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TECHNICAL MEMORANDUM

INFORMATION REQUEST #1 – BACT FOR EU IDS 15-20 AND 29-34

PREPARED FOR:	Enric Fernandez, Donlin Gold
PREPARED BY:	Kevin Lewis, Air Sciences
PROJECT NO.:	281-22B-1
DATE:	March 9, 2022

This memorandum provides the information requested by Mr. Dave Jones of the Alaska Department of Environmental Conservation (ADEC) on February 18, 2022, regarding Donlin Gold Project's Construction Permit AQ0934CPT02 Application (application).

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1.0 Introduction

The cost effectiveness of Selective Catalytic Reduction (SCR) and oxidation catalyst (Ox Cat) for EU ID 15-20 and 29-34 has been recalculated per ADEC's request. In addition, the availability of low NOx burners (LNB) and flue gas recirculation (FGR) for EU ID 15-20 has been re-evaluated. The results of these analyses are summarized as follows:

- SCR continues to not be cost effective at $8,617 to $432,894 per ton of NO_X removed.
- Ox Cat continues to not be cost effective at $8,378 to $25,536 per ton of CO and VOC combined removed.
- LNB are not available for the for the process boilers (ED IU 15-17) and the process heater (EU ID 18).
- FGR is available for the process boilers (ED IU 15-17) and the process heater (EU ID 18).
- The available control technology for the dual fuel space heaters (EU ID 19-20) is good combustion practices (GCP).

Detailed responses to each of ADEC's requested items are provided in the following sections of the memorandum.

2.0 Boilers and Heaters EUs 15 – 20

2.1 ADEC Request Item 1

Request:

1. Please provide the Department with updated NOx and CO BACT analyses for the boilers and heaters rated at 16 MMBtu/hr or greater (EUs 15 – 20). For these analyses please:

- *Provide the analyses in Microsoft Excel format.*
- *Use the methodology from the most recent EPA Air Pollution Control Cost Manual, available on the following website: https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-reports-and-guidance-air-pollution.*
- *Obtain new cost estimates instead of using costs from 1999 and adjusting for inflation, unless using spreadsheets provided by EPA (e.g. SCR Cost Calculation Spreadsheet in Section 4 of cost manual website).*
- *Use an appropriate equipment life for the Capital Recovery Factor (CRF) portion of the analyses and justify if a shorter equipment life is warranted.*
- *Use the current bank prime loan interest rate for the CRF portion of the analyses available here: https://www.federalreserve.gov/releases/h15/.*
- *For selective catalytic reduction (SCR) calculations for NOx, please use the maximum emissions scenario resulting from the firing of ULSD.*
- *For the oxidation catalyst analyses, please include the emission reductions to both CO and VOC emissions in one cost calculation.*

Response:

EPA's Microsoft Excel cost analysis workbooks for SCR (file: scrcostmanualspreadsheet_june-2019vf.xlsm) and Ox Cat (file: oxidizers_calc_sheet_finalversion_1-16-2018.xlsm) were used for the process steam boilers (EU ID 15-17), the process elution heater (EU ID 18), and the power plant space heaters (EU ID 19-20). These workbooks are available for download via the link provided in Appendix B. The workbook abbreviated file names are provided in Table 1. The following inputs were used in each workbook:

- The EPA default emission reduction efficiencies
- The 2021 Chemical Engineering Plant Cost Index (CEPCI) of 772.5 (Towering Skills 2022)
- The EPA default life expectancy of the control system
- The Donlin Gold Project borrowing interest rate of eight percent (Annett, K. 2022)

The eight percent interest rate used in the Capital Recovery Factor (CRF) is based on consideration of the weighted average cost of capital (WACC) and the capital asset pricing model (CAPM) for Donlin Gold (Annett, K. 2022).

Table 1. EPA Cost Workbooks for Boilers and Heaters, EU ID 15-20

File Name	EU ID	Pollutant	Fuel	Control	Operation
EUID15-16_CO-VOC_NG_	15-16	CO and VOC	Natural gas	Ox Cat	Potential
EUID15-16_CO-VOC_Oil_	15-16	CO and VOC	ULSD	Ox Cat	Potential
EUID15-16_NOx_dual_	15-16	NOX	Dual fuel	SCR	Potential
EUID15-16_NOx_dualA_	15-16	NOX	Dual fuel	SCR	Actual
EUID15-16_NOx_NG_	15-16	NOX	Natural gas	SCR	Potential
EUID15-16_NOx_NGA_	15-16	NOX	Natural gas	SCR	Actual
EUID15-16_NOx_Oil_	15-16	NOX	ULSD	SCR	Potential
EUID15-16_NOx_OilA_	15-16	NOX	ULSD	SCR	Actual
EUID17_CO-VOC_NG_	17	CO and VOC	Natural gas	Ox Cat	Potential
EUID17_CO-VOC_Oil_	17	CO and VOC	ULSD	Ox Cat	Potential
EUID17_NOx_dual_	17	NOX	Dual fuel	SCR	Potential
EUID17_NOx_dualA_	17	NOX	Dual fuel	SCR	Actual
EUID17_NOx_NG_	17	NOX	Natural gas	SCR	Potential
EUID17_NOx_NGA_	17	NOX	Natural gas	SCR	Actual
EUID17_NOx_Oil_	17	NOX	ULSD	SCR	Potential
EUID17_NOx_OilA_	17	NOX	ULSD	SCR	Actual
EUID18_CO-VOC_NG_	18	CO and VOC	Natural gas	Ox Cat	Potential
EUID18_CO-VOC_Oil_	18	CO and VOC	ULSD	Ox Cat	Potential
EUID18_NOx_dual_	18	NOX	Dual fuel	SCR	Potential
EUID18_NOx_dualA_	18	NOX	Dual fuel	SCR	Actual
EUID18_NOx_NG_	18	NOX	Natural gas	SCR	Potential
EUID18_NOx_NGA_	18	NOX	Natural gas	SCR	Actual
EUID18_NOx_Oil_	18	NOX	ULSD	SCR	Potential
EUID18_NOx_OilA_	18	NOX	ULSD	SCR	Actual
EUID19-20_CO-VOC_NG_	19-20	CO and VOC	Natural gas	Ox Cat	Potential
EUID19-20_CO-VOC_Oil_	19-20	CO and VOC	ULSD	Ox Cat	Potential
EUID19-20_NOx_dual_	19-20	NOX	Dual fuel	SCR	Potential
EUID19-20_NOx_NG_	19-20	NOX	Natural gas	SCR	Potential

