APPENDIX C

Cost Effectiveness Analysis
For Proposed Amendments to Rule 4702

July 20, 2021

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COST EFFECTIVENESS ANALYSIS FOR PROPOSED RULE 4702

I. SUMMARY

The California Health and Safety Code (CH&SC) Section 40920.6(a) requires the District to conduct both an absolute cost effectiveness analysis and an incremental cost effectiveness analysis of available emission control options before adopting each Best Available Retrofit Control Technology (BARCT) rule. The purpose of conducting a cost effectiveness analysis is to evaluate the economic reasonableness of the pollution control measure or rule. The analysis also serves as a guideline in developing the control requirements of a rule.

Absolute cost effectiveness of a control option is the added annual compliance cost to meet the proposed rule’s requirements, in dollars per year, divided by the emission reduction achieved in tons of pollutant reduced per year.

Table 1 shows the costs and the results of the cost effectiveness analysis for engines in the District inventory that are greater than 50 bhp, and that would have annualized costs and emissions reductions due to the proposed rule amendment. District staff estimates that operators will need to retrofit, replace, or update a permit for a total of 594 engines to comply with the emissions limits proposed in Rule 4702. Costs and emission reduction calculations for engines that may need to be replaced is based on the assumption that they will be replaced at the end of their useful life. Additionally, for engines that are currently source testing below the proposed limits, a capital cost of $2,000 was allocated for the high end potential cost associated with a required permit amendment. It is due to this estimated permitting fee that the cost effectiveness values for AO Rich Burn engines 14 ppmv and 20 ppmv range from $0 to up to approximately $23,000-$26,000.

Table 1 - Summary of Compliance Costs and Cost Effectiveness

Compliance Scenario (Current Permitted Limit to Proposed New Limit)	Expected Cost-Effectiveness Per Engine ($/ton)	Cost Effectiveness Range ($/ton)
AO Lean-Burn		
Replace Engine 50 ppmv to 11 ppmv	$13,120	$10,257 - $15,989
Replace Engine 70 ppmv to 11 ppmv	$3,426	$3,426
Replace Engine 80 ppmv to 11 ppmv	$4,753	$2,199 - $6,894
Replace Engine 150 ppmv to 11 ppmv	$2,526	$1,143 - $4,607
Convert to Rich Burn 90 ppmv to 11 ppmv	$21,857	$18,088 - $25,682
Convert to Rich Burn 150p ppmv to 11 ppmv	$9,013	$4,297 - $18,474
Replace & Upgrade NSCR 90 ppmv to 11 ppmv	$5,336	$5,282 - $5,390

Compliance Scenario (Current Permitted Limit to Proposed New Limit)	Expected Cost-Effectiveness Per Engine ($/ton)	Cost Effectiveness Range ($/ton)
AO Rich-Burn		
Upgrade/Replace NSCR 14 ppmv to 11 ppmv	$20,890	$0 - $23,030
Upgrade/Replace NSCR 20 ppmv to 11 ppmv	$8,764	$0 - $26,573
Upgrade/Replace NSCR 30 ppmv to 11 ppmv	$18,321	$4,550 - $37,515
Upgrade/Replace NSCR 40 ppmv to 11 ppmv	$11,250	$2,781 - $20,193
Upgrade/Replace NSCR 70 ppmv to 11 ppmv	$5,394	$1,624 - $9,164
Upgrade/Replace NSCR 90 ppmv to 11 ppmv	$5,643	$603 - $16,470
LB Gas Compression		
Low-Emission Combustion System 60 ppmv to 40 ppmv	$1,206	$48 - $2,405
Low-Emission Combustion System 80 ppmv to 40 ppmv	$658	$10 - $1,312
Low-Emission Combustion System 90 ppmv to 40 ppmv	$462	$25 - $998
Low-Emission Combustion System 100 ppmv to 40 ppmv	$363	$8 - $706
LB Waste Gas		
Low-Emission Combustion System 41-49 ppmv to 40 ppmv	$5,972	$675 - $11,269
Low-Emission Combustion System 50 ppmv to 40 ppmv	$3,630	$267 - $6,993
Low-Emission Combustion System 60 ppmv to 40 ppmv	$1,800	$68 - $3,518
RB Cyclic Loaded, Field Gas Fueled		
Upgrade/Replace NSCR 50 ppmv to 11 ppmv	$879	$313 - $1,530
RB Limited Use		
Upgrade/Replace NSCR 30 ppmv to11 ppmv	$5,063	$252 - $12,700
RB Not Listed Above		
Upgrade/Replace NSCR 30 ppmv to 11 ppmv	$1,269	$515 - $2,023

