

PROPOSAL

Presented To:

Derwick Associates

for

**3 x LM6000 Gas Turbine
Equipment**

Prepared By



Proposal No. 709-2485

June 15, 2009

**This document is privileged and contains confidential information intended for use only by
Derwick Associates.**

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1.0 INTRODUCTION

ProEnergy Services ("ProEnergy") is pleased to provide this proposal to Derwick Associates ("Derwick") for three (3) GE LM6000 PC Gas Turbines. (1) One Refurbished and (2) Two Never Used.

The GE LM6000 PC is a highly reliable, mid-sized packaged power plant developed for either 50 or 60 hertz applications with design emphasis placed on energy efficiency, availability, performance and maintainability.

2.0 SCOPE OF SUPPLY

2.1 Basic Scope Description

2.1.1 *Gas Turbine*

General Electric gas turbine model LM6000 is a two-shaft/two-spool engine consisting of a five-stage low pressure compressor, a fourteen-stage high pressure compressor, a two-stage high pressure turbine, and a five-stage low pressure turbine. The engine is equipped with a stainless steel mesh screen in the inlet air stream for "last chance" protection against foreign object damage. The engine is shock mounted and shipped in position, with the exception of the coupling spacer, which is removed and shipped in a separate container.

2.1.2 *Generator*

Air cooled, 2-pole generator operating at 13.8 kV, 60 Hz. Generator is capable of handling Purchaser power requirement throughout a wide ambient temperature range. A cooling water loop and its associated fans and pumps are not required. The generator includes a brushless excitation system with permanent magnet generator. Neutral and line side cubicles are included.

2.1.3 *Unit Enclosure*

The basic equipment package is supplied with weatherproof acoustic enclosures with sound attenuation to an average of 85 dB(A) at 3ft 3 in (1 m) from the face of the equipment at 4 ft 11 in (1.5 m) above ground. The enclosures are completely assembled and mounted over the equipment prior to testing and shipment. The turbine and generator compartment is fully ventilated with belt driven fans. Explosion-proof lighting is provided in both compartments.

2.1.4 Gas Turbine / Generator Baseplate

The basic equipment package is supplied with the support structures for the gas turbine generator set consisting of a two-piece skid assembly, which is sectioned between the gas turbine and the generator. The full depth, bolted section is designed to provide the full structural properties of the wide flange I-beams. Full depth crossmembers are utilized to provide for a rigid design that is suitable for installation in earthquake areas (U.S. Seismic Zone 4) as well as providing a convenient structure for transportation. The baseplate support system is enhanced by the installation of a heavy-duty, welded superstructure, which utilize structural tubing for wall columns and roof beams.

2.1.5 Air Inlet System

The basic equipment package is supplied with a modular, multi-stage filtration system consisting of inlet screens, a prefilter and a final barrier filter. All air for ventilation systems is filtered to the same level as turbine combustion air. An evaporative cooling system is included in the basic equipment package scope. Filtered air is silenced before entering the turbine plenum. This design results in a compact arrangement and eliminates the need for Purchaser supplied inlet ducting when the standard design is utilized. Internal lighting of the filter house is provided to facilitate inspection and service.

Package is also supplied with platforms and ladders to service the inlet filter. These items are packaged separately for shipment. Ladders, platforms and stairways to service other portions of the gas turbine generator enclosure are not included. Special or customized filter arrangements can be supplied, and they are quoted on an individual basis.

2.1.6 Turbine Exhaust

The basic equipment package is supplied with a circular, axial exhaust outlet with connection flange to facilitate in-line mounting of an HRSG or simple cycle exhaust stack.

2.1.7 Fuel System

The basic equipment package is supplied with a natural gas fuel system using an electronically controlled fuel-metering valve. All necessary shutoff valves, piping and instruments between the auxiliary skid connection and the turbine are included. For full-load operation, the gaseous fuel must be supplied to the baseplate at 675 psig \pm 20 (4,658 \pm 138 kPag). All necessary shutoff valves, piping

and instruments between the baseplate connection and the turbine are included. Gas fuel must meet General Electric specification MID-TD-0000-1.

2.1.8 Lube Oil Systems

The basic equipment package is supplied with two separate lube oil systems: one for the gas turbine (synthetic oil) and one for the generator (mineral oil). The oil reservoirs and piping are all stainless steel, and the lube oil system valves have stainless steel trim. Each lube oil system has duplex filters, duplex shell and tube coolers, and thermostatically-controlled electric heaters. The coolers, oil reservoir, and filters for each system are mounted on an auxiliary equipment module located next to the gas turbine baseplate. The auxiliary equipment module provides simplified piping connections and reduces Purchaser's installation time and costs. Purchaser must supply cooling water to the shell and tube coolers. Turbine lube oil must meet MID-TD-0000-6.

2.1.9 Electro-Hydraulic Start System

The basic equipment package is supplied with an electric motor driven hydraulic pump assembly, filters, cooler and controls, mounted on the auxiliary equipment module. A hydraulic motor is also mounted on the gas turbine accessory gearbox. Hydraulic hoses are furnished to connect the auxiliary equipment module and the main baseplate.

2.1.10 Fire Protection System

The basic equipment package is supplied with a factory installed fire protection system complete with optical flame detection, hydrocarbon sensing and thermal detectors, piping and nozzles in both generator and engine compartments. The fire protection system includes cylinders containing CO₂ mounted on a separate skid. A 24 V DC battery and charger to power the fire protection system is also included. All alarms and shutdowns are annunciated at the turbine control panel (TCP). An alarm sounds at the turbine if the gas detectors detect high gas levels, or if the system is preparing to release the CO₂. When the system is activated, the package shuts down, and the primary CO₂ cylinders are discharged into the turbine and generator compartments via multiple nozzles, and the ventilation dampers automatically close. After a time delay and if required, the reserve supply of CO₂ is discharged.

2.1.11 Digital Control System

The basic equipment package is supplied with a free-standing control panel suitable for mounting in an indoor, non-hazardous area. The control system

features an integrated Woodward MicroNet Plus turbine control system, vibration monitor, digital meter, digital generator protective relay module and an HMI (human machine interface) display of key discrete and analog data. The operator selects HMI displays with convenient touch screen control. Alarm and shutdown events are displayed on the HMI automatically. An Ethernet TCP/IP EGD or RS485 Modbus Port is provided to transmit unit conditions (status, pressures, temperature, etc.) to the Purchaser's distributed control system. Power for the control panel is provided by a dedicated 24V DC battery system with dual 100% capacity chargers, which are shipped separately for installation by others.

2.1.12 Generator Protective Relays

The basic equipment package is supplied with a microprocessor-based generator protective relay module, mounted in the TCP. The protective relay system includes functions necessary for protection of the generator.

2.1.13 Soak Wash System

The basic equipment package is supplied with a turbine cleaning system, which allows Purchasers to clean the compressor section of the turbine during full power operation. The same system reservoir and piping are utilized for off-line soak washing. Auxiliary skid connections are provided for Purchaser supplied purified water at a maximum of 50 psig (345 kPag) and air at 100 – 120 psig (689 – 827 kPag). Purchaser is required to provide purified water meeting MID-TD-0000-4, detergent meeting MID-TD-0000-5 (See Attachment 16), and air filtered to ISA S7.3 standards.

2.1.14 Component Testing and Package Full Load Test

Every new gas turbine is performance tested under load in a GE Test Cell, using procedures developed for flight turbine reliability. The generator is tested to ANSI C50.14 or IEC 34.3 standards at its factory of manufacture.

All gas turbine generator sets receive a rigorous 400-point static test including:

- Switch State (N.O. or N.C., actuation, wiring, and setpoint)
- Temperature element output, and wiring
- Transmitter range, output, and wiring
- Solenoid operation
- Control valve torque motor, excitation, and return signal
- Fire system continuity, and device actuation
- System flushing verification
- Tubing integrity

2.1.15 Drawings, Data and Manuals

The basic equipment package is supplied with a Purchaser drawing package that includes general arrangement drawings, flow and instrument diagrams, electrical one-line drawings and interconnection plan drawings. Additional electrical schematic diagrams and logic drawings are provided for record.

Maintenance manuals are provided and are printed in English. The manuals cover operating concepts for power generating equipment, guides to troubleshooting, basic information on components, and equipment within the turbine generator set.

2.1.16 Training (Optional)

The base scope of supply includes hands-on training for up to 10 operators and supervisors, where students are assumed to have at least a journeyman's knowledge of electrical generating plant operation and to be proficient in reading piping flow and instrument drawings, mechanical drawings, and have a working knowledge of electrical generators, and gas turbines. The course is designed around an eight-hour day, five consecutive day schedule with an hour lunch break and fifteen-minute breaks every one and one half hours. Experienced instructors, using specially developed training materials, provide a firm groundwork of basic theory, plus advanced concepts with classroom and hands-on training. Training includes Gas Turbine Familiarization plus System Design & Operations and Maintenance.

2.1.17 Improvements and Changes

It is understood that the Seller has the right to make changes in product design and add improvements to products or services at any time without incurring any obligations to install the same on or in connection with the Equipment or Services provided hereunder.

