PUC DOCKET 19-02 RFI
The Application of the Guam Power Authority Requesting Approval of the Procurement for a New ULSD Pipeline

Response Date	October 16, 2018
In the Matter Of:	The Application of the Guam Power Authority Requesting Approval of the Procurement for a New ULSD Pipeline
Details:	Response PUC Requests for Information

QUESTION 1:

1. Both in its Petition and CCU Resolution No. 2018-21, GPA asserts that it is required by USEPA to use Ultra Low Sulfur Diesel (ULSD) oil to fuel its power plants by 2021. However, no authority is attached to the Petition or the Resolution supporting this assertion. Please provide copies of all materials or authorities demonstrating that GPA is required to use ULSD and to build the new ULSD Pipeline. The response should include applicable USEPA rules or regulations, decisions, statutory authority, or any other materials, which require the use of ULSD by 2021.

GPA RESPONSE:

The Piti #7 Combustion Turbine Power plant, previously using 0.5%Sulfur Diesel Fuel, has been using ULSD, as required by Public Law 30-184 (Reference: Attachment A – Public Law30-184).

On January 9, 2018 US EPA published Federal Register (FR 83, No. 6, page 1171) classifying Guam as non-attainment for the 6.074 km within the Cabras-Piti Area, and the rest of the island as Unclassifiable/Attainment for Sulfur Dioxide emissions. In 2012, USEPA required Reciprocating Engines to comply with the National Emission Standards for Hazardous Air Pollutants(40 CFR 63 Subpart ZZZZ).

The Piti #8 and #9 Slow Speed Diesel Plants, if required to comply with the RICE MACT and future NAAQS standards for SO_2 emissions, will need to convert to ULSD. GPA requested for exemption from this rule for the MEC plant which was subsequently denied by USEPA (Reference: Attachment B – RICE MACT Filing). Based on a feasibility study conducted by GPA's environmental consultant, to comply with RICE MACT, MEC would need to convert

Exhibit "A"

to ULSD. (Reference: Attachment C – TRC Study)

For the new power plants, combustion turbine units using Ultra-Low Sulfur Diesel or cleaner fuel such as Liquified Natural Gas, can meet the regulations.

In order to receive ULSD shipments via the F-1 dock into the GPA Fuel Bulk Storage Facility, a new pipeline will have to be installed and inter-connected into the existing Tristar pipeline at the Navy Tie-in. Such pipeline will also allow direct delivery of ULSD from any leased tank or tanks Tristar into the GPA Fuel Bulk Storage Facility. Such configuration will improve supply of fuel to the power plants, increase reliability of fuel supply, and reduce supply/delivery issues as well as costs incurred in delivery of fuel. GPA plans to align the schedule of the installation of the ULSD pipeline with the tank internal inspection, repair and conversion to ULSD storage, both of which need to be completed prior to the operation of the new combined-cycle plant.

QUESTION 2:

2. In CCU Resolution No. 2018-21, reference is made to operation and maintenance of the ULSD pipeline system "under United States Environmental Protection Agency (USEPA) and American Petroleum Institute (API) guidelines and regulations." Please provide all specific guidelines and regulations to which Resolution No. 2018-21 refers.

GPA RESPONSE:

Resolution No. 2018-21 refers to regulations from USEPA and API that refer to operation and management of pipelines such as the schedules for external and internal inspection to determine the integrity of the pipeline, and the Spill Prevention, Control and Countermeasure Plan (SPCC Plan).

QUESTION 3:

3. Attached to CCU Resolution No. 2018-21 is Exhibit "A", PROJECT COST BREAKDOWN, GPA TANK FARM NEW ULSD PIPELINE SYSTEM. The Breakdown is very general and only gives broad total amounts for each category of expenditure. Is there a more detailed breakdown for each cost item listed? Please provide such

breakdown for the items which comprise the total cost of $5,900,000.00.

GPA RESPONSE:

At this time, GPA's best estimates on cost are already provided as Exhibit A of CCU Resolution 2018-21. Detailed cost estimate can be provided after design of pipeline is completed.

QUESTION 4:

4. In the SPECIAL PROVISIONS section of the IFB, No. 4 indicates that the time for completion of the project is two hundred and seventy (270) calendar days after the specified date in the Notice to Proceed. However, Special Provision No. 5 indicates that Liquidated Damages will be assessed if the work remains incomplete after 240 days from the date for the beginning of the project. Is this an inconsistency which needs to be corrected?

GPA RESPONSE:

Time for completion of project will be two hundred and seventy (270) Calendar Days. Correction will be applied to reflect completion time of two hundred seventy (270) Calendar Days on all references to completion time in the bid documents.

GUAM POWER AUTHORITY
ATURIDÅT ILEKTRESEDÅT GUAHAN
P.O. BOX 2977, HÅGÅTÑA, GUAM 96932-2977

August 6, 2012

Doug McDaniel
Chief Enforcement Officer
Air Division, U.S. EPA Region IX
75 Hawthorne Street, San Francisco, CA 94105

Re: Request for Extension and Exemption - Guam Power Authority
National Emission Standards for Hazardous Air Pollutants (NESHAP) for Reciprocating Internal Combustion Engines at area sources (40 CFR Part 63, Subpart ZZZZ)

Dear Mr. McDaniel:

In accordance with 40 CFR §63.6(i)(4) through (7), the Guam Power Authority of 1911 Route 16, Harmon, Guam 96911 USA hereby submits this request for an extension of the compliance date until May 3, 2014. The following units are included in this request:

Unit Location	Horsepower (HP)	Unit Type	Fuel Type
Tenjo Units # 1-6	6095	Diesel	Ultra Low Sulfur
Dededo Diesel # 1-4	3600	Diesel	Ultra Low Sulfur
Manenggon Units # 1&2	7400	Diesel	Ultra Low Sulfur
Talofofo Units # 1&2	6095	Diesel	Ultra Low Sulfur

GPA further requests an exemption from the Diesel MACT for the following units:

Unit Location	Horsepower (HP)	Unit Type	Fuel Type
Cabras Units 3 & 4	52,680	Diesel	RFO #6
MEC Units 8 & 9	59,249	Diesel	RFO #6

The request for an exemption is made for the following reasons:

a. The rule states that Guam is exempt from the requirement in the MACT to change fuels. These units are currently fired with residual oil, either 2% sulfur content or 1.19% sulfur content. The rule and the regulatory Impact Analysis, do not contemplate that compliance will be achieved using this fuel. As a result, there is no EPA guidance on how to achieve 23 ppm CO emissions and no guidance on the control device to use. Oxidation catalyst systems are precluded from use on exhaust streams of greater than 500-600 ppm of sulfur dioxide because the catalyst will become contaminated in a relatively short amount of time and the effect of oxidation of the sulfur dioxide will create copious amounts of H_2SO_4 (sulfuric acid) which would have to be exhausted or controlled. Additionally, vendors will not guarantee performance for exhaust streams above 500 ppm sulfur dioxide.

b. In order to use an oxidation catalyst, GPA would have to purchase and use a lower sulfur fuel oil, in direct contradiction of the exemption. In order to get the sulfur dioxide content to the 500-600 ppm range, a low sulfur residual oil would have to be purchased for these four diesel engines. The logistical problem of constructing new tankage to store this new fuel grade will be difficult due to lack of space. Additionally, the cost differential for this fuel is on the order of $73,000,000 per year for the four units.

c. Even if it were reasonable to acquire the reduced sulfur fuel, the cost of the oxidation catalyst systems would be about $6,500,000 with annual maintenance costs of $1,170,000. The total burden to the Guam rate payers would be substantial.

d. The cost differential of the fuel could be reduced if a dry scrubber system and baghouse were installed to reduce the exhaust sulfur dioxide to 500-600 ppm. Such a system would involve significant capital costs of about $410,000,000 and annual operating costs of $64,000,000. The total burden to the Guam rate payers would be substantial.

e. Because the current CO emissions from these units are measured at 65 ppm, they are not significant producers of the Hazardous Air Pollutants for which the rule seeks reduced emissions. These generation units are slow speed diesels. Slow Speed Diesels are highly efficient at producing power.