File Name	EU ID	Pollutant	Fuel	Control	Operation
EUID19-20_NOx_Oil_	19-20	NOX	ULSD	SCR	Potential

Operation: Potential is the potential fuel use assuming 8,760 hours per year of operation at the maximum design operating rate. Actual is the "estimated actual annual fuel consumption" (Cell C14 of the SCR Data Input sheet), which is used to determine the actual cost effectiveness.
ULSD: Ultra Low Sulfur Diesel.

Table 1 describes the fuel and the operation scenario used in each workbook. A summary of the results from each workbook is provided in Appendix A. Potential and actual operations are defined as follows:

- Potential is the potential fuel use assuming 8,760 hours per year of operation at the maximum design operating rate.
- Actual is the "estimated actual annual fuel consumption" (Cell C14 of the SCR Data Input sheet), which is used to determine the actual cost effectiveness.

The primary fuel for the process steam boilers (EU ID 15-17), the process elution heater (EU ID 18), and the power plant space heaters (EU ID 19-20) is natural gas. The SCR cost effectiveness of controlling NO_X emissions from the primary fuel is summarized in Table 2. The Ox Cat cost effectiveness of controlling CO and VOC emissions from the primary fuel is summarized in Table 3. As shown in these tables below and discussed in the following section (Section 2.2), the combustion practice of FGR is now being proposed for EU ID 15-18.

Table 2. SCR Cost Effectiveness for the Primary Fuel of Natural Gas

				Potential Operation		
EU ID	NO_X Combustion Practice	Heat Input (MMBtu/hr)	TCI ($)	Annual Cost ($/yr)	NO_X Reduced (ton/yr)	Cost Effectiveness ($/ton)
15-16	FGR	29.29	$1,489,017	$163,685	5.3	$31,000
17	FGR	20.66	$1,186,771	$129,710	3.7	$34,827
18	FGR	16	$1,005,341	$109,916	3.6	$30,486
19-20	GCP	16.5	$1,026,386	$113,369	6.0	$18,824

FGR: Flue Gas Recirculation
GCP: Good Combustion Practices

Table 3. Ox Cat Cost Effectiveness for the Primary Fuel of Natural Gas

				Potential Operation		
EU ID	CO+VOC Combustion Practice	Heat Input (MMBtu/hr)	TCI ($)	Annual Cost ($/yr)	CO+VOC Reduced (ton/yr)	Cost Effectiveness ($/ton)
15-16	FGR	29.29	$471,656	$170,576	10.0	$16,980
17	FGR	20.66	$389,664	$150,442	7.1	$21,232
18	FGR	16	$338,800	$138,075	8.0	$17,165
19-20	GCP	16.5	$344,555	$139,444	6.3	$22,212

FGR: Flue Gas Recirculation
GCP: Good Combustion Practices

As described previously, the cost-effectiveness of SCR and Ox Cat were determined for both natural gas (NG) and ultra-low sulfur diesel (ULSD) firing, and for both potential and actual operations. The results of these analyses are discussed below.

For the SCR costs, the natural gas (NG) firing operating condition resulted in a higher total capital investment (TCI) and annual cost than the ULSD firing mode for the same dual fuel units. Because the SCR would need to be designed for both fuels, the dual fuel workbooks are set to natural gas to determine the maximum TCI and annual cost, and the emissions are based on the maximum emissions scenario resulting from firing ULSD. This yields the minimum cost effectiveness dollar amount for the dual fuel boilers and heaters.

The SCR workbook asks the following question: "What is the estimated actual annual fuel consumption?" The actual fuel amount was entered in this cell for the workbooks to determine the actual cost effectiveness of SCR in addition to the potential fuel consumption as noted in Table 1.

Table 4 provides a summary of the SCR cost effectiveness of controlling NO_X emissions from the process steam boilers (EU ID 15-17), the process elution heater (EU ID 18), and the power plant space heaters (EU ID 19-20) for the maximum emissions fuel scenario. As discussed in the application, the POX boilers (EU ID 15-16) are only used for autoclave startups. The oxygen plant process boiler (EU ID 17) is used to provide a controlled amount of heat to cryogenic processes. As such, these boilers operate intermittently and at partial load. The process elution heater (EU ID 18) also operates at partial load. Therefore, the actual cost effectiveness for these processes is higher than the potential cost effectiveness due to there being less emissions available for control, as shown in Table 4.

