REGIONAL HAZE FOUR-FACTOR ANALYSIS

El Paso Natural Gas Company, LLC
Washington Ranch Storage Facility

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1. EXECUTIVE SUMMARY

In the 1977 amendments to the Clean Air Act (CAA), Congress set a nation-wide goal to restore national parks and wilderness areas to natural conditions by remedying existing anthropogenic visibility impairment and preventing future impairments. On July 1, 1999, the U.S. Environmental Protection Agency (EPA) published the final Regional Haze Rule (RHR). The objective of the RHR is to restore visibility to natural conditions in 156 specific areas across the United States, known as Federal Class I areas. The CAA defines Class I areas as certain national parks (over 6,000 acres), wilderness areas (over 5,000 acres), national memorial parks (over 5,000 acres), and international parks that were in existence on August 7, 1977.

The RHR requires states to set goals that provide for reasonable progress towards achieving natural visibility conditions for each Class I area in their jurisdiction. In establishing a reasonable progress goal for a Class I area, each state must:

(A) Consider the costs of compliance, the time necessary for compliance, the energy and non-air quality environmental impacts of compliance, and the remaining useful life of any potentially affected sources, and include a demonstration showing how these factors were taken into consideration in selecting the goal. 40 CFR 51. 308(d)(1)(i)(A).

This is known as a four-factor analysis.

(B) Analyze and determine the rate of progress needed to attain natural visibility conditions by the year 2064. To calculate this rate of progress, the State must compare baseline visibility conditions to natural visibility conditions in the mandatory Federal Class I area and determine the uniform rate of visibility improvement (measured in deciviews) that would need to be maintained during each implementation period in order to attain natural visibility conditions by 2064. In establishing the reasonable progress goal, the State must consider the uniform rate of improvement in visibility and the emission reduction. 40 CFR 51. 308(d)(1)(i)(B).

The uniform rate of progress or improvement is sometimes referred to as the glidepath and is part of the state's Long Term Strategy (LTS).

The second implementation planning period (2018-2028) for national regional haze efforts is currently underway. There are a few key distinctions from the processes that took place during the first planning period (2004-2018). Most notably, the second planning period analysis distinguishes between natural or biogenic and manmade or anthropogenic sources of emissions. Using a Photochemical Grid Model (PGM), the Western Region Air Partnership (WRAP), in coordination with the EPA, is tasked with comparing anthropogenic source contributions against natural background concentrations.

Pursuant to 40 CFR 51.308(d)(3)(iv), the states are responsible for identifying the sources that contribute to the most impaired days in the Class I areas. To accomplish this, the New Mexico Environment Department (NMED) reviewed 2016 emission inventory data for major sources and assessed each facility's impact on visibility in Class I areas with a "Q/d" analysis, where "Q" is the magnitude of emissions that impact ambient visibility and "d" is the distance of a facility to a Class I area. From this analysis, 24 facilities were identified by the NMED. On July 18, 2019 the NMED informed El Paso Natural Gas Company LLC (EPNG) that its Washington Ranch Storage (Washington Ranch) facility was identified as one of the sources contributing to regional haze at the Carlsbad Caverns National Park Class I area.

In coordination with WRAP, the NMED devised criteria to determine specific equipment that is subject to the four-factor analysis. In the NMED's July 18, 2019 notification letter to EPNG, it specifies that any single piece of equipment with a potential to emit (PTE) greater than 10 pounds per hour (lb/hr) and/or 5 tons per year (tpy) of Nitrogen Oxides (NO_X) or Sulfur Dioxide (SO_2) shall be included in this analysis. The equipment at Washington Ranch as listed in TV Permit P064-R3, the PTE associated with that equipment, and the applicability of a four-factor analysis for each pollutant are reported in Table 1.