Permit Limits organized and grouped to the nearest 10

II. BACKGROUND

Revised Proposed Rule 4702 would implement more stringent NOx and VOC limits for spark-ignited engines greater than 50 bhp. The majority of these engines are operated on natural gas. It is the District’s experience that, when an emission limit is reduced, a small percentage of operators will choose to replace their IC engines with electric motors rather than retrofit with an emission control system. It would be speculative, at best, to determine which engines would become electrified; therefore the following compliance costs and cost effectiveness analysis do not include any cost-of-electrification scenarios.

For rich-burn engines, non-selective catalytic reduction (NSCR) is the most likely retrofit control technology. Most rich-burn engines already have NSCR and the majority of those can already achieve the proposed NOx limit. The engines that currently do not meet the proposed NOx limit would have to either install a new NSCR system or upgrade their existing NSCR systems and add more catalyst, or possibly replace the engine and NSCR system in order to meet the proposed NOx limit.

For lean-burn engines, there are no cost effective retrofits available, and as such all affected engines would either need to be replaced or tuned in order to meet the proposed limits. All lean-burn engines that would be required to limit their emissions to 11 ppmv are already source testing below that limit, and would not require the installation of a new selective catalytic reduction (SCR) system. All other existing engines are either meeting the proposed limits or should be able to do so with minor adjustments or upgrades, such as new air/fuel ratio controllers and O2 sensors. The costs used for this analysis assume that the operator would not have to install an SCR system. Additionally, for lean-burn AO engines that were previously rich-burn or would need to be replaced within the next 10 years, it is assumed that by 2030 the engine would be converted/replaced with a rich-burn engine. Calculations for costs and emissions reductions reflect that assumption. For the lean-burn engines that were assumed to be replaced with rich-burn engines, an additional operations and maintenance cost was added to reflect the maintenance of catalysts and potential increase of fuel usage. This increased operation and maintenance cost was not included for engines that were assumed to remain as lean-burn.

A. Estimated Compliance Cost

District staff used cost information provided by control equipment manufacturers and vendors, and from stakeholders to conduct a cost effectiveness analysis of the proposed NOx limits in Draft Rule 4702. The data used in the analysis came from the following sources:

1. Agricultural engine stakeholder(s)
2. MIRATECH Corporation
3. MurCal, Inc.
4. Pennsylvania Department of Environmental Protection, Bureau of Air Quality Technical Support Document For the General Plan Approval and/or General Operating Permit for Unconventional Natural Gas Well Site Operations and Remote Pigging Stations (BAQ-GPA/GP-5A, 2700-PM-BAQ0268) And the Revisions to the General Plan Approval and/or General Operating Permit for Natural Gas Compressor Stations,

Processing Plants, and Transmission Stations (BAQ-GPA/GP-5, 2700-PM-BAQ0267) (Final June 2018)
5. Quinn Company
6. TGP West
7. Valley Power Systems

Generally, OAQPS methodologies were used to estimate installation costs and, in some cases, annual operation and maintenance costs. Cost information provided to the District or estimated by the information provided is summarized in Table 2.

