October 30, 2019 Reference No. 11203587

Mark Jones
New Mexico Environment Department
Air Quality Bureau
525 Camino de los Marquez, Suite 1
Santa Fe, New Mexico 87505

Dear Mr. Jones:

Re: Four Factor Analysis
Mountainair Compressor Station
Transwestern Pipeline Company, LLC

GHD Services, Inc. (GHD) is submitting, on behalf of Transwestern Pipeline Company, LLC., a four-factor analysis of the Mountainair Compressor Station to the New Mexico Environment Department (NMED). This report is for the NMED Regional Haze Second Planning Period Progress Analysis under the Clean Air Act (CAA) and Regional Haze Rule (40 CFR §51.300 to 51.309).

If you have any questions or concerns, please contact myself at (720) 974-0937 or Larry Campbell at (575) 625-8022.

Sincerely,

GHD

Sergio Guerra
Project Manager

SG/PH/1

Encl. Four-Factor Analysis

cc: Larry Campbell – Transwestern Pipeline Company, LLC.

Four-Factor Analysis for Regional Haze Planning in New Mexico

Mountainair Compressor Station No. 7
Torrance County, New Mexico
Title V Operating Permit No. P153-R3M1
AIRS No. 35-057-0001

Transwestern Pipeline Company, LLC

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Appendix Index

List of Acronyms

AFGD	Advanced Flue Gas Desulfurization
APCD	Air Pollution Control Division
BART	Best Available Retrofit Technology
CAA	Clean Air Act
CAIR	Clean Air Interstate Rule
CaSO3	Calcium sulfite
CaSO4	Calcium sulfate
CO	Carbon Monoxide
CO2	Carbon Dioxide
CPI	Consumer Price Index
DEP	Department of Environmental Protection
DEQ	Department of Environmental Quality
DNR	Department of Natural Resources
DSI	Dry Sorbent Injection
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FGD	Flue Gas Desulfurization
FGR	Flue Gas Recirculation
ICI	Industrial, Commercial, Institutional
HEIS	High Energy Ignition Systems
LADCO	Lake Michigan Air Directors Consortium
LNB	Low NOx Burners
MACT	Most Achievable Control Technology
MARAMA	Mid-Atlantic Regional Air Management Association
N2	Nitrogen gas
NCASI	National Council for Air and Stream Improvement
NESCAUM	Northeast States for Coordinated Air Use Management
NESHAP	National Emission Standards for Hazardous Air Pollutants
NH3	Ammonia
NOx	Nitrogen Oxides
NSCR	Non-Selective Catalytic Reduction
NSPS	New Source Performance Standards
OFA	Over-Fired Air
PM	Particulate Matter
RICE	Reciprocating Internal Combustion Engine
RSCR	Regenerative Selective Catalytic Reduction
SCR	Selective Catalytic Reduction
SD	Spray Dry
SIP	State Implementation Plan
SNCR	Selective Non-Catalytic Reduction
SO2	Sulfur Dioxide
SSM	Startup, Shutdown, Maintenance
ULNB	Ultra Low NOx Burners
WRAP	Western Regional Air Partnership
VOC	Volatile Organic Compound

1. Executive Summary

In response to the New Mexico Environment Department (NMED) letter dated July 18, 2019, GHD Services, Inc. (GHD) was retained by ETC Texas Pipeline, LTD, the parent company of Transwestern Pipeline Company, LLC, to prepare a four-factor analysis for the NMED Regional Haze Second Planning Period Progress Analysis under the Clean Air Act (CAA) and Regional Haze Rule (40 CFR §51.300 to 51.309). As a part of this Progress Analysis, NO_x and SO_2 emissions were evaluated at the Mountainair Compressor Station (Mountainair CS).

The four-factor analysis is codified in 40 CFR §51.308(d)(1)(i)(A) and is designated as a means for establishing reasonable progress goals towards achieving natural visibility conditions. The four factors to consider are:

1. The costs of compliance
2. The time necessary for compliance
3. The energy and non-air quality environmental impacts of compliance
4. The remaining useful life of any potentially affected sources

The purpose of the four-factor analysis is to identify control measures for reducing emissions that could be used to establish the long-term strategy for attaining the states visibility goals. The NMED has requested that evaluations be completed for individual equipment that have a potential to emit (PTE) greater than ten pounds per hour of NO_x or SO_2. The source categories identified at Mountainair CS for evaluation are three existing compressor engines (Units 701, 702, and 703). NMED also instructed to use actual emissions from reporting year 2016 as baseline emissions to calculate emission reductions for control options evaluated. The cost range for emission reductions reflects the range of operation time in 2016 between the two RICE compressor engines analyzed. The results of the subsequent four-factor analysis are in Table 1.1 below.

