be a complete list, as there may be other manufacturers of this type of equipment.

Gordon-Piatt Group
Division of John Zink Company, LLC
(Formerly Gordon-Piatt Energy Group, Inc.)
John Zink Company, LLC
11920 East Apache
Tulsa, OK 74116
Phone: 918-234-1800 or 800-421-9242 (U.S. and Canada)
Email: jzinfo@kochind.com
URL: http://www.johnzink.com/products/burners/html_gp/burn_gp.htm

Entropy Technology & Environmental Consultants, LP
12337 Jones Road, #414
Houston, TX 77070
Phone: (218) 807-7007
FAX: (218) 807-1414
Email: info@etecinc.net
URL: www.etecinc.net

Coen Company, Inc.
Steam Generation Systems Division
1510 Tanforan Avenue
Woodland, CA 95776

Phone: (530) 668-2100
FAX: (530) 668-2171
Email: marketing@coen.com
URL: www.coen.com

Related Links:

None.

Sources:

Bayard de Volo, Nick, Energy Technology Consultants, Inc., December 11, 1995, correspondence to John R. Guerra, Brooks Air Force Base, TX.
Evaluation of Air Pollution Control Technologies for Industrial Boilers, prepared by HSC/YAL, December 1995.
Steam: Its Generation and Use, The Babcock & Wilcox Company, 40th edition, 1992.
NOx Control Technology Data Source Book, EPA-600/2-91-029, NTIS PB91-217364.
Evaluation and Costing of NOx Controls for Existing Utility Boilers, EPA-453/2-92-010.

Article

Experimental Investigation of Primary De-NO_x Methods Application Effects on NO_x and CO Emissions from a Small-Scale Furnace

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Abstract: Nitrogen oxides (NO_x) from combustion contribute significantly to atmospheric pollution. An experimental setup was employed to investigate the application of three primary denitrification methods, i.e., reburning (staged combustion), overfiring air (OFA), and flue-gas recirculation (FGR), individually and in combination, combusting natural gas (NG) and propane–butane gas (PBG). Fuel heat inputs of 16 and 18 kW and air excess coefficients of 1.1 and 1.2, respectively, were tested. The highest individual denitrification efficiency of up to 74% was obtained for FGR, followed by reburning and OFA. A denitrification efficiency between 8.9% (reburning + OFA) and 72% (reburning + OFA + FGR) with NG combustion was observed. Using a 20% FGR rate yielded denitrification efficiency of 74% for NG and 65% for PBG and also led to a significant decrease in carbon monoxide (CO) emissions, so this can be recommended as the most efficient denitrification and de-CO method in small-scale furnaces. Reburning alone led to a sharp, more than 12-fold increase in CO emissions compared to the amount without any other method application. The presented results and the difference between our experimental data and the literature data acquired in some other studies indicate the need for further research.

Keywords: nitrogen oxides; reburning; flue-gas recirculation; furnace; combustion

1. Introduction

The use of primary energy sources (fuels) burdens the environment and impacts human health, both in the fuel mining and processing phases [1] as well as in the conversion processes to heat and power [2] or to mechanical energy in transportation systems [3]. Combustion of fuels yields, besides heat, harmful substances emitted into the atmosphere, such as fly-ash, particulate matter, carbon, sulphur, and nitrogen oxides as well as light and heavy metals (often radioactive), especially in liquid and solid fuel combustion. Nitrogen oxides (especially NO and NO₂) and their formation and reduction strategies, therefore, play an important role in the protection of the atmosphere [4].

NO_x formation during combustion is influenced by several parameters. The most important ones include combustion temperature, fuel nitrogen content and fuel composition [5,6], air excess coefficient [7] and air staging [7,8], combustion process reaction pathways [9], hydrodynamics, burner design [10] and load [5,7], and flue gas residence time [11]. Numerical studies using dedicated software enable their synergies to be assessed [12–15].

Oxycombustion is a widely studied means of combustion process energy efficiency improvement nowadays but with an ambiguous effect on NO_x formation [16–18]. A recent review by Liu et al., 2019 [19], surveyed the most important experimental research in the field of oxycombustion, concluding that NO_x formation was case-sensitive, strongly dependent on system design and operation specificities, and no general conclusion could be drawn on the impact of oxygen enrichment on NO_x formation.

The development and application of advanced flue gas denitrification methods have facilitated meeting the nitrogen oxide limit concentrations, which are steadily becoming more stringent [20]. Denitrification methods can be classified into primary and secondary ones [4,21]. Primary de- NO_x methods are based on nitrogen formation suppression directly during fuel combustion through the creation of a reduction zone, which lowers the flame temperature [22]. Secondary de- NO_x methods are based on nitrogen oxide reduction or scavenging from the flue gas downstream of combustion processes [23,24].

Primary methods include overfire air (OFA) [10,11,25–28], reburning [12,29–37], flue-gas recirculation (FGR) [13,23,38–41], and their combinations [14,42–45]. They are cheaper than the secondary ones, however the thermal efficiency of combustion aggregate decreases as a result of combustion temperature lowering, and there is a subsequent increase in unburnt carbon content in ash and fly-ash. OFA is based on substoichiometric ($m = 0.7$ to 0.8) fuel combustion with air [25]. The resulting reduction atmosphere suppresses nitrogen oxide formation. Previous studies [10,27,28] confirm that staged air introduction can help in reducing NO_x emissions from combustion but can negatively impact the energy performance of the combustion process. The “reburning” method includes the creation of a zone in the combustion chamber with a lack of oxygen, which in turn leads to nitrogen oxide reduction [12,29]. Low-quality gaseous or solid fuel or waste fuels can be used for this purpose [30]. Primary fuel is combusted with a substantial air excess coefficient, which decreases flame temperature and suppresses NO_x formation [31]. Optimal means of reburning integration with other denitrification methods for further improvement in NO_x emissions reduction were proposed in [14,42]. Flue-gas recirculation (FGR) is one of the simplest and cheapest denitrification methods. It is based on returning part of the obtained flue gas back to the combustion zone. Internal recirculation is achieved in modified burners, resulting in combustion air and flue gas mixing [38,39]. External recirculation is characterized by returning part of the partly cooled flue gas into the space above the burners [15,40]. Flue-gas recirculation is a cheap denitrification method, which is often used to assist other methods in achieving greater denitrification.

Analyzed studies suggest that the synergic effect of simultaneous application of multiple primary denitrification methods varies significantly with the fuels combusted as well as with combustor operation and design. Effects on the emissions of other pollutants, such as carbon monoxide, are to be considered along with NO_x emissions to truly prove the beneficial environmental impact of specific denitrification methods. Comprehensive information on their application can be found in a few recently published studies [35,44] with significant differences in their findings. So the key question to be answered with the intention of contributing significantly to environmental protection is: which individual method and which combination of methods would serve as the best for reducing nitrogen oxide emissions while also preventing an increase in other gaseous pollutants? The present experimental study addresses this question by investigating the application and resulting denitrification efficiency of several primary denitrification methods and their combinations and evaluating their impact on carbon monoxide emissions as well. The methods and combinations applied were:

1. OFA
2. Reburning
3. FGR
4. OFA + reburning
5. OFA + reburning + FGR

Natural gas and propane–butane gas served as widely available gaseous fuels. In this way, problems related to particle sizes and their distribution, their porosities, moisture content, and many others, which must be considered when testing solid fuels, did not arise. Carbon monoxide is a common product of incomplete combustion, thus studying changes in its emission levels along with the application of various denitrification methods can be considered representative enough to assess those of other relevant greenhouse gases as well.

2. Materials and Methods

2.1. Experimental Setup

The experimental setup used for denitrification efficiency estimation of individual nitrogen oxide emissions reduction methods and their combination is shown in Figure 1. The following parameters were adjusted in the FGR method: recirculation rate, combustion air excess, and fuel flow rate. The reburning method used an adjustable reburning fuel flow rate. Denitrification efficiency in all three primary methods applied individually and in combination was evaluated at a constant fuel heat input.

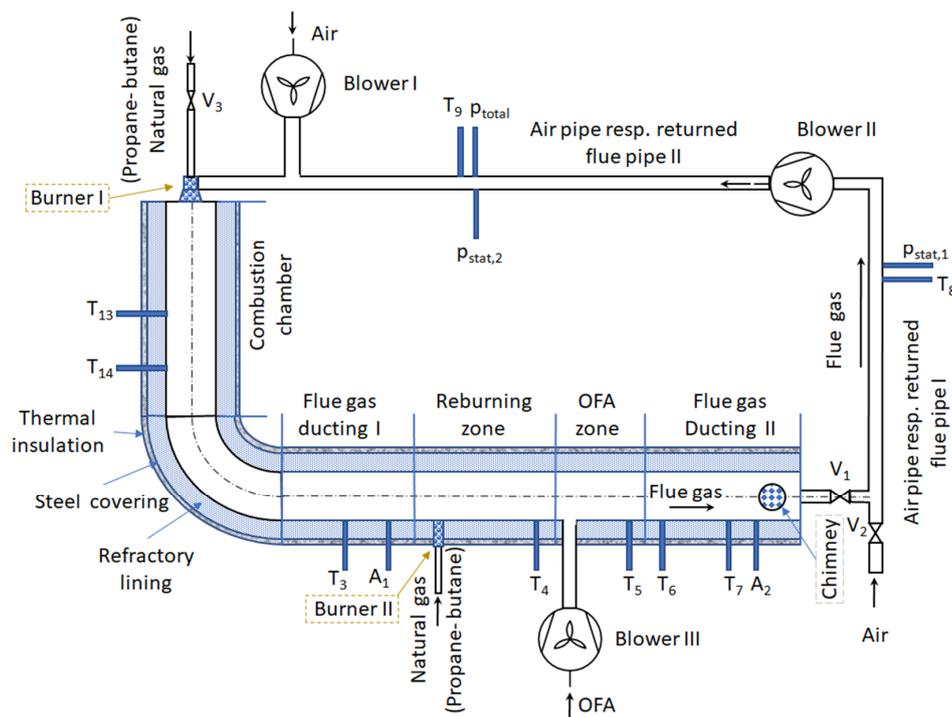


Figure 1. Experimental setup scheme with main equipment dimensions listed in mm. Legend: T—thermocouple, A—analyzer, V—throttle valve, p_{stat} —static pressure, p_{total} —total pressure, OFA— overfire air.