2.2 Optional Equipment and Services Checklist and Descriptions

(I) included in base offer at prices indicated in Article 3

2.2.1 Factory Options

I	Option A	SPRINT® Power Augmentation
I	Option B	NO _x Control - Water Injection System

I	Option C	Inlet Air Cooling – Evaporative Cooling
I	Option D	Lube Oil Cooler - Fin/Fan
I	Option E	Left-handed Piping Connections
I	Option F	Left-handed Lineside Cubicle
I	Option G	Lineside Cubicle Entry Configuration Options
I	Option H	DC Backup Lighting
I	N/A	Auxiliary Skid Enclosure

2.2.2 Factory Options Descriptions

Option A SPRINT® Power Augmentation

SPRINT® boosts engine performance using a demineralized water spray intercooling design that significantly increases the mass flow by cooling the air during the compression process. The system is based on an atomized water spray injected through spray nozzles placed at two locations, one between the high pressure and low-pressure compressors, and the second at inlet bellmouth. Water is atomized using high-pressure air taken off of the eighth stage bleed. The water flow rate is metered, using the appropriate engine control schedules and at the inlet bellmouth. Bellmouth and inter-stage portions on SPRINT® alternate operation based on turbine inlet temperature. Purchaser supplies 30 gpm (114 lpm) of demineralized water to the connection on the unit. Water must meet GE specification MID-TD-0000-3 (See Attachment 16)

Option B NOx Control - Water Injection System

A water injection system for control of NOx emissions shall be provided. The demineralized water injection system consists of inlet strainer, pump, valves, piping and controls for use with a gaseous fuel, liquid fuel or dual fuel system. Water injection shall reduce NOx emissions to 25 ppm (51 mg/N m³) (Ref. 15% O₂) on gaseous fuel. For gaseous fuel applications, Purchaser must provide a demineralized water supply of up to 55 gpm (208 lpm) and at 20-40 psig (138-276 kPag). Water must meet GE specification MID-TD-0000-3 (See Attachment 16). The minimum Purchaser supplied pressure and temperature is determined by the water injection rate required and the type of fuel nozzle utilized.

Option C Inlet Air Cooling – Evaporative Cooling

Evaporative cooling shall be utilized in the inlet air cooling system to lower the dry bulb temperature of the inlet ambient air, thus increasing power output of the LM6000 equipment.

This system is designed for recirculation of evaporative cooling water from a sump in the bottom of the inlet air filter. A recirculation pump, a conductivity probe, blowdown and make-up valves, piping and wiring shall be provided. Purchaser must supply filtered, potable water to a flanged connection on the filter house and must dispose of wastewater from the blowdown valve. Flow rates will vary based on blow down. Water must meet GE specification GEK 107158.

Option D Lube Oil Cooler - Fin/Fan

This replaces the standard simplex shell and tube coolers for the lube oil systems. A simplex core fin-fan cooler complete with changeover valve mounted on a separate base plate with dual fans is installed on a separate foundation.

Option E Left-handed Piping Connections

The Seller shall furnish one (1) right hand (standard) configuration and one (1) left hand configuration LM6000 Unit. The left hand Unit shall be built with the Purchaser's piping connections on the left side, as viewed from the exciter. The turbine removal door is placed on the side opposite the piping connections.

Option F Left-handed Lineside Cubicle

For the left hand Unit, the generator line-side cubicle shall be located on the left-hand side and the neutral cubicle shall be located on the right-hand side. However, the termination box for generator instrument and control wiring box, (MGTB) must remain on the right-hand side, and the turbine main terminal box (MTTB) must remain on the left.

Option G Lineside Cubicle Entry Configuration Options

Top Bus Duct Entry

The standard lineside cubicle is configured for bottom cable entry. With this option, the lineside cubicle is configured for top bus duct entry.

Top Cable Entry

The standard lineside cubicle is configured for bottom cable entry. With this option, the lineside cubicle is configured for top cable entry.

NOTE for Option E, Option F, Option G:

Purchaser has elected to choose quantity one (1) Unit to be “Left-hand” configuration and one (1) Unit to be “Right-hand” configuration as described above. Configurations and delivery sequence to be finalized at the Order Definition Meeting. If the configuration or delivery sequence is changed after the Order Definition Meeting, Seller reserves the right to adjust Contract price and schedule accordingly.

Option H DC Backup Lighting

Seller shall furnish DC backup lighting in the turbine and generator enclosures as an option. The DC lights turn on anytime the normal AC power fails.

Option I Combustion Air Cooling – Chiller Coil

Lowering the combustion air inlet temperature can increase the power output of the LM6000 generator set. When specified, GE Energy can furnish high performance inlet air chilling coils as an integral part of the air inlet system. Purchaser provides adequate quantities of chilled water and interconnecting piping to GE Energy furnished chilling coils at the filter house. The same coils can be used for anti-icing.

(Option) Transportation Services

Seller arranges for shipment on behalf of the Buyer. The Buyer pays the Seller for all fees and expenses including, but not limited to, those covering preparation of consular documents, freight, loading fees at storage, storage, transit insurance and warehouse-to-warehouse insurance.

3.0 LIMITS OF SELLER SCOPE & EXCLUSIONS

3.1 Limits of Seller Scope

Listed below are the limits/exclusions to the Seller standard Scope of Supply. All piping, wiring, cables, ducts, etc. connecting to these points is furnished by Purchaser (others) unless modified by specification agreement.

Equipment System	Limits of Seller Scope
All piping, including Fuel Gas, Fuel Oil, Steam, Cooling Water, Heating Water, Demineralized Water, Lube Oil, Compressed Air, Instrument Air, Hydraulic Start Oil	Flanged or threaded connection on Seller baseplate.
Inlet Air-to-Filter	Atmosphere (non-standard duct by others)
Turbine Package Ventilation/Cooling Air	Atmosphere (non-standard duct by others)
Turbine Exhaust	Exhaust flange on main baseplate
Instruments on Seller's Baseplate	Terminal box on baseplate
Instrument wiring in Turbine Control Panel	Wiring Terminal block in Turbine Control Panel
High Voltage Connections	Bus bar in Seller Lineside cubicle
Generator Ground Connections	Seller Neutral cubicle
Electric Motors	Terminal box on individual motor
Ladders and Platforms for Air Filter	Ladders and Platforms for Inlet Air Filter maintenance only
24 V DC Batteries and Chargers for Control System and Fire and Gas Systems	Battery terminals to baseplate (if supplied loose)

3.2 Exclusions

- Civil engineering design of any kind
- Building and civil works
- Site facilities
- Drains and/or vent piping from the gas turbine package to a remote point
- Fuel storage, treatment and forwarding system
- Site grounding
- Lightning protection
- Power system studies

- Sensing and metering voltage transformers
- Machine power transformers, and associated protection
- Grid failure detection equipment
- Off-loading, transportation and storage
- Off-skid cabling, and design of off-skid cable routing
- Balance of plant and energy optimization controls
- Anchor bolts, embedments, and grouting (quoted separately)
- Distributed plant control
- Purchaser's remote control
- Field supervision (quoted separately)
- High voltage transformer(s), cables, and associated equipment
- Interconnecting piping, conduit, and wiring between equipment modules
- Plant utilities, including compressed air supply and off-skid piping
- Battery containment
- Lube oil measurement other than that defined in the scope of supply
- Additional lube oil breather ducting other than that defined in the scope of supply
- Fuel transfer pump
- Off-skid fuel block and vent valves
- Fuel supply pipework beyond the scope of supply
- Generator controls other than that defined in the scope of supply
- Load sharing control
- Balance of plant controls
- Field Performance Testing
- Site Labor
- Ladders, Stairs, and Platforms for equipment beyond the gas turbine

4.0 **SCHEDULED DATE(S)**

Reference	Equipment Description	Scheduled Date
Unit 1&2	LM6000PC Generating Set (Never Used)	90 Days From Contract
Unit 3	LM6000PC Generating Set (Refurbished)	120 Days From Contract

5.0 FUEL SPECIFICATIONS

GE Aero Derivative gas turbines have the ability to burn a wide range of gaseous fuels as shown in Table 1. These gases present a broad spectrum of properties due to both active and inert components. This specification is designed to define guidelines that must be followed in order to burn these fuels in an efficient, trouble-free manner, while protecting the gas turbine and supporting hardware.

**Table 1
Fuel Gas Usability**

Fuel Type	LHV Btu/SCF (kJ/NM ³)	Wobbe Number	Major Components	Operational Comments	Applicability	
					SAC	DLE
Pipeline Natural Gas	850-1200 (33383-47128)	45-60	Methane	No Restrictions	Yes	Yes
Medium BTU Natural Gas	400 - 850 (15709-33838)	20-45	Methane, Hydrocarbons (HC), carbon dioxide, Nitrogen	Requires > 700 BTU/scf (27492 kJ/NM ³) for starting. May require modified fuel nozzles. Contact	Yes	No, See Note 8.
Liquefied Petroleum Gas (LPG)	2300- 3200 (90330-125676)	70-75	Propane, Butane	May require specific fuel nozzles. Contact GE	Yes	No
Gasification Gases - Air Blown - Oxygen Blown	150-200 (5891-7855) 200- 400 (7855-15709)	6-8 8-20	Carbon monoxide, Hydrogen, HC, Nitrogen, Water Vapor Carbon monoxide, Hydrogen, HC, Water Vapor	Contact GE Contact GE	Yes	No
Process Gases	300- 1000 (11782-39274)	15-50	Methane, Hydrogen, Carbon monoxide, Carbon dioxide	Requires >700 BTU/scf (27492 kJ/NM ³) for starting. Restricted transient operation.	Yes	See Note 8
Refinery Gases	1000- 1300 (39274-51056)	45-60	Methane, Hydrogen, Carbon monoxide, Ethylene,	No restrictions. Hydrogen content should be reviewed by GE.	Yes	See Note 8

Notes:

1. When considering the use of alternate fuels, provide details of the fuel constituents, fuel temperature, and expected engine usage conditions and operating characteristics to GE for evaluation and recommendations.
2. Values and limits apply at the inlet of the gas fuel control module.

6.0 DESIGN CRITERIA

The following table outlines the criteria conditions at the proposed jobsite for the design of the equipment:

Location	TBD
Elevation	TBD
Design Point Ambient Temperature / Relative Humidity	TBD
Primary Fuel Source	TBD
Secondary Fuel Source	TBD
Seismic Design Criteria (BOP Equipment)	TBD
Maximum Wind Speed (Wind Load), MPH	TBD
Near Field Noise at 3 ft horizontal and 5 ft vertical, dBA NOTE 1	TBD
Far Field Noise, dBA NOTE 1	TBD at 400 ft / TBD at 700 ft

NOTE:

1. Far field noise is based on single-unit only operation. Multiple units operating at the same time will have an impact on both near and far field noise levels.