Table 1.1 Summary of Mountainair CS Four Factor Analysis Results

Source Category	Regional Haze Pollutant Analyzed	Average Cost in 2019 Dollars (dollars per ton of pollutant reduction)	Compliance Timeframe	Energy & Non-Air Quality Impacts	Remaining Useful Life
RICE Engines (Units 701, 702, and 703)	NO_x; Low Emission Controls (LEC)	\$2,000 - \$13,000	2-5 Years	None known for LEC	25 years for controls; Indefinite for RICE engines
	NO_x; Selective Catalytic Reduction (SCR)	\$1,400 - \$7,000	2-5 Years	Storage and handling of hazardous materials	25 years for controls; Indefinite for RICE engines

2. Source Category Analysis for RICE Engines

2.1 Source Category Description

Mountainair CS operates three (3) Reciprocating Internal Combustion Engines (RICE) that are subject to the requirements of the four-factor analysis. Mountainair CS's compression engines are 4,500-hp natural gas-fired Cooper-Bessemer LSV-16G compressor engines (Units 701, 702, and 703) used for transportation of natural gas.

Mountainair CS also operates two (2) 335-hp natural gas-fired Ingersoll-Rand PSVG-6 generator engines. These generators are already utilizing best available control technology (BACT) for NO_x as Units 721 and 722 are controlled by non-selective catalytic reduction (NSCR). According to recent engine performance tests, NO_x emission rates are reduced by over 85% with the installed catalysts.

2.2 Clean Air Act and State Regulations

The engines subject to this analysis are subject to the following state and federal regulations:

20.2.61.109 NMAC

This regulation limits opacity to 20% applies to Stationary Combustion Equipment, such as engines, boilers, heaters, and flares unless your equipment is subject to another state regulation that limits particulate matter such as 20.2.19 NMAC (see 20.2.61.109 NMAC). Units 701, 702, 703, 721 and 722 are subject to this regulation.

20.2.82 NMAC

This regulation applies to all sources emitting hazardous air pollutants, which are subject to the requirements of 40 CFR Part 63, as amended through August 29, 2013.

MACT 40 CFR 63, Subpart ZZZZ

Facilities are subject to this subpart if they own or operate a stationary RICE, except if the stationary RICE is being tested at a stationary RICE test cell/stand. The generator engines (Units 721 and 722) at this station are stationary RICE that are existing engines subject to this subpart.

2.3 NO_x Emissions and Control Options

NO_x is generated from the combustion of natural gas used to power the applicable compressor engines. The exhaust gases are released to the atmosphere through stacks associated with each engine.

There are several different categories of NO_x formation in combustion processes. The combustion process taking place in RICE predominantly produces thermal NO_x[1] which is formed when nitrogen and oxygen unite during high temperature and high pressure combustion.[2]

While neither engine currently utilizes NO_x emission controls, two control options were assessed for the applicable engines: Low Emission Controls (LEC) and Selective Catalytic Reduction (SCR).

2.3.1 Low Emission Controls (LEC)

LEC is a combination of combustion controls in which various engine modifications, upgrades, and tuning methods provide lower emission combustion.

One upgrade includes increasing the air-to-fuel ratio (AFR) to reduce thermal NO_x formation by diluting combustion gases and lowering peak flame temperature. Upgrades to the AFR controller and turbocharger would be required. Adjusting ignition timing is another modification associated with LEC. This control delays ignition in the power stroke when the chamber is below its maximum pressure. This causes ignition at a lower temperature, thus lowering thermal NO_x formation during combustion. Other LEC options include installing cylinder heads fitted with pre-combustion chambers, larger intercooling applications, enhanced mixing, bypass valves, and increased ignition energy.[3]

A quotation provided by Cooper Machinery Services[10] shows that these LEC upgrades can lower NO_x emission rates to 2.5 g/hp-hr.

2.3.2 Selective Catalytic Reduction (SCR)

SCR is a post-combustion control for lean-burn combustion in which ammonia or urea is mixed with exhaust gases over a catalyst to (ideally) convert NO_x to nitrogen gas (N_2) and water (H_2O). While SCR has been applied to large boilers and turbines in the power generation industry, its application on new RICE in the gas transmission industry has been rare, and retrofitted applications for existing lean burn RICE had not occurred as of 2014.[4]

There are several factors that make SCR difficult for this application. Technical concerns, such as reagent injection control, exhaust temperature requirements, and variations in the exhaust NO/NO_2 ratio, pose limitations on the effectiveness and feasibility of SCR. NOx reduction may not be achieved, or even more ammonium sulfates may be emitted if the reagent feed rate and/or operating temperature is not precisely tuned to the fluctuating exhaust properties.[4]

Another challenge is that combustion byproducts and engine oil carryover often contaminate the catalytic elements in SCR applications. Routine cleaning and replacement as well as greater management are required for effective use.[4]

For these reasons, LEC is the preferred control method for Units 701, 702, and 703.