The experimental setup comprised the following: combustion chamber, flue-gas duct, stack, and three fans. The main burner combusting premixed primary fuel with air (primary air in the OFA application) was located at the front of the combustion chamber. Two Pt-RhPt thermocouples (T13, T14)

were located in the combustion chamber. Reburning fuel could be introduced into the central part of the flue-gas duct, and the reburning zone was followed by OFA entry and the afterburning zone.

Temperature in the flue-gas duct was measured by means of five Cr-Al thermocouples (T3 to T7). Two flue-gas analyzers (A1 and A2) served for flue-gas composition estimation in the duct and at the flue gas to stack discharge point. Supplementary burners were operated at the top of the stack to reduce CO emissions into the environment. Fuel flow rates were regulated with throttling valves. Natural gas was provided from the distribution network and propane–butane gas was supplied from gas cylinders. The composition of NG and PBG is provided in Tables 1 and 2, respectively.

Table 1. Composition of natural gas (NG) in % vol.

CH ₄	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₅ H ₁₂	CO ₂	N ₂
98.04%	0.77%	0.26%	0.08%	0.02%	0.06%	0.77%

Table 2. Composition and properties of propane–butane gas (PBG).

Propane–Butane	Density in the Liquid Phase (kg/dm ³)	Density in the Gas Phase (kg/m ³)	Calorific Value (Lower Heating Value) (MJ/m ³)	Composition (% vol.)
C ₃ H ₈	0.508	2.019	92.97	40
C ₄ H ₁₀	0.585	2.59	123.74	60

Thermocouple T3 and analyzer A1 were located in the first part of the duct, enabling us to monitor flue-gas temperature and composition before reburning and the OFA zone. The other four thermocouples were located downstream: T4 at the end of the reburning zone, T5 at the afterburning zone end, and T6 and T7 in the second part of the duct.

Positions of individual thermocouples and their distance from the burner, as shown in Figure 1, are specified in Table 3.

Table 3. Distance of individual thermocouples from burner outflow.

Thermocouple	T13	T14	T3	T4	T5	T6	T7
Distance (m)	0.25	0.35	0.95	1.7	1.95	2.0	2.1

The following gas meters were used for fuel flow rate estimation:

Primary fuel: type G 4 BK, $Q_{\max} = 6 \text{ m}^3/\text{h}$, $Q_{\min} = 0.016 \text{ m}^3/\text{h}$, $V = 1.2 \text{ dm}^3$, $p_{\max} = 20 \text{ kPa}$, 1 imp 0.01 m³,

Reburning fuel: type G 1.6 BK, $Q_{\max} = 2.5 \text{ m}^3/\text{h}$, $Q_{\min} = 0.016 \text{ m}^3/\text{h}$, $V = 1.2 \text{ dm}^3$, $p_{\max} = 20 \text{ kPa}$, 1 imp 0.01 m³.

Testo 350 XL (A2) and Testo 325 (A1) analyzers were employed for the flue-gas composition analysis. Appendix A contains detailed information about NO_x and CO measurement methods and measurement errors of both analyzers.

2.2. Primary Denitrification Methods Application

Measurements with NG used both as main and reburning fuel were conducted under steady air excess coefficient conditions ($m = 1.1$ or 1.2) and under steady fuel thermal inputs of 16 or 18 kW, respectively.

NO_x emissions were measured first without any de-NO_x method application, followed by application of individual methods and subsequently their combinations.

Emissions of nitrogen oxides and carbon monoxide as well as flue-gas temperature measurements were performed for various natural gas total heat inputs under various process modifications. An overview of performed experiments with individual methods and their combinations is provided in Table 4.

Table 4. Primary methods applied individually and in combination. Legend: FGR—flue-gas recirculation.

Ratio	Combustion without/with Primary Denitrification Method Applied Individually			
	Without	FGR	Reburning	OFA
10, 15, 20% 10, 15, 20, 25%				
Combustion with Primary Denitrification Methods Applied in Combination				
Combination			10, 15, 20% Reburning	OFA
Combination		10, 15, 20% FGR	10% Reburning	OFA

Measurements with PBG combusted were conducted under steady air excess coefficient conditions ($m = 1.1$ or 1.2) and under steady fuel thermal inputs of 16 to 22 kW, respectively. Combustion without any primary method application was compared with flue-gas recirculation rate of 10 to 20% in measurements.

A detailed description of performed measurements is provided in Appendix B.

3. Results

3.1. Natural Gas (NG) Combustion Experiments

This section presents the results of applying primary de- NO_x methods to a natural gas-fired system. Denitrification efficiency of flue-gas recirculation, reburning, overfire air use, and combinations of these were evaluated at natural gas thermal inputs of $Q = 1.5$ and $1.8 \text{ m}^3/\text{h}$ and air excess coefficients of $m = 1.1$ and 1.2 , respectively.

Figure 2 depicts the measured nitrogen oxide emissions and denitrification efficiency of individual primary methods and their combinations at $Q = 1.5 \text{ m}^3/\text{h}$ and $m = 1.1$. Reburning proved to be an efficient primary method; with a rising reburning ratio from 10 to 25%, the denitrification efficiency rose from 9 to over 60%. Overfire air use, whether applied separately or in combination with reburning, did not lead to a significant nitrogen emissions reduction.

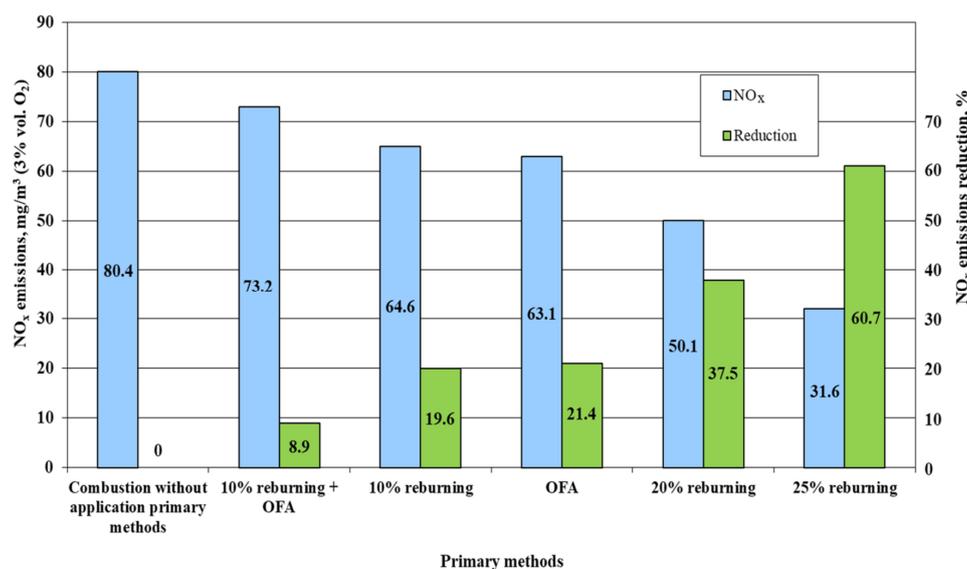


Figure 2. Nitrogen oxide emissions (expressed in mg/m^3 at 3% vol. oxygen in dry flue gas under normal temperature and pressure) and their reduction after the application of reburning and overfire air methods at total fuel input $Q = 1.5 \text{ m}^3/\text{h}$ and air excess coefficient $m = 1.1$.

The effects of flue-gas recirculation on nitrogen emissions and its comparison with reburning application at $Q = 1.5 \text{ m}^3/\text{h}$ and $m = 1.1$ are shown in Figure 3. Flue-gas recirculation halved the NO_x emissions even at 10% recirculation, and the final NO_x emissions at 20% flue-gas recirculation dropped to roughly $20 \text{ mg}/\text{m}^3$, representing denitrification efficiency of almost 75%. A further increase in flue-gas recirculation was hindered by a significant increase in CO emissions, leading us to conclude that flue-gas recirculation of 20% is the upper limit for feasible combustor operation. Comparison with reburning shows that flue-gas recirculation is a more efficient NO_x emissions reduction method, as it reduced them by half at a reburning ratio of over 20% (compare Figures 2 and 3), while 25% represents the upper limit of commonly applied reburning ratios.