Table 4. SCR Cost Effectiveness for the Maximum Emissions Fuel Scenario at Potential and Actual Operations

				Potential Operation			Actual Operation		
EU ID	NOx Combus-tion Practice	Fuel Firing Mode	TCI ($)	Annual Cost ($/yr)	NO_X Reduced (ton/yr)	Cost Effective-ness ($/ton)	Annual Cost ($/yr)	NO_X Reduced (ton/yr)	Cost Effective-ness ($/ton)
15-16	FGR	ULSD	$1,489,017	$168,101	14.3	$11,732	$147,496	0.3	$432,894
17	FGR	ULSD	$1,186,771	$132,825	10.1	$13,143	$123,022	3.8	$32,626
18	FGR	ULSD	$1,005,341	$114,651	13.3	$8,617	$111,875	10.6	$10,510
19-20	GCP	ULSD	$1,026,386	$115,047	9.4	$12,161	-	-	-

FGR: Flue Gas Recirculation
GCP: Good Combustion Practices

Table 5 provides a summary of the Ox Cat cost effectiveness of controlling the combined CO and VOC emissions from the boilers and heaters for the maximum emissions fuel scenario. Because the potential costs shown in this table are above the amount normally considered cost effective, the higher actual costs were not calculated.

Table 5. Ox Cat Cost Effectiveness for the Maximum Emissions Fuel Scenario

				Potential Operation		
EU ID	CO+VOC Combustion Practice	Fuel Firing Mode	TCI ($)	Annual Cost ($/yr)	CO+VOC Reduced (ton/yr)	Cost Effectiveness ($/ton)
15-16	FGR	ULSD	$493,283	$174,091	20.5	$8,486
17	FGR	ULSD	$407,532	$153,293	14.5	$10,593
18	FGR	ULSD	$354,332	$140,388	16.8	$8,378
19-20	GCP	NG	$344,555	$139,444	6.3	$22,212

FGR: Flue Gas Recirculation
GCP: Good Combustion Practices

In summary, the estimated TCI for an SCR system is $1,005,341 to $1,489,017 per unit, and the total annual cost is $109,916 to $168,101 per year per unit. The resulting cost effectiveness is $8,617 to $34,872 per ton of NO_X removed (with an actual range of $10,510 to $432,894). At this cost, SCR is not considered cost effective for these units.

The estimated TCI for an Ox Cat system is $338,800 to $493,283 per unit, and the total annual cost is $138,075 to $174,091 per year per unit. The resulting cost-effectiveness is $8,378 to $22,212 per ton of CO and VOC removed. At this cost, Ox Cat is not considered cost effective for these units.

Table 6 provides the breakdown of Ox Cat cost effectiveness by pollutant.

Table 6. Ox Cat Cost Effectiveness for the Maximum Emissions Fuel Scenario per Pollutant

	Fuel	Emission Reduction (ton/yr)			Annual Cost	Cost Effectiveness ($/ton)		
EU ID	Mode	CO	VOC	CO+VOC	($/yr)	CO	VOC	CO+VOC
15-16	ULSD	20.32	0.20	20.52	$174,091	$8,567	$892,112	$8,486
17	ULSD	14.33	0.14	14.47	$153,293	$10,695	$1,113,660	$10,593
18	ULSD	16.65	0.11	16.76	$140,388	$8,431	$1,316,957	$8,378
19-20	NG	5.89	0.39	6.28	$139,444	$23,666	$361,447	$22,212

FGR: Flue Gas Recirculation
GCP: Good Combustion Practices

2.2 ADEC Request Item 2

Request:

2. Please provide an explanation as to why one set of dual-fuel heaters (EUs 19 and 20) are compatible with low NOx burners, while the other heaters and boilers are not. Additionally, please provide justification as to why Donlin is proposing the same NOx emissions rates for the boilers with low NOx burners as the boilers without low NOx burners.

Response:

The LNB stated in the application for the power plant space heaters (EU ID 19-20) is an error, although the proposed BACT emission levels are correctly stated at 0.098 lb/MMBtu for NG and 0.154 lb/MMBtu for ULSD. The combustion emission control for these units should be good combustion practices (GCP). A search of the RACT/BACT/LAER Clearinghouse (RBLC) on February 28, 2022 for the last 10 years has verified that there are no LNB determinations for oil or dual fuel space heaters of any size.

Air Sciences has contacted the manufacturers (Clayton Industries and Sigma Thermal) to reassess the combustion options of FGR and LNB for the process boilers (EU ID 15-17) and the process elution heater (EU ID 18). Per the manufacturers, the LNB technology is not available for dual fuel operation. The FGR technology, however, is available at a reduced turndown range. The Clayton Industries standard combustor for the dual fuel process boilers has a boiler turndown modulation of five to one (Lewis, K. 2022a). The FGR turndown modulation is only four to one (Lewis, K. 2022a). Similarly, the process heater will have a lower turndown modulation with FGR (Lewis, K. 2022b).