Table 1. Summary of Equipment and Applicability of the Four-Factor Analysis

Equipment	NO_X PTE (lb/hr)	NO_X PTE (tpy)	NO_X Subject to Analysis? (Yes/No)	SO_2 PTE (lb/hr)	SO_2 PTE (tpy)	SO_2 Subject to Analysis? (Yes/No)
Cooper-Bessemer / 12Q155HC2 2SLB RICE Unit A-01	27.3	119.5	Yes	0.48	2.1	No
Cooper-Bessemer / 12Q155HC2 2SLB RICE Unit B-02	27.3	119.5	Yes	0.48	2.1	No

Once the applicability of equipment and pollutants has been determined, potential retrofit control technologies must be identified. In accordance with 40 CFR 51 Appendix Y and at the recommendation of the NMED,[1] this is primarily achieved by utilizing the Reasonably Available Control Technology (RACT) / Best Available Control Technology (BACT) / Lowest Achievable Emission Reduction (LAER) Clearinghouse (RBLC) data. In order to determine the most relevant and current retrofit controls available, the RBLC is queried for the previous ten years. A summary of identified available retrofit controls along with a technical feasibility assessment for each control is provided in Section 2. The four-factor analysis is then conducted for those controls that are technically feasible.

[1] NMED 2021 Regional Haze Planning Website ("Links to other information"). https://www.env.nm.gov/air-quality/reg-haze/

2. BACKGROUND INFORMATION & TECHNICAL FEASIBILITY

2.1. TWO-STROKE LEAN-BURN ENGINES

Washington Ranch has two (2) natural gas-fired two-stroke lean-burn (2SLB) reciprocating internal combustion engines (RICE), Units A-01 and B-02, that are subject to this four-factor analysis. The only pollutant subject to evaluation for these units is NO_X.

2.1.1. Two-Stroke Lean-Burn Engines Background

Natural gas-fired RICE are separated into multiple design classes, including 2SLB, 4-stroke lean-burn (4SLB), and 4-stroke rich-burn (4SRB). The four-stroke design uses four strokes of the piston, or two turns of the crankshaft, to complete the power cycle. The two-stroke design completes the power cycle in a single revolution of the crankshaft. Rich-burn engines are designed to operate close to the stoichiometric, or chemically balanced, air-to-fuel ratio (around 16:1) with exhaust oxygen levels less than 4 %, while lean-burn engines operate at significantly higher air-to-fuel ratios (ranging from 20:1 to 50:1), with exhaust oxygen levels of 12 % or more.[2]

NO_X is formed in reciprocating engines via three mechanisms:

(1) Thermal NO_X - the thermal dissociation and subsequent reaction of nitrogen (N_2) and oxygen (O_2) molecules during combustion,
(2) Fuel NO_X - the evolution and reaction of fuel-bound nitrogen compounds with oxygen, and
(3) Prompt NO_X - the early reactions of nitrogen intermediaries and hydrocarbon radicals in fuel.

The Washington Ranch engines use natural gas fuel, which contains a negligible amount of nitrogen compounds. Therefore, the formation of prompt and fuel NO_X will be insignificant. This analysis will focus on thermal NO_X. The rate of NO_X formation through the thermal NO_X mechanism is highly dependent upon the air-to-fuel ratio, combustion temperature, and residence time at the combustion temperature. Maximum thermal NO_X formation occurs near the stoichiometric air-to-fuel mixture ratio because combustion temperatures are greatest at this ratio.[3]

NO_X reduction in natural gas-fired RICE can be accomplished by three general methods, as follows:

(1) Post-combustion NO_X control technologies, which employ various strategies to chemically reduce NO_X.
(2) Combustion control techniques, for example reducing the peak flame temperature by introducing inerts that limit initial NO_X formation.
(3) Operational control methods, such as adjusting the timing or other operating parameters.

The PTE from each engine is reported in the facility's Title V permit P064-R3, as well as above in Table 1.

[2] "Emission Control Technology for Stationary Internal Combustion Engines," Manufacturers of Emission Controls Association, 2015
[3] U.S. EPA, AP-42, Section 3.2, "Natural Gas-Fired Reciprocating Engines"

2.1.2. Potential NO_X Controls for 2SLB Engines

Retrofit control options identified for 2SLB RICE were identified via comprehensive review of the RBLC and available technical literature and are summarized in Table 2. A detailed description and discussion of the technical feasibility and anticipated performance of each control is provided below.