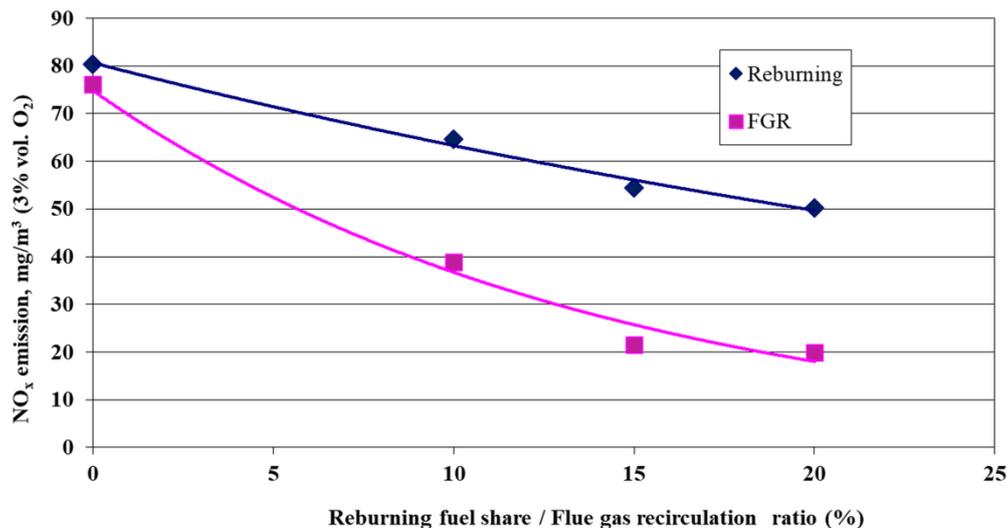


Figure 3. Flue-gas recirculation and reburning methods: denitrification efficiency comparison at total fuel input $Q = 1.5 \text{ m}^3/\text{h}$ and air excess coefficient $m = 1.1$.

The nitrogen oxide reduction values shown in Figure 2 were calculated as relative nitrogen oxide emission differences resulting from measured nitrogen oxide emissions after primary methods application compared to those measured without any denitrification method applied, as follows:

$$R = \frac{(C_{WAPM} - C_{APM})}{C_{WAPM}} \cdot 100 (\%) \quad (1)$$

where R refers to emissions reduction (%), C_{WAPM} stands for nitrogen oxide emissions without application of primary methods, and C_{APM} represents emissions with application of primary methods.

Figure 4 presents the trends in carbon monoxide content in flue gas with the application of individual primary methods and their combinations. Flue-gas recirculation applied alone helped in decreasing CO emissions, compared to the situation without the application of any de- NO_x method. Therefore, it can be concluded that the FGR method was able to significantly reduce both NO_x and CO emissions (see Figure 3 for comparison) and could thus be considered as a very promising method when striving towards reduction of combustion processes' environmental impact. All other de- NO_x methods and their combinations resulted in increased CO emissions by around $30 \text{ mg}/\text{m}^3$ (OFA + 10% reburning) to over $1100 \text{ mg}/\text{m}^3$ (20% reburning). Reburning itself proved to be a less effective de- NO_x method than FGR (see Figure 3), yielding substantially higher CO emissions than FGR. Therefore, the application of reburning alone does not appear sensible. Its combination with overfire air, however, reduced the NO_x emissions significantly (see Figure 2) and helped approach the emission limit for CO ($200 \text{ mg}/\text{m}^3$). This results from the fact that overfire air introduction leads to oxidation of a major portion of the carbon monoxide formed in the reburning zone.

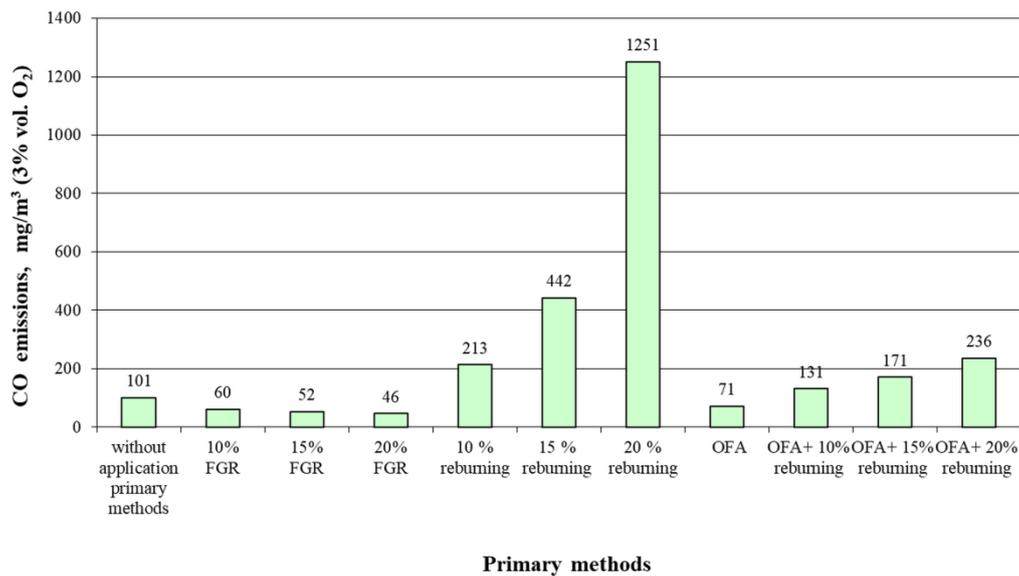


Figure 4. CO content in flue gas is a result of application of individual de-NO_x methods and their combinations at total fuel input $Q = 1.5 \text{ m}^3/\text{h}$ and air excess coefficient $m = 1.1$.

Figure 5 explains the reaction mechanisms leading to NO_x and CO formation in individual temperature zones of the furnace and allows monitoring of temperature trends resulting from primary de-NO_x methods application.

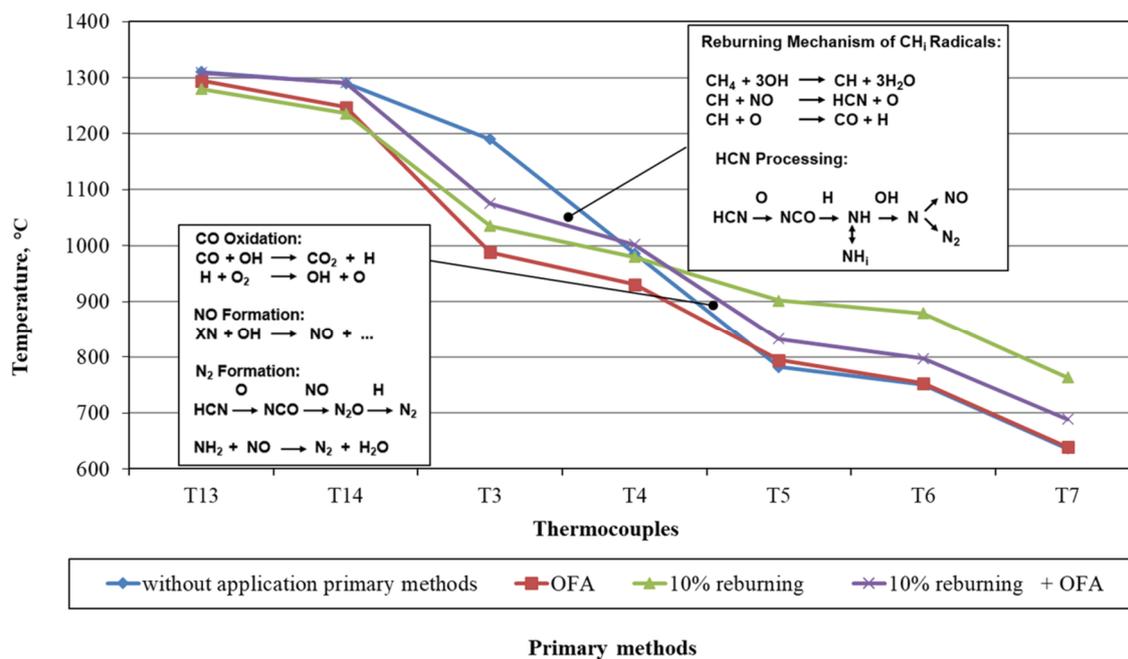


Figure 5. Measured flue-gas temperatures through the furnace during experiments involving fuel input $Q = 1.5 \text{ m}^3/\text{h}$ and air excess coefficient $m = 1.1$.

NO_x generated in the main combustion zone (Figures 1 and 5, between T13–T14) reacted with fuel remnants injected into the reburn zone (Figures 1 and 5, between T3–T4), which reduced it to molecular nitrogen. Reburning chemistry involves fuel radicals, which reduce NO to N₂ [32,46]. Reburning increases the flue-gas temperature from thermocouple T4 onwards, compared to OFA application or no de-NO_x-method use.

The addition of overfire air completed combustion in the burn-out zone (Figures 1 and 5, between T4–T5), but the reaction heat released by CO and hydrocarbon fragments was not enough to compensate for the cold, fresh air introduced, and as a result the flue-gas temperature decreased from T5 onwards, compared to the application of reburning alone.

A similar series of measurements was conducted at natural gas thermal input $Q = 1.8 \text{ m}^3/\text{h}$ and air excess coefficient $m = 1.2$, with the results shown in Figures 6 and 7. A comparison of the data shown in Figures 2 and 6 revealed that the latter combustor operation conditions generally yielded higher NO_x emissions by around 75 to 100%, which is in accordance with current knowledge on nitrogen oxide formation in combustion processes. Considering the previous finding about FGR application effects, this method was combined with modest reburning (reburning ratio of 10%) and overfire air. Figure 6 documents that the combination of 10% reburning ratio, overfire air, and 10% FGR more than halved the NO_x emissions compared to the situation without any primary de- NO_x method application. Further increases in denitrification efficiency can be followed in Figure 7 with increasing FGR, with the highest efficiency value of over 70% being reached at 20% FGR. In contrast to this, application of either modest reburning (reburning ratio of 10%) or overfire air or their combination did not lead to significant denitrification, and the same could be observed at a lower burner load and lower air excess coefficient—see Figure 2. In both situations the denitrification efficiencies reached below or around 20% maximally.

As Figure 6 further shows, denitrification efficiency is closely coupled with combustion temperature. The decrease in combustion temperature resulting from the application of primary denitrification methods hinders the formation of thermal NO_x , which, together with the creation of a reductive environment, leads to effective nitrogen oxide emissions reduction. Test experiments aimed at verification of both temperature measurements' stability and sensitivity to combustion conditions were performed and their results, shown in Appendix C, prove that temperature changes of around $10 \text{ }^\circ\text{C}$ and higher can be clearly recognized and attributed to process condition changes. This justifies the conclusions drawn from the analysis of the temperature data and their trends presented in Figures 5 and 6.