The Guam Power Authority is supportive of EPA's efforts to reduce harmful emissions but respectfully requests EPA to consider the substantial burden that will be passed on to our customers.

Respectfully,

JOAQUIN C. FLORES, P.E.
General Manager

Cc: Michael Mann, USEPA Region IX (Guam Program Manager)
Kerry Drake, USEPA Region IX
Roger Kohn, USEPA Region IX
Eric Palacios, Guam EPA
Pete Cruz, Guam EPA
File: P&R, SPORD
Generation
MEC

7008 3230 0001 7957 0510

U.S. Postal Service™
CERTIFIED MAIL™ RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com®

OFFICIAL USE

Postage	$ .45
Certified Fee	2.95
Return Receipt Fee (Endorsement Required)	
Restricted Delivery Fee (Endorsement Required)	
Total Postage & Fees	$ 3.40

Postmark Here

BARRIGADA GU MPO
AUG 8 2012
USPS

Sent To: Doug McDaniel
Street, Apt. No.; or PO Box No.: USEPA 75 Hawthorne St.
City, State, ZIP+4: SF CA 94105

PS Form 3800, August 2006 — See Reverse for Instructions

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105

January 16, 2013

Joaquin C. Flores, P.E.
General Manager
Guam Power Authority
P.O. Box 2977
Agana, Guam U.S.A. 96932-2977

Subject: Extension and Exemption Request from the National Emission Standards for Hazardous Air Pollutants (NESHAP) for Reciprocating Internal Combustion Engines (RICE) - (40 CFR Part 63, Subpart ZZZZ)

Dear Mr. Flores:

The U.S. Environmental Protection Agency (EPA) has reviewed your one year extension request dated August 6, 2012 for RICE at Tenjo, Dededo, Manenggon and Talofofo. According to the provisions under 40 CFR 63.6(i), a reason must be given for the extension request. No such reason was given in your August 6, 2012 letter. Please resubmit your extension request and include the reason for the extension.

Regarding the exemption request for Cabras 3 & 4 and MEC Units 8 & 9, we cannot grant your request because to do so would be in violation of the Clean Air Act (CAA). If you believe EPA has authority under the CAA to grant such a request, please let us know.

If you have any questions, please contact John Brock of my staff at 415-972-3999 or email at brock.john@epa.gov.

Sincerely,

Calvin Ho for Douglas McDaniel

Douglas K. McDaniel
Chief, Air Enforcement Office

cc: Eric Palacois, Guam EPA
Peter Cruz, Guam EPA

Feasibility and Cost Study Report

Carbon Monoxide Oxidation Catalyst Retrofit
Piti/Marianas Energy Corporation Units #8 & #9

Guam Power Authority
Piti, Guam

June 2016

Results you can rely on

Feasibility and Cost Study Report

Carbon Monoxide Oxidation Catalyst Retrofit
Piti/Marianas Energy Corporation Units #8 & #9

Guam Power Authority
Piti, Guam

June 2016

150 N Patrick Blvd, Suite 180, Brookfield, WI 53045, • 262.879.1212 Phone • 262.879.1220 Fax • www.TRCsolutions.com

Table of Contents

List of Tables

List of Appendices

Abbreviations and Acronyms

ACFM	Actual cubic feet per minute	LNG	Liquefied natural gas
AIG	Ammonia injection grid	LSRFO	Low sulfur residual fuel oil, at 1.19 percent sulfur content
BWSC	Burmeister & Wain Scandinavian Contractor A/S	MACT	Maximum Achievable Control Technology
°C	Degrees Celsius	MEC	Marianas Energy Corporation
CEM	Continuous Emissions Monitor	mg	Milligrams
CFR	Code of Federal Regulations	mmWC	Millimeters of water column
CO/CO_2	Carbon monoxide/carbon dioxide	min	Minute
$CO(NH_2)_2$	Urea	MM	Millimeter
CPAICS	Cabras/Piti Area Intermittent Control Strategy	MW	Megawatt
cu. in.	Cubic inches	NAAQS	National Ambient Air Quality Standards
d.a.	Dry air	NA/ND	Not available/determined
dB	Decibels	NESHAP	National Emission Standards for Hazardous Air Pollutants
DSCFM	Dry standard cubic feet per minute	NH_3	Ammonia
°F	Degrees Fahrenheit	Nm^3	Normal cubic meters
g	Grams	$N_2/NO/NO_2/NO_x$	Nitrogen/Nitric oxide/Nitrogen dioxide/Oxides of nitrogen
GPA	Guam Power Authority	O_2	Oxygen
gal	Gallon	PGM	Platinum group metals
H_2SO_4	Sulfuric acid	ppmdv @ 15% O_2	Parts per million dry volume corrected to 15 percent oxygen
hr	Hour	RICE	Reciprocating Internal Combustion Engine
HRSG	Heat recovery steam generator	RPM	Revolutions per minute
HSRFO	High sulfur residual fuel oil, at 2.0 percent sulfur content	SCFM	Standard cubic feet per minute
Hz	Hertz	SCR	Selective catalytic reduction
inWC	Inches of water column	SO_2/ SO_3	Sulfur dioxide/Sulfur trioxide
kg	Kilogram	THC	Total hydrocarbons
kWh	Kilowatt hour	TRC	TRC Environmental Corporation
L	Liter	ULSRFO	Ultra-low sulfur residual fuel oil, at 0.5 percent sulfur content
lb	Pound	ULSD	Ultra-low sulfur diesel, at 0.015 percent sulfur content
%	Percent	US EPA	United States Environmental Protection Agency

Section 1 Introduction

1.1 Background

Guam Power Authority (GPA), in conjunction with the independent power producer, Marianas Energy Corporation, LLC (MEC), operate four low speed diesel engine/generators to produce electricity at the Cabras and Piti baseload stations. The individual units are referred to as Cabras Units #3 and #4 and Piti or MEC Units #8 and #9. These engines are subject to applicable requirements and emissions limits of the National Emission Standards for Hazardous Air Pollutants (NESHAP) for Reciprocating Internal Combustion Engines (RICE), 40 Code of Federal Regulations (CFR), Part 63, Subpart ZZZZ, commonly referred to as RICE Maximum Achievable Control Technology (MACT). The RICE MACT regulations were originally promulgated by the United States Environmental Protection Agency (US EPA) on March 3, 2010. Subsequently, US EPA proposed amendments to the RICE MACT several times before promulgated final rules, which were published in the Federal Register on January 30, 2013. The RICE MACT limits the emission of carbon monoxide (CO) from engines as a surrogate for hazardous air pollutants.

