Appendix Q- BACT/RACT Analyses

Appendix Q, Table Q-1. Top-Down BACT Analysis for Sulfur Treatment Unit (STU) $PM_{10}/PM_{2.5}$

Process	Pollutant
U237 Sulfur Treatment Unit (STU) equipped with thermal oxidizers	$PM_{10}/PM_{2.5}$

		Control Technology	**Baghouse/Fabric Filter**	**Dry Electrostatic Precipitator - Pipe Type (ESP)**	**Wet Electrostatic Precipitator - Wire Type (ESP)**	**Wet Scrubber**	**High-Efficiency Cyclones**
Step 1.	**IDENTIFY AIR POLLUTION CONTROL TECHNOLOGIES**	**Control Technology Description**	A fabric filter unit (or baghouse) consists of one or more compartments containing rows of fabric bags. Particle-laden gases pass along the surface of the bags then through the fabric. Particles are retained on the upstream face of the bags and the cleaned gas stream is vented to the atmosphere. Fabric filters collect particles with sizes ranging from submicron to several hundred microns in diameter. Fabric filters are used for medium and low gas flow streams with high particulate concentrations.	A dry electrostatic precipitator (ESP) is a particle control device that uses electrical forces to move the particles out of the gas stream onto collector plates. This process is accomplished by the charging of particles in the gas stream using positively or negatively charged electrodes. The particles are then collected as they are attracted to oppositely opposed electrodes. Once the particles are collected on the plates, they are removed by knocking them loose from the plates, allowing the collected layer of particles to fall down into a hopper.	A wet electrostatic precipitator (ESP) is a particle control device that uses electrical forces to move the particles out of the gas stream onto collector tubes. This process is accomplished by the charging of particles in the gas stream using positively or negatively charged electrodes. The particles are then collected as they are attracted to oppositely opposed electrodes. Once the particles are collected on the conductive tubes, they are removed by being washed intermittently or continuously by a spray of liquid, usually water, allowing the wet effluent to be collected with a drainage system. [3]	A wet gas scrubber is an air pollution control device that removes $PM_{2.5}$ from stationary point sources waste streams. PM_{10} and $PM_{2.5}$ are primarily removed through the impaction, diffusion, interception, and/or absorption of the pollutant onto droplets of liquid. Wet scrubbers have some advantages over ESPs and baghouses in that they are particularly useful in removing PM with the following characteristics: (1) Sticky and/or hygroscopic materials; (2) Combustible, corrosive or explosive materials; (3) Particles that are difficult to remove in dry form; (4) PM in the presence of soluble gases; and (5) PM in gas stream with high moisture content.	A cyclone separator (cyclone) operates on the principle of centrifugal separation. The exhaust enters the inlet and spirals around towards the outlet. As the particles proceed through the cyclone, the heavier material hits the outside wall and drops out where it is collected. The cleaned gas escapes through an inner tube. Cyclones are generally used to reduce dust loading and collect large particles.
		Typical Operating Temperature	Up to 550 °F [1]	Up to 1,300 °F [2]	Lower than 170 - 190 °F [3]	40 - 700 °F [4]	Up to 1,000 °F [5]
		Typical Inlet Flow Rate	Varies	100,000 - 200,000 scfm [2]	1,000 - 100,000 scfm [3]	500 - 75,000 scfm [4]	1,060 - 25,400 scfm [5]
		Typical Inlet Pollutant Concentration	0.5 - 10 grains/dscf [1]	0.5 - 5 grains/dscf [2]	0.5 - 5 grains/dscf [3]	0.20 grains/scf [4]	1.0 - 100 grains /scf [5]
		Other Considerations	Moisture and corrosives content are the major gas stream characteristics requiring design consideration. Standard fabric filters can be used in pressure or vacuum service, but only within the range of about ± 640 millimeters of water column (25 inches of water column).	Dry ESPs are used to capture coarse particles at high concentrations. Small particles at low concentrations are not effectively collected by an ESP.	Wet ESPs not suitable for use in processes which are highly variable because they are sensitive to fluctuation in gas stream conditions.	PM and acid gases are primarily removed through the impaction, diffusion, interception and/or absorption of the pollutant onto droplets of liquid. Considering the low concentration of small size of particulate, the wet scrubber efficiency would be reduced.	Cyclones perform more efficiently with higher pollutant loadings, provided that the devices does not become choked. Higher pollutant loading are generally associated with higher flow designs. [5]
Step 2.	**ELIMINATE TECHNICALLY INFEASIBLE OPTIONS**	**RBLC Database Information**	Not included in the RBLC for control of PM emissions from thermal oxidizers at petroleum refineries.	Not included in the RBLC for control of PM emissiona from thermal oxidizers at petroleum refineries.	Not included in the RBLC for control of PM emissions from thermal oxidizers at petroleum refineries.	Not included in the RBLC for control of PM emissions from thermal oxidizers at petroleum refineries.	Not included in the RBLC for control of PM emissions from thermal oxidizers at petroleum refineries.
		Feasibility Discussion	Temperatures much in excess of 550°F require special refractory mineral or metallic fabrics which can be expensive. Fabric filters cannot be operated in a moist enviroment.[1] Due to the high moisture content the baghouse is not a technically feasible option.	The STU thermal oxidizers exhaust flowrates will approximately be 585 scfm which is much lower than the typical gas flowrates for dry ESPs. In addition, dry ESPs are not recommended for removing sticky or moist particles.[2] Therefore, the dry ESP is not a technically feasible control option.	Wet ESPs are limited to operating at stream temperatures under approximately 170 °F to 190 °F. The exhaust temperature for the STU thermal oxidizers will be above approximately 500 °F. Therefore, the exhaust temperature of the gas will be outside the acceptable temperature range for wet ESPs and will require cooling equipment. In addition, the STU thermal oxidizers exhaust flowrates will approximately be 585 scfm which is much lower than the typical gas flowrates for wet ESPs. Therefore, the dry ESP is not a technically feasible control option.	Technically feasible control option.	The control efficiency is not high enough to meet BACT. In addition, the STU thermal oxidizers exhaust flowrates will approximately be 585 scfm which is much lower than the typical gas flowrates for a cyclone. Therefore, a cyclone is technically infeasible.
Step 3.	**RANK REMAINING CONTROL TECHNOLOGIES**	**Overall Control Efficiency**	99 - 99.9% [1]	90 - 99.9% [2]	90 - 99.9% [3]	98% [5]	20-70% [6]
Step 4.	**EVALUATE AND DOCUMENT MOST EFFECTIVE CONTROLS**	**Cost Effectiveness ($/ton)**	N/A - Technically infeasible control technology	N/A - Technically infeasible control technology	N/A - Technically infeasible control technology	The scrubber is proposed as BACT.	N/A - Technically infeasible control technology
Step 5.	**SELECT BACT**					**BACT: Wet scrubber**	