Because the process boilers and heater will be used for process control, the operating range is critical to providing a controlled amount of heat to the autoclaves during startup, the oxygen plant cryogenic processes, and the eluent solution. However, Donlin is willing to commit to purchasing the FGR system for all three process boilers (EU ID 15-17) and the process elution heater (EU ID 18). The NO_X emissions from the process boilers with FGR are 30-40 ppm for natural gas and 90-100 ppm for ULSD at an additional cost of $20,000 per unit (Lewis, K. 2022a). The NO_X emissions from the process heater with FGR are 30-50 ppm for natural gas and 100-150 ppm for ULSD at an additional cost of $15,000 to $20,000 per unit (Lewis, K. 2022b). With FGR, higher CO emission are expected. The new proposed BACT emissions for EU ID 15-18 with FGR and the originally proposed BACT emissions for EU ID 19-20 with GCP are provided in Table 7.

Table 7. Proposed NO_X and CO BACT for the Process Boilers, Process Heater, and Space Heaters

EU ID	Burner NO_X Control	NO_X Emissions NG (lb/MMBtu)	NO_X Emissions ULSD (lb/MMBtu)	CO Emissions NG (lb/MMBtu)	CO Emissions ULSD (lb/MMBtu)
15-16	FGR	0.048	0.131	0.074	0.160
17	FGR	0.048	0.131	0.074	0.160
18	FGR	0.061	0.223	0.111	0.240
19-20	GCP	0.098	0.154	0.082	0.038

FGR: Flue Gas Recirculation
GCP: Good Combustion Practices

2.3 ADEC Request Item 3

Request:

3. Please provide justification as to why flue gas recirculation was not included as a possible NOx control method when the Department found multiple instances of flue gas recirculation used on natural gas fired boilers and heaters less than 100 MMBtu/hr.

Response:

The FGR determinations in Table 2-14 of Appendix C of the application were combined with LNB or standard combustion for natural gas firing. The RBLC search returned no FGR determinations for ULSD. Table 8 provides a corrected Table 2-14 of Appendix C of the application with FGR broken out.

Table 8. Corrected Table 2-14 of Appendix C of the Application

	Number of Determinations		Emission Limit (lb/MMBtu)	
Control Technology	Gas-fired	Oil-fired	Gas-fired	Oil-fired
SCR	9		0.006 to 0.15	
Low-NO_X burner with FGR	30		0.0085 to 0.05	
Low-NO_X burner	93	2	0.0011 to 0.18	0.023 to 0.09
Flue Gas Recirculation (FGR)	4		0.015	
Good combustion practices	18	2	0.0075 to 0.18	No data
No control specified	21	2	0.006 to 0.18	0.14 to 0.21

3.0 Black Start and Emergency Engine Generators EUs 29 – 34

3.1 ADEC Request Item 4

Request:

1. Please provide the Department with updated NOx and CO BACT analyses for the limited use engines rated at 600 and 1,500 kWe (EUs 29 – 34). For these analyses please:

- *Provide the analyses in Microsoft Excel format using new cost estimates.*
- *Use the methodology from the most recent EPA Air Pollution Control Cost Manual, available on the following website: https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-reports-and-guidance-air-pollution.*
- *Use an appropriate equipment life for the Capital Recovery Factor (CRF) portion of the analyses and justify if a shorter equipment life is warranted.*
- *Use the current bank prime loan interest rate for the CRF portion of the analyses available here: https://www.federalreserve.gov/releases/h15/.*
- *For the oxidation catalyst analyses, please include the emission reductions to both CO and VOC emissions in one cost calculation. Additionally, if one piece of control equipment is being used to*

satisfy the emissions reduction (e.g. EPA Tier 4 Final engine controls), please include the cost of each criteria pollutant reduced.

Response:

EPA's Microsoft Excel cost analysis workbooks for SCR (file: scrcostmanualspreadsheet_june-2019vf.xlsm) and Ox Cat (file: oxidizers_calc_sheet_finalversion_1-16-2018.xlsm) were used for the black start emergency generators (EU ID 29-30) and the emergency power generators (EU ID 31-34). These workbooks are available for download via the link provided in Appendix B. The workbook abbreviated file names are provided in Table 9. The following inputs were used in each workbook:

- The EPA default emission reduction efficiencies
- The 2021 Chemical Engineering Plant Cost Index (CEPCI) of 772.5 (Towering Skills 2022)
- The EPA default life expectancy of the control system
- The Donlin Gold Project borrowing interest rate of eight percent (Annett, K. 2022)

The eight percent interest rate used in the Capital Recovery Factor (CRF) is based on consideration of the weighted average cost of capital (WACC) and the capital asset pricing model (CAPM) for Donlin Gold (Annett, K. 2022).

Table 9. EPA Cost Workbooks for Emergency Generators, EU ID 29-34

File Name	EU ID	Pollutant	Fuel	Control	Operation
EUID29-30_CO-VOC_Oil_	29-30	CO and VOC	ULSD	Ox Cat	Potential
EUID29-30_NOx_Oil_	29-30	NOX	ULSD	SCR	Potential
EUID31-34_CO-VOC_Oil_	31-34	CO and VOC	ULSD	Ox Cat	Potential
EUID31-34_NOx_Oil_	31-34	NOX	ULSD	SCR	Potential

ULSD: Ultra Low Sulfur Diesel.

Table 10 provides the SCR cost effectiveness of controlling NO_X emissions from the emergency generators (EU ID 29-34). Potential emissions for emergency generators are based on 500 hours per year of operation per EPA guidance. This guidance clarifies that for emergency generators "inherent physical limitations, and operational design features which restrict the potential emissions of the individual emission units, can be taken into account." (Seitz, J. 1995). The guidance goes on to state that, "[a]lthough such source owners could in most cases readily accept enforceable limitations restricting the operation to its designed level, EPA believes this administrative requirement for such sources to be unnecessary and burdensome" (Seitz, J. 1995). Therefore, the potential to emit of these units is inherently limited to 500 hours per year without the inclusion of a 500 hour per year BACT limit in the construction permit.