7.0 **COMMERCIAL TERMS**

7.1 Validity

This proposal is valid until July 15, 2009. Subject to prior Sale.

7.2 Taxes

No sales or use taxes have been included in this quotation. These prices quoted exclude any federal, state or local taxes or fees which may be associated with the export, import or purchase of equipment and/or services.

7.3 Price

Three (3) GE LM6000 Gas Turbine Generator Set including optional equipment specified as included (I) as described in the scope of supply. All pricing is based on ex-works factory delivery unless otherwise stated.

GTG UNIT

Generators set price (Three Units).....US\$50,500,000

7.4 Payment Schedule

This proposal is based upon receipt of the following progress payments and a Contract Agreement by both Parties by the Validity date Seller may request at any time, Purchaser will demonstrate its financial capability to continue to carry out its obligations under this Contract. This demonstration may require that Purchaser furnish adequate payment security.

	Payment Event	% of Equipment Price
1	Within five days of signature of the Contract Agreement by both Parties, paid against Seller's invoice.	20%
2	In equal monthly installments, commencing thirty days following signature of the Contract Agreement until thirty days before the first scheduled Shipment Date, paid against Seller's invoices.	70%
3	Upon notice of Ready to Ship, pro-rata by shipment (See terms below)	10%

Name: ProEnergy Services LLC
Bank: US Bank
Routing # 081000210
Account # 152305958703
Swift Code: USBKUS 44IMT (that is an "i" not a 1)

On the Notice of Readiness to Ship Milestone, payment must be received at least 5 days before shipment, but no later than 15 or 30 days [depending on terms] from notification of Readiness to Ship.

7.5 Warranty

ProEnergy will provide a one (1) year warranty on the entire gas turbine generator package and any other balance of plant equipment provided.

7.6 Terms & Conditions

This proposal shall be valid for thirty (30) days; provided, however, the obligation to treat this proposal as confidential, and that it cannot be shared with any third party without the prior written consent of ProEnergy shall survive.

ProEnergy and Derwick will negotiate in good faith to establish general terms and conditions that are usual and customary of the sale of used equipment.

8.0 SITE SERVICES

ProEnergy would be pleased to also provide a proposal for the installation, startup and commissioning of the facility. This would include providing construction supervision as well as startup engineers for all equipment provided.

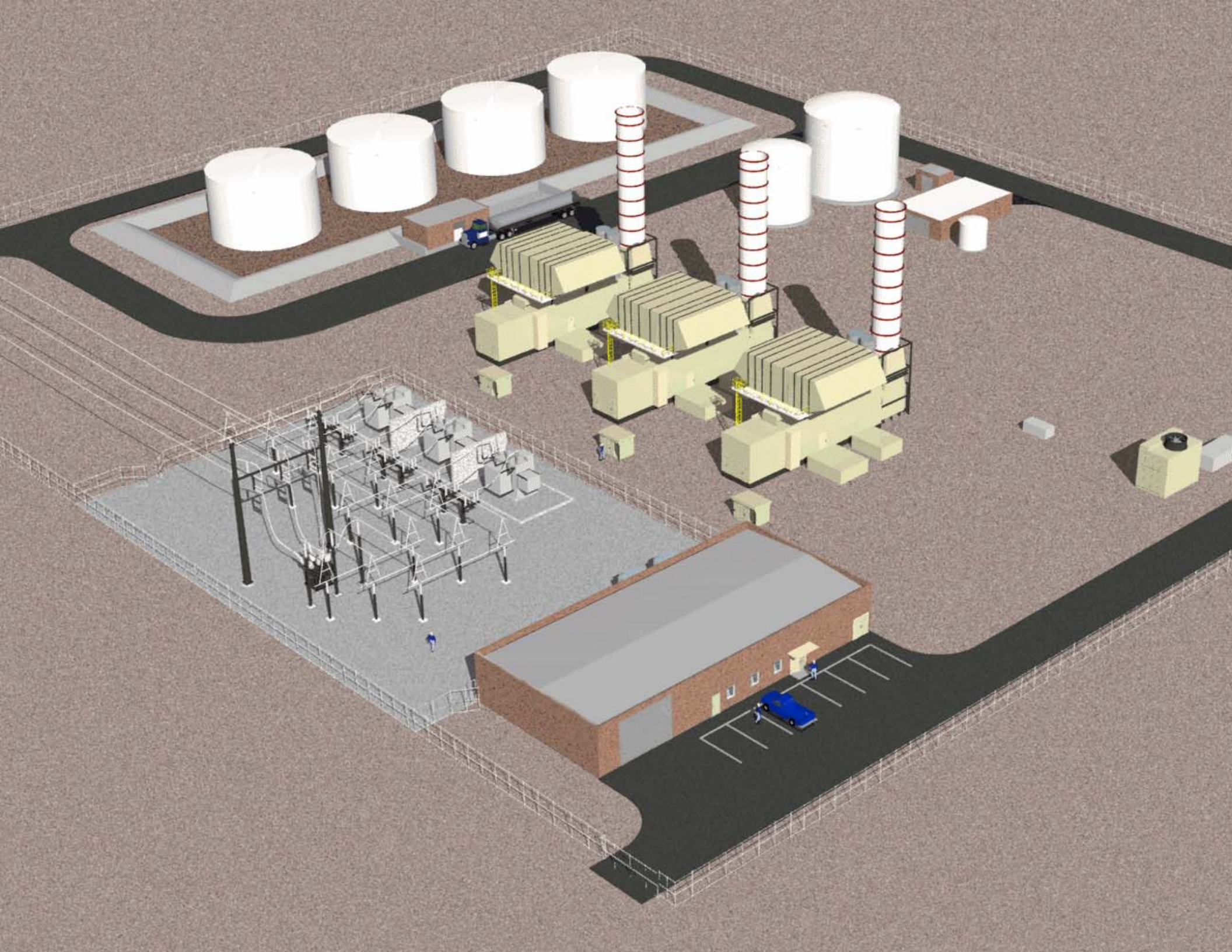
ProEnergy can also provide an experienced service representative to assist the operating personnel during the first two (2) months after the equipment goes online.