Table 2. Potential Control Options for 2SLB RICE

Control Equipment	Technically Feasible	NO_X Control Efficiency
Selective Catalytic Reduction	**No**	**N/A**
Clean Burn Technology	**Yes**	**27% - 82%**
Good Combustion Practices and Fuel Selection	**Yes**	**Base Case**

2.1.2.1. Selective Catalytic Reduction

Selective Catalytic Reduction (SCR) is the process by which a nitrogen-based reagent, such as ammonia or urea, is injected into the exhaust stream of a combustion unit. Within a reactor vessel containing a metallic or ceramic catalyst, the injected reagent reacts selectively with the NO_X in the exhaust to produce molecular nitrogen (N_2) and water (H_2O).[4] The chemical reactions for this process are shown in the equations below.

$$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O$$
$$2\ NO_2 + 4\ NH_3 + O_2 \rightarrow 3\ N_2 + 6\ H_2O$$

An SCR system includes the catalyst, reagent storage tank, reagent injector, reagent pump, pressure regulator, and electronic controls to accurately meter the quantity of reagent injected as a function of engine load, speed, temperature, and NOx emissions to be achieved. The lifespan of the catalyst is primarily determined by the erosion caused by the flue gas, deactivation caused by ammonium bisulfate (NH_4HSO_4) poisoning, as well as the build-up and fouling by the catalyst.

The characteristic exhaust temperature for 2SLB engines shows higher excess O_2 in the exhaust stack. For 2SLB engines, with typical exhaust O_2 from 14 to 16% (depending on make, model and operating condition), typical exhaust temperature is in the range of 450 to 600°F. Exhaust temperature is a critical design parameter for SCR performance, and accordingly, the catalyst material is selected based on the design temperature of the exhaust. Based on current technology and practices, SCR's optimal exhaust temperature is between 450 and 850°F range. Therefore, SCR's use as a control technology is limited to sources where the exhaust temperature is within that range.

A catalyst may perform at temperatures below 450°F, however complications such as reagent decomposition, reagent slip, catalyst contamination due to unreacted reagent (salt formation), etc. may arise. Catalysts may perform at lower temperatures (e.g., 450°F or lower), but other complications can arise at lower temperature (e.g., urea decomposition, competing reactions that form nitrates). Temperatures below the desired range reduce the reduction efficiency – i.e., increase NO_X and ammonia emissions.

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[4] U.S. EPA, Office of Air Quality Planning and Standards, "Air Pollution Control Technology Fact Sheet (Selective Catalytic Reduction (SCR))," EPA-452/F-03-032.

At higher temperatures, ammonia may "slip," meaning that a small amount of ammonia is not consumed in the reactions and is emitted in the exhaust stream. Unreacted reagent in the exhaust can form ammonium sulfates, which may plug or corrode downstream equipment, and/or catalyst damage may occur. Streams carrying large amounts of ammonium sulfates may blind the catalyst and may necessitate the application of a soot blower.

When compared to the typical 450 – 600°F temperature range for 2SLB engines, no single catalyst material offers high, stable performance across that range. Thus, even if other SCR technical issues (e.g., associated with reagent control) are addressed, current catalysts are not adequate to ensure stable, high-level performance for 2SLB engines.

In addition to the temperature issues, use of an aqueous reagent is common for engine applications. The water associated with aqueous urea (or ammonia) injection for an engine with higher NO_X emissions (e.g., NO_X is not controlled) could decrease exhaust temperature by 5 to 20 °F. This further complicates system engineering and catalyst material requirements.

For engines that typically operate at variable loads, such as engines on gas transmission pipelines, an SCR system may not function effectively, causing either periods of ammonia slip or insufficient ammonia injection to gain the reductions needed.[5] In the case of Washington Ranch, the two engines run at ongoing variable loads.

Finally, there has been no application of SCR on this model of Cooper engines (see attached RBLC results). A thorough twenty-year review of the RBLC tables was conducted and there were no examples of an SCR being used as a control for 2SLB engines. The lack of availability or comparable use of an SCR on these Cooper engines presents the case that this control technology is considered technically infeasible. Consequently, SCR is not evaluated further in this four-factor analysis.