1. U.S. EPA, Office of Air Quality Planning and Standards, "Air Pollution Control Technology Fact Sheet (Baghouse)," EPA-452/F-03-025.
2. U.S. EPA, Office of Air Quality Planning and Standards, "Air Pollution Control Technology Fact Sheet (Dry Electrostatic Precipitator - Wire Plate Type)," EPA-452/F-03-027.
3. U.S. EPA, Office of Air Quality Planning and Standards, "Air Pollution Control Technology Fact Sheet (Wet Electrostatic Precipitator - Wire-Pipe Type)," EPA-452/F-03-029.
4. U.S. EPA, Office of Air Quality Planning and Standards, "Air Pollution Control Technology Fact Sheet (Packed-Bed/Packed-Tower Wet Scrubber)," EPA-452/F-03-015.
5. The manufacturer has guaranteed a 98% PM control efficiency for the wet scrubber.
6. U.S. EPA, Office of Air Quality Planning and Standards, "Air Pollution Control Technology Fact Sheet (Cyclones)," EPA-452/F-03-005.

Appendix Q, Table Q-2. Top-Down BACT Analysis for Sulfur Treatment Unit (STU) SO_2

Process	Pollutant
U237 Sulfur Treatment Unit (STU) equipped with thermal oxidizers	SO_2