Engineering details for the engines are summarized in Table 1. Fuel switching is being considered for these engines, and therefore, the RICE MACT compliance deadline for these sources has yet to be established. However, it is likely that end-of-pipe controls, such as oxidation catalyst, will be required to allow these engines to comply with the RICE MACT requirements for stationary, non-emergency compression ignition engines greater than 500 horsepower capacity constructed or re-constructed before June 12, 2006, which includes limiting the CO concentration in the engine exhaust emissions to 23 parts per million on a dry volume basis (ppmvd) at a stack oxygen concentration of 15 percent, or reduce CO emissions by a minimum of 70 percent. In early 2013, GPA requested a "Consent Decree" from the US EPA Region 9, which would allow the delay of compliance with RICE MACT requirements for these engines. To date the Consent Decree has not been finalized.

The US EPA has granted GPA a Section 325 waiver from the Clean Air Act. As part of the requirements of this waiver, power plants within the Cabras/Piti area must comply with the Cabras/Piti Area Intermittent Control Strategy (CPAICS) as required by 69.11(a)(3)(i) of 40 CFR Part 69 Subpart A, as amended, and any modification to the CPAICS approved by US EPA as defined in 69.11(a)(3)(ii). Under the CPAICS, GPA is allowed to use high sulfur residual fuel oil (HSRFO at a nominal 2.0 percent sulfur content) at the Cabras and Piti facilities whenever

15-minute average wind direction and wind speeds are within acceptable limits. Outside these acceptable limits, GPA must use low sulfur residual fuel oil (LSRFO at a nominal 1.19 percent sulfur content). Thus, the current fuels fired in the Piti #8 and #9 engines are HSRFO and LSRFO.

Pending National Ambient Air Quality Standards (NAAQS) requirements for oxides of nitrogen (NOx) and for sulfur dioxide (SO_2) might also drive the need for fuel switching to low sulfur fuels, and NOx emission controls for these sources. Further, the explosion and fire at the Cabras station the morning of August 21, 2015, and subsequent declaration that Unit #4 is a total loss and indeterminate future for Unit #3, has focused this feasibility study to address only the Piti station.

GPA has requested TRC Environmental Corporation's (TRC's) assistance in developing a concept and budgetary equipment and installation costs for retrofitting the Piti engines with CO oxidation catalyst. This report documents the conceptual engineering work required to develop a feasible concept and the resulting estimate of costs. At the request of GPA, NOx emission controls, in the form of selective catalytic reduction (SCR), have also been considered in this report.

1.2 Methodology and References

TRC's approach to this analysis included a review of the available location options for the installation of CO oxidation catalyst, a review of documentation on existing foundations, and to confirm the engine system design parameters (*e.g.*, fuel consumption, exhaust displacement, temperatures, lube oil type and consumption, pressure losses, and emissions) with the facility's original constructor Burmeister & Wain Scandinavian Contractor A/S (BWSC), and current operator MEC. A structural and a mechanical engineer from TRC conducted a site visit to the Piti facility during the period of March 3 to 12, 2016 and established the following parameters for design of the emission controls retrofit:

- Feasible location for the emission control equipment;
- Installation scheduling and constructability issues;
- Process flow and material requirements for ductwork, valves, and piping;
- Preliminary sizes and material specifications for the equipment and ancillary components; and
- Utility locations and requirements.

For estimating the costs of installation and operation and maintenance of the CO oxidation system, and later the SCR system, TRC followed traditional air pollution control system cost estimating methodology, relying on our past experience from other similar installations, soliciting study level costs bids from CO and SCR catalyst suppliers, including Johnson Matthey and Haldor Topsoe, and referencing the following guidance documents:

- *Air Pollution Control Cost Manual*, US EPA Office of Air Quality Planning and Standards, Sixth Edition, January 2002, EPA/452/B-02-001
- *Coal Utility Environmental Cost (CUECost)*, US EPA Office of Research and Development Air Pollution Prevention and Control Division, Version 5.0, September 2009, EPA/600/R-09/131
- *Mechanical Cost Data*, RSMeans, a division of Reed Construction Data, *Construction Publishers & Consultants*, 2011

As the *Air Pollution Control Cost Manual* is appropriate only for industrial sources, its use was limited to formatting and factoring. CUECost is specific to coal-fired utility boilers larger than 100 megawatts (MW) and, therefore, its use was limited to providing a check of the costing of SCR.

The objective of developing a design concept and cost estimate for CO oxidation catalyst is for high level decision making and planning purposes. As such, TRC does not make any claim for an accuracy greater than the nominal +/- 30 percent rough order of magnitude expected of conceptual study level costing.

Section 2
General Information

2.1 Current Systems and Processes

Piti Units #8 and #9 are currently fired on LSRFO and HSRFO, with a switch to ultra-low sulfur liquid fuels (ULSRFO at 0.5 percent sulfur content and ULSD at 0.0015 percent sulfur content) being considered for compliance and compatibility with CO oxidization catalyst and SCR system. Engine exhaust conditions by fuel are summarized in Table 3. Lube oil and cylinder oil is SK Supermar AS, a refined mineral oil. Each engine system is configured with exhaust gas flow from the engine passing through a silencer, then the heat recovery steam generator (HRSG), and finally through the stack. The stack is lined with separate flues for each engine. Continuous emission monitors (CEMs) are installed to monitor carbon dioxide (CO_2), oxygen (O_2), SO2, NO_x, CO, and total hydrocarbon (THC) emissions from each engine. Engine operating parameters, including design pressure losses through the silencer and HRSG are summarized in Table 2.

2.2 Physical Environment

The Piti #8 and #9 power plant was completed in 1999, and is being operated under contract by MEC. The current contract between GPA and MEC expires on September 30, 2016. The plant consists of two low speed diesel engines type MAN B&W 10K90MC-S called, respectively Unit #8 and Unit #9, each rated at a nominal capacity of 87 megawatts. The diesel engines are operating on residual fuel oil, also known as fuel oil No. 6, in low and high sulfur contents.

The engine generators are turbo charged and equipped with primary NOx-reduction by means of water injection into the fuel oil before combustion. The plant also includes two HRSGs, waste heat recovery boilers for the production of steam, and a common steam turbine generating set utilizing the waste heat for the production of electricity.

Referring to the site plans contained in Appendix A, the Piti #8 and #9 plant is located north-east of the now mothballed Piti #4 and #5 boiler power plant, and consists of the following buildings and areas:

- Powerhouse and annexes;
- Administrative building;
- Fuel oil treatment building;

- Tank farm;
- Radiator cooler area;
- Stack and boiler area; and
- Air cooled condenser area.

The powerhouse has interior dimensions of approximately 116 feet by 123 feet, and the layout is centered on the engine hall with the two diesel engine generating units in the middle and the auxiliary annexes towards the east, south, and north perimeter walls. The engines occupy a majority of the powerhouse footprint, with only 14 feet between the engines and exterior walls, and much of this space occupied by the large building support columns. Diesel engine generator Unit #8 is located in the northern part of the engine hall, with diesel engine generator Unit #9 in the southern part, arranged in an east-west orientation. Each engine system is configured with gas flow from the engine passing through a silencer, then the HRSG, and finally through the stack. The stack has separate flues for each engine. The exhaust ductwork is asymmetrical, with the stack positioned directly west of and closer to Unit #9. The exhaust ductwork from Unit #8 includes a 90 degree elbow and additional length of duct to the stack breech. The engine hall is serviced by two overhead cranes travelling north-south, each with 80 and 10 ton hoists. There is limited headspace above the engines because of these cranes.

The administration building is located north of the powerhouse and west of the Piti #4 and #5 boiler power plant. With the current arrangement of buildings, equipment, and paved road surfaces, there is limited existing outdoor area for placement of any new equipment. Demolition of the Piti Units #4 and #5 boiler power plant would need to be considered to make space for new air pollution control equipment for Piti Units #8 and #9.