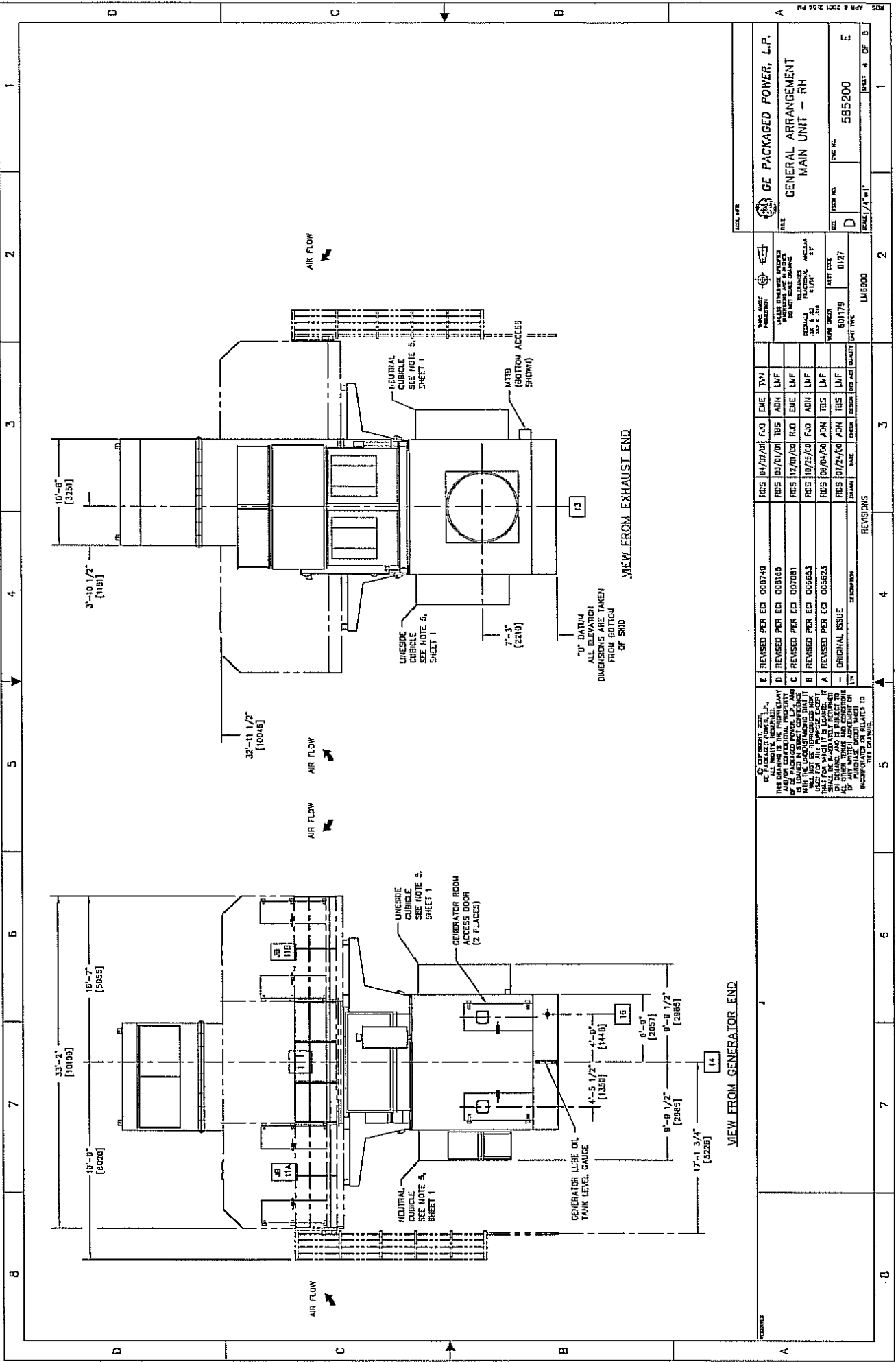
9.0 FOLLOW UP

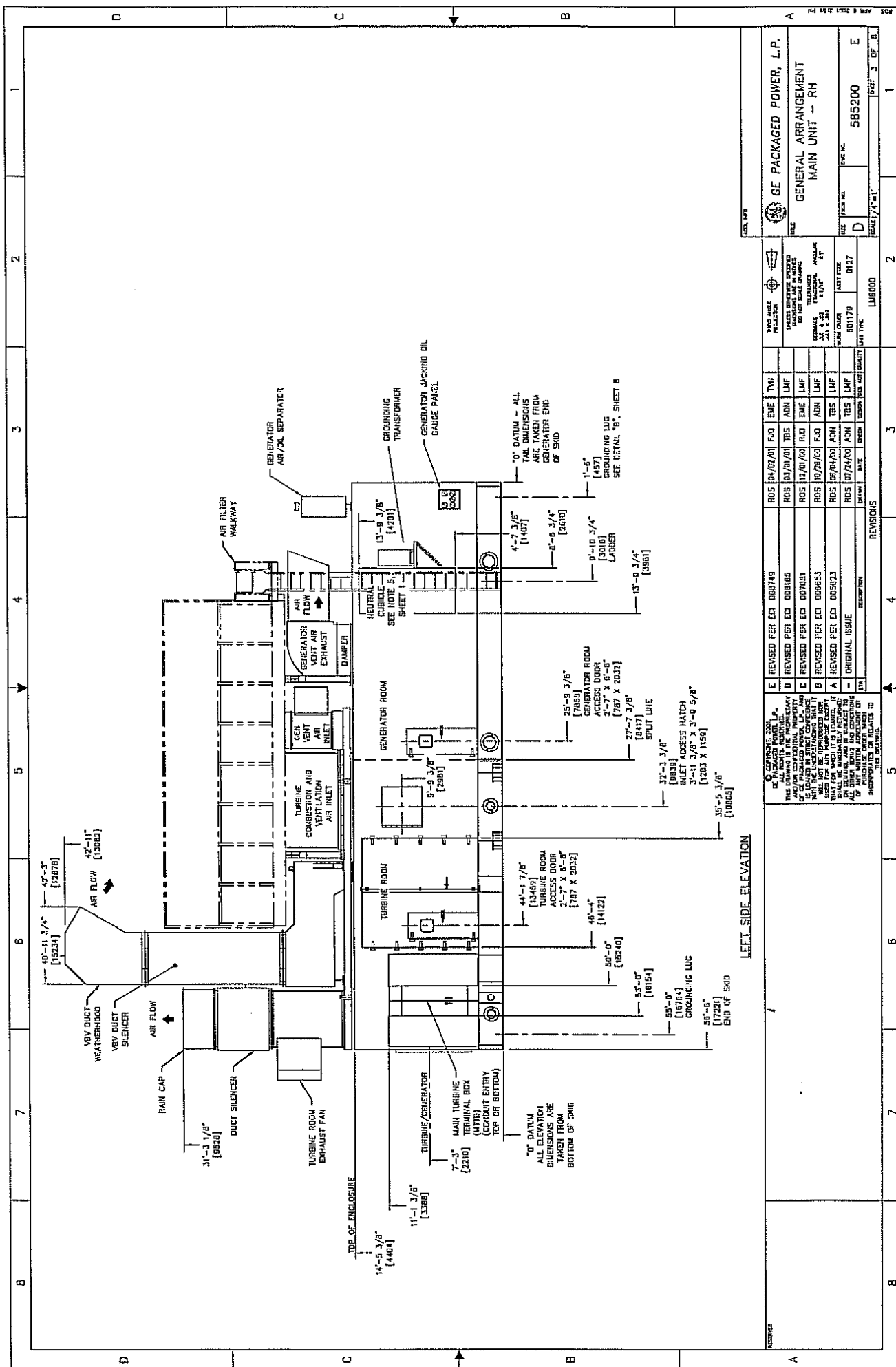
Please contact the following person at ProEnergy for information regarding this proposal:

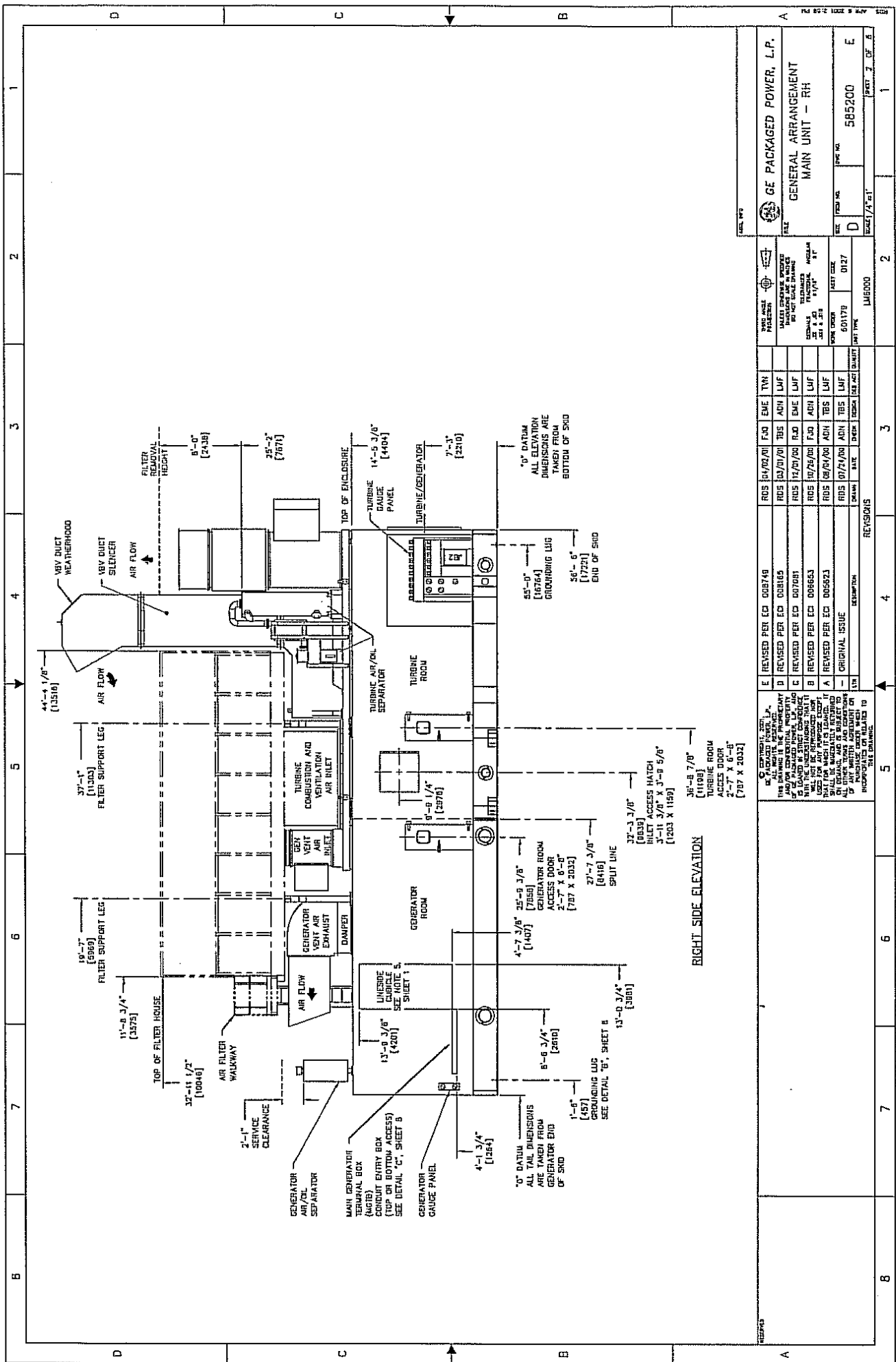
Joaquin Mavares, Director of International Sales
jmavares@proenergyservices.com
Office: 660.829.5100
Cell: 713.992.1790