		Control Technology	Wet Scrubber	Dry Scrubber
Step 1.	**IDENTIFY AIR POLLUTION CONTROL TECHNOLOGIES**	**Control Technology Description**	A wet scrubber is a control technology that is capable of removing inorganic fumes, vapors and gases such as SO_2. Caustic solution is the most common scrubbing liquid used for acid-gas control (e.g., SO_2, HCl). When the acid gases are absorbed into the scrubbing solution, they react with the alkaline compounds to produce neutral salts. The rate of absorption of the acid gases is dependent upon the solubility of the acid gases in the scrubbing liquid.	A dry scrubber is a control technology used to remove water soluble contaminants such as SO_2. Dry scrubbers inject either dry, powdered sorbent or an aqueous slurry that contains a high concentration of the sorbent. Wet scrubbers achieve higher SO_2 removal efficiencies than dry scrubbers. [2]
		Typical Operating Temperature	40 - 700 °F [1]	Spray dry systems: 20 - 30 °F [3] Dry sorbent injection system: 300 - 350 °F [3]
		Typical Inlet Flow Rate	500 - 75,000 scfm[1]	--
		Typical Inlet Pollutant Concentration	250 to 10,000 ppmv[1]	Approximately 2,000 ppm [3]
		Other Considerations	For gas absorption the solvent must be treated to remove the captured pollutant from the solution. The effluent from the column can be recycled and re-used.	Dry scrubber will require emission stream pretreatment. The flue gas must be cooled to a lower temperature range. This will also prevent deposition on downstream equipment. The gas can be cooled via heat recovery boiler, an evaporative cooler or a heat exchanger. [3]
Step 2.	**ELIMINATE TECHNICALLY INFEASIBLE OPTIONS**	**RBLC Database Information**	Not included in the RBLC for control of SO2 emissions from thermal oxidizers at petroleum refineries.	Not included in the RBLC for control of SO2 emissions from thermal oxidizers at petroleum refineries.
		Feasibility Discussion	Technically feasible	SO_2 removal efficiency is lower than wet scrubbers at 85-95%.[2] In addition, cooling equipment will be required to lower the temperature of the exhaust gas to an optimal temperature range. Therefore, a dry scrubber is not a technically feasible control technology.
Step 3.	**RANK REMAINING CONTROL TECHNOLOGIES**	**Overall Control Efficiency**	99.9% [4]	85-95% [2]
Step 4.	**EVALUATE AND DOCUMENT MOST EFFECTIVE CONTROLS**	**Cost Effectiveness ($/ton)**	The scrubber is proposed as RACT.	N/A - Technically infeasible control technology Less efficient that wet scrubber
Step 5.	**SELECT BACT**		**BACT: Wet scrubber**	

1. U.S. EPA, Office of Air Quality Planning and Standards, "Air Pollution Control Technology Fact Sheet (Packed-Bed/Packed-Tower wet Scrubber)," EPA-452/F-03-015.
2. U.S. EPA SO2 and Acid Gas Controls, "Chapter 1 Wet and Dry Scrubbers for Acid Gas Control".
3. U.S. EPA, Office of Air Quality Planning and Standards, "Air Pollution Control Technology Fact Sheet (Flue Gas Desulfurization (FGD) - Wet, Spray Dry, and Dry Scrubbers", EPA-452/F-03-034.
4. The manufacturer has guaranteed a 99.9% control efficiency for the wet scrubber. This grain loading rate meets and exceeds NSPS requirements. This is believed to be the best that can be offered for impeller mill baghouse systems based on a review of multiple vendor

Appendix Q, Table Q-3: Cost-Effectiveness for SCR Projects **Confidential Business Information**

			A	B	C	D	E
Year	Company	Location	Flue Gas Capacity	SCR Only ($MM)	Total Installed Cost ($MM)	Total Installed Cost per thou lb/hr flue gas D = C ÷ A	Adjusted Installed Cost ($MM) E = D x 30.944 thou lb/hr
2019		Carson/Wilmington, CA	62,491 lb/hr	$0.86	$14.60	$233,633.64	$7.23
2019		Carson/Wilmington, CA	68,121 lb/hr	$0.92	$20.15	$295,797.18	$9.15
2019		El Segundo, CA	210 MMSCFD (730,000 lb/hr)	$1.98	$64.05	$87,739.73	$2.72
2019		Wilmington, CA	585,000 lb/hr		$23.00	$39,316.24	$1.22
2019		Carson/Wilmington, CA	178,935 lb/hr (design), 131,288 Norm	$0.30	$16.90	$94,447.70	$2.92
2019		Martinez, CA	1,322,000 lb/hr		$122.26	$92,481.09	$2.86
2022		Rodeo, CA	30,944 lb/hr (total for 2 units)	$1.50	$15.60		$15.60