The electrical annex is connected with the engine hall and facing east. The main components in the electrical annex are medium voltage switchboards, excitation equipment for the alternators, and step-up transformers located just outside.

South of the engine hall is the common annex on two levels, with the steam turbine generator set, black start diesel generator set, maintenance stores, workshop, and laboratory on the ground floor, and low voltage and control room on the first floor. Located outside of the common annex is the station auxiliary transformers.

Towards the west of the engine hall is a connected mechanical annex. The mechanical annex is also on two levels and accommodates the mechanical auxiliaries for the diesel engines. Located on the roof of the mechanical annex are the steam drums and feed water tank for the steam system.

Outside the mechanical annex are the HRSGs, water treatment, and the common stack with separate flues for each engine. The stack is positioned directly west of Unit #9, and thus has an asymmetrical exhaust duct arrangement. This area is referenced as the stack and boiler area, with the air cooled condenser area adjacent towards the south containing the air cooled steam condenser and extraction pump.

North of the powerhouse is the first set of radiator coolers, and at the northern boundary of the tank farm separated by fire access roads. The radiator cooler area contains air cooled radiators for cooling of the diesel engines, generators, and auxiliaries. The radiator coolers for Unit #8 are located towards the east, and the coolers for Unit #9 are located towards the west.

The tank farm contains storage and service tanks for both fuel oil and lubrication oil, with the fuel oil treatment building located on the western end. The building contains transfer and supply pumps as well as the fuel oil treatment plant.

2.3 System Objectives

Expected exhaust conditions, including exhaust displacement, fuel consumption, temperature, moisture, and composition for each fuel potential fired in the Piti Units #8 and #9 engines are summarized in Table 3.

CO oxidation catalyst promotes the conversion of CO to CO_2 without being consumed in the reactions it promotes. The temperature required for this conversion is typically above 400°F. Platinum group metals (PGM) including platinum, palladium, and rhodium are most often used in emission control catalysts, with modern catalytic converters for internal combustion engines utilizing an extruded honeycomb monolith substrate coated with the PGM metal compounds and packaged into a housing. The honeycomb is made either of ceramics or metallic foil. Its structure of many small parallel channels that maximizes catalytic surface area for contact with the exhaust gases. As the hot exhaust gases flow through the channels and contact the catalyst, several exhaust pollutants can be converted, including hydrocarbons, NOx, and SO_2. The conversion of NOx and SO_2 are undesirable as the oxidized forms of these compounds are corrosive and can form visible stack plumes. The oxidation catalyst composition can be formulated to be CO specific and minimize oxidation of nitrogen compounds. For stationary diesel engines, particularly those firing higher sulfur fuels, a catalyst composition of palladium only over a metallic substrate is typically applied. CO oxidation catalyst systems frequently require extra air, called secondary air, to be introduced into the exhaust system in front of the catalyst to provide sufficient oxygen for the reactions.

The objective of applying CO oxidation catalyst to the Piti station engines would be to limit the CO concentration in the engine exhaust emissions to a maximum of 23 parts per million on a dry volume basis (ppmvd) at a stack oxygen concentration of 15 percent, or reduce CO emissions by a minimum of 70 percent in accordance with the RICE MACT regulations.

If NOx emission controls are required, a minimum 90 percent reduction in NOx using selective catalytic reduction (SCR) would be the objective.

The technology of SCR is applied by the injection of a reducing agent, either a urea solution, $CO(NH_2)_2$, or ammonia, NH_3, into the flue gas stream upstream of an SCR catalyst. Different SCR catalysts, such as vanadium oxide or metal substituted zeolites, have different operating temperature windows and sulfur tolerance and must be carefully selected for a particular SCR process. As with the CO oxidation catalyst, SCR catalysts are often applied to an extruded ceramic honeycomb monolithic substrate, but several suppliers use a corrugated mat style substrate. Typical exhaust gas temperature requirements range from 500 °F to 650 °F. In order to meet the temperature requirement with a diesel engine, a warm up time is needed at startup and often an exhaust bypass or reheat system is needed to maintain this temperature during operation, particularly at low loads. The catalyst is placed in a reactor housing in the exhaust gas duct at a point where the reducing agent can react with the NOx to form nitrogen (N_2) and water. Ammonia-SCR has typically been used in industrial processes, in stationary diesel engines, and in some marine engines. Urea-SCR technology—using urea as an ammonia precursor— is typically used for mobile diesel engines.

2.4 Issues

Several issues are presented when considering the addition of CO oxidation catalyst and an SCR system for NOx emissions control to a low speed diesel engine. These issues and a discussion of each are presented below:

- **Fuels** – The Piti engines currently fire high (2.0%) and low (1.19%) sulfur residual oils, and ultra-low sulfur residual oil (0.5%) and distillate oil (0.015%) are being considered. The concern with the sulfur content of the fuels is the formation of acids and ammonium sulfate, as discussed below:
  - **Acids**: In the presence of a CO oxidation catalyst and water vapor in the flue gas, sulfur can form sulphurous (SO_3) and sulphuric acids (H_2SO_4) which can corrode the exhaust duct, catalyst housing, and stack flue.
  - **Ammonium Sulfate Particulate**: With the addition of the reducing agent in an SCR system, ammonium sulfate salts are formed which, when formed below the dew point temperature of the salt (625°F to 660°F when firing HSRFO), can blind the

catalyst and result in an undesirable white plume from the exhaust stack. To avoid this, the lowest possible fuel sulfur content is preferred. Even with ultra-low sulfur liquid fuels, a warm up period at startup is required and bypass valving at the turbochargers or an exhaust gas reheater may be required to increase exhaust gas temperatures at low loads and start-up. Also, soot blowing, with a sonic or compressed air system is likely required even with ultra-low sulfur liquid fuels to avoid deactivation of the catalyst by ammonium sulfate deposition and fouling of the surface of the catalysts. Soot-blowing can also result in potential visible opacity at the stack exit.

- **NOx emissions** – Similar to the above discussion of the sulfur content of the fuels, the oxidation of nitric oxide (NO) across the CO catalyst can occur, increasing nitrogen dioxide (NO_2) emissions and resulting in a visible, reddish-brown plume at the stack. A highly selective CO oxidation catalyst is required to avoid this.
- **Catalyst deactivation** – Heavy residual fuels, lubricant oils, and water used within the engines for NOx reduction can contain catalyst poisons, such as alkali metals (*e.g.*, sodium from water, vanadium in the fuels, or phosphorous from lubricant oil). Prior to the selection and design of the CO oxidation catalyst and SCR catalyst, it is necessary to measure the trace element concentrations in the fuels, oils, and water, to quantify the catalyst deactivation rate and predict a replacement schedule. During operation, periodic measurement of catalyst activity, by core sampling, and comparison to original activity to further predict deactivation rate should be conducted. Primary NOx-reduction by means of water injection into the fuel oil before combustion may need to be eliminated to reduce the deactivation rate.
- **Reactor design** – To accommodate both the CO and SCR catalyst and the ammonia injection grid (AIG), adequate space and inlet duct configuration is required for uniform distribution of exhaust flow and ammonia mixing. Computational fluid dynamics modeling of the exhaust configuration, catalyst housing, and AIG will be required, particularly for SCR.
- **Ammonia slip** – The SCR process requires precise control of the ammonia injection rate. Insufficient ammonia can result in unacceptably low NOx conversion. An ammonia injection rate which is too high can result in undesirable releases of ammonia to the atmosphere. Known as ammonia slip, this increases at higher NH_3/NOx ratios and decreases with increasing temperature. Ammonia slip can be avoided by limiting the NH_3/NOx ratio to between 0.9 and 1.0, using a NOx continuous emissions monitoring system (CEMS) to control the ammonia injection rate and/or, installing a guard catalyst can be installed downstream of the SCR catalyst.