Table 10. SCR Cost Effectiveness

EU ID	Engine Tier	Fuel	TCI ($)	Annual Cost ($/yr)	NO_X Reduced (ton/yr)	Cost Effectiveness ($/ton)
29-30	Tier 2	ULSD	$421,682	$42,991	2.2	$19,118
31-34	Tier 2	ULSD	$762,516	$78,444	5.6	$13,953

Table 11 provides the Ox Cat cost effectiveness of controlling the combined CO and VOC emissions from the emergency generators. Note that the application BACT analysis grouped NO_X and VOC emissions together per the Tier 2 limit of 8.0 g/kW-hr (6.0 g/hp-hr). For this analysis, the AP-42, Section 3.4 *Large Stationary Diesel and All Stationary Dual-fuel Engines*, VOC emission factor of 0.000705 lb/hp-hr was used to conservatively estimate VOC emissions separately for the table below. Table 12 provides the breakdown of Ox Cat cost effectiveness by pollutant.

Table 11. Ox Cat Cost Effectiveness

EU ID	Engine Tier	Fuel	TCI ($)	Annual Cost ($/yr)	CO+VOC Reduced (ton/yr)	Cost Effectiveness ($/ton)
29-30	Tier 2	ULSD	$246,464	$40,161	1.57	$25,536
31-34	Tier 2	ULSD	$406,923	$64,493	3.93	$16,403

Table 12. Ox Cat Cost Effectiveness Per Pollutant

	Emission Reduction (ton/yr)			Annual Cost	Cost Effectiveness ($/ton)		
EU ID	CO	VOC	CO+VOC	($/yr)	CO	VOC	CO+VOC
29-30	1.43	0.14	1.57	$40,161	$28,039	$286,057	$25,536
31-34	3.58	0.35	3.93	$64,493	$18,011	$183,749	$16,403

4.0 References

Annett, K. 2022. "FW: ADEC BACT RFI." Email from K. Annett, Barrick, to D. Graham, Donlin Gold., February 25.

Lewis, K. 2022a. "Clayton Industries Boiler NOx Control." Record of communication prepared for E. Fernandez, Donlin Gold, by K. Lewis, Air Sciences, March 1.

—. 2022b. "Sigmal Thermal Process Heater NOx Control." Record of communication prepared for E. Fernandez, Donlin Gold, by K. Lewis, Air Sciences, March 1.

Seitz, J. 1995. "Calculating Potential to Emit (PTE) for Emergency Generators." John S. Seitz, Director, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, September 6. Accessed March 2, 2022. https://www.epa.gov/sites/default/files/2015-08/documents/emgen.pdf.

Towering Skills. 2022. "Cost Index." Febraury 14. Accessed February 28, 2022. https://www.toweringskills.com/financial-analysis/cost-indices/.

Williams, R. 2022. "RE: ADEC BACT RFI #2." Email from R. Williams, NovaGold, to E. Fernandez, Donlin Gold, February 24.

Appendix A – BACT Cost Calculations

AIR SCIENCES INC.	Project Title: Donlin	By: K. Lewis
	Project No: 281-22B-1	Page 1 of 3, Sheet EU ID 15-20
AIR EMISSION CALCULATIONS	Subject: Revised Boiler/Heater BACT Costs	Date: March 8, 2022

Revised BACT Costs Using EPA's Workbook

Interest Rate for Capital Recovery Factor (CR 8% (Annett, K. 2022)

EU ID	EU Description	Design Rating mmbtu/h	Annual Capacity Factor
15-16	POX Boilers #1-2	29.29	2.378%
17	Oxygen Plant Boiler	20.66	37.3%
18	Carbon Elution Heater	16	80%
19-20	Power Plant Auxiliary Heaters	16.5	-

SCR Cost (File: scrcostmanualspreadsheet_june-2019vf.x ***Potential Fuel Consumption***

	NOx Comb.	Annual Capacity	NOx Emissions lb/mmbtu		SCR TCI ($)		SCR Annual ($/y)			SCR NOx Ctrl (ton/y)		SCR Cost Effectiveness ($/ton)		
EU ID	Practice	Factor	NG	ULSD	NG	ULSD	NG	ULSD	Dual [1]	NG	ULSD	NG	ULSD	Dual [1]
15-16	FGR	100%	0.048	0.131	$1,489,017	$1,230,251	$163,685	$143,746	$168,101	5.3	14.3	$31,000	$10,033	$11,732
17	FGR	100%	0.048	0.131	$1,186,771	$980,530	$129,710	$113,303	$132,825	3.7	10.1	$34,827	$11,211	$13,143
18	FGR	100%	0.061	0.223	$1,005,341	$830,630	$109,916	$98,052	$114,651	3.6	13.3	$30,486	$7,369	$8,617
19-20	GCP	100%	0.098	0.154	$1,026,386	$848,017	$113,369	$98,097	$115,047	6.0	9.4	$18,824	$10,393	$12,161

SCR Cost (File: scrcostmanualspreadsheet_june-2019vf.x ***Actual Fuel Consumption***