Table 2.1 below summarizes the control technology options.

Table 2.1 Summary of Potential NO_x Control Options

Technology	Description	Applicability	Feasibility	Performance (% reduction)
Low Emission Combustion (LEC)	Engine tuning improvements to increase combustion efficiency.	Units 701, 702, and 703	Potentially feasible	58-75%[10]
Selective Catalytic Reduction (SCR)	Exhaust control for lean-burn combustion that converts NO_x to nitrogen and water using ammonia or urea.	Units 701, 702, and 703	Not feasible based on documented difficulty implementing technology on RICE engines	70-90%[5]

2.3.3 Four Factor Analysis of Potential NO_x Control Options

2.3.3.1 Factor 1: Cost of Compliance

A quotation was provided by Cooper Machinery Services[10] which outlined the proposed LEC upgrades to Units 701, 702, and 703. Modifications include:

- Installing new cylinder heads fitted with pre-combustion chambers;
- Replacing existing water-cooled pulse exhaust manifold with a dry constant pressure exhaust manifold;
- Adding turbocharger bypass valves to exhaust manifold;
- Upgrading turbocharger to increase air-to-fuel ratio;
- Replacing current intercoolers with larger intercoolers; and
- Adding pilot fuel lines and pressure control for pre-combustion chamber fuel.

Cost effectiveness estimates from these upgrades range from $2,000 to $13,000 per ton of NO_x removed. See Appendix A for cost estimate calculations.

The capital costs for SCR, if one were to assume this was an 'achievable technology' for this application, are varied. There are a number of published cost estimates for typical coal- oil- and gas-fired medium to large sized boilers. The same cannot be said for a retrofit of a natural gas-fired compressor engine. In addition, the cost to retrofit an engine with SCR is much higher than an original SCR installation, which would apply to this analysis. SCR systems used to retrofit an existing unit increase in costs by 30%.[5] O&M costs may also be substantial depending on reagent usage, catalyst replacement, and increased electrical usage. The cost effectiveness of SCR was estimated from $1,400 to $6,600 per ton removed.

See Appendix A for emission reductions and cost calculations.

Table 2.2 Summary of Cost Effectiveness of Potential NO_x Control Options

Control Option	Specific Design Parameters	Cost Effectiveness (2019 $/ton)	Factors Affecting Cost	Potential Applicability to Specific Affected Units
Low Emissions Controls (LEC)	Power cylinder heads, upgraded water coolers, high efficiency turbocharger, and miscellaneous on-engine assemblies.	$2,000 - $13,000	Annual hours of operation, target NO_x emission factor	Potentially applicable to units 701, 702, and 703
Selective Catalytic Reduction (SCR)	Exhaust control that converts NO_x to nitrogen and water using ammonia or urea.	$1,400 - $6,600	Contamination from byproducts, excessive routine maintenance, reagent usage	Potentially applicable to units 701, 702, and 703

2.3.3.2 Factor 2: Time Necessary for Compliance

According to NMED guidance, sources are generally given between two and five years to implement changes for compliance with new regulations and implementation of this LEC would fall within that timeframe. Although no specific data was found, it would be reasonable to assume that a two to five year period would also be appropriate for the installation of SCR.

2.3.3.3 Factor 3: Energy and Non-Air Impacts

The LEC technology does not require the handling or storage of hazardous materials and does not require changes that could create an energy demand penalty.

As described above, SCR systems require ammonia (aqueous and/or anhydrous) or urea-to-ammonia reagents. Anhydrous ammonia is considered a hazardous material, and would be subject to storage, transportation, and operational regulations.

2.3.3.4 Factor 4: Remaining Useful Life of the Source

Although the engines were manufactured in the 1960s, they are planned for continuous operation until they are no longer functional. The estimated service life of the assessed control equipment (LEC and SCR) is 25 years.[6] Based on this information, the control options are considered the limiting factor for useful life of the source. The cost effectiveness for applying the control options considers this as the minimum lifespan.