2.5 Assumptions and Constraints

- **Foundations** – During TRC's site visit we reviewed the original project design drawings as well as structural calculations prepared for the HRSGs and exhaust duct support steel, exterior to the building, for Piti Units #8 and #9. These documents were prepared by FB Engineering AB of Goteborg, Sweden during dates ranging from September 16, 1997, to June 22, 2001. We also confirmed that the as-built plan dimensions and structural steel shape designations corroborated with the field conditions. The structure supporting the HRSG was designed to accommodate a total static weight, including the weight of contained water, of 322,000 pounds. The proposed CO oxidation catalyst housing and SCR reactor is estimated to weigh approximately 90,000 pounds. It is, therefore, our opinion that the present foundation system possesses sufficient capacity to support the proposed equipment alterations, assuming that the existing HRSGs will be removed.
- **Fuel Sulfur** – If fuel sulfur contents greater than 0.5 percent are to be used with SCR, a scrubber and particulate filtration, either fabric filter or electrostatic precipitator will be required as part of the air pollution control train. It is assumed that a fuel switch to ULSD will occur before SCR is considered.
- **Catalyst** – Different catalyst formulations are available for both the CO oxidation catalyst and the SCR catalyst and they each have different selectivity and characteristics with respect to issues such as SO_2 oxidation, NO oxidation, and NH_3 inhibition. Generally, the Johnson Matthey PLC and Haldor Topsoe A/S catalysts were considered in developing the study level costs, as these suppliers offer contrasting formulations for both catalysts:
  - **CO catalyst:** Both suppliers use a metallic substrate (vanadium) with palladium only, no platinum, to be highly selective to CO and avoid nitric oxide oxidation to nitrogen dioxide. Haldor Topsoe's CO catalyst formulation can tolerate higher sulfur up to 500 ppm, but is not as CO selective and oxidation of nitric oxide to nitrogen dioxide could be an issue. The Johnson Matthey CO catalyst would require conversion to ULSD.
  - **SCR catalyst:** Similar for all suppliers, with a composition of vanadium pentoxide, molybdenum, and tungsten on a titanium dioxide ceramic substrate. However, the substrates are different. Generally, the SCR catalyst suppliers offer either an extruded ceramic honeycomb or a corrugated ceramic mat substrate with differences in porosity, as follows:
    - **Extruded ceramic honeycomb** – Cormetech Inc., Ceram Environmental Inc. and Johnson Matthey PLC
    - **Corrugated ceramic mat** – Haldor Topsoe A/S and Mitsubishi Hitachi Power Systems

The low exhaust temperature of the engines is a concern with SCR and even with ultralow sulfur liquid fuels, a warm up period at startup is required and bypass valving at the turbochargers or an exhaust gas reheater may be required to increase exhaust gas temperatures at low loads. Also, soot blowing, with a sonic or compressed air system is likely required even with ultra-low sulfur liquid fuels to avoid deactivation of the catalyst by ammonium sulfate deposition and fouling of the surface of the catalysts. A contingency for engine side modifications has been allotted for in the study level cost estimate.

- **Reducing agent** – The available NOx reducing agents include anhydrous ammonia, aqueous ammonia, and urea. Anhydrous ammonia is toxic, hazardous, and requires thick-shell, pressurized storage tanks and piping due to its high vapor pressure. Aqueous ammonia and urea are less hazardous and easier to handle, however, because of their high water content, are costly to ship and require a significant footprint for storage. Given the limitations of shipping costs and footprint, anhydrous ammonia is recommended for this project.
- **Instrumentation** – the instrumentation required for CO oxidation is considerably less than would be required for both CO oxidation and SCR, as follows:
  - **CO only:** Inlet and outlet temperature and CO catalyst pressure drop, each layer
  - **CO and SCR**: NOx and oxygen (O_2) outlet CEMs tied to the reducing agent feed system, reactor inlet temperature, CO catalyst pressure drop (each layer), CO catalyst outlet temperature, SCR catalyst pressure drop (each layer), reactor outlet temperature, reducing agent flow and pressure, and soot blower controls

Section 3
Alternatives

3.1 Descriptions and Comparisons

Several location alternatives have been considered for installation of the CO oxidation catalyst. The alternatives include the following:

1. Interior installation – tapping into the engine exhaust manifold, supporting the catalyst housing from building beside or above the engine, and returning the exhaust to the exhaust duct prior to the silencer.

2. Silencer replacement – replacing the existing silencer with a new housing containing both the CO oxidation catalyst and serving as the silencer.

3. HRSG removal – removing the existing heat recovery steam generator and installing the catalyst housing in its place.

Of the alternatives, it quickly became apparent during TRC's site visit that only removal of the HRSGs would provide a feasible location alternative. The limited interior building space beside and above the engines precludes an interior installation, and the allowable pressure drop across the existing silencer, of 0.59 inches of water, is not sufficient to allow for the pressure drop across the CO oxidation catalyst.

Further, if NOx emission controls is considered, the additional pressure losses across the SCR catalyst, the additional space required for the combined SCR reactor and CO catalyst housing, and the additional space required for the reducing agent storage tanks and delivery pumps, would be better accommodated by removal of the HRSGs and the associated steam piping and turbine generator.

3.2 Costs

Based on the issues, assumptions, and constraints discussed earlier in this report, Appendix B contains a tabular presentation of estimate capital and costs for CO oxidation catalyst only systems and a dual system with CO oxidation and SCR for each engine generator. The study level cost estimates are summarized below.

	CO Oxidation only		CO Oxidation and SCR	
	Haldor Topsoe	Johnson Matthey	Haldor Topsoe	Johnson Matthey
Total Capital Investment	$4,000,000	$3,500,000	$6,500,000	$6,500,000
Total Annual Costs	$212,000	$191,000	$1,912,000	$1,903,000

3.3 Schedule

The engineering, fabrication, and installation of the CO oxidation and SCR systems are estimated to take approximately 16 months from the beginning of the first tasks. If CO oxidation only is perused, little schedule improvement would be gained as the catalyst housing/reactor would need to be designed and fabricated to accommodate the future SCR system. Efficient overlap of tasks may expedite the project to take as little as 12 months. The tasks, listed in order with approximate durations, are as follows:

1. Preliminary Engineering – 8 weeks;
2. Permitting – 24 to 48 weeks;
3. CFD Modeling, Fuel Analysis for Catalyst – 4 weeks;
4. Catalyst Specification and Procurement – 6 weeks;
5. Detailed Engineering – 12 weeks;
6. Housing Fabrication – 16 weeks;
7. Shipping – 6 weeks;
8. Demolition of HRSGs, Steam Turbine, and Ancillaries – 4 weeks;
9. Assembly and Installation – 8 weeks;
10. Engine Outage – 1 week, each; and
11. Commissioning and Confirmation Testing – 2 weeks

Engine outage is expected to require five to eight days, for each engine during which time final duct connections will be made from the new housing to the existing exhaust flues. During demolition of the HRSGs and installation of the new catalyst housing units, the exhaust gas will be diverted to bypass the HRSGs directly to the stack using the existing dampers. The dampers are not expected to form an air-tight seal and blind flanges are to be fabricated in advance. The total engine outage may be discontinuous depending when the catalyst is able to be loaded into the housing (*i.e.,* the exhaust gas may flow through the empty housing if duct installation and catalyst loading must take place at separate times). When the catalyst units are installed and operational, two additional weeks are scheduled for commissioning and testing to assess catalyst and engine performance.