	NOx Comb.	Annual Capacity	NOx Emissions lb/mmbtu		SCR TCI ($)		SCR Annual ($/y)			SCR NOx Ctrl (ton/y)		SCR Cost Effectiveness ($/ton)		
EU ID	Practice	Factor	NG	ULSD	NG	ULSD	NG	ULSD	Dual [1]	NG	ULSD	NG	ULSD	Dual [1]
15-16	FGR	2.378%	0.048	0.131	$1,489,017	$1,230,251	$147,392	$121,968	$147,496	0.1	0.3	$1,173,868	$357,973	$432,894
17	FGR	37.31%	0.048	0.131	$1,186,771	$980,530	$121,860	$102,970	$123,022	1.4	3.8	$87,696	$27,308	$32,626
18	FGR	80%	0.061	0.223	$1,005,341	$830,630	$108,070	$95,145	$111,875	2.9	10.6	$37,468	$8,938	$10,510

[1] The cost of SCR for dual fuels is based on the highest annual cost of each fuel divided by the greatest emissions reduction of each fuel.

Fixed Bed Catalytic Oxidizer Cost (File: oxidizers_calc_sheet_finalversion_1-16-2018.xls ***Potential Fuel Consumption***

	CO-VOC Comb.	Annual Capacity	CO+VOC Emis. ppmv		Ox Cat TCI ($)		Ox Cat Annual ($/y)		Ox Cat CO+VOC Ctrl (ton/y)		Ox Cat Cost Effect. ($/ton)	
EU ID	Practice	Factor	NG	ULSD	NG	ULSD	NG	ULSD	NG	ULSD	NG	ULSD
15-16	FGR	100%	102.4	201.8	$471,656	$493,283	$170,576	$174,091	10.0	20.5	$16,980	$8,486
17	FGR	100%	102.4	201.8	$389,664	$407,532	$150,442	$153,293	7.1	14.5	$21,232	$10,593
18	FGR	100%	152.4	301.8	$338,800	$354,332	$138,075	$140,388	8.0	16.8	$17,165	$8,378
19-20	GCP	100%	114.1	49.8	$344,555	$360,366	$139,444	$142,279	6.3	2.9	$22,212	$49,779

Cost per criteria pollutant

	CO-VOC Comb.	Fuel Firing	Ox Cat Emissions (ton/y)			EPA Default	Ox Cat Reduction (ton/y)			Annual Cost	Ox Cat Cost Effectiveness ($/ton)		
EU ID	Practice	Mode	CO	VOC	CO+VOC	Control	CO	VOC	CO+VOC	($/y)	CO	VOC	CO+VOC
15-16	FGR	ULSD	20.53	0.20	20.72	99%	20.32	0.20	20.52	$174,091	$8,567	$892,112	$8,486
17	FGR	ULSD	14.48	0.14	14.62	99%	14.33	0.14	14.47	$153,293	$10,695	$1,113,660	$10,593
18	FGR	ULSD	16.82	0.11	16.93	99%	16.65	0.11	16.76	$140,388	$8,431	$1,316,957	$8,378
19-20	GCP	NG	5.95	0.39	6.34	99%	5.89	0.39	6.28	$139,444	$23,666	$361,447	$22,212

Conversions:

8760	h/y
2000	lb/ton
35.315	ft3/m3
1020	btu/scf
130,167	btu/gal
1E+06	unit/million units

Process Design Annual Fuel Consumption:

EU ID	Actual Annual NG Consumption m3/y	mmscf/y	mmbtu/y	Design Rating at 8760 hr/y mmbtu/h	mmbtu/y	Actual Annual Capacity	Reference
15-16	169,412	5.98	6,102	29.29	256,580	2.378%	*(Williams, R. 2022)*
17	1,874,700	66.20	67,529	20.66	180,982	37.31%	*(Williams, R. 2022)*
18						80%	*(Williams, R. 2022)*

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Revised BACT Costs Using EPA's Workbook - continued

Conversion of ppm to lb/mmbtu

EU ID 15-17

Natural gas firing with FGR

40 scf NOx	lb-mol	46.0055 lb NOx	8710 scf	20.9 - 0	=	0.048 lb NOx
1E+06 scf	386.5 scf NOx	lb-mol	mmbtu	20.9 - 3		mmbtu

ULSD firing with FGR

100 scf NOx	lb-mol	46.0055 lb NOx	9190 scf	20.9 - 0	=	0.131 lb NOx
1E+06 scf	386.5 scf NOx	lb-mol	mmbtu	20.9 - 3.5		mmbtu

Natural gas firing with FGR

100 scf CO	lb-mol	28.01 lb NOx	8710 scf	20.9 - 0	=	0.074 lb CO
1E+06 scf	386.5 scf NOx	lb-mol	mmbtu	20.9 - 3		mmbtu

ULSD firing with FGR

200 scf CO	lb-mol	28.01 lb NOx	9190 scf	20.9 - 0	=	0.160 lb CO
1E+06 scf	386.5 scf NOx	lb-mol	mmbtu	20.9 - 3.5		mmbtu

EU ID 18

Natural gas firing with FGR

50 scf NOx	lb-mol	46.0055 lb NOx	8710 scf	20.9 - 0	=	0.061 lb NOx
1E+06 scf	386.5 scf NOx	lb-mol	mmbtu	20.9 - 3		mmbtu

ULSD firing with FGR

170 scf NOx	lb-mol	46.0055 lb NOx	9190 scf	20.9 - 0	=	0.223 lb NOx
1E+06 scf	386.5 scf NOx	lb-mol	mmbtu	20.9 - 3.5		mmbtu