3. References

1. U.S Environmental Protection Agency (USEPA). *Technical Support Document for Controlling NOx Emissions from Stationary Reciprocating Internal Combustion Engines and Turbines*. March 2007.
2. U.S Environmental Protection Agency (USEPA). *Nitrogen Oxides (NOx), Why and How They Are Controlled.* November 1999.
3. INGAA Foundation, Inc. *Potential Impacts of the Ozone and Particulate Matter NAAQS on Retrofit NOx Control for Natural Gas Transmission and Storage Compressor Drivers*. December 2017.
4. INGAA Foundation, Inc. *Availability and Limitations of NOx Emission Control Resources for Natural Gas-Fired Reciprocating Engine Prime Movers Used in the Interstate Natural Gas Transmission Industry.* July 2014.
5. U.S Environmental Protection Agency (USEPA). *EPA Air Pollution Control Technology Fact Sheet for SCR.*
6. U.S Environmental Protection Agency (USEPA). *EPA Air Pollution Control Cost Manual, 6th Edition*, USEPA Research Triangle Park, NC. January 2002.
7. Northeast States for Coordinated Air Use Management (NESCAUM). *Status Report on NOx Controls for Gas Turbines, Cement Kilns, Industrial Boilers, Internal Combustion Engines*. December 2000.
8. U.S Environmental Protection Agency (USEPA). *Guidance on Regional Haze State Implementation Plans for the Second Implementation Period*. August 20, 2019.
9. Western Regional Air Partnership (WRAP). *Reasonable Progress Source Identification and Analysis Protocol, WRAP Regional Haze Planning Work Group – Control Measures Subcommittee*. February 2019.
10. Cost estimate from email correspondence with Bob Bailey with Cooper Machinery Services.

Appendix A
RICE Engine Baseline Emissions, Reductions, and Control Cost Analysis

Appendix A

RICE Engine Baseline Emissions, Reductions, and Control Cost Analysis
Mountainair Compressor Station- Torrance County, New Mexico

2016 EI	**Unit 701**	
Rated HP	4500	
Operating Hours	1535	
Nox Emission Rate (lb/hr)	59.07	
Nox emissions (ton/yr)	45.34	

LEC		**SCR**	
Rated HP	4500	Rated HP	4500
NOx Emission Factor [1] (g/hp-hr)	2.5	NOx Emission Factor (g/hp-hr)	0.60
2016 Operating Hours	1535	2016 Operating Hours	1535
New Nox Emission Rate (lb/hr)	24.80	New NOx Emission Rate (lb/hr)	5.91
Nox Emission Equivalent (ton/yr)	19.04	NOx Emission Equivalent (ton/yr)	4.53
Difference (tons)	26.30	Difference (tons)	40.81
% Reduction	**58%**	**% Reduction[3]**	**90%**
2019 $/ton	**$ 13,002**	**2019 $/ton**	**$ 6,596**

2016 EI	**Unit 702**	
Rated HP	4500	
Operating Hours	3116	
Nox Emission Rate (lb/hr)	98.03	
Nox emissions (ton/yr)	152.73	

LEC		**SCR**	
Rated HP	4500	Rated HP	4500
NOx Emission Factor [1] (g/hp-hr)	2.5	NOx Emission Factor (g/hp-hr)	0.99
2016 Operating Hours	3116	2016 Operating Hours	3116
New NOx Emission Rate (lb/hr)	24.80	New NOx Emission Rate (lb/hr)	9.80
NOx Emission Equivalent (ton/yr)	38.64	NOx Emission Equivalent (ton/yr)	15.27
Difference (tons)	114.09	Difference (tons)	137.46
% Reduction	**75%**	**% Reduction[3]**	**90%**
2019 $/ton	**$ 2,998**	**2019 $/ton**	**$ 2,114**

2016 EI	**Unit 703**	
Rated HP	4500	
Operating Hours	4586	
Nox Emission Rate (lb/hr)	100.86	
Nox emissions (ton/yr)	231.27	

LEC		**SCR**	
Rated HP	4500	Rated HP	4500
NOx Emission Factor [1] (g/hp-hr)	2.5	NOx Emission Factor (g/hp-hr)	1.02
2016 Operating Hours	4586	2016 Operating Hours	4586
New NOx Emission Rate (lb/hr)	24.80	New NOx Emission Rate (lb/hr)	10.09
NOx Emission Equivalent (ton/yr)	56.87	NOx Emission Equivalent (ton/yr)	23.13
Difference (tons)	174.40	Difference (tons)	208.14
% Reduction	**75%**	**% Reduction[3]**	**90%**
2019 $/ton	**$ 1,961**	**2019 $/ton**	**$ 1,372**

[1] Lowest achievable emission factor, per Cooper Machinery quote

[2] SCR Reduction efficiency from *TECHNICAL SUPPORT DOCUMENT FOR CONTROLLING NOx EMISSIONS FROM STATIONARY RECIPROCATING INTERNAL COMBUSTION ENGINES AND TURBINES,* Illinois Environmental Protection Agency, December 2017

LEC Cost	
Quote From Cooper Machinery Services - 10/17/19	
LEC Cost Description	**2019 $**
Total Capital Cost	1,800,000
Annual O&M Cost (estimate)	270,000
Total Annual Cost per Year	342,000

*Estimated useful life of LEC: 25 years
*Estimated Annual O&M cost as a percent of the Total Capital Investment: 15 %