Tables

Table 1
Engineering Details of the Cabras #3 and #4 and Piti #8 and #9 Low Speed Diesel Engines

Parameter	Units	Cabras	Piti
		3 and 4	8 and 9
Manufacturer	NA	**Doosen**	**Mitsui**
Designer	NA	MAN B&W	MAN B&W
Current Operator	NA	Doosen Engine Group (DEG)	Marianas Energy Company (MEC)
Completion	NA	1995	1999
Type	NA	2-Stroke, Low Speed	2-Stroke, Low Speed
Model	NA	12K80MC-S (Mk5)	10K90MC-S
Current Fuels	NA	LSRFO and HSRFO	LSRFO and HSRFO
Proposed Fuels	NA	ULSRFO/ULSD/LNG	ULSRFO/ULSD/LNG
Cylinders	#	12	10
Bore	mm	800	900
Stroke	mm	2300	2300
Speed	rpm	102.9	109.1
Displacement	L	13,873	14,632
	cu. in.	846,599	892,897
Frequency	Hz	60	60
Rated Capacity	MW	39.3	44.2

Table 2
Design Parameters for the Piti #8 and #9 Low Speed Diesel Engines

Engine Parameter	*Units*	*Piti #8 and #9*
Exhaust Displacement with Liquid Fuels (LSRFO, HSRFO, ULSRFO, and ULSD)	Nm^3/h	333,220 (1013 mbar/0°C)
	ACFM @ peak	413,181 (195 Am^3/s)
	lb/hr	933,112
	kg/hr	423,180
Exhaust Displacement with Gas Fuel (LNG)	lb/hr	1,004,779
	kg/hr	455,760
Design Exhaust Temperature @ 100% Load	°F +/-	473 +/- 27
Peak Exhaust Temperature	°F	572 - 608
	°C	320
Lube Oil Consumption	g/kWh	0.15
Lube Oil Type	NA	SK Supermar AS
Cylinder Oil Consumption	g/kWh	1.5
Cylinder Oil Type	NA	SK Supermar AS
Existing Silencer Pressure Drop, Max.	mmWC	15
	inWC	0.59
Existing Silencer Insertion Loss at 500 Hz	dB	25
Waste Heat Recovery Boiler Pressure Drop, Max.	mmWC	200
	inWC	7.87

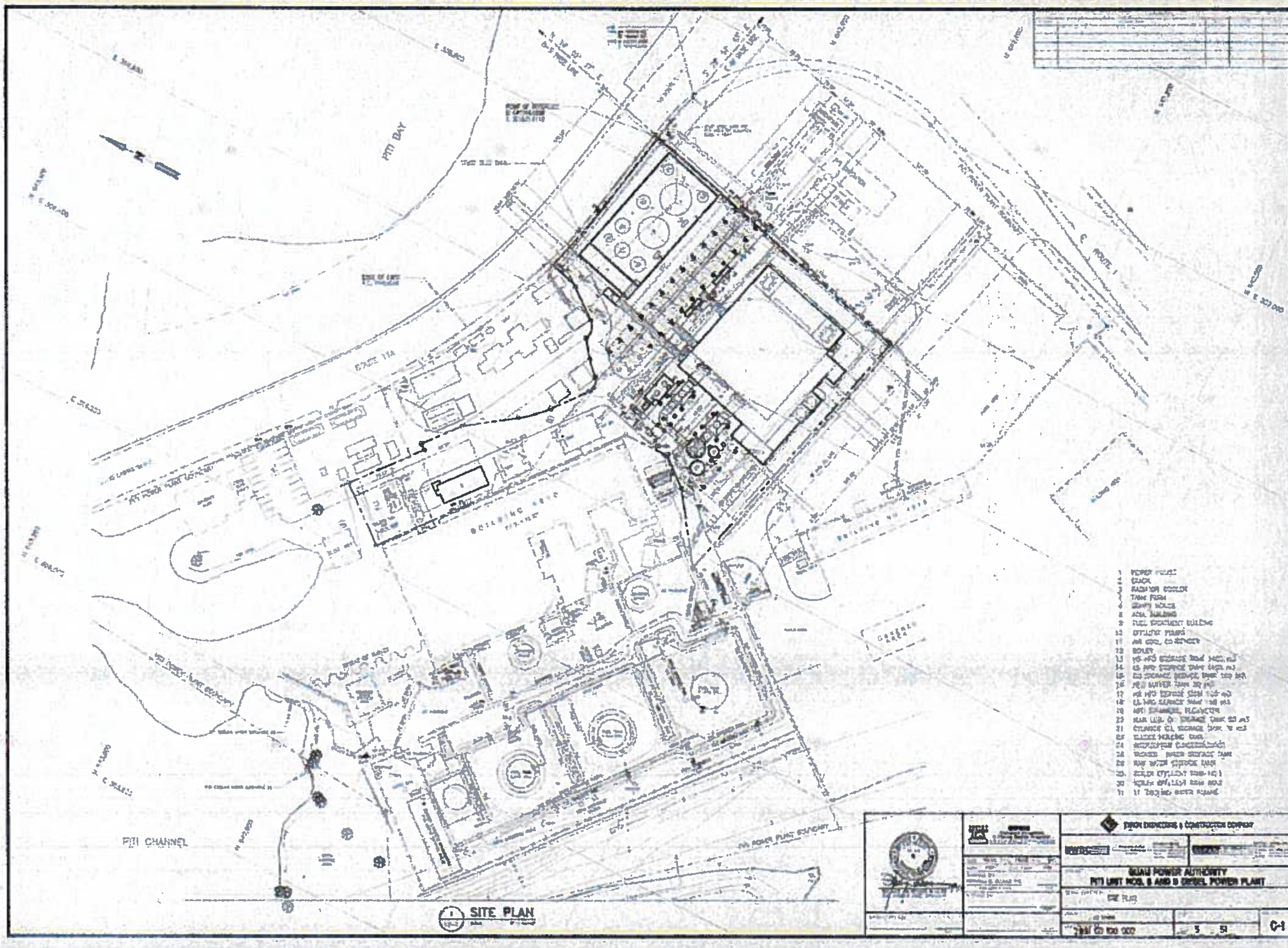
Table 3
Summary Exhaust Conditions by Fuel for Piti #8 and #9 Low Speed Diesel Engines