**ATTACHMENT A
GENERAL ARRANGEMENT**

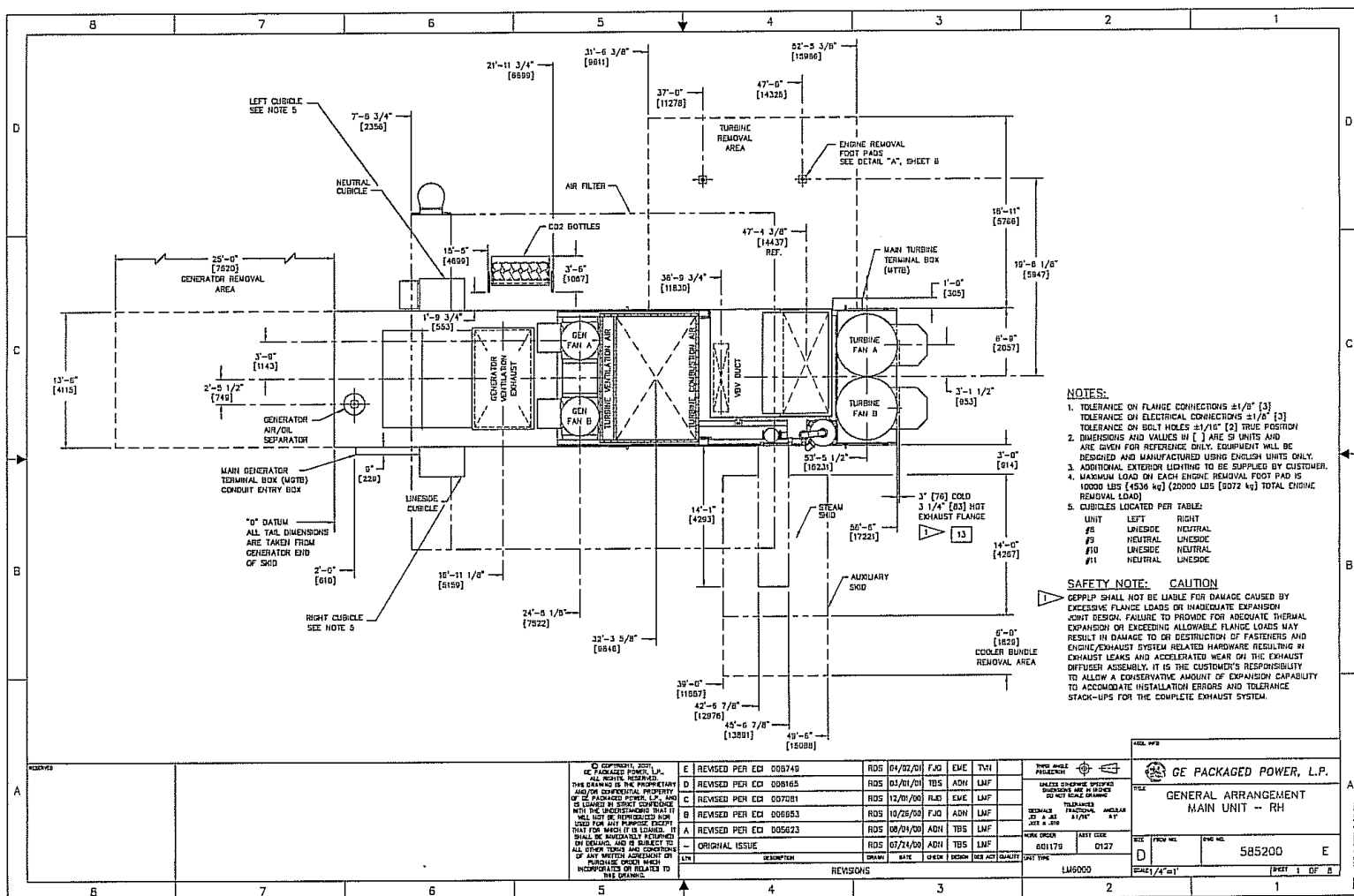











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ATTACHMENT B
FUEL GAS SPECIFICATION

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GE Energy

Process Specification Fuel Gases For Combustion In AeroDerivative Gas Turbines

These instructions do not purport to cover all details or variations in equipment or to provide for every possible contingency to be met in connection with installation, operation or maintenance. Should further information be desired or should particular problems arise which are not covered sufficiently for the purchaser's purposes the matter should be referred to the GE Company.

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1 GENERAL

GE AeroDerivative gas turbines have the ability to burn a wide range of gaseous fuels as shown in Table 1. These gases present a broad spectrum of properties due to both active and inert components. This specification is designed to define guidelines that must be followed in order to burn these fuels in an efficient, trouble-free manner, while protecting the gas turbine and supporting hardware.

Table 2 identifies the acceptable test methods to be used in determining gas fuel properties.

TABLE 1 FUEL GAS USABILITY						
Fuel Type	LHV Btu/SCF (kJ/NM ³)	Wobbe Number	Major Components	Operational Comments	Applicability SAC DLE	
Pipeline Natural Gas	850-1200 (33383-47128)	45-60	Methane	No Restrictions	Yes	Yes
Medium BTU Natural Gas	400 - 850 (15709-33838)	20-45	Methane, Hydrocarbons (HC), carbon dioxide, Nitrogen	Requires > 700 BTU/scf (27492 kJ/NM ³) for starting. May require modified fuel nozzles. Contact GE	Yes	No, See Note 8.
Liquefied Petroleum Gas (LPG)	2300-3200 (90330-125676)	70-75	Propane, Butane	May require specific fuel nozzles. Contact GE	Yes	No
Gasification Gases - Air Blown	150-200 (5891-7855)	6-8	Carbon monoxide, Hydrogen, HC, Nitrogen, Water Vapor	Contact GE	Yes	No
- Oxygen Blown	200- 400 (7855-15709)	8-20	Carbon monoxide, Hydrogen, HC, Water Vapor	Contact GE	Yes	No
Process Gases	300-1000 (11782-39274)	15-50	Methane, Hydrogen, Carbon monoxide, Carbon dioxide	Requires >700 BTU/scf (27492 kJ/NM ³) for starting. Restricted transient operation.	Yes	See Note 8
Refinery Gases	1000-1300 (39274-51056)	45-60	Methane, Hydrogen, Carbon monoxide, Ethylene, Propylene, Butylene	No restrictions. Hydrogen content should be reviewed by GE.	Yes	See Note 8

Notes:

1. When considering the use of alternate fuels, provide details of the fuel constituents, fuel temperature, and expected engine usage conditions and operating characteristics to GE for evaluation and recommendations.
2. Values and limits apply at the inlet of the gas fuel control module.

3. Heating value ranges shown are provided as guidelines. Specific fuel analysis must be furnished to GE for evaluation. The standard configured single annular combustor (SAC) gas turbines require a fuel with a LHV no less than of 6500 BTU/pound. The Dry Low Emissions (DLE) combustion system requires a minimum LHV of 18000 BTU/pound. (Reference Section 3.1)
4. The quantity of sulfur in gas fuels is not limited by this specification. Experience has shown that oxidation/corrosion rates are not significantly affected by fuel sulfur levels up to 1.3% sulfur. Hot corrosion of hot gas path parts is affected by the presence of the specified trace metals. Sulfur levels shall be considered when addressing HRSG Corrosion, selective catalytic reduction (SCR) deposition, exhaust emissions, system material requirements, elemental sulfur deposition and iron sulfide. (Reference Section 4.3)
5. The fuel gas supply shall be 100% free of liquids. Admission of liquids can result in combustion and/or hot gas path component damage. (Reference Section 3.3)
6. Wobbe Number, or Modified Wobbe Number Index, is described in 3.2.
7. Gases with Wobbe Number Index greater than 40 may be applicable for DLE. Contact GE.
8. Process and refinery gases with <5% hydrogen content and low CO and CO₂ content may be acceptable for DLE application. Contact GE.

NM³ is at 0°C, 101.325kPa (sea level)

TABLE 2
TEST METHODS FOR GASEOUS FUELS

PROPERTY	ASTM METHOD
Gas Composition to C6+	D1945 - Standard method for constituents of gases by gas chromatography
Heating Value	D3588 - Procedure for calculating calorific value and specific gravity of gaseous fuels
Specific Gravity	D3588 - Procedure for calculating calorific value and specific gravity of gaseous fuels
Compressibility Factor	D3588 - Procedure for calculating calorific value and specific gravity of gaseous fuels
Dew Point (see note 1)	D1142 - Water vapor content of gaseous fuels by measurement of dew point temperature
Sulfur	D1072 - Test for total sulfur in fuel gases (see note 2) D3246 - Test for total sulfur in fuel gases
Chemical Composition	D2650 - Standard method for chemical composition of gases by mass spectrography

Notes:

1. Hydrocarbon and water dew points shall be determined by direct dew point measurement (Chilled Mirror Device). If dew point cannot be measured, an extended gas analysis, which identifies hydrocarbon components from C1 through C14, shall be performed. This analysis must provide an accuracy of greater

than 10 ppmv. A standard gas analysis to C6+ is normally not acceptable for dew point calculation unless it is known that heavier hydrocarbons are not present, as is most often the case with liquefied natural gases.

2. This test method will *not* detect the presence of condensable sulfur vapor. Specialized filtration equipment is required to measure sulfur at concentrations present in vapor form. Contact GE for more information.

2 FUEL GAS CLASSIFICATION

2.1 Natural and Liquefied Petroleum Gas (LPG)

Natural gases are predominantly methane with much smaller quantities of the slightly heavier hydrocarbons such as ethane, propane and butane. Liquefied petroleum gas is propane and/or butane with traces of heavier hydrocarbons.

2.1.1 Pipeline Natural Gas

Natural gases normally fall within the calorific heating value range of 850 to 1200 Btu/SCF (33383-47128 kJ/NM³) (LHV). Actual calorific heating values are dependent on the percentages of hydrocarbons and inert gases contained in the gas.

2.1.2 Medium BTU Natural Gas

Natural gases are found in and extracted from underground reservoirs. These “raw gases” may contain varying degrees of nitrogen, carbon dioxide, hydrogen sulfide, and contain contaminants such as salt water, sand and dirt. Processing by the gas supplier normally reduces and/or removes these constituents and contaminants prior to use in the gas turbine. A gas analysis must be performed to ensure that the fuel supply to the gas turbine meets the requirements of this specification.

2.1.3 Liquefied Petroleum Gases

The heating values of Liquefied Petroleum Gases (LPGs) normally fall between 2300 and 3200 Btu/SCF (90330-125676 kJ/NM³) (LHV). Based on their high commercial value, these fuels are normally utilized as a back-up fuel to the primary gas fuel for gas turbines. Since LPGs are normally stored in a liquid state, it is critical that the vaporization process and gas supply system maintains the fuel at a temperature above the minimum required superheat value. Fuel heating and heat tracing is required to ensure this.

2.2 Gasification Fuels

Other gases that may be utilized as gas turbine fuel are those formed by the gasification of coal, petroleum coke or heavy liquids. In general, the heating values of gasification fuel are substantially lower than other fuel gases. These lower heating value fuels require that the fuel nozzle gas flow passages be larger than those utilized for fuels of higher heating values.