SCR Cost						
	Unit 701		Unit 702		Unit 703	
SCR Cost Description	**1994 $**	**2019 $**	**1994 $**	**2019 $**	**1994 $**	**2019 $**
Total Capital Cost	634,900	1,100,282	634,900	1,100,282	634,900	1,100,282
Annual O&M Cost (estimate)	-	225,152	-	246,513	-	241,474
Total Annual Cost per Year	-	269,163	-	290,525	-	285,485

*Cumulative rate of Consumer Price Index (CPI) inflation from 1994 to 2019: 73.3 %
*Estimated useful life of SCR: 25 years

Appendix A

RICE Engine Baseline Emissions, Reductions, and Control Cost Analysis
Mountainair Compressor Station- Torrance County, New Mexico

Unit 701 SCR Costs			
Total Capital Cost (TCC)			Source
Lean Burn	*TCC = $310,000 + $72.70 * HP*		Pg III-30, NESCAUM, December 2000
Engine HP		4,500	
TCC (1994 dollars) =		$ 637,150.00	
CPI 1994		148.2	
CPI 2019		254.95	
TCC (2019 dollars) =		**$ 1,096,095.77**	
Total Annual Costs (TAC)			Source
Direct Annual Costs			
	Operator Labor Costs		
	Operator labor hours (hrs/day)	4	Sec 2.5, EPA Control Cost Manual
	Operator labor rate ($/hr)	$60	Sec 2.5, EPA Control Cost Manual
	Days of SCR operation (days/yr)	365	
Operator Labor		**$87,600**	
Supervisor	*15% of Operator*	**$13,140**	
	Materials		
	Ammonia ($Ammonia/yr)	**$ 24,389.69**	
	Catalyst ($/replacement catalyst layer)	**$ 9,740.81**	
	Maintenance		
	*Annual Maintenance Cost = 0.005*TCI*	**$ 5,480.48**	Eq. 2.57, EPA Control Cost Manual
Indirect Annual Costs	*Indirect Annual Cost = (Administrative Charges) + (Capitol Recovery)*		Eq. 2.68
Administrative Charges	*Administrative Charges = 0.03*((Operator Labor Cost)+0.4*(Annual Maintenance Cost))*	$ 3,087.97	Eq. 2.69
Capitol Recovery	*Capitol Recovery = CRF * TCI*	$ 81,713.23	Eq. 2.70
Capitol Recovery Factor (CRF)	$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$ n = 25 yrs, i = 5.5%	0.0745	Eq. 2.71
Indirect Annual Costs		**$ 84,801.20**	
Total Annual Costs (TAC)	*TAC = Direct Annual Costs + Indirect Annual Costs*	**$225,152**	

Unit 701 SCR Reagent and Catalyst Costs Backup Calculations				
			Unit	Source
Selective Catalytic Reduction		90%		
Uncontrolled emissions		59.07	lb/hr	2019 Stack Test
Engine Horsepower		4,500	hp	Permit
Engine Fuel Consumption		7728.00	Btu/hp-hr	2019 Stack Test
Max Heat Input (Q_B)		34.78	MMBTU/hr	Calculated
Stoichiometric Ratio Factor (SRF)		1.05		
Flue Gas Flow Rate ($q_{fluegas}$)		18853.18	acfm	2019 Stack Test
dscfm		7368.32	dscfm	2019 Stack Test
CF_plant		1		
Nox Removal Efficiency (η_{NOx})		90%		
N_{SCR}	*Number of SCRs*	1		
Catalyst Volume ($Vol_{catalyst}$)	$2.81*Q_B*\eta_{adj}*slip_{adj}*Nox_{adj}*S_{adj}*T_{adj}/N_{SCR}$	528.24	ft^3	Eq. 2.22, EPA Control Cost Manual
η_{adj}	$(0.2869+(1.058+\eta_{NOx}))$	2.24		Eq. 2.23, EPA Control Cost Manual
Slip	$(SRF-\eta_{NOx})$	0.15		
$Slip_{adj}$	*1.2835-(0.0567*slip)*	1.27		Eq. 2.24, EPA Control Cost Manual
NOx_{in}	Uncontrolled emissions / Q_B	1.70	lb/MMBTU	Calculated
NOx_{adj}	$0.8524+(0.3208*NOx_{in})$	1.40		Eq. 2.25, EPA Control Cost Manual
S, Sulfur in fuel		0.01		Section 2.5, EPA Control Cost Manual
S_{adj}	*0.9636+(0.0455*S)*	0.96		Eq. 2.26, EPA Control Cost Manual
SCR inlet temp		600	F	
SCR inlet temp		588.7	K	
T_{adj} for inlet T not - 700 F	*15.16-(0.03937*T)+(2.74E-5*T^2)*	1.402		Eq. 2.27, EPA Control Cost Manual
$A_{catalyst}$	$(q_{fluegas}/(16*60)$	19.64	ft^2	Eq. 2.28, EPA Control Cost Manual
n_{layer}	$V_{catalyst}/(h'_{layer}*A_{catalyst})$	8.68		Eq. 2.31, EPA Control Cost Manual
h_{layer}		4.1	ft	Eq. 2.32, EPA Control Cost Manual
h'_{layer}		3.1	ft	
$m_{reagent}$	$NOx_{in}*Q_B*\eta_{NOx}*SRF*MW_{reagent}/(MW_{NOx})$	20.63	lb/hr	Eq. 2.35, EPA Control Cost Manual
$MW_{reagent}$	*MW of ammonia*	17		
MW_{NOx}	*MW of NOx*	46		
C_{sol}	*Concentration of ammonia in aqueous solution*	0.29		Section 2.5, EPA Control Cost Manual
m_{sol}	$m_{reagent}/C_{sol}$	71.14	lb/hr	Eq. 2.36, EPA Control Cost Manual
ρ_{sol}		56	lb/ft^3	
ν_{sol}		7.4805	gal/ft^3	
q_{sol}	$(m_{sol}/\rho_{sol})*7.4805$	9.50	gal/hr	Eq. 2.37, EPA Control Cost Manual
t_{op}		8760	hrs	
Vol_{tank}	$Voltank = q_{sol}*t_{op}$	83241.25	gallons	Eq. 2.38, EPA Control Cost Manual
cost of reagent		0.293	$/gallon	
Cost of reagent (per hour)		2.78	$/hr of ammonia	
Cost of reagent (per year)		**$ 24,389.69**	$/yr of ammonia	
Catalyst Cost (CC)		$ 160.00	$/ft^3	
Catalyst cost Replacement	$N_{SCR}*Vol_{catalyst}*(CC/n_{layer})$	**$ 9,740.81**	$/replacement layer/year	Eq. 2.63, EPA Control Cost Manual