Natural gas firing with FGR

150 scf CO	lb-mol	28.01 lb CO	8710 scf	20.9 - 0	=	0.111 lb CO
1E+06 scf	386.5 scf NOx	lb-mol	mmbtu	20.9 - 3		mmbtu

ULSD firing with FGR

300 scf CO	lb-mol	28.01 lb CO	9190 scf	20.9 - 0	=	0.240 lb CO
1E+06 scf	386.5 scf NOx	lb-mol	mmbtu	20.9 - 3.5		mmbtu

	Burner	NOx Emissions		CO Emissions		VOC Emissions	
	NOx	lb/mmbtu		lb/mmbtu		lb/mmbtu	
EU ID		NG	ULSD	NG	ULSD	NG	ULSD
15-16	FGR	0.048	0.131	0.074	0.160	0.0054	0.00154
17	FGR	0.048	0.131	0.074	0.160	0.0054	0.00154
18	FGR	0.061	0.223	0.111	0.240	0.0054	0.00154
19-20	GCP	0.098	0.154	0.082	0.038	0.0054	0.00154
		TRUE	TRUE				

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SCR Cost Effectiveness for the Primary Fuel of Natural Gas

	NOx			Potential Operation			
	Combus-tion	Heat input	TCI	Annual Cost	NOx Reduced	SCR Cost	
EU ID	Practice	mmbtu/h	($)	($/y)	(ton/y)	($/ton)	
15-16	FGR	29.29	$1,489,017	$163,685	5.3	$31,000	TRUE
17	FGR	20.66	$1,186,771	$129,710	3.7	$34,827	TRUE
18	FGR	16	$1,005,341	$109,916	3.6	$30,486	TRUE
19-20	GCP	16.5	$1,026,386	$113,369	6.0	$18,824	TRUE

Ox Cat Cost Effectiveness for the Primary Fuel of Natural Gas

	CO-VOC			Potential Operation			
	Combus-tion	Heat input	TCI	Annual Cost	CO-VOC Reduced	Ox Cat Cost	
EU ID	Practice	mmbtu/h	($)	($/y)	(ton/y)	($/ton)	
15-16	FGR	29.29	$471,656	$170,576	10.0	$16,980	TRUE
17	FGR	20.66	$389,664	$150,442	7.1	$21,232	TRUE
18	FGR	16	$338,800	$138,075	8.0	$17,165	TRUE
19-20	GCP	16.5	$344,555	$139,444	6.3	$22,212	TRUE

SCR Cost Effectiveness for the Maximum Emissions Fuel Scenario at Potential and Actual Operations

				Potential Operation			Actual Operation			
	NOx Comb.	Fuel Firing	TCI	Annual Cost	NOx Reduced	SCR Cost	Annual Cost	NOx Reduced	SCR Cost	
EU ID	Practice	Mode	($)	($/y)	(ton/y)	($/ton)	($/y)	(ton/y)	($/ton)	
15-16	FGR	ULSD	$1,489,017	$168,101	14.3	$11,732	$147,496	0.3	$432,894	Dual [1]
17	FGR	ULSD	$1,186,771	$132,825	10.1	$13,143	$123,022	3.8	$32,626	Dual [1]
18	FGR	ULSD	$1,005,341	$114,651	13.3	$8,617	$111,875	10.6	$10,510	Dual [1]
19-20	GCP	ULSD	$1,026,386	$115,047	9.4	$12,161	-	-	-	Dual [1]

Ox Cat Cost Effectiveness for the Maximum Emissions Fuel Scenario

				Potential Operation		
	CO-VOC Comb.	Fuel Firing	TCI	Annual Cost	CO-VOC Reduced	Ox Cat Cost
EU ID	Practice	Mode	($)	($/y)	(ton/y)	($/ton)
15-16	FGR	ULSD	$493,283	$174,091	20.5	$8,486
17	FGR	ULSD	$407,532	$153,293	14.5	$10,593
18	FGR	ULSD	$354,332	$140,388	16.8	$8,378
19-20	GCP	NG	$344,555	$139,444	6.3	$22,212

	SCR	Ox Cat
TCI Range	1005341 to 1489017	338800 to 493283
Annual Range	109916 to 168101	138075 to 174091
CE PTE Range	8617 to 34827	8378 to 22212
CE Act Range	10510 to 432894	

Oxidation Catalyst Cost Effectiveness Per Pollutant

	Fuel Firing	Ox Cat Reduction (ton/y)			Annual Cost	Ox Cat Cost Effectiveness ($/ton)		
EU ID	Mode	CO	VOC	CO+VOC	($/y)	CO	VOC	CO+VOC
15-16	ULSD	20.32	0.20	20.52	$174,091	$8,567	$892,112	$8,486
17	ULSD	14.33	0.14	14.47	$153,293	$10,695	$1,113,660	$10,593
18	ULSD	16.65	0.11	16.76	$140,388	$8,431	$1,316,957	$8,378
19-20	NG	5.89	0.39	6.28	$139,444	$23,666	$361,447	$22,212

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Revised BACT Costs Using EPA's Workbook

Interest Rate for Capital Recovery Factor (CRF): 8% (Annett, K. 2022)

EU ID	EU Description	Design Rating kWe	Design Rating mmbtu/h	Annual Hours h/y	ULSD Use gal/y
29-30	Black Start Generators	600	5.632	500	21,635
31-34	Emergency Generators	1500	14.081	500	54,087