Table 2 - Estimated Capital Cost for Control Technology by Engine Size

Category	Size (bhp)	Estimated Installation Cost
NSCR for RB IC Engine	200	$4,671
NSCR for RB IC Engine	200	$5,418
NSCR for RB IC Engine	250	$6,291
NSCR for RB IC Engine	250	$8,406
NSCR for RB IC Engine	250	$8,856
NSCR for RB IC Engine	250	$11,313
NSCR for RB IC Engine	256	$6,291
NSCR for RB IC Engine	256	$9,252
NSCR for RB IC Engine	256	$12,680
NSCR for RB IC Engine	685	$9,840
NSCR for RB IC Engine	1,320	$13,382
SCR for LB IC Engine	1,320	$147,600
SCR for LB IC Engine for Oil and Gas Operations	450	$167,300
SCR for LB IC Engine for Oil and Gas Operations	1,000	$196,800
SCR for LB IC Engine for Oil and Gas Operations	1,000	$263,860
SCR for LB IC Engine for Oil and Gas Operations	1,200	$216,480
SCR for LB IC Engine for Oil and Gas Operations	1,200	$276,730
SCR for LB IC Engine for Oil and Gas Operations	1,500	$236,160
SCR for LB IC Engine for Oil and Gas Operations	1,500	$296,030
SCR for LB IC Engine for Oil and Gas Operations	2,000	$236,160
SCR for LB IC Engine for Oil and Gas Operations	2,000	$328,200
SCR for LB IC Engine for Oil and Gas Operations	4,000	$314,880
SCR for LB IC Engine for Oil and Gas Operations	4,000	$456,900
SCR for LB IC Engine for Oil and Gas Operations	5,500	$373,920
SCR for LB IC Engine for Oil and Gas Operations	5,500	$553,420
New RB IC Engine with NSCR	175	$95,000
New LB IC Engine converted from RB	140	$47,522

Category	Size (bhp)	Estimated Installation Cost
New LB IC Engine converted from RB	200	$67,406
New LB IC Engine converted from RB	250	$86,053
New LB IC Engine	241	$86,400
New LB IC Engine	323	$85,000
New LB IC Engine	323	$95,800

III. Cost Effectiveness Analysis Procedure

To illustrate the cost effectiveness of complying with the proposed limits, District staff's analysis provides varying cost effectiveness values depending on the size of the unit, and the annual capacity factor that the unit is operated. The actual compliance costs and cost effectiveness values would depend on several factors such as the type of unit, site-specific operating conditions, and the appropriate emission limits the unit has to meet.

A. Absolute Cost Effectiveness (ACE) Calculation Method

The absolute cost effectiveness of a control technology is calculated as follows:

1. Determine an equivalent annual equipment cost using a capital recovery factor based on an assumed interest rate of 10 percent and equipment life of 10 years.
2. Determine the annual electricity, fuel, and operation and maintenance costs of a control technology.
3. Calculate the total annual cost by adding the costs calculated in Step 1 and Step 2.
4. Calculate the emission reduction in tons/year. Appendix B provides a detailed explanation of the calculations performed to determine the emission reductions for the potential rule limits.
5. Calculate the absolute cost effectiveness by dividing the total annual cost in Step 3 by the emissions reduction in Step 4.

B. Incremental Cost Effectiveness (ICE) Calculation Method

The incremental cost effectiveness of a control technology is calculated as follows:

1. Identify the complying control options appropriate for the existing equipment.
2. Estimate the annual average cost of each control option by using Steps 1 to 3 of the ACE calculation method.

3. Calculate the potential emission reduction for each control option. The potential emission reductions (PE) are the difference between the current emissions and the potential emissions using the new control technology.

IV. Absolute Cost Effectiveness

A. Retrofit of AO and Non-AO Spark-Ignited Engines

District staff queried the Permit Services Permits Database to compile a list of permitted engines, and the returned records were then manually sorted into one of three groups: emergency standby/dormant engines; rich-burn engines; and lean-burn engines. The emergency standby engines and dormant engines were removed from the analysis.

Compliance costs include both one-time costs and on-going annual costs. Examples of one-time costs are the purchase of equipment and installation costs. On-going costs are items like maintenance costs, reagent purchases, and the additional fuel burned because of the control technology (fuel penalty). In order to determine a single figure for costs, District staff use a capital recovery factor to allocate the one-time costs over the life of the equipment. For all cost analyses in this report, District staff used a 10 percent rate of return and a 10-year equipment life to convert the capital costs to equivalent annual cost.

Costs were submitted to the District for certain sizes of engines. In order to determine costs for engines with sizes different than those for which costs were submitted, District staff used a linear interpolation equation based on the size of the engine (bhp), and engine type. Each facility is unique and has its own challenges in adding new equipment, which can affect the cost of the equipment. With this in mind, District staff reviewed several sources of cost data. The lower cost may be more likely for smaller engines that need relatively simple modifications and the higher cost may reflect larger engines involving more extensive modifications.