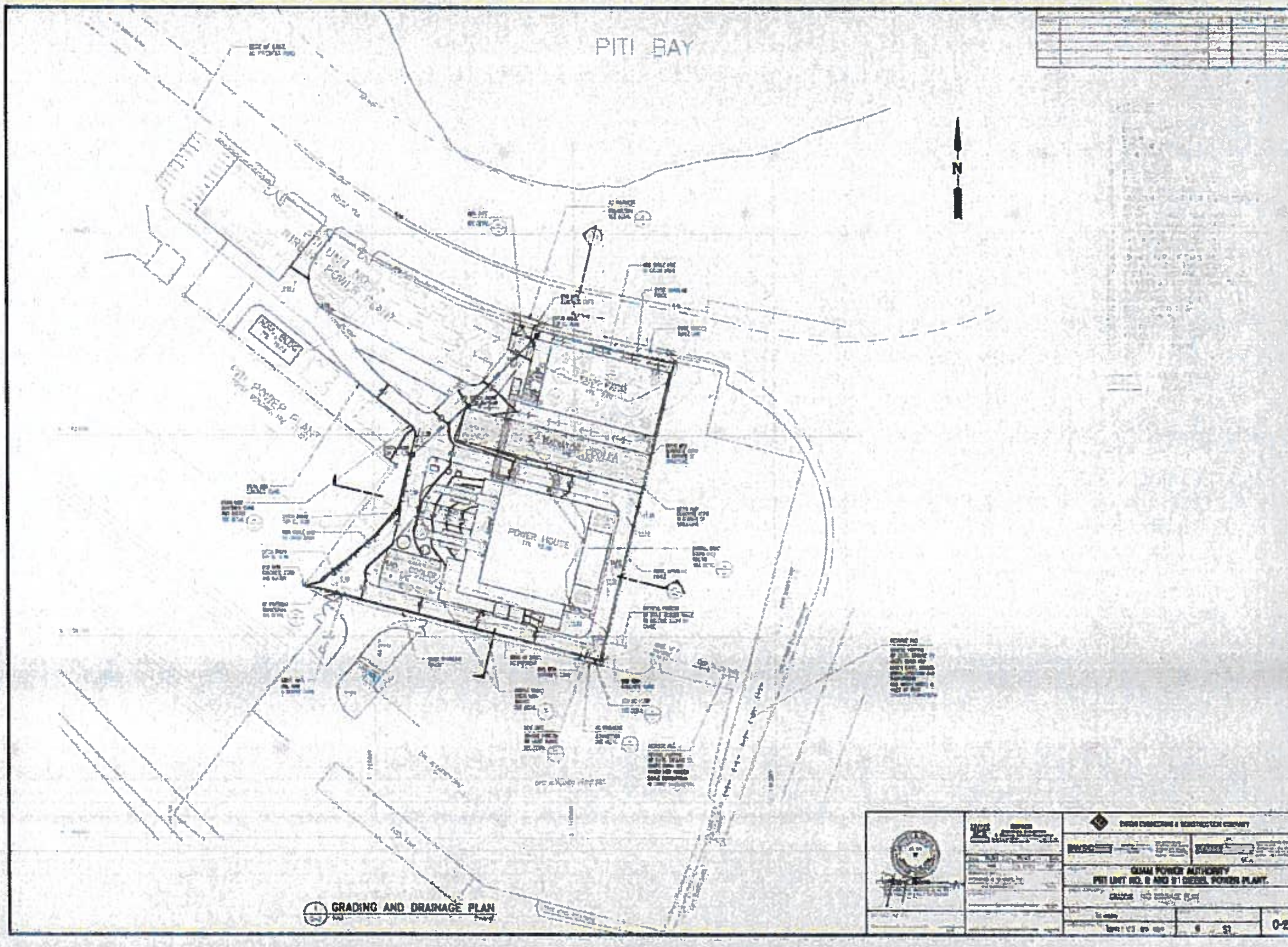
Exhaust Gas Parameter	*Unit*	*Permit Limit*[1, 2] *or (Test Result)*[3]	*Fuel*[4, 5] LoS RFO (Sulfur @ 1.19%)	HIS RFO (Sulfur @ 2.0%)	ULS RFO (Sulfur @ 0.5%)	ULSD (Sulfur @ 0.0015%)	LNG
Displacement	Nm^3/hr	(304,156)	333,220 (1013 mbar/0°C)				358,813
	ACFM	(381,829)	413,181 (195 Am^3/s), peak				444,915
	SCFM	(207,824)	234,712				252,739
	DSCFM	(192,820)	ND				ND
	lb/hr	(867,690)	933,112				1,004,779
	kg/hr	(393,578)	423,180				455,760
Fuel Consumption	L/min	262.2	262.2			ND	ND
	gal/hr	4,156	4,156			ND	ND
	gal/kWh	0.0013	0.0013			ND	ND
Temperature	°F	(514)	473				ND
Moisture	lb water/lb d.a.	(0.078)	ND	ND	ND	ND	ND
O_2	%	(14.7)	ND	ND	ND	ND	ND
CO_2	%	(4.9)	ND	ND	ND	ND	ND
NOx, as NO_2	ppmdv @ 15% O_2	950 (713)	950				
	lb/hr	1,366 (1,040)	1,038				
SO_2	ppmdv @ 15% O_2	(295)	232	390	98	0.5	0.05
	lb/hr	780 (597)	541	909	228	1.2	0.12
CO	ppmdv @ 15% O_2, full load/<full load	140/299 (49.3)	140				200
	lb/hr, full load/<full load	125/135 (43.8)	143				204
THC	ppmdv @ 15% O_2	(15.4)	~15				
	lb/hr, full load/<full load	154/175 (21.4)	24.1				
PM	lb/hr	168 as PM_{10} (57.5)	352.6			161.6	161.6
	mg/Nm^3	ND	240			110	110
Opacity	%	20 (6.9)	ND	ND	ND	ND	ND

Notes:

1. Permit limits from Piti Power Plant's permit to operate, issued March 29, 2007.
2. Permit limits for CO and THC are shown with lower, full load value and higher, below full load value.
3. Test results shown in parentheses are averages of Units #8 and #9 across three separate tests performed in 2012, 2013, and 2014.
4. Estimated emissions for the five fuel scenarios were obtained from Burmeister & Wain Scandinavian Contractors A/S (BWSC).
5. Exhaust displacement for ULSD is assumed to be equal to that for residual fuel oils.

Appendix A
Site Plans


PITI BAY
PITI CHANNEL
ROUTE 1
GUAM POWER AUTHORITY
PITI UNIT NOS. 8 AND 9 DIESEL POWER PLANT
C-1
SITE PLAN


PITI BAY
N
POWER HOUSE
GUAM POWER AUTHORITY
C-2
GRADING AND DRAINAGE PLAN

Appendix B
Costing Summaries

Carbon Monoxide Oxidation Catalyst
Study Level Cost Estimate
Guam Power Authority
Piti Units #8 and #9

CAPITAL COSTS:

	Item	Cost Estimation Factor		Value, Halder Topsoe	Value, Johnson Matthey	Note
Purchased Equipment Costs	New Catalyst Media and Frames		Cat.	$ 657,000	$ 600,000	From study level pricing provided by catalyst suppliers
	Catalyst Housing	-	-	$ 300,000	$ 300,000	From study level pricing provided by catalyst suppliers
	Catalyst Housing Support, Platforms, Stairs	-	-	$ 150,000	$ 150,000	Estimated cost from structural engineer based on existing supports, platforms, and stairs
	New Ductwork (Corten A)	-	-	$ 252,000	$ 252,000	Estimated from scaled values from RSMeans 2011 using length of duct to be replaced
			A	$ 1,359,000	$ 1,302,000	
	Instrumentation	0.1	A	$ 136,000	$ 130,000	Includes temperature and catalyst differential pressure instruments only.
	Sales Tax	0.03	A	$ 41,000	$ 39,000	
	Freight	0.05	A	$ 68,000	$ 65,000	
	Purchased equipment cost, PEC		B'	$ 1,604,000	$ 1,536,000	
	PEC, Adjusted for Guam		B	$ 2,165,000	$ 2,074,000	Additional 35% added to purchased equipment to account for remote site
Direct Installation Costs	Demolition	-	-	$ 200,000	$ 200,000	Labor cost scaled from RSMeans 2011 demolitions costs, includes transportation of scrap material
	Foundations & Supports	0	B	$ -	$ -	No modifications to foundations expected to be required
	Handling & Erection	0.14	B	$ 303,000	$ 290,000	
	Electrical	0.04	B	$ 87,000	$ 83,000	
	Piping	0	B	$ -	$ -	No piping required for CO catalyst installation only
	Insulation for Ductwork	0	B	$ -	$ -	Ductwork insulation included in replacement cost above
	Painting	0.02	B	$ 43,000	$ 41,000	
	Direct Installation Cost	0.2	B	$ 633,000	$ 614,000	
	Site Preparation		SP	$ -	$ -	Assumes no site preparation beyond demoligion required
	Buildings		Bldg.	$ -	$ -	Assumes no new buildings required
	Total Direct Cost		DC	$ 2,798,000	$ 2,688,000	Total DC = (PEC) + (Direct Installation Cost) + (Site Prep.) + (Buildings)
Indirect Installation Costs	Engineering	0.1	B	$ 217,000	$ 207,000	
	Construction and Field Expenses	0.05	B	$ 108,000	$ 104,000	
	Contractor Fees	0.1	B	$ 217,000	$ 207,000	
	Start-up	0.02	B	$ 43,000	$ 41,000	
	Performance Test	0.01	B	$ 22,000	$ 21,000	
	Contingencies	0.1	B	$ 217,000	$ 207,000	
	Total Indirect Cost		IC	$ 824,000	$ 787,000	
	Total Capital Investment		TCI	$ 4,000,000	$ 3,500,000	Total Capital Investment = (Total Direct Cost) + (Total Indirect Cost), rounded up to nearest $0.5 million

ANNUAL COSTS:

Catalyst Life (yr): 15
Frequency of Catalyst Washing (per yr): 2
Interest Rate: 7%
Capital Recovery Factor: 0.1098

Item	Cost Estimation Factor		Value, Halder Topsoe	Value, Johnson Matthey	Note
General Maintenance and Materials	0.03	TCI	$ 120,000	$ 105,000	
Catalyst Washing Labor and Materials	-	-	$ 20,000	$ 20,000	Estimated labor cost of biannual catalyst washing, to be performed in under 24 hours
Reagent Cost	-	-	$ -	$ -	No reagent required for CO catalyst installation only
Electricity Cost	-	-	$ -	$ -	No significant additional electricity required
Annualized Catalyst Replacement Cost	0.1098	Cat.	$ 72,000	$ 66,000	Forward-paying annualized catalyst replacement cost (*i.e.*, new catalyst paid for by the end of current catalyst life)
Total Variable Costs			$ 212,000	$ 191,000	

Carbon Monoxide Oxidation Catalyst and Selective Catalytic Reduction
Study Level Cost Estimate
Guam Power Authority
Piti Units #8 and #9

CAPITAL COSTS:

	Item	Cost Estimation Factor		Value, Haldor Topsoe	Value, Johnson Matthey	Note
Purchased Equipment Costs	CO, NOx catalysts		Cat.	$ 1,005,000	$ 918,000	From study level pricing provided by catalyst suppliers. Johnson Matthey value scaled from CO catalyst quote
	Catalyst Housing	-	-	$ 500,000	$ 500,000	From study level pricing provided by catalyst suppliers, including ammonia injection grid
	Catalyst Housing Support, Platforms, Stairs	-	-	$ 150,000	$ 150,000	Estimated cost from structural engineer based on existing supports, platforms, and stairs
	New Ductwork (Corten A)	-	-	$ 252,000	$ 252,000	Estimated from scaled values from RSMeans 2011 using length of duct to be replaced
	Reagent Storage Tanks	-	-	$ 217,000	$ 217,000	Estimated from RSMeans 2011 data for pressurized storage tanks
			A	$ 2,124,000	$ 2,037,000	
	Instrumentation	0.2	A	$ 425,000	$ 407,000	Includes temperature, catalyst differential pressure, and reagent delivery system instrumentation. Existing NOx and O_2 CEMS instruments are to be tied into new control system to control ammonia injection
	Sales Tax	0.03	A	$ 64,000	$ 61,000	
	Freight	0.05	A	$ 106,000	$ 102,000	
	Purchased equipment cost, PEC		B'	$ 2,719,000	$ 2,607,000	
	PEC, Adjusted for Guam		B	$ 3,671,000	$ 3,519,000	Additional 35% added to purchased equipment to account for remote site
Direct Installation Costs	Demolition	-	-	$ 200,000	$ 200,000	Labor cost scaled from RSMeans 2011 demolitions costs, includes transportation of scrap material
	Foundations	0	B	$ -	$ -	No modifications to foundations expected to be required
	Handling & Erection	0.14	B	$ 514,000	$ 493,000	
	Electrical	0.04	B	$ 147,000	$ 141,000	
	Piping	0.04	B	$ 147,000	$ 141,000	Piping cost included for reagent delivery from storage to exhaust duct
	Insulation for Ductwork	0	B	$ -	$ -	Ductwork insulation included in replacement cost above
	Painting	0.02	B	$ 73,000	$ 70,000	
	Direct Installation Cost	0.24	B	$ 1,081,000	$ 1,045,000	
	Site Preparation		SP	$ -	$ -	Assumes no site preparation beyond demolition required
	Buildings		Bldg.	$ -	$ -	Assumes no new buildings required
	Total Direct Cost		DC	$ 4,752,000	$ 4,564,000	Total DC = (PEC) + (Direct Installation Cost) + (Site Prep.) + (Buildings)
Indirect Installation Costs	Engineering	0.1	B	$ 367,000	$ 352,000	
	Construction and Field Expenses	0.05	B	$ 184,000	$ 176,000	
	Contractor Fees	0.1	B	$ 367,000	$ 352,000	
	Start-up	0.02	B	$ 73,000	$ 70,000	
	Performance Test	0.01	B	$ 37,000	$ 35,000	
	Contingencies	0.15	B	$ 551,000	$ 528,000	Includes allowance for turbe valving or exhaust reheat, if necessary
	Total Indirect Cost		IC	$ 1,579,000	$ 1,513,000	
	Total Capital Investment		TCI	$ 6,500,000	$ 6,500,000	Total Capital Investment = (Total Direct Cost) + (Total Indirect Cost), rounded up to nearest $0.5 million

ANNUAL COSTS:

Catalyst Life (yr):	15
Frequency of Catalyst Washing (per yr):	2
Interest Rate:	7%
Capital Recovery Factor:	0.1098

Item	Factor		Haldor Topsoe	Johnson Matthey	Note
General Maintenance and Materials	0.03	TCI	$ 195,000	$ 195,000	
Catalyst Washing Labor and Materials	-	-	$ 20,000	$ 20,000	Estimated labor cost of biannual catalyst washing, to be performed in under 24 hours
Reagent Cost	-	-	$ 1,587,000	$ 1,587,000	Cost of reagent at 5% excess of 90% stoichiometric amount, assuming $650 per ton ammonia cost
Electricity Cost	-	-	$ 200	$ 200	Estimated pump energy usage to deliver about 4 gallons reagent per minute to catalyst bed
Annualized Catalyst Replacement Cost	0.1098	Cat.	$ 110,000	$ 101,000	Forward-paying annualized catalyst replacement cost (*i.e.*, new catalyst paid for by the end of current catalyst life)
Total Variable Costs			$ 1,912,000	$ 1,903,000	