Appendix A

RICE Engine Baseline Emissions, Reductions, and Control Cost Analysis
Mountainair Compressor Station- Torrance County, New Mexico

Unit 702 SCR Costs			
Total Capital Cost (TCC)			Source
Lean Burn	*TCC = $310,000 + $72.70 * HP*		Pg III-30, NESCAUM, December 2000
Engine HP		4,500	
TCC (1994 dollars) =		$ 637,150.00	
CPI 1994		148.2	
CPI 2019		254.95	
TCC (2019 dollars) =		**$ 1,096,095.77**	
Total Annual Costs (TAC)			Source
Direct Annual Costs			
	Operator Labor Costs		
	Operator labor hours (hrs/day)	4	Sec 2.5, EPA Control Cost Manual
	Operator labor rate ($/hr)	$60	Sec 2.5, EPA Control Cost Manual
	Days of SCR operation (days/yr)	365	
Operator Labor		**$87,600**	
Supervisor	*15% of Operator*	**$13,140**	
	Materials		
	Ammonia ($Ammonia/yr)	**$ 40,476.06**	
	Catalyst ($/replacement catalyst layer)	**$ 15,015.51**	
	Maintenance		
	*Annual Maintenance Cost = 0.005*TCI*	**$ 5,480.48**	Eq. 2.57, EPA Control Cost Manual
Indirect Annual Costs	*Indirect Annual Cost = (Administrative Charges) + (Capitol Recovery)*		Eq. 2.68
Administrative Charges	*Administrative Charges = 0.03*((Operator Labor Cost)+0.4*(Annual Maintenance Cost))*	$ 3,087.97	Eq. 2.69
Capitol Recovery	*Capitol Recovery = CRF * TCI*	$ 81,713.23	Eq. 2.70
Capitol Recovery Factor (CRF)	$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$ n = 25 yrs, i = 5.5%	0.0745	Eq. 2.71
Indirect Annual Costs		**$ 84,801.20**	
Total Annual Costs (TAC)	*TAC = Direct Annual Costs + Indirect Annual Costs*	**$246,513**	