1. Rich-Burn Engines

The District worked with numerous facilities, vendors, and manufacturers to determine the costs to retrofit and/or replace these engines. Costs were submitted to the District for certain sizes of engines. District staff assumed that the engines that are subject to the 11 ppmv NOx limit would have a NSCR system on the engine. Table 6 outlines the basis for estimating compliance costs.

Using the costs submitted by stakeholders and technology vendors, and using a linear equation to adjust for different sized engines District staff was able to determine the costs of amending the NOx and VOC limits. Engines in this category with emissions over the proposed limits of 11 ppmv NOx and 90 ppmv VOC would need to upgrade their NSCR system. For this type of modification, there would be no additional operation and maintenance costs. The cost-effectiveness of engines grouped by engine size is presented in Table 3. Table 6 outlines the basis for estimating compliance costs.

Category Rich-Burn
Technology Needed to Achieve Proposed Rule Limit of 11 ppmv by **2024**:

- Tuning existing engines with NSCR, Retrofit engines with NSCR, or Replace with a new rich-burn engine
- Annual Hours for AO engines: 1,800
- Annual Hours for Non-AO engines: 8,760
- Load Factor for AO engines: 0.8
- Load Factor for Non-AO engines: 1.0

Table 3 - Cost-Effectiveness Analysis for Rich-Burn Engines

Engine Power (bhp)	Technology Needed	Capital Cost	O&M ($/yr)	Annualized Cost ($/yr)	Emission Reductions (tons/yr)	Cost-Effectiveness ($/ton NOx)
50	Upgrade/Replace NSCR	$6,100	$720	$1,700	0.09	$18,900
100	Upgrade/Replace NSCR	$7,000	$720	$1,900	0.17	$11,200
200	Upgrade/Replace NSCR	$7,300	$720	$1,900	0.35	$5,400
300	Upgrade/Replace NSCR	$7,600	$720	$2,000	0.51	$3,900
400	Upgrade/Replace NSCR	$8,000	$720	$2,000	0.70	$2,900
500	Upgrade/Replace NSCR	$8,500	$720	$2,100	0.90	$2,300
600	Upgrade/Replace NSCR	$9,100	$720	$2,200	1.08	$2,000
700	Upgrade/Replace NSCR	$9,600	$720	$2,300	1.26	$1,800

Capital Costs, Annualized Costs, & Cost Effectiveness rounded to the nearest $100

2. Lean-Burn Engines

The limits for the lean-burn engine categories were determined by current inventory, potential costs, and the NOx emissions associated with new lean-burn engines. As explained in Section II of the Rule 4702 Staff Report, the addition of an SCR system to lean-burn engines, or the replacement of engines with electrification and/or solar have been determined to not be cost effective control systems, and as such the proposed NOx limits were determined based on the emissions of a new lean-burn engine, and a low emission combustion system. A limit of 11 ppmv NOx is being proposed for the lean-burn Not Listed Above category, as all Not Listed Above engines currently in the Districts inventory source test below 11 ppmv NOx and would not need to be retrofit with a new SCR system to meet the proposed limit. A NOx limit of 40 ppmv is being proposed for some lean-burn Non-AO engines as that is the lowest limit that can be reached by fine tuning the existing engines with a low emission combustion system. For agricultural lean-burn engines specific considerations were taken into account when determining the 43 ppmv NOx limit, such as the location and life span of the engines. As outlined in section IV F of the Rule 4702 Staff Report the proposed NOx and VOC limits represent RACT and BARCT.

When calculating the compliance costs for lean-burn engines, District staff assumed that the engines that are subject to the 40+ ppmv NOx and 90 ppmv VOC limits would currently have no SCR to control emissions and that through low-emission combustion technology, and engine tune-ups, the engines would be able to meet the limits without the installation of an SCR system. Some lean-burn engines would need to install an oxidation catalyst, and have additional operations and maintenance costs in order to meet the proposed 90 ppmv VOC limit. The variation in what control technology would be required, and the size of the engines results in a range of possible costs.