Gasification fuels are produced by either an Oxygen Blown or Air Blown gasification process.

2.2.1 Oxygen Blown Gasification

The heating values of gases produced by oxygen blown gasification fall in the range of 200 to 400 Btu/SCF (7855-15709 kJ/NM³). The Hydrogen (H₂) content of these fuels is normally above 30% by volume and have H₂/CO mole ratio between 0.5 to 0.8. Oxygen blown gasification fuels are often mixed with steam for thermal NO_x control, cycle efficiency improvement and/or power augmentation. When utilized, the steam is injected into the combustor by an independent passage. The current guideline for Hydrogen plus CO constituent is limited to 75% by volume for LM6000 and to 85% for the other AeroDerivative gas turbines. Due to high hydrogen content of these fuels, oxygen blown gasification fuels are normally not suitable for Dry Low Emissions (DLE) applications, for which the Hydrogen content is limited to 5% by volume.. The high flame speeds resulting from high hydrogen fuels can result in flashback or primary zone re-ignition on DLE pre-mixed combustion systems. Utilization of these fuels shall be reviewed by GE.

2.2.2 Air Blown Gasification

Gases produced by air blown gasification normally have heating values between 150 and 200 BTU/ SCF (5891-7855 kJ/NM³) LHV. The Hydrogen (H₂) content of these fuels can range from 8% to 20% by volume and have a H₂/CO mole ratio 0.3 to 3:1. The use and treatment of these fuels are similar to that identified for oxygen blown gasification.

For Gasification fuels a significant part of the total turbine flow comes from the fuel. In addition, for oxygen blown fuels there is a diluent addition for NO_x control. Careful integration of the gas turbine with the gasification plant is required to assure an operable system. Due to the low volumetric heating value of both oxygen and air blown gases, special fuel system and fuel nozzles are required.

2.3 Process Gases

Many chemical processes generate surplus gases that may be utilized as fuel for gas turbines. (i.e. tail or refinery gases). These gases often consist of methane, hydrogen, carbon monoxide, and carbon dioxide that are normally byproducts of petrochemical processes. Due to the hydrogen and carbon monoxide content, these fuels have large rich to lean flammability limits. These types of fuels often require inerting and purging of the gas turbine gas fuel system upon unit shutdown or a transfer to a more conventional fuel. When process gas fuels have extreme flammability limits such that the fuel will auto ignite at turbine exhaust conditions, a more “conventional” start-up fuel, such as methane, is required.

Additional process gases utilized as gas turbine fuels are those which are byproducts of steel production. These are:

2.3.1 Blast Furnace Gases (BFGs)

Blast Furnace Gases (BFGs), alone, have heating values below minimal allowable limits. These gases must be blended with other fuel to raise the heating value to above the required limit. Coke Oven and/or Natural Gases or hydrocarbons such as propane or butane can be utilized to accomplish this.

2.3.2 Coke Oven Gases

Coke oven gases are high in H₂ and H₄C and may be used as fuel for single annular combustion (SAC) systems, but are not suitable for Dry Low Emissions (DLE) combustion applications. These fuels often contain trace amounts of heavy hydrocarbons, which when burned could lead to carbon buildup on the fuel nozzles. The heavy hydrocarbons must be “scrubbed” or removed from the fuel prior to delivery to the gas turbine.

2.3.3 COREX Gases

COREX gases are similar to oxygen blown gasified fuels, and may be treated as such. They are usually lower in H₂ content and have lower heating values than oxygen blown gasified fuels. Further combustion related guidelines could be found in Bureau of Mines Circulars 503 and 622.

2.3.4 Hydrogen

The presence of gaseous hydrogen in the fuel can present special problems due to the high flame speed and high temperatures associated with combustion, and the very wide flammability limits of this gas. Treatment of fuels containing hydrogen are separated into three categories, less than 5% by volume, 6% to 30% by volume and over 30%. If the hydrogen fuel content is 5% or less, no special precautions are necessary and starting on this fuel mixture can be permissible, assuming there are no other restrictive substances in the mix.

For fuels containing more than 5%, but 30% or less hydrogen, an alternative starting fuel may be required by local safety codes and a special exhaust system purge cycle is incorporated into the gas turbine start sequence to eliminate accumulated fuels from an aborted start. In addition, special high point venting is required for both the fuel gas and turbine compartments since the fuel constituents are normally lighter than air. The vents hold the compartment at a slight vacuum relative to local ambient. Special precautions must also be taken to completely seal the fuel delivery system from leaks. Consult the local authorities for specific local safety codes.

If the fuel contains more than 30% hydrogen, electrical devices used in the fuel gas and turbine compartments should be certified for use in Group B (explosive) atmospheres. Consult the local authorities for specific local safety codes.

2.4 Refinery Gases

Many hydrocarbon fuels contain olefin hydrocarbon compounds which have been thought to prohibit their use in aeroderivative gas turbines.

Fuel temperature is also a consideration in order to use standard fuel nozzles and to avoid the possibilities of fuel polymerization. Maximum fuel temperature of 125°F (52°C) is recommended. It may be possible to go as high as 190°F (88°C), but this may require non-standard fuel nozzle sizing and should be considered on a case by case basis. Please contact GE for assistance.

Because refinery gas fuels usually have significant higher hydrocarbon and olefin content the combustor flame temperatures are typically higher, resulting in higher than normal (high methane gas) NOx emissions. Contact GE for effect on emissions.

3 FUEL PROPERTIES

3.1 Heating Value

A fuel's heat of combustion, or heating value, is the amount of energy, expressed in Btu (British thermal unit), generated by the complete combustion, or oxidation, of a unit weight of fuel. The amount of heat generated by complete combustion is a constant for a given combination of combustible elements and compounds.

For most gaseous fuels, the heating value is determined by using a constant pressure, continuous type calorimeter. This is the industry standard. In these units, combustible substances are burned with oxygen under essentially constant pressure conditions. In all fuels that contain hydrogen, water vapor is a product of combustion, which impacts the heating value. In a bomb calorimeter, the products of combustion are cooled to the initial temperature and all of the water vapor formed during combustion is condensed. The result is the HHV, or higher heating value, which includes the heat of vaporization of water. The LHV, or lower heating value, assumes all products of combustion including water remain in the gaseous state, and the water heat of vaporization is not available.

3.2 Modified Wobbe Index Range

While gas turbines can operate with gases having a very wide range of heating values, the amount of variation that a single specific fuel system can accommodate is much less. Variation in heating value as it affects gas turbine operation is expressed in a term identified as modified Wobbe Index (Natural Gas, E. N. Tiratsoo, Scientific Press Ltd., Beaconsfield, England, 1972). This term is a measurement of volumetric energy and is calculated using the Lower Heating Value (LHV) of the fuel, specific gravity of the fuel with respect to air at ISO conditions, and the fuel temperature, as delivered to the gas turbine. The mathematical definition is as follows:

$$\text{Modified Wobbe Index} = \text{LHV} / (\text{SG}_{\text{gas}} \times T)^{1/2}$$

This is equivalent to:

$$\text{Modified Wobbe Index} = \text{LHV} / [(MW_{\text{gas}} / 28.96) \times T]^{1/2}$$

Where:

- LHV = Lower Heating Value of the Gas Fuel (Btu/scf)
- SG_{gas} = Specific Gravity of the Gas Fuel relative to Air
- MW_{gas} = Molecular Weight of the Gas Fuel
- T = Absolute Temperature of the Gas Fuel (Rankine)
- 28.96 = Molecular Weight of Dry Air

The allowable modified Wobbe Index range is established to ensure that required fuel nozzle pressure ratios be maintained during all combustion/turbine modes of operation. When multiple gas fuels are supplied and/or if variable fuel temperatures result in a Modified Wobbe Index that exceed the $\pm 10\%$ limitation, independent fuel gas trains, which could include control valves, manifolds and fuel nozzles, may be required for standard combustion systems. For DLE applications the Wobbe Index range must be between 40 and 60. An accurate analysis of all gas fuels, along with fuel gas temperature profiles shall be submitted to GE for proper evaluation.

3.3 Superheat Requirement

The superheat requirement is established to ensure that the fuel gas supplied to the gas turbine is 100% free of liquids. Dependent on its constituents, gas entrained liquids could cause degradation of gas fuel nozzles, and for DLE applications, premixed flame flashbacks or re-ignitions. A minimum of 50°F (28°C) of superheat is required and is specified to provide enough margin to compensate for temperature reduction due to pressure drop across the gas fuel control valves.

3.4 Flammability Ratio

Fuel gases containing hydrogen and/or carbon monoxide will have a ratio of rich to lean flammability limits that is significantly larger than that of natural gas. Typically, gases with greater than 5% hydrogen by volume fall into this range and require a separate startup fuel. Consult the local authorities for specific local safety codes.

Fuel gases with large percentage of an inert gas such as nitrogen or carbon dioxide will have a ratio of rich-to-lean flammability limits less than that of pure natural gas. Flammability ratios of less than 2.2 to 1 as based on volume at ISO conditions (14.696 psia and 59°F (101.325 kPa and 15°C)), may experience problems maintaining stable combustion over the full operating range of the turbine.

3.5 Gas Constituent Limits

Gas constituents are not specifically limited except to the extent described in Fuel Gas Classification. These limitations are set forth to assure stable combustion through all gas turbine loads and modes of operation. Limitations are more stringent for DLE combustion systems where “premixed” combustion is utilized. A detailed gas analysis shall be furnished to GE for proper evaluation.

3.6 Gas Fuel Supply Pressure

Gas fuel supply pressure requirements are dependent on the gas turbine model and combustion design, the fuel gas analysis and unit specific site conditions. Minimum and maximum supply pressure requirements can be determined by GE for specific applications.