Appendix Q, Table Q-3 above provides cost estimates for several projects for other types of processes in which SCR units were installed. Also shown in the last entry in Table Q-3 is a cost estimate from the equipment vendor for an add-on SCR (two SCR units) immediately downstream of the proposed U237 STU. This SCR is guaranteed by the vendor to achieve an outlet concentration of 32 ppmv @ 3% O2. In Table Q-3, four of these projects are for Phillips 66's Carson/Wilmington refinery (in SCAQMD's jurisdiction) in 2019, one is for another refinery in SCAQMD's jurisdiction in 2019, and two are in BAAQMD's jurisdiction (including the aforementioned estimate from the equipment vendor). Cost effectiveness is calculated using:

-The US EPA Air Pollution Control Cost Manual, 7th Edition (EPA-452-02-001, 2002, SCR Chapter updated in 2019), control equipment parameters shown in Table Q-4
-The estimated annual NOx emissions (of 10.1 tons) removed by the add-on SCR provided in Tables Q-5 and Q-6
-The installed capital costs that have been proportionally adjusted based on the flue gas capacity of the aforementioned add-on SCR provided by the equipment vendor.

Based on the lowest adjusted installed cost estimate of $1.22 million (as shown in Table Q-3), the cost-effectiveness calculated based on the methodology above was $21,531/ton of NOx reduced (see Appendix Q, Table Q-5) , which exceeds the current BACT threshold of $17,500/ton of NOx reduced. Since the use of an SCR has been demonstrated above to exceed the cost-effectiveness thresholds for BACT, it follows that an SCR will also exceed the cost-effectiveness threshold for RACT, which is expected to be lower than that for BACT.

Furthermore, based on the quote provided by the equipment vendor, installing an SCR would require redesign of the STU and installation of an additional burner. These changes would result far higher cost-effectiveness calculation of $236,382/ton of NOx reduced (as shown in Appendix Q, Table Q-6). Thus, while the addition of an SCR may be technologically feasible, the Air District has determined it does not constitute RACT when considering cost-effectiveness and the extent of necessary modifications to the source.

Appendix Q, Table Q-4
Design Analysis for SCR RACT Analysis
For 2 SCRs (one for each thermal oxidizer at U237)
Phillips 66 Company - San Francisco Refinery
Rodeo, CA

Parameter	Description	Value	Units	Notes
Q_B	Heat input rate	14.8	MMBtu/hr	
CF	Capacity factor	1.0	--	Year-round operation
h_{NOx}	NO_x removal efficiency	78%	--	
$q_{fluegas}$	Flue gas flow rate	5,291	cu ft/min	Vendor data
$Vol_{catalyst}$	Volume of catalyst	44.2	cu ft	
h_{adj}	NO_x efficiency adjustment factor	1.11	--	
$Slip_{adj}$	Ammonia slip adjustment factor	1.0	--	assume 5 ppm slip
NOx_{adj}	Inlet NO_x adjustment factor	0.96	--	
NOx_{in}	Uncontrolled NO_x in flue gas	0.33	lb/MMBtu	
S_{adj}	Sulfur in coal adjustment factor	1.0	--	Only relevant for units fired on coal
T_{adj}	Temperature adjustment factor	1.0	--	assume reactor inlet temp of 700 deg F
$A_{catalyst}$	Catalyst cross-sectional area	6	sq ft	
n_{layer}	Number of catalyst layers	3	--	
n_{total}	Total catalyst layers (including empty layers)	3	--	
h_{layer}	Height of one catalyst layer	4.1	ft	
h_{SCR}	Height of SCR reactor	42.3	ft	
DP_{duct}	Pressure drop (duct)	2	in H_2O	
$DP_{catalyst}$	Pressure drop (catalyst)	0.75	in H_2O	
$m_{reagent}$	Mass flow of reagent	5.2	lb/hr	Assume urea as reagent
m_{sol}	Mass flow of aqueous reagent solution	10	lb/hr	
C_{sol}	Urea concentration by weight	50%	--	
q_{sol}	Solution volume flow rate	0.15	gal/hr	
TV	Tank volume for reagent storage	1,000	gallons	

Reference:

USEPA, "EPA Air Pollution Control Cost Manual, 7th Edition," EPA-452-02-001, 2002.
SCR Chapter Updated 2019

Appendix Q, Table Q-5

Cost Analysis for SCR RACT Analysis for SCR with Lowest Cost Estimate from Prior SCR Projects (see Table Q-3)

For 2 SCRs (one for each thermal oxidizer at U237)