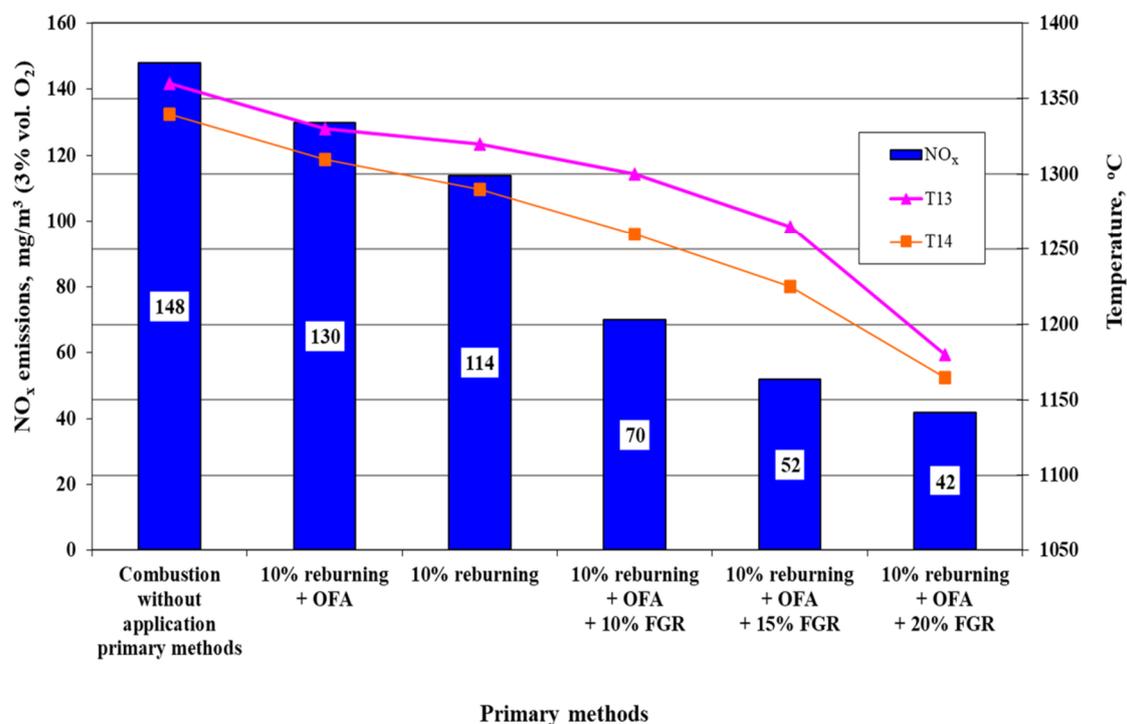


Figure 6. NO_x emissions (expressed in mg/m^3 at 3% vol. oxygen in dry flue gas under normal temperature and pressure) and measured temperatures in the combustion chamber after the application of primary methods in combination at total fuel input $Q = 1.8 \text{ m}^3/\text{h}$ and air excess coefficient $m = 1.2$.

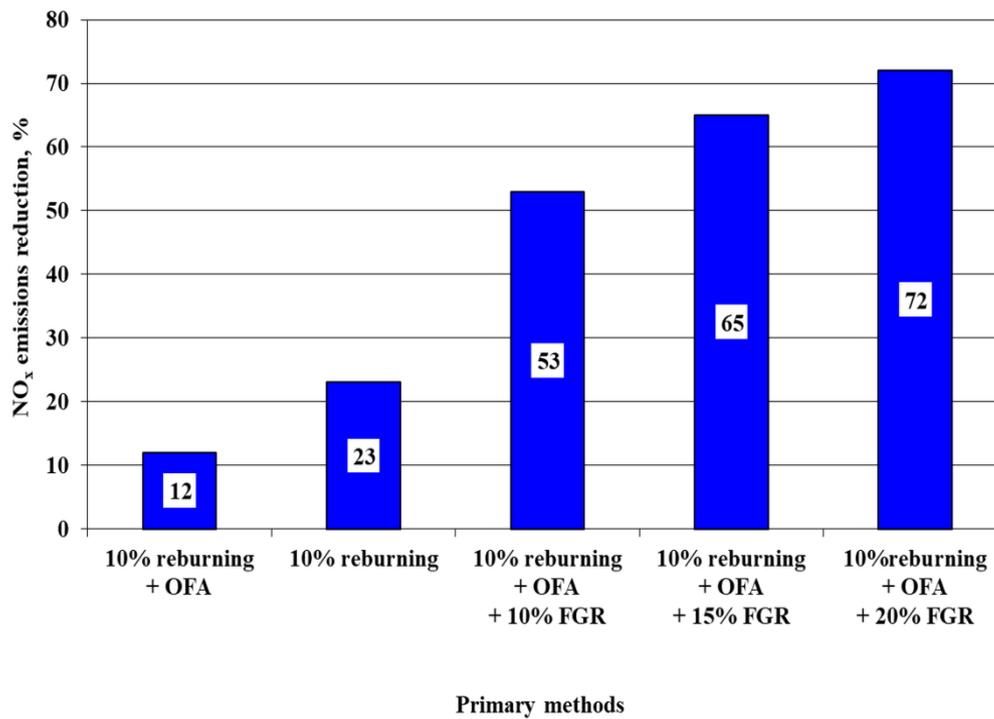


Figure 7. NO_x emissions reduction achieved after application of primary methods and their combinations at total fuel input $Q = 1.8 \text{ m}^3/\text{h}$ and air excess coefficient $m = 1.2$.

It can be concluded that OFA application should be part of any combined primary de-NO_x method, as it is able to reduce both NO_x and CO contents in flue gas on its own, and when applied together with reburning and OFA it should ensure very efficient denitrification while still meeting the CO emission limits.

3.2. Propane–Butane Gas (PBG) Combustion Experiments

This section presents the results of primary de-NO_x methods application during propane–butane gas combustion, carried out in parallel with our natural gas combustion experiments. The combustion conditions involved a range of total fuel input $Q = 16$ to 22 kW and overall air excess coefficient $m = 1.1$ and 1.2 , respectively. Having found that flue-gas recirculation was the most efficient denitrification method in natural gas combustion experiments, it was applied as the sole de-NO_x method in our PBG experiments as well.

Figure 8 provides a comparison of NO_x emissions in PBG experiments as a result of different fuel input and air excess coefficient values, with no other denitrification method applied. As expected, and in line with our NG experiment results, increased fuel input and air excess coefficient led to an increase in emissions. Nitrogen oxide emissions values in our PBG experiments were around 20% higher than those observed in the NG experiments under identical conditions (i.e., $Q = 1.5 \text{ m}^3/\text{h}$ and $m = 1.1$; $Q = 1.8 \text{ m}^3/\text{h}$ and $m = 1.2$): compare Figures 2 and 6.

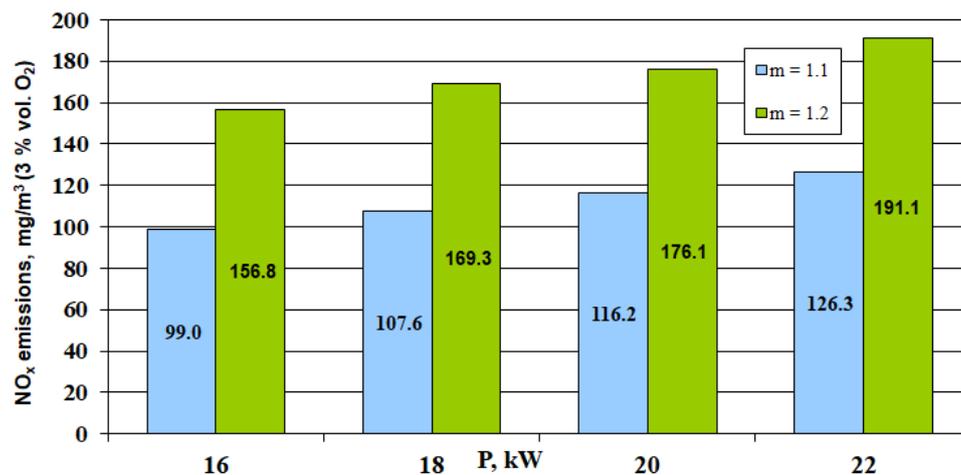


Figure 8. Nitrogen oxide formation (expressed in mg/m^3 at 3% vol. oxygen in dry flue gas under normal temperature and pressure) as a result of variable burner fuel input and air excess coefficient $m = 1.1$ and 1.2.

The impact of FGR application on NO_x emissions reduction in PGB experiments at burner power input 16 kW and air excess coefficient $m = 1.1$ is shown in Figure 9. The obtained results are similar to those in our NG experiments, yielding an NO_x content decrease with the introduction and increased share of flue-gas recirculation. Both Figures 3 and 9 reveal that the application of 10% FGR decreased the NO_x emissions approximately by half, and a further emissions reduction was achieved with greater FGR increase. Denitrification efficiency of almost 65% was achieved at 20% FGR in our PGB experiments, which is somewhat lower than the almost 75% efficiency documented in the NG experiments under identical conditions.