2.1.2.2. Clean Burn Technology

Clean Burn Technology (CBT) is another term for utilizing combustion mixtures in engines with fuel-lean air-to-fuel ratios. This method of reducing NO_X emissions involves reconfiguring the engines by adding or enhancing an air-to-fuel ratio controller, making the unit capable of operating at optimal air-to-fuel ratios.

As described in Section 2.1.1 of this report, rich-burn engines are normally designed to operate close to the stoichiometric, or chemically balanced, air-to-fuel ratio of 16:1, while lean-burn engines operate at significantly higher air-to-fuel ratios (ranging from 20:1 to 50:1). A combustion mixture with a higher air-to-fuel ratio results in reduced NO_X emissions, because using fuel-lean mixtures lowers the combustion temperature by diluting energy input. 2SLB engines are typically designed to operate at the high air-to-fuel ratios employed in CBT; however, further increasing the air-to-fuel ratio in lean-burn engines can decrease the NO_X emissions.[6]

In order to avoid derating the engine (which can result in lower engine efficiency), combustion air must be increased at constant fuel flow. To achieve this, the engine will need to be retrofitted with a turbocharger, which forces additional air into the combustion chamber, as well as an automatic air-to-fuel ratio controller.

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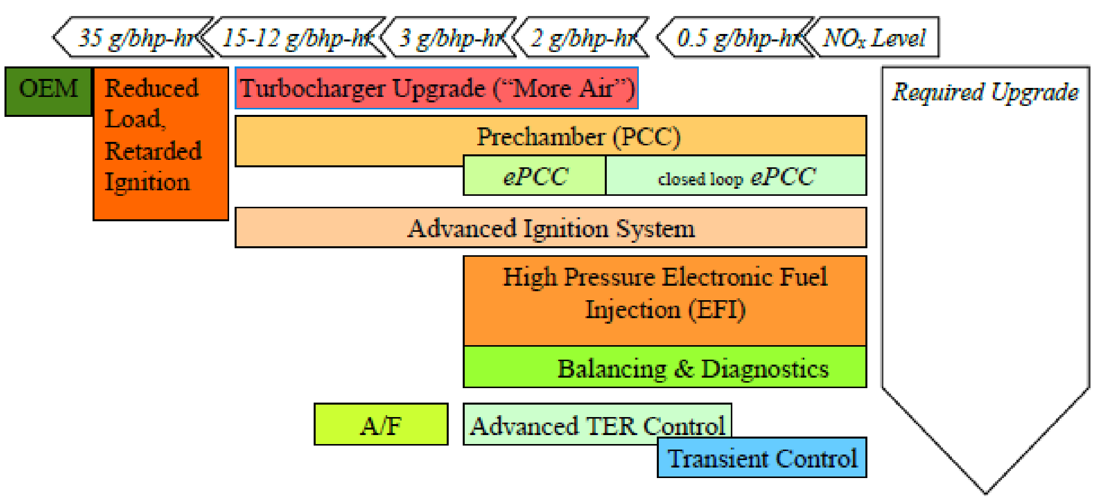
[5] U.S. EPA, AP-42, Section 3.2, "Natural Gas-Fired Reciprocating Engines"
[6] State of the Art (SOTA) Manual for Reciprocating Internal Combustion Engines, State of New Jersey Department of Environmental Protection, 2003.

Many 2SLB engines, such as naturally aspirated engines, do not have identical air-to-fuel ratios in each cylinder, which can result in limited ability to vary the air-to-fuel ratio. To maintain acceptable engine performance at lean conditions, high-energy ignition systems (HEIS) have been developed that promote flame stability at very lean conditions.[7]

2SLB engines are mechanically capable of being retrofitted with more sensitive air-to-fuel ratio controllers and running on higher air-to-fuel ratio combustion to control NO_X emissions. Therefore, it has been determined that this method of NO_X control is feasible for the 2SLB engines at Washington Ranch. Air-to-fuel ratio adjustment generally achieves a 5 to 30% reduction in NO_X emissions; however, this reduction is very specific to each engine and typical loading[8].