Unit 702 SCR Reagent and Catalyst Costs Backup Calculations				
			Unit	Source
Selective Catalytic Reduction		90%		
Uncontrolled emissions		98.03	lb/hr	2019 Stack Test
Engine Horsepower		4,500	hp	Permit
Engine Fuel Consumption		7726.00	Btu/hp-hr	2019 Stack Test
Max Heat Input (Q_B)		34.77	MMBTU/hr	Calculated
Stoichiometric Ratio Factor (SRF)		1.05		
Flue Gas Flow Rate ($q_{fluegas}$)		29062.27	acfm	2019 Stack Test
dscfm		11358.3	dscfm	2019 Stack Test
CF_plant		1		
Nox Removal Efficiency (η_{NOx})		90%		
N_{SCR}	*Number of SCRs*	1		
Catalyst Volume ($Vol_{catalyst}$)	$2.81*Q_B*\eta_{adj}*slip_{adj}*Nox_{adj}*S_{adj}*T_{adj}/N_{SCR}$	664.03	ft^3	Eq. 2.22, EPA Control Cost Manual
η_{adj}	$(0.2869+(1.058+\eta_{NOx}))$	2.24		Eq. 2.23, EPA Control Cost Manual
Slip	$(SRF-\eta_{NOx})$	0.15		
$Slip_{adj}$	*1.2835-(0.0567*slip)*	1.27		Eq. 2.24, EPA Control Cost Manual
NOx_{in}	*Uncontrolled emissions* / Q_B	2.82	lb/MMBTU	Calculated
NOx_{adj}	$0.8524+(0.3208*NOx_{in})$	1.76		Eq. 2.25, EPA Control Cost Manual
S, Sulfur in fuel		0.01		Section 2.5, EPA Control Cost Manual
S_{adj}	*0.9636+(0.0455*S)*	0.96		Eq. 2.26, EPA Control Cost Manual
SCR inlet temp		600	F	
SCR inlet temp		588.7	K	
T_{adj} for inlet T not - 700 F	*15.16-(0.03937*T)+(2.74E-5*T^2)*	1.402		Eq. 2.27, EPA Control Cost Manual
$A_{catalyst}$	$(q_{fluegas}/(16*60)$	30.27	ft^2	Eq. 2.28, EPA Control Cost Manual
n_{layer}	$V_{catalyst}/(h'_{layer}*A_{catalyst})$	7.08		Eq. 2.31, EPA Control Cost Manual
h_{layer}		4.1	ft	Eq. 2.32, EPA Control Cost Manual
h'_{layer}		3.1	ft	
$m_{reagent}$	$NOx_{in}*Q_B*\eta_{NOx}*SRF*MW_{reagent}/(MW_{NOx})$	34.24	lb/hr	Eq. 2.35, EPA Control Cost Manual
$MW_{reagent}$	*MW of ammonia*	17		
MW_{NOx}	*MW of NOx*	46		
C_{sol}	*Concentration of ammonia in aqueous solution*	0.29		Section 2.5, EPA Control Cost Manual
m_{sol}	$m_{reagent}/C_{sol}$	118.05	lb/hr	Eq. 2.36, EPA Control Cost Manual
ρ_{sol}		56	lb/ft^3	
ν_{sol}		7.4805	gal/ft^3	
q_{sol}	$(m_{sol}/\rho_{sol})*7.4805$	15.77	gal/hr	Eq. 2.37, EPA Control Cost Manual
t_{op}		8760	hrs	
Vol_{tank}	$Voltank = q_{sol}*t_{op}$	138143.55	gallons	Eq. 2.38, EPA Control Cost Manual
cost of reagent		0.293	$/gallon	
Cost of reagent (per hour)		4.62	$/hr of ammonia	
Cost of reagent (per year)		**$ 40,476.06**	$/yr of ammonia	
Catalyst Cost (CC)		$ 160.00	$/ft^3	
Catalyst cost Replacement	$N_{SCR}*Vol_{catalyst}*(CC/n_{layer})$	**$ 15,015.51**	$/replacement layer/year	Eq. 2.63, EPA Control Cost Manual

Appendix A

RICE Engine Baseline Emissions, Reductions, and Control Cost Analysis
Mountainair Compressor Station- Torrance County, New Mexico

Unit 703 SCR Costs			
Total Capital Cost (TCC)			Source
Lean Burn	*TCC = $310,000 + $72.70 * HP*		Pg III-30, NESCAUM, December 2000
Engine HP		4,500	
TCC (1994 dollars) =		$ 637,150.00	
CPI 1994		148.2	
CPI 2019		254.95	
TCC (2019 dollars) =		**$ 1,096,095.77**	
Total Annual Costs (TAC)			Source
Direct Annual Costs			
Operator Labor Costs			
	Operator labor hours (hrs/day)	4	Sec 2.5, EPA Control Cost Manual
	Operator labor rate ($/hr)	$60	Sec 2.5, EPA Control Cost Manual
	Days of SCR operation (days/yr)	365	
Operator Labor		**$87,600**	
Supervisor	*15% of Operator*	**$13,140**	
Materials			
	Ammonia ($Ammonia/yr)	**$ 41,644.55**	
	Catalyst ($/replacement catalyst layer)	**$ 8,807.60**	
Maintenance			
	*Annual Maintenance Cost = 0.005*TCI*	**$ 5,480.48**	Eq. 2.57, EPA Control Cost Manual
Indirect Annual Costs	*Indirect Annual Cost = (Administrative Charges) + (Capitol Recovery)*		Eq. 2.68
Administrative Charges	*Administrative Charges = 0.03*((Operator Labor Cost)+0.4*(Annual Maintenance Cost))*	$ 3,087.97	Eq. 2.69
Capitol Recovery	*Capitol Recovery = CRF * TCI*	$ 81,713.23	Eq. 2.70
Capitol Recovery Factor (CRF)	n = 25 yrs, i = 5.5% $CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$	0.0745	Eq. 2.71
Indirect Annual Costs		**$ 84,801.20**	
Total Annual Costs (TAC)	*TAC = Direct Annual Costs + Indirect Annual Costs*	**$241,474**	