Phillips 66 Company - San Francisco Refinery

Rodeo, CA

Installed Capital Costs			
SCR duct, catalyst, ammonia vaporization skid, and aqueous ammonia storage	$ 1,216,602	Vendor quote	No utilities, no installation, no maintenance
Direct Annual Costs			
Operating and Supervisory Labor	$0		
Maintenance Labor (0.015 installed capital cost)	$18,249		
Annual Reagent Consumption Cost	$33,922		
Ammonia volume flow rate	13	lb/hr	
Ammonia reagent cost	$0.30	$/lb	
Capacity factor	1.0	--	
Annual Electricity Cost	$3,295		
Heat input rate	14.8	MMBtu/hr	
Input NO_x concentration	0.38	lb/MMBtu	
Pressure drop (duct)	2	in H_2O	
Number of catalyst layers	3	--	
Pressure drop (catalyst)	0.75	in H_2O	
Capacity factor	1.0	--	
Electricity cost	$0.10	$/kWh	
Annual Catalyst Replacement Cost	$0.01		
Catalyst volume	44.2	cu ft	
Catalyst cost	$240	$/cu ft	
Catalyst replacement factor (R_{layer})	1		
Catalyst operating life	8,760	hours	
Term of FWF	175.2	years	
Future Worth Factor (FWF)	0.00	--	
Subtotal (DAC)	$52,171		
Indirect Annual Costs (TCI x CRF)	$165,297		
Capital Recovery Factor (6% over 10 years)	0.136		
Total Annual Costs (TAC)	**$217,468**		
Uncontrolled NO_x emissions	13	tons/yr	
Removal efficiency	78%		
Controlled NO_x emissions[1]	2.9	tons/yr	
Annual NO_x removed	10.1	tons/yr	
Cost Effectiveness	**$21,531**	**$/ton NOx**	
BAAQMD NOx cost effectiveness threshold	**$17,500**	**$/ton NOx**	

[1] Vendor Guarantee

Reference:

USEPA, "EPA Air Pollution Control Cost Manual, 7th Edition," EPA-452-02-001, 2002.

SCR Chapter Updated 2019

Appendix Q, Table Q-6

Cost Analysis for SCR RACT Analysis for SCRs from Equipment Vendor

For 2 SCRs (one for each thermal oxidizer at U237)

Phillips 66 Company - San Francisco Refinery

Rodeo, CA

Installed Capital Costs			
SCR duct, catalyst, ammonia vaporization skid, and aqueous ammonia storage	$15,600,000	Vendor quote	No utilities, no installation, no maintenance
Direct Annual Costs			
Operating and Supervisory Labor	$0		
Maintenance Labor (0.015 installed capital cost)	$234,000		
Annual Reagent Consumption Cost	$33,922		
Ammonia volume flow rate	13	lb/hr	
Ammonia reagent cost	$0.30	$/lb	
Capacity factor	1.0	--	
Annual Electricity Cost	$3,295		
Heat input rate	14.8	MMBtu/hr	
Input NO_x concentration	0.38	lb/MMBtu	
Pressure drop (duct)	2	in H_2O	
Number of catalyst layers	3	--	
Pressure drop (catalyst)	0.75	in H_2O	
Capacity factor	1.0	--	
Electricity cost	$0.10	$/kWh	
Annual Catalyst Replacement Cost	$0.01		
Catalyst volume	44.2	cu ft	
Catalyst cost	$240	$/cu ft	
Catalyst replacement factor (R_{layer})	1		
Catalyst operating life	8,760	hours	
Term of FWF	175.2	years	
Future Worth Factor (FWF)	0.00	--	
Subtotal (DAC)	$267,922		
Indirect Annual Costs (TCI x CRF)	$2,119,540		
Capital Recovery Factor (6% over 10 years)	0.136		
Total Annual Costs (TAC)	**$2,387,462**		
Uncontrolled NO_x emissions	13	tons/yr	
Removal efficiency	78%		
Controlled NO_x emissions[1]	2.9	tons/yr	
Annual NO_x removed	10.1	tons/yr	
Cost Effectiveness	**$236,382**	**$/ton NOx**	
BAAQMD NOx cost effectiveness threshold	**$17,500**	**$/ton NOx**	

[1] Vendor Guarantee

Reference:

USEPA, "EPA Air Pollution Control Cost Manual, 7th Edition," EPA-452-02-001, 2002.

SCR Chapter Updated 2019