EPNG employs Hoerbiger as a vendor for units A-01 and B-02. Hoerbiger utilizes the "Layered Approach Strategy" (Figure 1) to efficiently run the units at Washington Ranch. The two units at Washington Ranch are currently equipped with a turbocharger, advanced ignition system, Pre-Combustion Chambers (PCC) System, High Pressure Fuel Injection, and an Automatic Balancing Platform. Based on manufacturer guidance, the addition of these clean burn technologies allows the engines to range from 2.75 to 0.5 g/hp-hr, which allows for a 27% to 82% reduction in NO_X emissions; thus, no further assessment of these control practices is included in this report.

Figure 3. Hoerbiger's Layered Approach Strategy for Clean Burn Technologies



2.1.2.3. Good Combustion Practices and Fuel Selection

NO_X emissions are caused by oxidation of nitrogen gas in the combustion air during fuel combustion. This occurs due to high combustion temperatures and insufficiently mixed air and fuel in the cylinder where pockets of excess oxygen occur. By following concepts from engineering knowledge, experience, and manufacturer's recommendations, good combustion practices for operation of the units can be developed and maintained by training maintenance personnel on equipment maintenance, routinely scheduling inspections, conducting overhauls as appropriate for equipment involved, and using pipeline quality natural gas. By maintaining good combustion practices, the unit will operate as intended with the lowest NO_X emissions.

[7] Ibid
[8] Ibid

Utilizing good combustion practices and fuel selection was identified in this review of the RBLC for the control of NO_X emissions from large natural gas-fired lean-burn stationary internal combustion engines; therefore, it has been determined that this method of NO_X control is feasible for the 2SLB engines at Washington Ranch. EPNG has developed Reciprocating Mechanical Inspection and Maintenance Best Practices procedures, which are based on manufacturer recommendation, and EPNG has systems in place to ensure that the engines are operated in accordance with this at Washington Ranch. No further assessment of these control practices is included in this report.

3. SUMMARY & CONCLUSIONS

Based on a comprehensive review of the RBLC, available literature, and vendor input of available control technologies for the natural gas fired engines located at Washington Ranch, EPNG has determined that clean burn technology and good combustion practices are the only technically feasible control options for the two units. As EPNG already deploys these control technologies, there are no further factors to evaluate.

4. SUPPORTING DOCUMENTATION

Appendix A – RBLC Tables

Appendix B – EPNG Best Practices Procedures

APPENDIX A – RBLC TABLES

RBLC Analysis for Natural Gas-Fired Lean-Burn Stationary Internal Combustion Engines – NO_x