Unit 703 SCR Reagent and Catalyst Costs Backup Calculations				
			Unit	Source
Selective Catalytic Reduction		90%		
Uncontrolled emissions		100.86	lb/hr	2019 Stack Test
Engine Horsepower		4,500	hp	Permit
Engine Fuel Consumption		7079.00	Btu/hp-hr	2019 Stack Test
Max Heat Input (Q_B)		31.86	MMBTU/hr	Calculated
Stoichiometric Ratio Factor (SRF)		1.05		
Flue Gas Flow Rate ($q_{fluegas}$)		17046.96	acfm	2019 Stack Test
dscfm		6662.4	dscfm	2019 Stack Test
CF_plant		1		
Nox Removal Efficiency (η_{NOx})		90%		
N_{SCR}	*Number of SCRs*	1		
Catalyst Volume ($Vol_{catalyst}$)	$2.81*Q_B*\eta_{adj}*slip_{adj}*Nox_{adj}*S_{adj}*T_{adj}/N_{SCR}$	646.92	ft^3	Eq. 2.22, EPA Control Cost Manual
η_{adj}	$(0.2869+(1.058+\eta_{NOx}))$	2.24		Eq. 2.23, EPA Control Cost Manual
Slip	$(SRF-\eta_{NOx})$	0.15		
$Slip_{adj}$	*1.2835-(0.0567*slip)*	1.27		Eq. 2.24, EPA Control Cost Manual
NOx_{in}	*Uncontrolled emissions* / Q_B	3.17	lb/MMBTU	Calculated
NOx_{adj}	$0.8524+(0.3208*NOx_{in})$	1.87		Eq. 2.25, EPA Control Cost Manual
S, Sulfur in fuel		0.01		Section 2.5, EPA Control Cost Manual
S_{adj}	*0.9636+(0.0455*S)*	0.96		Eq. 2.26, EPA Control Cost Manual
SCR inlet temp		600	F	
SCR inlet temp		588.7	K	
T_{adj} for inlet T not - 700 F	*15.16-(0.03937*T)+(2.74E-5*T^2)*	1.402		Eq. 2.27, EPA Control Cost Manual
$A_{catalyst}$	$(q_{fluegas}/(16*60)$	17.76	ft^2	Eq. 2.28, EPA Control Cost Manual
n_{layer}	$V_{catalyst}/(h'_{layer}*A_{catalyst})$	11.75		Eq. 2.31, EPA Control Cost Manual
h_{layer}		4.1	ft	Eq. 2.32, EPA Control Cost Manual
h'_{layer}		3.1	ft	
$m_{reagent}$	$NOx_{in}*Q_B*\eta_{NOx}*SRF*MW_{reagent}/(MW_{NOx})$	35.22	lb/hr	Eq. 2.35, EPA Control Cost Manual
$MW_{reagent}$	*MW of ammonia*	17		
MW_{NOx}	*MW of NOx*	46		
C_{sol}	*Concentration of ammonia in aqueous solution*	0.29		Section 2.5, EPA Control Cost Manual
m_{sol}	$m_{reagent}/C_{sol}$	121.46	lb/hr	Eq. 2.36, EPA Control Cost Manual
ρ_{sol}		56	lb/ft^3	
ν_{sol}		7.4805	gal/ft^3	
q_{sol}	$(m_{sol}/\rho_{sol})*7.4805$	16.23	gal/hr	Eq. 2.37, EPA Control Cost Manual
t_{op}		8760	hrs	
Vol_{tank}	$Voltank = q_{sol}*t_{op}$	142131.58	gallons	Eq. 2.38, EPA Control Cost Manual
cost of reagent		0.293	$/gallon	
Cost of reagent (per hour)		4.75	$/hr of ammonia	
Cost of reagent (per year)		**$ 41,644.55**	$/yr of ammonia	
Catalyst Cost (CC)		$ 160.00	$/ft^3	
Catalyst cost Replacement	$N_{SCR}*Vol_{catalyst}*(CC/n_{layer})$	**$ 8,807.60**	$/replacement layer/year	Eq. 2.63, EPA Control Cost Manual

about GHD

GHD is one of the world's leading professional services companies operating in the global markets of water, energy and resources, environment, property and buildings, and transportation. We provide engineering, environmental, and construction services to private and public sector clients.

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