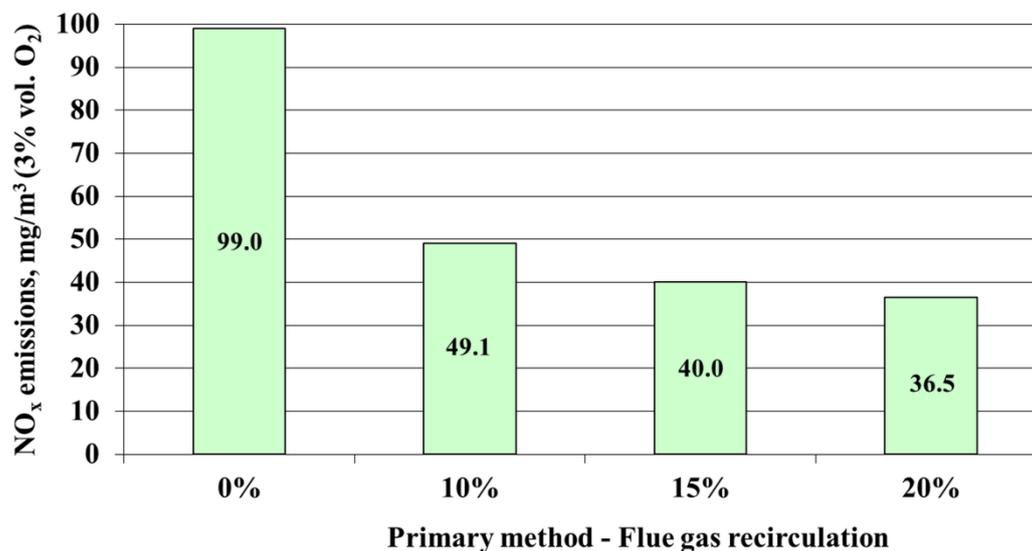


Figure 9. NO_x emissions (expressed in mg/m^3 at 3% vol. oxygen in dry flue gas under normal temperature and pressure) dependence on flue-gas recirculation at burner power input 16 kW and air excess coefficient $m = 1.1$.

Similar to the NG experiments, denitrification was found to be closely related to flue-gas temperature in the PGB combustion chamber. Its values for 10%, 15%, and 20% FGR are provided in Figure 10. The more modest decrease in combustion temperature (thermocouples T13 and T14) of around 50 °C documented in Figure 10 resulting from an FGR increase from 10% to 20% is lower than

the over 100 °C combustion temperature decrease shown in Figure 6 resulting from FGR increase in the same range in the NG experiments. This probably allows for a partial explanation of why the denitrification efficiency increase in our PBG experiments in the range of 10% to 20% FGR is lower than in the NG experiments.

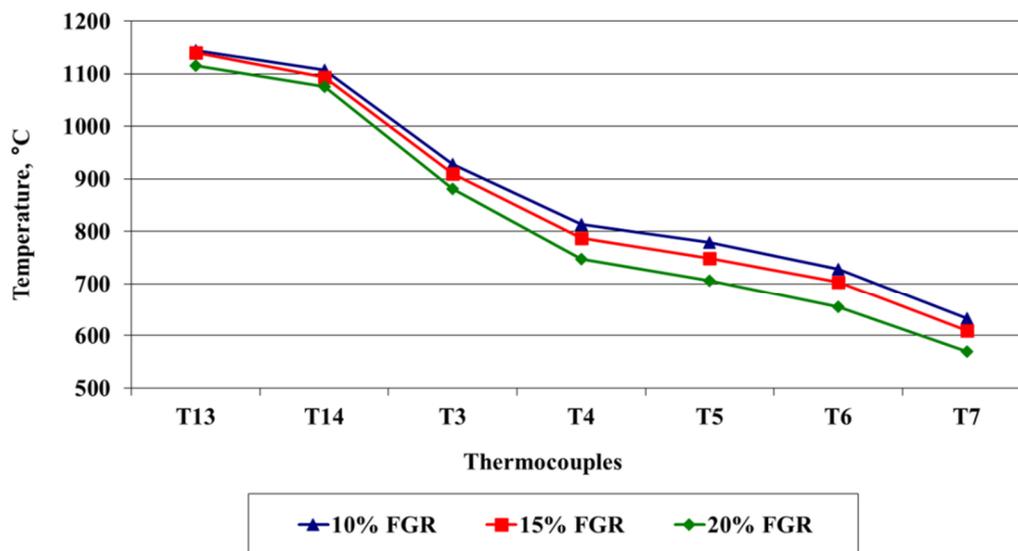


Figure 10. Effect of increasing flue-gas recirculation share on the course of the temperature field through the furnace at burner power input 16 kW and air excess coefficient $m = 1.1$.

For this reason, experiments with FGR application alone during both NG and PBG combustion are compared in Figure 11 in terms of calculated NO_x emissions reduction efficiency.

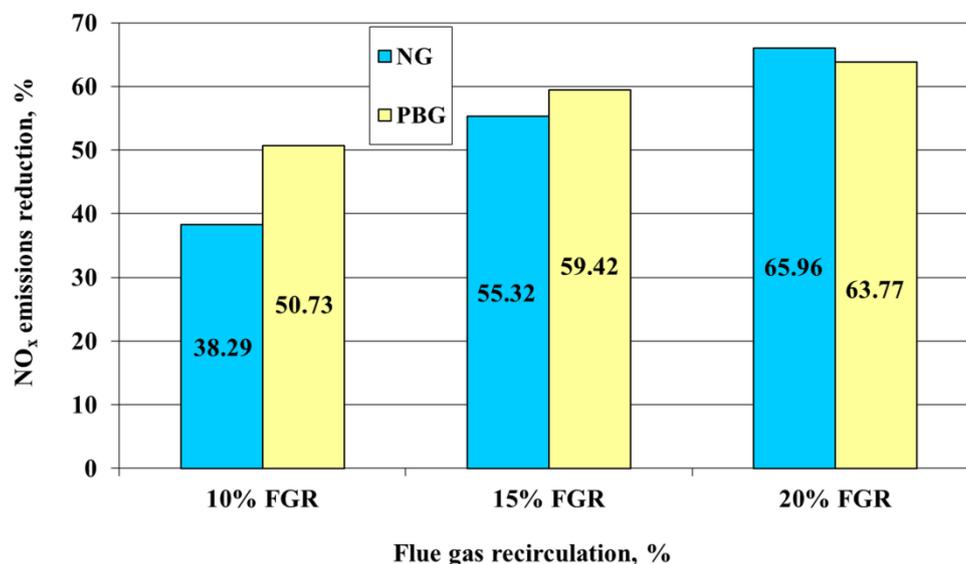


Figure 11. Nitrogen oxide emissions reduction after the application of flue-gas recirculation: comparison of natural gas (NG) and propane-butane gas (PBG) combustion at various flue-gas recirculation rates. For both fuels, burner power input was 16 kW and air excess coefficient $m = 1.1$.

The trend in nitrogen oxide emissions decrease with increasing FGR can be readily observed in both fuel-type experiments, while the previously commented steeper NO_x emissions decrease in NG experiments is clearly confirmed. As a result of the NO_x formation reaction mechanisms, the emissions

were suppressed due not only to the lower combustion temperature but also to the lower oxygen partial pressure resulting from FGR implementation. The greater NO_x emissions reductions observed in our PBG experiments compared to those in the NG experiments most probably resulted from slower combustion of PBG fuel and from its higher volumetric heating value. Higher PBG adiabatic flame temperature compared to NG can play a significant role in this respect too. It results from the observations above that combusted fuel type as well as combustion conditions play an important role in NO_x formation and reduction processes. Combustion of PBG yields lower volumetric flow of recirculated flue gas compared to NG for the same burner heat input.

4. Discussion

Our experiments conducted with natural gas and PBG fuels allowed us to document several trends regarding nitrogen oxide and carbon monoxide contents in flue gas from a laboratory furnace:

1. Considering de-NO_x methods applied individually (Figures 2 and 3), FGR yielded the highest denitrification efficiencies of up to 74% (at 20% FGR), followed by reburning (61% at 25% reburning ratio), whereas OFA application resulted only in a modest 21% NO_x concentration decrease. FGR appears to be the most promising method for decreasing NO_x emissions, regardless of the type of gaseous fuel combusted (compare Figures 3 and 9). A range of flue-gas denitrification efficiencies due to FGR implementation is reported in the literature, starting with up to 30% or up to 50% in burners equipped with internal flue-gas recirculation systems [38,39] and exceeding this in external recirculation systems [15]. Thus, it can be concluded that external flue-gas recirculation appears to be a more efficient de-NO_x method, though it requires bigger intervention in boiler or furnace design than the mere implementation of burners with internal recirculation.
2. Combined application of de-NO_x methods revealed negative synergic effects with OFA + 10% reburning, achieving a lower NO_x concentration reduction than the application of OFA and 10% reburning individually (Figures 2 and 6). In contrast, the available experimental and numerical studies [14,42] propose the reburning + OFA combination as a very effective means of flue-gas denitrification and report positive synergy effects. Combined application of 10% reburning + OFA + 20% FGR reduced the NO_x content in flue gas by 72%, which is in line with de-NO_x efficiencies of over 50% for combined method application reported in the available literature. For comparison, [43] used a combined OFA + FGR method in a 100 kW facility, combusting various gaseous and solid fuels, reaching up to 80% decrease in NO content in flue gas.
3. Increasing the burner load from 16 to 18 kW and the air excess coefficient from 1.1 to 1.2 resulted in 50% to 70% higher NO_x emissions, regardless of whether NG or PBG was combusted (Figures 2, 6 and 8), with the air excess coefficient increase visibly playing the major role in NO_x emissions increase, which is in line with the findings of the study by Dutka et al., 2016 [5]. However, denitrification efficiencies of individual methods and their combinations appeared to be only modestly affected by burner load and air excess coefficient in our experiments (Figures 2, 3 and 7).
4. FGR, as the most promising de-NO_x method, was applied in our PBG combustion tests, achieving similar denitrification efficiency as in the NG combustion tests (Figure 11). However, denitrification efficiency increase with rising flue-gas recirculation was more pronounced in the case of NG combustion. This could be explained in terms of the far more pronounced temperature drop in the main combustion chamber (thermocouples T13, T14) observed in our NG combustion tests with rising flue-gas recirculation. Comparison of the respective temperature values in Figures 6 and 10 reveals that temperature drops of over 100 °C could be documented for NG combustion compared to around only 50 °C for PBG combustion. This finding deserves more attention and further investigation in the future, as the relevant literature surveyed [43] suggests that similar trends should be obtained with similar gaseous reburning fuels.
5. FGR yielded a visible decrease in carbon monoxide emissions (Figure 4). A modest decrease in flue-gas CO content could be seen after OFA application as well; however, reburning produced a