	Control Technology	Selective Catalytic Reduction (SCR) [a,b]	Non-Selective Catalytic Reduction (NSCR) [b]	Clean Burn Technology	Good Combustion Practices and Fuel Selection [c]
IDENTIFY AIR POLLUTION CONTROL TECHNOLOGIES	Control Technology Description	A nitrogen-based reagent (e.g., ammonia, urea) is injected into the exhaust stream downstream of the combustion unit. The reagent reacts selectively with NO_x to produce molecular N_2 and water in a reactor vessel containing a metallic or ceramic catalyst.	This technique uses residual hydrocarbons and CO in rich-burn engine exhaust as a reducing agent for NO_x. In an NSCR, hydrocarbons and CO are oxidized by O_2 and NO_x. The excess hydrocarbons, CO, and NO_x pass over a catalyst (usually a noble metal such as platinum, rhodium, or palladium) that oxidizes the excess hydrocarbons and CO to H_2O and CO_2, while reducing NO_x to N_2.[b]	Natural gas fueled engines that operate with a fuel-lean air/fuel ratio are capable of low NO_x emissions.	NO_x emissions are caused by oxidation of nitrogen gas in the combustion air during fuel combustion. This occurs due to high combustion temperatures and insufficiently mixed air and fuel in the cylinder where pockets of excess oxygen occur. By following EPA's "Good Combustion Practices" guidance document, good combustion practices can be maintained by training maintenance personnel on equipment maintenance, routinely scheduling inspections, conducting overhauls as appropriate for equipment involved, and using pipeline quality natural gas. By maintaining good combustion practices the unit will operate as intended with the optimal NO_x emissions.
	Other Considerations	Typically, a small amount of ammonia is not consumed in the reactions and is emitted in the exhaust stream. These ammonia emissions are referred to as "ammonia slip." Unreacted reagent may form ammonium sulfates which may plug or corrode downstream equipment. Particulate-laden streams may blind the catalyst and may necessitate the application of a soot blower.	N/A	N/A	N/A
ELIMINATE TECHNICALLY INFEASIBLE OPTIONS	RBLC Database Information	Not included in RBLC for the control of NO_x emissions from large natural gas-fired lean-burn stationary internal combustion engines.	Not included in RBLC for the control of NO_x emissions from large natural gas-fired lean-burn stationary internal combustion engines.	Included in RBLC for the control of NO_x emissions from large natural gas-fired lean-burn stationary internal combustion engines.	Included in RBLC for the control of NO_x emissions from large natural gas-fired lean-burn stationary internal combustion engines.
	Feasibility Discussion	Technically infeasible. For engines which typically operate at variable loads, such as engines on gas transmission pipelines, an SCR system may not function effectively, causing either periods of ammonia slip or insufficient ammonia to gain the reductions needed.	Technically infeasible. The NSCR technique is limited to engines with normal exhaust oxygen levels of 4 percent or less. This includes 4-stroke rich-burn naturally aspirated engines and some 4-stroke rich-burn turbocharged engines. Lean-burn engines could not be retrofitted with NSCR control because of the reduced exhaust temperatures.	Technically feasible.	Technically feasible.
RANK REMAINING CONTROL TECHNOLOGIES	Overall Control Efficiency			27% - 82%	Base Case

a. U.S. EPA, Office of Air Quality Planning and Standards, "Air Pollution Control Technology Fact Sheet (Selective Catalytic Reduction (SCR))," EPA-452/F-03-032.
b. U.S. EPA, AP-42, Section 3.2, "Natural Gas-Fired Reciprocating Engines"
c. EPA Guidance document "Good Combustion Practices" available at: http://www.epa.gov/ttn/atw/iccr/dirss/gcp.pdf.

Raw RBLC Review

RBLC ID	Facility Name	EPA Region	Permit Number	Process Name	Primary Fuel	Throughput	Throughput Unit	Process Notes	Polluntant	Standard Emission Limit	Standard Emission Limit Unit	Cost Effectiveness	Incremental Cost Effectiveness	Cost Verified	Pollutant Compliance Notes
NE-0015	KN ENERGY. INC	7	56628R01	2-CYCLE LEAN BURN ENGINE, UNIT 2505E	NATURAL GAS	1000	HP	ALL CONTROLLED BY 2ND GENERATION CLEAN BURN CONTROLS.	Nitrogen Oxides (NOx)	2	G/BHP-H	0	0	N	standard units estimated using process information.
NE-0015	KN ENERGY. INC	7	56628R01	IC ENGINE, 2503E, COOPER GMVA-10	NATURAL GAS	1265	HP		Nitrogen Oxides (NOx)	12	G/BHP-H	0	0	N	standardized units estimated from process information
NE-0015	KN ENERGY. INC	7	56628R01	IC ENGINE, 2504E, COOPER GMVA-6	NATURAL GAS	750	HP		Nitrogen Oxides (NOx)	12	G/BHP-H	0	0	N	standardized units estimated from process information
NE-0015	KN ENERGY. INC	7	56628R01	IC ENGINE, 2511E, COOPER GMVA-6	NATURAL GAS	750	HP		Nitrogen Oxides (NOx)	15	G/BHP-H	0	0	N	standardized units estimated from process information

APPENDIX B – EPNG BEST PRACTICES PROCEDURES

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1. Scope

1.1. General

Historically, some "Best Practices" documents were developed to cover specific regions, pipelines, or other limited-scope situations. While such documents may not agree with all provisions of Company Operating and Maintenance (O&M) Procedures, they contain vital information and considerations that may prove useful to many users.