4 CONTAMINANTS

Dependent on the type of fuel gas, the geographical location and the forwarding means there is the potential for the “raw” gas supply to contain one or more of the following contaminants:

1. Tar, lamp black, coke
2. Water, salt water
3. Sand, clay
4. Rust
5. Iron sulfide
6. Scrubber oil or liquid
7. Compressor Lube oil
8. Naphthalene
9. Gas Hydrates

It is critical that the fuel gas is properly conditioned prior to being utilized as gas turbine fuel. This conditioning can be performed by a variety of methods. These include but are not limited to media filtration, inertial separation,

coalescing and fuel heating. Trace metal, particulate and liquid contamination limits are given below. These limits are given in parts per million by weight (ppmw) corrected to the actual heating value of the fuel. It is critical that fuel gas conditioning equipment be designed and sized so that these limits are not exceeded.

4.1 Particulate

Contamination limits for particulates are established to prevent fouling and excessive erosion of hot gas path parts, erosion and plugging of combustion fuel nozzles and erosion of the gas fuel system control valves. The utilization of gas filtration or inertial separation is required. The filtration level should be a beta ratio of 200 minimum (efficiency of 99.5%) at 5μ or less. The total particulate should not exceed 30 ppm by weight. GE requires the use of stainless steel piping downstream of this last level of filtration.

4.2 Liquids

No liquids are allowed in the gas turbine fuel gas supply. Liquids contained in the fuel can result in nuisance and/or hardware damaging conditions. These include rapid excursions in firing temperature and gas turbine load, primary zone re-ignition and flashback of premixed flames, and when liquids carry over past the combustion system, melting of hot gas path components. When liquids are identified in the gas supply, separation and heating is employed to achieve the required superheat level.

4.3 Sulfur

There is no specific limit on natural gas fuel sulfur content if the engine is used in an application where both the fuel and environment are free of alkali metals. There are several concerns relative to the levels of sulfur contained in the fuel gas supply. Many of these are not directly related to the gas turbine but to associated equipment and emissions requirements. These concerns include but are not limited to:

4.3.1 Hot Gas Path Corrosion

Typically, use of sulfur bearing fuels will not be limited by concerns for corrosion in the turbine hot gas path unless alkali metals are present. Sodium, potassium and other alkali metals are not normally found in natural gas fuels, but are typically found to be introduced in the compressor inlet air in marine environments, as well as in certain adverse industrial environments. The total amount of sulfur and alkali metals from all sources shall be limited to form the equivalent of 0.6 ppm of alkali metal sulfates in the fuel. Unless sulfur levels are extremely low, alkali levels are usually limiting in determining hot corrosion of hot gas path materials. For low Btu gases, the fuel contribution of alkali metals at the turbine inlet is increased over that for natural gas and the alkali limit in the fuel is therefore decreased. The total amount of alkali metals ^(a) in gas fuels used with engines having marinized (corrosion-resistant) coatings on the high pressure turbine blading shall not exceed 0.2 ppm ^(b).

- (a) Sodium, potassium, and lithium. Experience has shown that sodium is by far the preponderant alkali metal, if any, found in gaseous fuels.
- (b) This limit assumes zero alkali metals in the inlet air or injected water or steam. When actual levels are above zero, the maximum allowable sodium content of the fuel must be reduced in accordance with the following relationship:

$$\begin{array}{rcl}
 \text{ppm sodium inlet air} \times \text{Air/Fuel Ratio} & = & \\
 \text{ppm sodium in water or steam} \times & & \\
 \quad \frac{\text{Water or Steam}}{\text{Fuel}} \text{ ratio} & = & \\
 \text{ppm sodium in fuel} & = & \\
 \text{Total fuel equivalence for sodium from all} & \text{_____} & \\
 \text{sources not to exceed} & & 0.2 \text{ ppm}
 \end{array}$$

4.3.2 HRSG Corrosion

If heat recovery equipment is used, the concentration of sulfur in the fuel gas must be known so that the appropriate design for the equipment can be specified. Severe corrosion from condensed sulfuric acid results if a heat recovery steam generator (HRSG) has metal temperatures below the sulfuric acid dew point. Contact the HRSG supplier for additional information.

4.3.3 Selective Catalytic Reduction (SCR) Deposition

Units utilizing ammonia injection downstream of the gas turbine for NO_x control can experience the formation of deposits containing ammonium sulfate and bisulfate on low temperature evaporator and economizer tubes. Such deposits are quite acidic and therefore corrosive. These deposits, and the corrosion that they cause, may also decrease HRSG performance and increase backpressure on the gas turbine. Deposition rates of ammonium sulfate and bisulfate are determined by the sulfur content of the fuel, ammonia content in the exhaust gas, tube temperature and boiler design. Fuels having sulfur levels above those used as odorants for natural gas should be reported to GE. In addition, the presence of minute quantities of chlorides in the inlet air may result in cracking of AISI 300 series stainless steels in the hot gas path. Contact the SCR supplier for additional information.

4.3.4 Exhaust Emissions

Sulfur burns mostly to sulfur dioxide, but 5% to 10% oxidizes to sulfur trioxide. The latter can result in sulfate formation, and may be counted as particulate matter in some jurisdictions. The remainder will be discharged as sulfur dioxide. To limit the discharge of acid gas, some localities may restrict the allowable concentration of sulfur in the fuel.

4.3.5 Elemental Sulfur Deposition

Solid elemental sulfur deposits can occur in gas fuel systems downstream of pressure reducing stations or gas control valves under certain conditions. These conditions may be present if the gas fuel contains elemental sulfur vapor, even when the concentration of the vapor is a few parts per billion by weight. Concentrations of this magnitude cannot be measured by commercially available instrumentation and deposition cannot therefore be anticipated based on a standard gas analysis. Should deposition take place, fuel heating will be required to maintain the sulfur in vapor phase and avoid deposition. A gas temperature of 130°F (54°C) or higher may be required at the inlet to the gas control valves to avoid deposition, depending on the sulfur vapor concentration. The sulfur vapor concentration can be measured by specialized filtering equipment. If required, GE can provide further information on this subject.

APPENDIX 1 – DEFINITIONS

Dew Point

This is the temperature at which the first liquid droplet will form as the gas temperature is reduced. Common liquids found in gas fuel are hydrocarbons, water and glycol. Each has a separate and measurable dew point. The dew point varies considerably with pressure and both temperature and pressure must be stated to properly define the gas property. Typically, the hydrocarbon dew point will peak in the 300 to 600 psia (2068 to 4137 kPa) range.

Dry Saturated Conditions

The gas temperature is at, but not below or above, the dew point temperature. No free liquids are present

Gas Hydrates

Gas hydrates are semi-solid materials that can cause deposits that plug instrumentation lines, control valves and filters. They are formed when free water combines with one or more of the C1 through C4 hydrocarbons. Typically the formation will take place downstream of a pressure reducing station where the temperature drop is sufficient to cause moisture condensation in a region of high turbulence. Because hydrates can cause major problems in the gas distribution network, the moisture content is usually controlled upstream at a dehydration process station.

Gas Hydrate Formation Line

This is similar to the dew point line except the temperature variation with pressure is much less. The hydrate line is always below or at the moisture dew point line as free water must exist in order for hydrates to form. Maintaining 50°F of superheat above the moisture dew point will eliminate hydrate formation problems.

Glycol

Glycol is not a natural constituent of natural gas but is introduced during the dehydration process. Various forms of glycol are used, diethylene and triethylene glycol being two most common. In some cases glycol is injected into the pipeline as a preservative. In most cases, glycol may only be a problem during commissioning of a new pipeline or if an upset has taken place at an upstream dehydration station.

Superheat

This is defined as the difference between the gas temperature minus the liquid dew point. The difference is always positive or zero. A negative value implies that the value is being measured at two differing states of pressure and temperature and is not valid. A measured gas temperature below the theoretical dew point means that the gas is in a wet saturated state with free liquids present.

Saturation Line

This is the same as the dew point line.

Wet Saturated Conditions

A point where a mixture consists of both vapor and liquids.

ATTACHMENT C
NO_x WATER PURITY

Requirements for Water and Steam Purity for Injection in Aero Derivative Gas Turbines

1.1 Scope

This document establishes the purity requirements for water for NOx suppression and SPRINT[®] injection into gas turbine engines and for Steam for injected into the gas turbine whether for NOx suppression or power augmentation.

1.2 Definitions

For the purpose of this specification, the following definitions shall apply:

NOx Suppression Water - Water introduced into the engine combustor for the purpose of suppressing the oxides of nitrogen (NOx) in the engine exhaust gases.

SPRINT[®] Water – Water introduced into the engine inlet or into the high pressure compressor inlet for purpose of power enhancement.

2. Applicable Documents

2.1 American Society of Testing and Materials Publications.

ASTM D512 Standard Test Method for Chloride Ion in Water

ASTM D516 Standard Test Method for Sulfate Ion in Water

ASTM D859 Standard Test Method for Silica in Water

ASTM D1066 Standard Practice for Sampling Steam

ASTM D1125 Standard Test Method for Electrical Conductivity and Resistivity of Water

ASTM D3370 Standard Practices for Sampling Water from closed Conduits

ASTM D4191 Standard Test Method for Sodium in Water by Atomic Absorbtion Spectography

ASTM D4192 Standard Test Method for Potassium in Water by Atomic Absorbtion Spectography

ASTM D5907 Standard Test Method for Filterable and Non-Filterable Matter in Water

ASTM D5464 Standard Test Method for pH of Water with Low Conductivity

2.2 Environmental Protection Agency (EPA) Test Methods

EPA 160.3	Residue, Non-Filterable and Total Suspended Solids
EPA 150.1	pH Electrometric
EPA 120.1	Conductance, Specific Conductance at 25°C
EPA 200.7	Metals & Trace Elements
EPA 325.3	Chloride, Titrimetric Mercuric Nitrate
EPA 375.4	Sulfate, Turbidimetric

3. Water Requirements

3.1 Water Sampling Requirements

The sampling shall be in accordance with ASTM D3370. A minimum of one (1) gallon or four (4) liters shall be supplied.