sharp, more than 12-fold increase in these emissions (1251 mg/m^3) compared to that without any de- NO_x method application (101 mg/m^3). This could partly be resolved by combined reburning + OFA application, but the reburning fuel share should be limited to around 15% in order not to violate the CO emissions limit of 200 mg/m^3 . In contrast to this, [35] did not observe any significant effect of reburning application on CO emissions, despite similar experimental furnace heat input (65 kW vs. 16 to 22 kW in this study) and despite the same fuel being used both as the main and reburning fuel (NG). [44] performed experiments with various recirculated flue-gas introduction spots in an experimental heavy fuel oil-fired furnace, namely direct mixing with primary air, separate introduction after primary air supply, and separate introduction after secondary air supply. Compared to basic-case CO emissions of around 20 mg/m^3 , all reburning options produced an increase in CO emissions, compared to operation without FGR. The differences documented above allow us to conclude that CO formation and conversion to CO_2 with primary de- NO_x methods application is a complex phenomenon yielding very variable results even under seemingly similar experimental conditions. Further work on this topic needs to be done.

5. Conclusions

An experimental laboratory furnace setup was used to assess the trends and variations in nitrogen oxide and carbon monoxide emissions from natural gas and propane–butane gas combustion. Individual primary flue-gas denitrification methods as well as their combined use allowed us to identify the most efficient individual method (flue-gas recirculation) and the most efficient combination of methods (overfire air + reburning + flue-gas recirculation). The achieved denitrification efficiencies (close to 65% for propane–butane gas combustion or even over 70% for natural gas combustion) are promising and suggest that further research should be aimed at investigating the use of wood gasification gas as fuel in the test rig. Combined application of 10% reburning + OFA + 20% FGR reduced the flue gas' NO_x content by 72% in the studied furnace under the given combustion conditions. Considering the given conditions, the fuels combusted, and the furnace geometry, this combination can be recommended as the most efficient one for flue-gas denitrification.

Our carbon monoxide emissions results practically ruled out the application of reburning in the experimental setup, and this became even worse when CO-rich gas was combusted instead of natural gas. Flue-gas recirculation appears to be the most viable method that can readily be applied to different combustion designs and fuels used, as it exhibits both significant de- NO_x and de-CO efficiency, although its application limits should be subject to more focused study.

Author Contributions: Conceptualization, L.L. and J.K.; methodology, L.L. and J.K.; validation, M.F. and G.J.; investigation, L.L. and P.L.; resources, M.R.; data curation, L.L. and J.J.; writing—original draft preparation, L.L., M.V., and G.J.; writing—review and editing, M.V., J.J., and P.L.; visualization, P.L.; supervision, G.J.; funding acquisition, L.L., M.R., and M.F. All authors have read and agreed to the published version of the manuscript.

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List of Symbols and Abbreviations

A	analyzer
FGR	flue-gas recirculation
LNB	low NO_x burner
m	air excess coefficient
NG	natural gas
NO_x	nitrogen oxides
OFA	overfire air

PBG	propane–butane gas	
Pt	thermal power input	kW
p	pressure	Pa
Q	volumetric flow	m ³ /h
T	temperature	°C
V	throttle valve	
R	emissions reduction	(%)
C _{WAPM}	nitrogen oxide emissions without application of primary methods	
C _{APM}	nitrogen oxides emissions with application of primary methods	
max	maximum	
min	minimum	
stat	static (pressure)	
total	total (pressure)	

Appendix A

Tables A1 and A2 provide information about the NO_x and CO measurement method for the Testo 350 analyzer (A2 analyzer) as stated by the manufacturer [47]. Likewise, Table A3 shows information relating to the Testo 325 (A3 analyzer) measurement method and error range as stated by the manufacturer [48].

Table A1. Nitrogen oxide measurement method and measurement error range stated by Testo 350 analyzer series manufacturer [47].

Testo 350 M and Testo 350 XL				
	NO		NO ₂	
Measurement method	Electrochemical sensor		Electrochemical sensor	
Metering range	0 to 3000 ppm		0 to 500 ppm	
Measurement error range	0 to 99.9 ppm	±5 ppm	0 to 99.9 ppm	±5 ppm
	100 to 1999.9 ppm	±5% of measured value	100 to 500 ppm	±5% of measured value
	2000 to 3000 ppm	±10% of measured value		-
Depiction accuracy	1 ppm		0.1 ppm	

Table A2. Carbon monoxide measurement method and measurement error range stated by Testo 350 analyzer series manufacturer [47].

Testo 350 M and Testo 350 XL		
	CO	
Measurement method	Electrochemical sensor	
Metering range	0 to 10,000 ppm	
Measurement error range	0 to 199 ppm	±10 ppm
	200 to 2000 ppm	±5% of measured value
	2001 to 10,000 ppm	±10% of measured value
Depiction accuracy	1 ppm	

Table A3. Measurement method and measurement error range stated by Testo 325-I analyzer manufacturer [48].

Testo 325-I				
	NO		CO	
Measurement method	Electrochemical sensor		Electrochemical sensor	
Metering range	0–1000 ppm		0–2000 ppm	
Measurement error range	0 to 400 ppm	<20 ppm	0 to 400 ppm	<20 ppm
	>200 ppm	<±5% of measured value	>400 ppm	<±5% of measured value
Depiction accuracy	1 ppm		1 ppm	

Appendix B

After primary burner ignition, the desired fuel volumetric flow and air excess coefficient were set for combustion without any primary denitrification method application. Afterwards, stable combustion conditions, a stable temperature profile, and stable oxygen concentration in the flue gas were reached, which took, depending on initial conditions, up to several hours. On reaching the stationary state, values of NO, NO₂, O₂, and CO concentrations measured by the analyzers and temperatures indicated by all thermocouples were recorded pointwise at five-minute intervals. Temperature readings were continuously recorded by the Comet data unit.

After all process parameter readings were done, additional air was introduced in the OFA zone (see Figure 1) so as to reach a constant final air excess coefficient ($m = 1.1$ or 1.2) in the place where analyzer A2 was located. After reaching stationary conditions (see the previous paragraph), readings of gas concentrations and temperatures were recorded periodically within 30 to 45 min of stable furnace operation at five-minute intervals.

In the FGR experiments, the evaluated process parameters included the amount of recirculated flue gas (10 to 20%), air excess coefficient, combustion temperature, and fuel volumetric flow. Various fuel volumetric flows were used in the experiments. The recirculation rate was estimated from the oxygen material balance setup using the data on the oxygen concentration (Analyzers A1,2) and on fuel and combustion air volumetric flows. Starting with zero FGR, flue-gas recirculation was introduced until the desired oxygen content in the air–flue gas mixture was reached. It was kept constant during the given measurement, which ensured a constant flue-gas recirculation rate. Flue-gas recirculation rate was increased afterwards until a new value of oxygen content in the air–flue gas mixture was reached, and the measurement was repeated.

When using the reburning method, the reburning fuel was introduced in the middle part of the flue-gas duct (see Figure 1) with its amount ranging between 10 to 25% of total fuel combusted (the sum of primary and reburning fuel), while the amount of total fuel combusted was kept constant.

Nitrogen oxide and carbon monoxide values shown and discussed in the manuscript are average concentration values obtained from individual measurements for the given fuel consumption and air excess coefficient.

Appendix C

Figures A1 and A2 show the time courses of measured temperature values in the furnace during test experiments. Test experiments were aimed at verifying sufficient stability of temperature measurements during stable furnace operation as well as their sufficient sensitivity to the changes of combustion conditions.

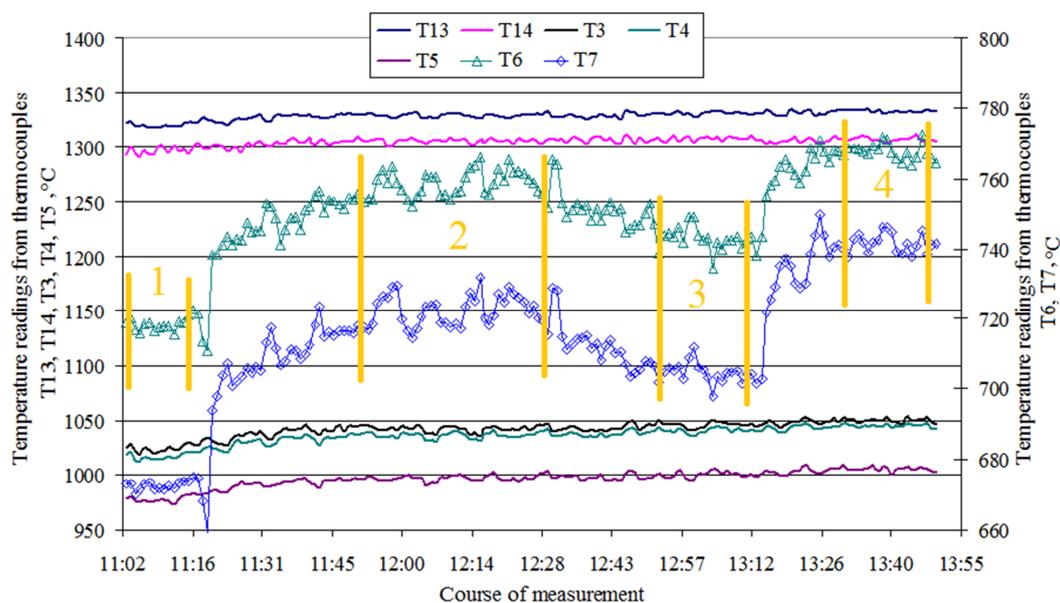


Figure A1. Measured flue-gas temperatures through the furnace during test experiments involving fuel input $Q = 1.6 \text{ m}^3/\text{h}^1$ and air excess coefficient $m = 1.1$ with varying reburning ratio. Stable operation states as indicated in the Figure: 1 = without any primary method applied; 2 = reburning share of 25%; 3 = reburning share of 20%; 4 = reburning share of 35%.