Within the AO lean-burn category, there are 69 engines that, for the cost calculations detailed below, the District assumed would be converted to rich-burn, and would be subject to the rich-burn emissions limits. Additionally, there were 33 engines that were assumed to need to be replaced with a new engine by December 31st, 2029 due to the age of the equipment. Due to the necessary replacement, no additional capital cost was included, although an estimated operations and maintenance cost was included to represent the increased cost of operating and maintaining an engine capable of meeting the lower emission limits required by the proposed rule. The cost effectiveness of engines that were assumed to be converted to rich-burn are grouped by engine size and presented in Table 4.

The estimated costs for each engine are based on initially reported costs from control technology vendors, equipment manufacturers, and facility operators. Reported costs were then scaled to the size of affected engines in the Valley inventory using a linear equation relating the installed cost to the size of the engine. District staff then used standard ratios to fill in other portions of a capital equipment project. Once the total capital cost was evaluated, a capital recovery factor was applied to convert this one-time expense into the equivalent annual costs. Annual operating costs were estimated based on information provided by vendors and any potential fuel penalty. The annualized capital cost and the annual operating costs were then added together for the total annual compliance cost. The cost-effectiveness of engines that would remain lean-burn and would require an emission combustion retrofit are grouped by engine size and presented in Table 5.

Category Non-AO Lean-Burn

Technology Needed to Achieve the Proposed Rule Limits of 11 or 40 ppmv by **2024**:

- Tuning existing engines with a low emission combustions retrofit, or Replace with rich-burn and retrofit with NSCR
- Annual Hours for Non-AO engines: 8,760
- Load Factor for Non-AO engines: 1.0

Category AO Lean-Burn

Technology Needed to Achieve Proposed Rule Limit of 43 ppmv by **2030**:

- Tuning existing engines with a low emission combustions retrofit, or Replace with rich-burn and retrofit with NSCR
- Annual Hours for AO engines: 1,800
- Load Factor for AO engines: 0.8

Table 4 - Cost-Effectiveness of Lean-Burn Engines Converted to Rich-Burn with NSCR or Replace Engine

Engine Power (bhp)	Technology Needed	Capital Cost ($)	O&M ($/yr)	Annualized Cost ($/yr)	NOx Emission Reduction (tons/yr)	Cost-Effectiveness ($/ton NOx)
50	Convert to Rich-Burn and Install NSCR	$9,600	$1,770	$3,300	0.14	$23,600
100	Convert to Rich-Burn and Install NSCR	$9,900	$2,180	$3,800	0.30	$12,700
200	Convert to Rich-Burn and Install NSCR	$10,400	$3,020	$4,700	0.62	$7,600
300	Convert to Rich-Burn and Install NSCR	$10,900	$3,850	$5,600	0.93	$6,000
400	Convert to Rich-Burn and Install NSCR	$11,500	$4,690	$6,600	1.24	$5,300
500	Convert to Rich-Burn and Install NSCR	$12,000	$5,520	$7,500	1.55	$4,800
600	Convert to Rich-Burn and Install NSCR	$12,600	$6,360	$8,400	1.86	$4,500
700	Convert to Rich-Burn and Install NSCR	$13,100	$7,190	$9,300	2.17	$4,300

Capital Costs, Annualized Costs, & Cost Effectiveness rounded to the nearest $100

Table 5 - Cost-Effectiveness of Lean-Burn Low Emission Combustion Retrofit

Engine Power (bhp)	Technology Needed	Capital Cost ($)	O&M ($/yr)	Annualized Cost ($/yr)	NOx Emission Reduction (tons/yr)	Cost-Effectiveness ($/ton)
300	Low-Emission Combustion	$22,400	-	$3,600	1.03	$3,500
500	Low-Emission Combustion	$32,600	-	$5,300	1.70	$3,100
1000	Low-Emission Combustion	$57,900	-	$9,400	3.40	$2,800
1500	Low-Emission Combustion	$81,200	-	$13,200	5.39	$2,400
2000	Low-Emission Combustion	$94,900	-	$15,400	8.74	$1,800
5500	Low-Emission Combustion	$190,800	-	$32,000	32.19	$1,000

Capital Costs, Annualized Costs, & Cost Effectiveness rounded to the nearest $100

V. ABSOLUTE COST EFFECTIVENESS ANALYSIS

Absolute cost effectiveness of a control option is the added annual cost, in dollars per year, of a control technology or technique divided by the emission reductions achieved, in tons reduced per year. The costs can include, but are not limited to, capital equipment costs, engineering design costs, and additional labor or fuel costs. The costs also can include any monetary savings realized by implementation of the pollution controls.