SCR Cost (File: scrcostmanualspreadsheet_june-2019vf.xlsm)

EU ID	Engines Tier	NOx Emissions g/kWh	NOx Emissions lb/mmbtu	SCR TCI ($)	SCR Annual Cost ($/y)	SCR NOx Reduced ton/y	SCR Cost Effectiveness ($/ton)
29-30	Tier 2	8	1.879	$421,682	$42,991	2.2	$19,118
31-34	Tier 2	8	1.879	$762,516	$78,444	5.62	$13,953

Fixed Bed Catalytic Oxidizer Cost (File: oxidizers_calc_sheet_finalversion_1-16-2018.xlsm)

EU ID	Engines Tier	CO Emissions g/kWh	CO Emissions lb/mmbtu	VOC Emissions lb/hp-h	VOC Emissions lb/mmbtu	Ox Cat TCI ($)	Ox Cat Annual Cost ($/y)	Ox Cat CO+VOC Reduced ton/y	Ox Cat Cost Effectiveness ($/ton)
29-30	Tier 2	4.375	1.027	7.05E-04	0.101	$246,464	$40,161	1.57	$25,536
31-34	Tier 2	4.375	1.027	7.05E-04	0.101	$406,923	$64,493	3.93	$16,403

Cost per criteria pollutant

EU ID	Engines Tier	Ox Cat Emissions (ton/y) CO	VOC	CO+VOC	EPA Default Control	Ox Cat Reduction (ton/y) CO	VOC	CO+VOC	Annual Cost ($/y)	Ox Cat Cost Effectiveness ($/ton) CO	VOC	CO+VOC
29-30	Tier 2	1.45	0.14	1.59	99%	1.43	0.14	1.57	$40,161	$28,039	$286,057	$25,536
31-34	Tier 2	3.62	0.35	3.97	99%	3.58	0.35	3.93	$64,493	$18,011	$183,749	$16,403

Conversions:

1.341	hp/kW	453.592	g/lb
7,000	btu/hp-hr	386.5	scf/lb-mol
130,167	btu/gal	28.01	lb CO/lb-mol
1E+06	unit/million units	78.11	lb VOC (as benzene)/lb-mol
2,000	lb/ton	9,190	scf/mmbtu, oil

Revised BACT Costs Using EPA's Workbook - continued

Conversion of g/kWh to ppm

EU ID 29-30 31-34 ULSD

$$\frac{4.375\text{ g CO}}{1\text{E}+06\text{ kWh}} \left| \frac{\text{lb}}{453.592\text{ g}} \right| \frac{\text{kW}}{1.34102\text{ hp}} \left| \frac{\text{hp-h}}{7000\text{ btu}} = \frac{1.0275\text{ lb CO}}{\text{mmbtu}}\right.$$

$$\frac{1.0275\text{ lb CO}}{\text{mmbtu}} \left| \frac{20.9 - 9}{20.9 - 0} \right| \frac{\text{mmbtu}}{9190\text{ scf}} \left| \frac{386.5\text{ scf}}{\text{lb-mol}} \right| \frac{\text{lb-mol}}{28.01\text{ lb CO}} = 878.42\text{ ppmv CO}$$

$$\frac{7.05\text{E-04 lb VOC}}{\text{hp-h}} \left| \frac{\text{hp-h}}{7000\text{ btu}} = \frac{0.1007\text{ lb VOC}}{\text{mmbtu}}\right.$$

$$\frac{0.1007\text{ lb VOC}}{\text{mmbtu}} \left| \frac{20.9 - 9}{20.9 - 0} \right| \frac{\text{mmbtu}}{9190\text{ scf}} \left| \frac{386.5\text{ scf}}{\text{lb-mol}} \right| \frac{\text{lb-mol}}{78.11\text{ lb VOC}} = 30.88\text{ ppmv VOC}$$

SCR Cost Effectiveness

EU ID	Engines Tier	Fuel	TCI ($)	Annual Cost ($/y)	NOx Reduced (ton/y)	SCR Cost ($/ton)
29-30	Tier 2	ULSD	$421,682	$42,991	2.2	$19,118
31-34	Tier 2	ULSD	$762,516	$78,444	5.6	$13,953

Oxidation Catalyst Cost Effectiveness

EU ID	Engines Tier	Fuel	TCI ($)	Annual Cost ($/y)	CO-VOC Reduced (ton/y)	Ox Cat Cost ($/ton)
29-30	Tier 2	ULSD	$246,464	$40,161	1.57	$25,536
31-34	Tier 2	ULSD	$406,923	$64,493	3.93	$16,403

Oxidation Catalyst Cost Effectiveness Per Pollutant

	Ox Cat Reduction (ton/y)			Annual Cost	Ox Cat Cost Effectiveness ($/ton)		
EU ID	CO	VOC	CO+VOC	($/y)	CO	VOC	CO+VOC
29-30	1.43	0.14	1.57	$40,161	$28,039	$286,057	$25,536
31-34	3.58	0.35	3.93	$64,493	$18,011	$183,749	$16,403

Appendix B – EPA's Microsoft Excel cost analysis workbooks and the memorandum reference documents

The EPA Microsoft Excel cost analysis workbooks for EU ID 15-20 and 29-34 and the reference documents for this memorandum are available for download via the following link:

https://ftps.airsci.com/?ShareToken=80B738FE2D69F7D0A57F4918E5D762B6A627D8E4