As can be recognized from both Figures A1 and A2, temperatures measured by individual thermocouples vary within a few °C during steady operation of the furnace. Contrary to that, changes of temperatures measured by thermocouples T6 and T7, resulting from performed step changes of reburning share, are clearly recognizable. Moreover, well-defined individual temperature plateaus corresponding to stable operation of the furnace with

different reburning shares can be seen as well. The results of preliminary experiments proved that the temperature measurements were both sufficiently stable and sensitive to the changes of the operation conditions.

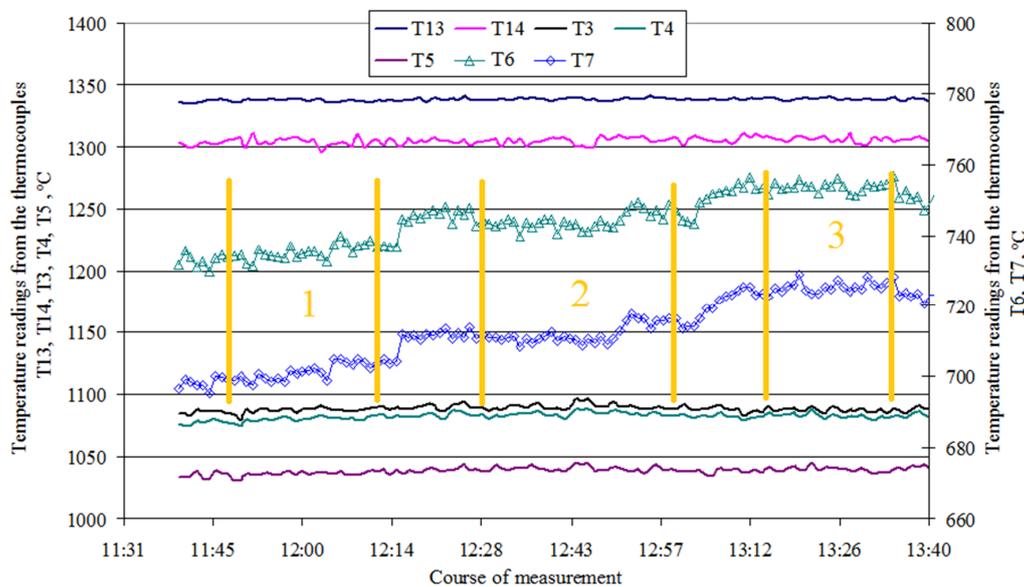


Figure A2. Measured flue-gas temperatures through the furnace during test experiments involving fuel input $Q = 1.8 \text{ m}^3/\text{h}$ and air excess coefficient $m = 1.1$ with varying reburning ratio. Stable operation states as indicated in the Figure: 1 = reburning share of 20%; 2 = reburning share of 25%; 3 = reburning share of 35%.

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2650 Old State Highway 113
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Number of Pages 3
Date Received 09/05/2019
Date Reported 09/05/2019

Telephone: (770) 684-0102
Attention: Christy Sieg

Job Number	Order Date	Client
100572	09/05/2019	BORALR

Project ID: KMC TOTAL METALS
Project Name: KMC Total Metals 2019
Site: 2650 Old State Highway 113
Taylorsville, GA 30178

Enclosed please find results of analyses of 1 solid sample which was analyzed as specified on the attached chain of custody. If there are any questions, please do not hesitate to call.

Checked By: _____

Approved By: _____

Cyrus Razmara, Ph.D.
Vice President



COOLER RECEIPT FORM

Client Name: <i>Boral Resources</i>			
Project Name:			
AETL Job Number: <i>100572</i>			
Date Received: <i>09/05/19</i>		Received by: <i>Antin</i>	
Carrier: <input type="checkbox"/> AETL Courier <input type="checkbox"/> Client <input type="checkbox"/> GSO <input checked="" type="checkbox"/> FedEx <input type="checkbox"/> UPS			
<input type="checkbox"/> Others:			
Samples were received in: <input type="checkbox"/> Cooler () <input checked="" type="checkbox"/> Other (Specify): <i>box</i>			
Inside temperature of shipping container No 1: , No 2: , No 3:			
Type of sample containers: <input type="checkbox"/> VOA, <input type="checkbox"/> Glass bottles, <input type="checkbox"/> Wide mouth jars, <input checked="" type="checkbox"/> HDPE bottles, <input type="checkbox"/> Metal sleeves, <input type="checkbox"/> Others (Specify):			
How are samples preserved: <input checked="" type="checkbox"/> None, <input type="checkbox"/> Ice, <input type="checkbox"/> Blue Ice, <input type="checkbox"/> Dry Ice			
<input checked="" type="checkbox"/> None, <input type="checkbox"/> HNO ₃ , <input type="checkbox"/> NaOH, <input type="checkbox"/> ZnOAc, <input type="checkbox"/> HCl, <input type="checkbox"/> Na ₂ S ₂ O ₃ , <input type="checkbox"/> MeOH			
<input type="checkbox"/> Other (Specify):			
	Yes	No, explain below	Name, if client was notified.
1. Are the COCs Correct?	<i>✓</i>		
2. Are the Sample labels legible?	<i>✓</i>		
3. Do samples match the COC?	<i>✓</i>		
4. Are the required analyses clear?	<i>✓</i>		
5. Is there enough samples for required analysis?	<i>✓</i>		
6. Are samples sealed with evidence tape?	<i>N/A</i>		
7. Are sample containers in good condition?	<i>✓</i>		
8. Are samples preserved?	<i>N/A</i>		
9. Are samples preserved properly for the intended analysis?	<i>✓</i>		
10. Are the VOAs free of headspace?	<i>N/A</i>		
11. Are the jars free of headspace?	<i>✓</i>		

PLEASE NOTE ALL SAMPLES WILL BE DISPOSED OF 90 DAYS AFTER RECEIVING DATE. IF AETL IS INFORMED OTHERWISE, THERE WILL BE A STORAGE CHARGE PER SAMPLE PER MONTH FOR ANY SAMPLE HELD BEYOND 90 DAYS.

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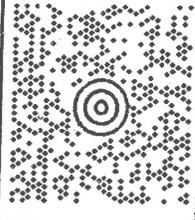
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1 OF 1

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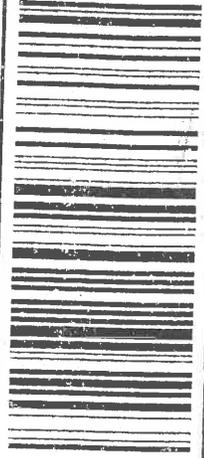


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Project ID: KMC TOTAL METALS
Date Received 09/05/2019
Date Reported 09/05/2019

Telephone: (770) 684-0102
Attention: Christy Sieg

Job Number	Order Date	Client
100572	09/05/2019	BORALR

CERTIFICATE OF ANALYSIS CASE NARRATIVE

AETL received 1 samples with the following specification on 09/05/2019.

Lab ID	Sample ID	Sample Date	Matrix	Quantity Of Containers
100572.01	2562 TS Nat PO22	09/04/2019	Solid	1
Method ^ Submethod	Req Date	Priority	TAT	Units
(6010B/7000CAM)	09/05/2019	1	Rush	mg/Kg

The samples were analyzed as specified on the enclosed chain of custody. No analytical non-conformances were encountered.

Unless otherwise noted, all results of soil and solid samples are based on wet weight.

Checked By: 

Approved By: 

Cyrus Razmara, Ph.D.
Vice President



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Site

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Telephone: (770)684-0102

Attn: Christy Sieg

Page: 2

Project ID: KMC TOTAL METALS
 Project Name: KMC Total Metals 2019

AETL Job Number	Submitted	Client
100572	09/05/2019	BORALR

Method: (6010B/7000CAM), Title 22 Metals (SW-846)

QC Batch No: 0905192C2

Our Lab I.D.		Method Blank	100572.01		
Client Sample I.D.			2562 TS Nat PO22		
Date Sampled			09/04/2019		
Date Prepared		09/05/2019	09/05/2019		
Preparation Method		3050B	3050B		
Date Analyzed		09/05/2019	09/05/2019		
Matrix		Solid	Solid		
Units		mg/Kg	mg/Kg		
Dilution Factor		1	1		
Analytes	MDL	PQL	Results	Results	
Antimony	1.0	5.0	ND	ND	
Arsenic	1.0	5.0	ND	ND	
Barium	2.5	5.0	ND	41.6	
Beryllium	1.0	2.5	ND	ND	
Cadmium	1.0	2.5	ND	ND	
Chromium	2.5	5.0	ND	9.94	
Cobalt	2.5	5.0	ND	ND	
Copper	2.5	5.0	ND	19.2	
Lead	2.5	5.0	ND	8.16	
Mercury (By EPA 7471)	0.1	0.2	ND	ND	
Molybdenum	2.0	5.0	ND	ND	
Nickel	2.5	5.0	ND	4.55J	
Selenium	1.0	5.0	ND	ND	
Silver	2.0	5.0	ND	ND	
Thallium	0.7	5.0	ND	ND	
Vanadium	2.5	5.0	ND	6.72	
Zinc	2.5	5.0	ND	24.2	