Table 6 outlines the cost multipliers used to calculate the total annual cost for each engine.

Table 6 - Cost Multipliers Used for Compliance Cost Evaluation

	Engine Size (bhp)	
	Equipment Cost ($)	
A.	NSCR cost	-
B.	Air To Fuel Ratio Controller when needed	-
C.	**Equipment Cost ($)**	A+B
D.	Sales tax	8% C
E.	Freight	5% C
F.	Instrumentation	10% C

G.	**Total Purchased Equipment Cost (PEC) ($)**	C+D+E+F
	Direct Installation Cost (DIC) ($)	
H.	Foundations and Supports	8% PEC
I.	Handling and Erection	14% PEC
	Direct Installation Cost (DIC) ($)	
J.	Electrical	4% PEC
K.	Piping	2% PEC
L.	Insulation for Piping	1% of PEC
M.	**Total Direct Installation Cost (DIC) ($)**	H+I+J+K+L
	Indirect Installation Cost (IIC) ($)	
N.	Engineering	10% PEC
O.	Construction and Field Expenses	5% PEC
P.	Contractor Fees	10% PEC
Q.	Startup	2% PEC
R.	Performance Test	1% PEC
S.	**Indirect Installation Cost (IIC) ($)**	N+O+P+Q+R
T.	**Total Installation Cost (IC) ($)**	DIC + IIC
U.	**Project Contingency ($)**	3% PEC
V.	**Total Capital Costs (TCC) ($)**	G+T+U
W.	***Annualized Capital Cost ($/yr) (10 years @ 10%)***	0.16275* TCC

A. Cost Scaling to Engine Size

Costs were submitted to the District for a certain size of engine. In order to determine costs for engines with output different than the submitted costs, District staff used the following equation:

$$\text{Cost}_{engine2} = \left[\frac{horsepower_{engine2}}{horsepower_{basis}}\right]^{0.6} \times \left(Cost_{basis}\right)$$

Where

$\text{Cost}_{engine2}$ = cost of the desired engine (unknown)
$Cost_{basis}$ = cost of the engine used as the basis of the calculation (known)
$horsepower_{engine2}$ = the rated output of the desired engine (known)
$horsepower_{basis}$ = the rated output of the engine used as the basis of the calculation (known)

B. Incremental Cost Effectiveness Analysis

Health and Safety Code section 40920.6 requires an incremental cost-effectiveness analysis for Best Available Retrofit Control Technology (BARCT) rules or emission reduction strategies when there is more than one control option which would achieve the emission reduction objective of the proposed amendments. The incremental cost effectiveness is the difference in cost between successively more effective controls divided by the additional emission reductions achieved. Incremental cost-effectiveness is calculated as follows:

$$\textit{Incremental cost-effectiveness} = (C_{alt} – C_{proposed}) / (E_{alt} – E_{proposed})$$

Where:
$C_{proposed}$ is the present worth value of the proposed control option;
$E_{proposed}$ are the emission reductions of the proposed control option;
C_{alt} is the present worth value of the alternative control option; and
E_{alt} are the emission reductions of the alternative control option

Proposed Rule 4702 requires engines to meet stringent emissions limits. The progressively more stringent control option is to require all lean-burn engines to be retrofit with a SCR system to meet a limit of 11 ppmv, and all rich-burn engines to upgrade their NSCR systems to meet a limit of 7 ppmv.

The progressively more stringent NOx control options would impact an additional 123 engines, cost $24,292,931 per year, and achieve 907 tons of NOx emissions reductions. The incremental cost-effectiveness for requiring a NOx limit of 7 ppmv for all rich-burn engines and 11 ppmv for lean-burn engines is $133,872 per ton of emissions reduced, as calculated below.

$$\textit{Incremental cost-effectiveness} = (\$24{,}292{,}931 – \$1{,}133{,}058) / (907_{tons/NOx} – 734_{tons/NOx})$$

Thus, the progressively more stringent control option was not chosen.