Best Practices documents are intended to *complement* Company O&M Procedures. As such, this procedure provides *recommendations* and *guidance* to supplement the Company and Code Requirements defined within O&M Procedures, Engineering Standards, and other Company Compliance Documents.

In all applications, Company O&M Procedures and Engineering Standards shall prevail as Company Requirements.

1.2. Reciprocating Mechanical Inspection/Maintenance - Low Speed

A Mechanical Inspection aids in evaluating an engine's condition, promoting high reliability and reduced maintenance costs.

2. Recommendations

A) A periodic Mechanical Inspection should be completed on each reciprocating engine and compressor. The Mechanical Inspection consists of a visual crankcase inspection, web deflection, bearing clearance checks, and distance piece/doghouse inspections.

B) The inspection interval for each inspection item is listed in Table A (below).

C) The inspection interval is to be developed by Operations, in consultation with the Field Engineer and the Mechanical Project Support Teams.

D) The inspection interval will consider engine type, utilization, condition, etc for each particular engine.

E) Also listed in Table A (below) is the maximum inspection interval in hours or months, whichever occurs first. Note that inspections may be performed more frequently than the values shown in Table A.

For additional technical reference on Bearing Inspection Procedures, Failure Modes, and checking Bearing Clearances, refer to **Attachment 1 - Technical References**, at the end of this document.

Inspection Items	Inspection Interval	Maximum Hours	Maximum Months
Crankcase Inspection	TBD	16,000	48
Crankshaft Deflection	TBD	16000	48
Bearing Clearances	TBD	16000	48
Bearing Inspection	TBD	As required	As required
Distance Piece/Doghouse	TBD	16000	48

Table A – Inspection Intervals

3. Procedure

All elements of the Mechanical Inspection should be performed. For additional technical reference on Bearing Inspection Procedures, Failure Modes, and checking Bearing Clearances, refer to Attachment 1 - Technical References, at the end of this document.

A) Crankcase Visual Inspection

1) Anytime a crankcase door is removed from an engine, that part of the crankcase should be inspected. In addition, the crankcase of each engine should be drained periodically and carefully inspected.

2) Thoroughly inspect the inside of the crankcase for any foreign matter such as babbitt, bronze dust, or iron filings which are the indicators of bearing or gear failures, piston and cylinder wear, etc.

3) When each door is removed, its crankcase side should be inspected for foreign material thrown there by the centrifugal force of the connecting rod.

4) The walls and bottom of the crankcase should always be carefully checked for metal particles.

5) Each main bearing cap and connecting rod cap should be checked for discoloration caused by over-heated bearings. The entire crankcase should be observed for any blue discoloration, and if any is found, a thorough investigation and dimensional check should be made.

6) All lubricating oil lines and fittings, such as those from the lube oil header to each main bearing, should be checked for integrity.

7) On units with pre-lube pumps, run the pump and visually check the oil from each side of the main bearings to determine if there is an abnormal oil flow.

8) Bolts, nuts, and studs require a complete inspection for tightness. Where it is not possible to use a wrench on a nut or bolt to check for tightness because cotter pins and wires are used for locking devices, a small hammer can be used to tap each bolt.

9) Review recent oil analysis reports and check the general condition of the oil by looking for lacquer formations on machined surfaces or deposits of sludge.

10) Each piston should be moved to top dead center and as much of the liner as possible checked for scuff or score marks. The piston should then be moved to bottom center and the piston skirt inspected for score marks and loss of piston plating.

B) Bearing Clearances

1) Bearing clearances are to be checked during the Mechanical Inspection of the engine, recorded on the Mechanical Inspection form and will become part of the permanent records of the engine.

C) Crankshaft Deflections

2) At the recommended inspection interval, web deflection readings are to be taken on each throw of the crankshaft.

3) Deflection readings are to be recorded on the Mechanical Inspection form and will become part of the permanent records of the engine.

D) Visual Inspection of Bearings

1) Bearings will be pulled and visually inspected when indications of bearing wear are noted (excessive bearing clearances).