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QUALITY CONTROL RESULTS

Ordered By

Boral Resources
 2650 Old State Highway 113
 Taylorsville, GA 30178-

Site

2650 Old State Highway 113
 Taylorsville, GA 30178

Telephone: (770)684-0102

Attn: Christy Sieg

Page: 3

Project ID: KMC TOTAL METALS
 Project Name: KMC Total Metals 2019

AETL Job Number	Submitted	Client
100572	09/05/2019	BORALR

Method: (6010B/7000CAM), Title 22 Metals (SW-846)

QC Batch No: 0905192C2; LCS: Blank; LCS Prepared: 09/05/2019; LCS Analyzed: 09/05/2019; Units: mg/Kg

Analytes	LCS	LCS	LCS	LCS DUP	LCS DUP	LCS DUP	LCS RPD	LCS/LCSD	LCS RPD	
	Concen	Recov	% REC	Concen	Recov	% REC	% REC	% Limit	% Limit	
Antimony	50.0	52.5	105	50.0	51.8	104	<1	75-125	<15	
Arsenic	50.0	53.0	106	50.0	52.4	105	<1	75-125	<15	
Barium	50.0	51.0	102	50.0	50.5	101	<1	75-125	<15	
Beryllium	50.0	51.5	103	50.0	51.1	102	<1	75-125	<15	
Cadmium	50.0	51.5	103	50.0	51.3	103	<1	75-125	<15	
Chromium	50.0	50.5	101	50.0	50.1	100	<1	75-125	<15	
Cobalt	50.0	50.5	101	50.0	50.3	101	<1	75-125	<15	
Copper	50.0	49.4	98.8	50.0	49.4	98.8	<1	75-125	<15	
Lead	50.0	48.7	97.4	50.0	48.1	96.2	1.2	75-125	<15	
Mercury (By EPA 7471)	0.500	0.472	94.4	0.500	0.482	96.3	2.0	75-125	<15	
Molybdenum	50.0	49.3	98.6	50.0	49.2	98.4	<1	75-125	<15	
Nickel	50.0	49.8	99.6	50.0	49.2	98.4	1.2	75-125	<15	
Selenium	50.0	54.0	108	50.0	52.0	104	3.8	75-125	<15	
Silver	50.0	50.5	101	50.0	50.3	101	<1	75-125	<15	
Thallium	50.0	48.8	97.6	50.0	48.2	96.4	1.2	75-125	<15	
Vanadium	50.0	51.0	102	50.0	50.9	102	<1	75-125	<15	
Zinc	50.0	55.0	110	50.0	54.3	109	<1	75-125	<15	



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Data Qualifiers and Descriptors

Data Qualifier:

- #: Recovery is not within acceptable control limits.
- *: In the QC section, sample results have been taken directly from the ICP reading. No preparation factor has been applied.
- B: Analyte was present in the Method Blank.
- D: Result is from a diluted analysis.
- E: Result is beyond calibration limits and is estimated.
- H: Analysis was performed over the allowed holding time due to circumstances which were beyond laboratory control.
- J: Analyte was detected . However, the analyte concentration is an estimated value, which is between the Method Detection Limit (MDL) and the Practical Quantitation Limit (PQL).
- M: Matrix spike recovery is outside control limits due to matrix interference. Laboratory Control Sample recovery was acceptable.
- MCL: Maximum Contaminant Level
- NS: No Standard Available
- S6: Surrogate recovery is outside control limits due to matrix interference.
- S8: The analysis of the sample required a dilution such that the surrogate concentration was diluted below the method acceptance criteria.
- X: Results represent LCS and LCSD data.

Definition:

- %Limi: Percent acceptable limits.
- %REC: Percent recovery.
- Con.L: Acceptable Control Limits
- Conce: Added concentration to the sample.
- LCS: Laboratory Control Sample
- MDL: Method Detection Limit is a statistically derived number which is specific for each instrument, each method, and each compound. It indicates a distinctively detectable quantity with 99% probability.



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Data Qualifiers and Descriptors

MS:	Matrix Spike
MS DU:	Matrix Spike Duplicate
ND:	Analyte was not detected in the sample at or above MDL.
PQL:	Practical Quantitation Limit or ML (Minimum Level as per RWQCB) is the minimum concentration that can be quantified with more than 99% confidence. Taking into account all aspects of the entire analytical instrumentation and practice.
Recov:	Recovered concentration in the sample.
RPD:	Relative Percent Difference

ANALYTICAL REPORT

Eurofins TestAmerica, Pensacola
3355 McLemore Drive
Pensacola, FL 32514
Tel: (850)474-1001

Laboratory Job ID: 400-174189-2
Client Project/Site: Kirkland Mining Total Metals 2019

For:
Boral Resources LLC
2650 Old State Highway 113
Taylorsville, Georgia 30178

Attn: Christy Sieg



Authorized for release by:
8/7/2019 4:16:29 PM

Mark Swafford, Project Manager I
(850)471-6207
mark.swafford@testamericainc.com

LINKS

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The test results in this report meet all 2003 NELAC and 2009 TNI requirements for accredited parameters, exceptions are noted in this report. This report may not be reproduced except in full, and with written approval from the laboratory. For questions please contact the Project Manager at the e-mail address or telephone number listed on this page.

This report has been electronically signed and authorized by the signatory. Electronic signature is intended to be the legally binding equivalent of a traditionally handwritten signature.

Results relate only to the items tested and the sample(s) as received by the laboratory.

Definitions/Glossary

Client: Boral Resources LLC
Project/Site: Kirkland Mining Total Metals 2019

Job ID: 400-174189-2

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
α	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
PQL	Practical Quantitation Limit
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)

Case Narrative

Client: Boral Resources LLC
Project/Site: Kirkland Mining Total Metals 2019

Job ID: 400-174189-2



Job ID: 400-174189-2

Laboratory: Eurofins TestAmerica, Pensacola

Narrative

**Job Narrative
400-174189-2**

Comments

No additional comments.

Receipt

The sample was received on 8/5/2019 11:20 AM. The temperature of the cooler at receipt was 18.0° C.

Metals

No analytical or quality issues were noted, other than those described in the Definitions/Glossary page.

Client Sample Results

Client: Boral Resources LLC
 Project/Site: Kirkland Mining Total Metals 2019

Job ID: 400-174189-2

Client Sample ID: 2562TS NATURAL POZZOLAN

Lab Sample ID: 400-174189-1

Date Collected: 08/02/19 15:00

Matrix: Solid

Date Received: 08/05/19 11:20

Percent Solids: 97.7

Method: 6010D - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Arsenic	1.1		0.97		mg/Kg	☼	08/06/19 13:17	08/07/19 08:34	1
Barium	41		0.97		mg/Kg	☼	08/06/19 13:17	08/07/19 08:34	1
Cadmium	<0.48		0.48		mg/Kg	☼	08/06/19 13:17	08/07/19 08:34	1
Chromium	9.1		0.97		mg/Kg	☼	08/06/19 13:17	08/07/19 08:34	1
Lead	9.3		0.97		mg/Kg	☼	08/06/19 13:17	08/07/19 08:34	1
Selenium	<1.9		1.9		mg/Kg	☼	08/06/19 13:17	08/07/19 08:34	1
Silver	<0.97		0.97		mg/Kg	☼	08/06/19 13:17	08/07/19 08:34	1

Method: 7471A - Mercury in Solid or Semisolid Waste (Manual Cold Vapor Technique)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.044		0.044		mg/Kg	☼	08/07/19 12:00	08/07/19 13:53	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Percent Moisture	2.3		0.1		%			08/07/19 05:30	1

Chain of Custody Record



Client Information (Sub Contract Lab)		Sampler:	Lab PM:	Carrier Tracking No(s):	COC No:
Shipping/Receiving		Phone:	Swafford, Mark H		400-217626.1
Company: TestAmerica Laboratories, Inc.		E-Mail:	mark.swafford@testamericainc.com	State of Origin:	Page: 1 of 1
Address: 6712 Benjamin Road, Suite 100, Tampa, FL, 33634		Accreditations Required (See note):		Job #:	400-174189-2
Phone: 813-885-7427 (Tel) 813-885-7049 (Fax)		Due Date Requested:		Preservation Codes:	
Email:		8/12/2019		A - HCL M - Hexane N - None O - AsNaO2 P - Na2O4S Q - Na2SO3 R - Na2SO4 S - H2SO4 T - TSP Dodecahydrate U - Acetone V - MCAA W - pH 4-5 X - EDTA Z - other (specify)	
Project Name: Kirkland Mining Total Metals 2019		TAT Requested (days):		Other:	
Site:		8/12/2019			
PO #:		8/12/2019			
WO #:		8/12/2019			
Project #: 40005206		Sample Date		Sample Type	
SSOW#:		8/2/19		(C=comp, G=grab)	
		15:00 Eastern		Matrix (W=water, S=solid, O=water/soil, BT=thru, A=air)	
		Sample Time		Preservation Code:	
		8/2/19		Solid	
		Sample Date		Field Filtered Sample (Yes or No)	
		15:00 Eastern		Perform MS/MSD (Yes or No)	
		Sample Time		6010D/3050B RCRA ICP Metals (Total or TCLP)	
		8/2/19		7417A/741A_Prep	
		Sample Date		Moisture	
		15:00 Eastern		X	
		Sample Time		X	
		8/2/19		X	
		Sample Date		Total Number of containers	
		15:00 Eastern		1	
		Sample Time		Special Instructions/Note:	
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