E) Distance Piece/Doghouse Inspections

1) Collect the required measurements per the Mechanical Inspection Form

F) Mainframe Movement Checks

1) Prior to shutting down the unit for Mechanical Inspection, ensure that a Engineer Technician has performed a mainframe movement check. (Refer to **Best Practices COMP103-1 - Engine Maintenance Analysis**)

4. Documentation

Some Pipelines and related Field Staff use one or more of the following:

- MAXIMO as an activities scheduling utility
- COMET for Compressor Data tracking

Until such time as these systems (MAXIMO, COMET, etc.) are superseded, the following information is provided for user reference:

MAXIMO PM

- Mechanical Inspection - Varies but NTE 48 months or 16,000 hours operated.

Mechanical Inspection Forms Workbook (COMP-2007)

- Retention - Life of Equipment
- Retention Location - Site

5. References

- **Best Practices COMP103-1 - Engine Maintenance Analysis**
- **COMP-2007 Mechanical Inspection Forms Workbook.xlsx**
- **Environmental, Health, and Safety Policy Manual**
- **O&M Procedures Manual**

Attachment 1 - Technical References

Bearing Inspection Procedure and Explanation

One cause of bearing failure is improper clearance between the bearings and the journal. Bearings are designed to run on a film of oil and will not normally come in contact with the journal when in operation. The flow of oil through the bearing dissipates the heat generated in the bearing, and too little or too much clearance between the bearing and journal upsets this balance of oil flow, heat dissipation, and temperature rise.

In the case of too little clearance, the oil film can 'thin out', allowing contact between the journal and bearing. Too much clearance allows the oil to escape from the bearing, allowing excessive impact to be transmitted into the bearing. This causes excessive wear or allows other bearings to become over-heated, because they are starved of oil.

Bearing failure can result in:

- Scored crankshaft
- Bent or destroyed shaft from excessive heat
- Heat checks in shaft
- Out-of-round journal
- Warped or distorted bearing support and bearing cap
- Destroyed connecting rod

Three acceptable methods for checking bearing clearances:

The feeler-gauge method consists of inserting a feeler gauge into the space between the shaft and the bearings. Vary the thickness until a thickness equal to the clearance is achieved. When the engine is shut down, the crankshaft should be resting on the bearing supports. It is important to determine this. A .0015-inch feeler gauge can be used to make this determination.

The Plastigage method requires that the bearing cap and one-half shell be removed. The Plastigage is then placed on the shaft. The bearing shell and cap are replaced and tightened. The Plastigage is squeezed into conformation with the clearance. When it is removed, its thickness may be measured, indicating the clearance. Soft fuse wire may be used instead of the Plastigage. Make sure that it is softer than the bearing material.

The Jack method consists of attaching a dial indicator to the frame of the engine with the button placed against the shaft. Place a jack under the shaft and jack up on the shaft; the clearance is measured on the dial indicator. Use skids or a metal plate to ensure that the load from the jack is distributed across the oil pan if necessary. On main bearings, it is necessary to make sure that the shaft is resting on the lower bearing shell. The jack should be placed on top of the shaft first, and pressure exerted on the shaft to determine if there is any downward movement that would be an indication the bearing is being bridged by the shaft. If a bridged bearing is detected, notify a Field Engineer immediately.

Any or all of these methods may be used. Each requires skill and practice to get repeatable readings. The manufacturer's instruction book should be checked for recommendations.

Any program of bearing inspection and maintenance should be designed to minimize the catastrophic results of bearing failure. Evidence that indicates possible failure may be any of the following:

- Excessive clearance
- Clearance closed up
- Loss of crush
- Bearing material particles in the crankcase or oil filter
- Bearing protective device shuts the engine down
- Discoloration of the bearing or bearing cap

Some general rules for bearing inspection:

Connecting Rod Bearings

On most engines, the connecting rod bearings must be removed to pull pistons. They should receive a close visual inspection at this time

They should be removed and inspected when visual evidence indicates possible failure.

If experience indicates that specific bearings require inspection after a certain length of time, they should be pulled and inspected.

Main Bearings

Main bearings should be removed and inspected when any evidence indicates possible failure.