3.2 Water Purity Requirements

The water shall meet the following requirements when tested in accordance with the designated test method:

	Limit	Test Method
Total Suspended Solids and Total Dissolved Solids, mg/L, max	5	ASTM D5907 or EPA 160.3
pH	6.0 - 8.0	ASTM D5464 or EPA 150.1
Conductivity, $\mu\text{S}/\text{cm}$ at 25°C	< 1.0	ASTM D1125 or EPA 120.1
Sodium + potassium, ppm, max	See 3.3	ASTM D4191 and D4192 or EPA 200.7
Silica (SiO_2), mg/L, max.	0.1	ASTM D859 or EPA 200.7
Chlorides, mg/L, max	0.5	ASTM D512 or EPA 325.3
Sulfates, mg/L, max	0.5	ASTM D516 or EPA 375.4

3.3 Sodium & Potassium Limits in Water or Steam

The maximum amount of Na + K allowed in the water or steam injected into the engine depends upon the total Na + K contamination from all sources; i.e., from the fuel, air, water and steam. The maximum Na + K allowed is determined from the equation:

$$(\text{ppmFuel}) + (\text{ppmAir}) * A/F + (\text{ppmWater}) * W/F + (\text{ppmSteam}) * S/F = 0.2 \text{ ppm}$$

Where:

ppmFuel	=	Parts per million Na + K in fuel
ppmAir	=	Parts per million Na + K in Air
ppmWater	=	Parts per million Na + K in water
ppmSteam	=	Parts per million Na + K in steam
A/F	=	Air/Fuel Ratio (Wt. Basis)
W/F	=	Water/Fuel Ratio (Wt. Basis)
S/F	=	Steam/Fuel Ratio (Wt. Basis)

3.4 Water Filtration Requirements

The water shall contain no particles larger than 20 microns absolute.

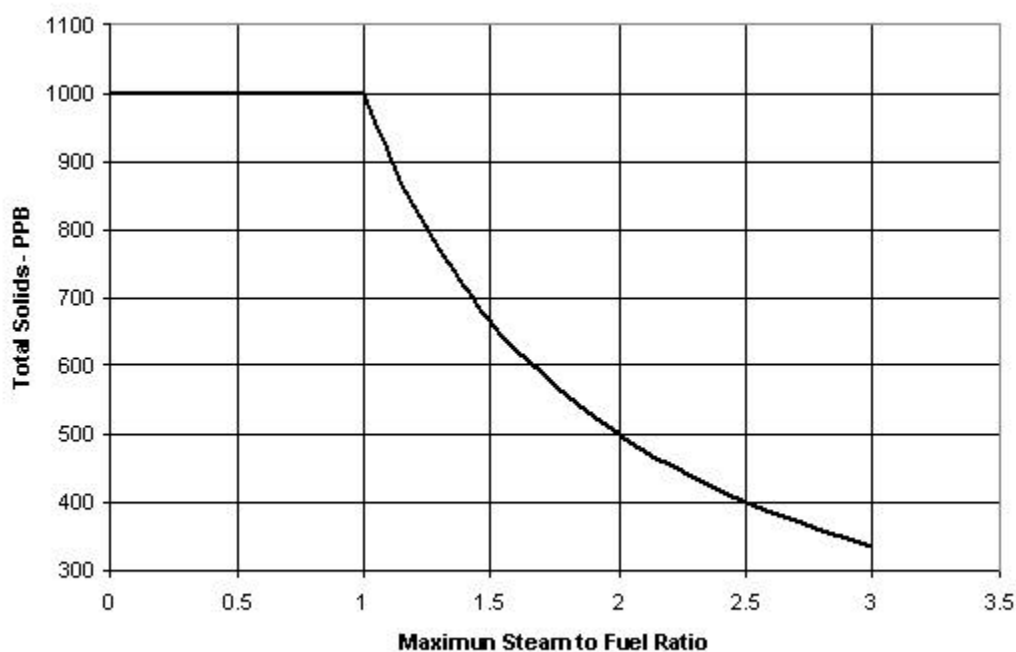
4.0 Steam Requirements

4.1 Steam Purity

The Steam shall meet the following requirements when tested in accordance with the designated test method:

- Sodium + Potassium (Na +K) – See paragraph 3.3
- Total Conductivity (Cation + Anion)
Normal: <1.5 $\mu\text{S}/\text{cm}$ (95% of operation time)
Abnormal: < 2.0 $\mu\text{S}/\text{cm}$ (5% of operating time)
- Total Solids

The maximum total solids depends on the steam/fuel weight ratios at which the gas turbine is to operate in the specific application. The value is determined from the following figure. Contaminant size shall not exceed 250 microns. With the exception of silica, there is no differentiation between types of solids as long as other limitations of this section are met. Silica in the steam is limited to 20 ppb.



4.2 Steam Sampling

Steam samples should be taken in accordance with ASTM D1066.

ATTACHMENT D
LUBE OIL SPECIFICATION

Lubricating Oil Specification for GE Aircraft Derivative Gas Turbines

This document provides the requirements and application guidelines for selection of lubricating oils which can be satisfactorily utilized in GE Marine and Industrial Aeroderivative Applications. It is recommended that the lubricating oil selected be reviewed with GE prior to its use.

1.0 Oil Specifications

Oils conforming to the US Department of Defense (DoD) Specifications shown in paragraph 2.1 are acceptable for use in GE Aircraft Derivative gas turbines, provided they are listed on the Qualified Product List (QPL) for the specific Specification.

1.1 Commercial Specifications

Commercially available synthetic based lubricating oils, per the Supplier's Specification, are acceptable for use in GE Aircraft Derivative gas turbines, provided they are listed in Section 4 of this document. Such oils largely conform to the primary requirements of the oils in Section 1.0, but certain variations have been approved. Such oils have been qualified by the Supplier to meet the requirements of this document.

2.0 Applicable Documents

The following documents shall form a part of this document to the extent specified herein. Unless a particular issue is specified, the latest revision shall apply.

2.1 US DoD Specifications

MIL-PRF-23699 Lubricating Oil, Aircraft Turbine Engines, Synthetic Base

MIL-L-7808 Lubricating Oil, Aircraft Turbine Engines, Synthetic Base, Type 1

2.2 American Society of Testing and Materials.

The following documents are available from American Society for Testing and Materials, Customer Service, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959:

ASTM D2532 Low Temperature Viscosity

ASTM D97 Pour Point

ASTM D445 Kinetic Viscosity

3.0 Requirements

The lubricating oil shall conform to the requirements of MIL-PRF -23699, however, exceptions to the following requirements will be considered:

- Low temperature Viscosity when tested per ASTM D2532.
- Pour Point when tested per ASTM D97.
- Viscosity at 40°C and 100°C when tested per ASTM D445
- Base Stock Composition

The specific variations to MIL-PRF-23699 shall be provided by the oil supplier, along with performance difference impacts, for review by GE.

3.1 Material Compatibility

The lubricating oil shall be compatible with the same elastomer seal and metallic materials as the MIL-PRF-23699 compliant lubricating oils are.

The lubricating oil shall be mixable with MIL-PRF-23699 or MIL-L-7808 compliant oil in a ratio of up to 5% of either oil, without adversely affecting the property integrity of the majority, or operating, oil. Mixing of oils is not intended, but will result due to engine location changes.

4.0 Qualification

Lubricating oil shall be considered qualified and acceptable for use in GE Aircraft Derivative gas turbines demonstrating conformance to the requirements and after being listed in paragraph 4.4. The qualification program shall be carried out by the oil supplier in conjunction with a sponsoring gas turbine owner/operator. GE's participation will be limited to technical consultation, review and final approval only.

4.1 Performance Tests

The oil supplier shall conduct tests in accordance with the requirements of MIL-PRF-23699 and compare the results with the requirements stated therein. All results, and specifically the variations to MIL-PRF-23699 requirements, shall be reviewed with GE prior to initiation of Service Evaluation Testing. Specifically, the material presented for review shall include, as minimum, the following:

- Physical/Chemical Properties and variations to MIL-PRF-23699
- Expected impact to operating systems due to Property variations
- Material Compatibility Lists & Test results
- Oil Coking Test Results

4.2 Service Evaluation Tests

The oil shall undergo service evaluation testing in a LM Series gas turbine application(s). The sponsoring operator will accept total responsibility for all results related to operating with the candidate lubricating oil. The service evaluation engine shall have a known hardware condition baseline, based on depot inspection or new delivery, immediately prior to the service evaluation test.

Service evaluation testing shall be conducted on a minimum of three LM series gas turbines, each accumulating at least 8,000 operating hours, at a baseload operating site, prior to inspection. During operation, periodic oil samples shall be tested and trended for physical and chemical property changes. Inspection shall be performed at an authorized depot, and shall be in accordance with the applicable repair manual.

Inspection shall be focused on the oil wetted parts, including the bearings, gears, elastomer seals, sump oil seals, actuators, and lube/hydraulic pumps. GE will be permitted to witness any of the inspections, at the discretion of GE.

4.3 Qualification Report

The oil supplier, and/or operator, shall prepare and submit a Final Qualification Report to GE. The report shall include, as a minimum, the following:

- Oil Brand Description including the complete formulation
- Certified physical, chemical and performance test results
- Material Safety Data Sheets
- Service evaluation test history including all significant operational and maintenance events
- Service evaluation oil sample trending results
- Final depot engine inspection results

Upon final review and approval of the Final Qualification Report by GE, the candidate oil will be included on the approved oils list.

Formulation changes affecting any approved performance characteristics must be reviewed with GE for impact on qualification results.

4.4 Approved Lubricating Oils

In addition to the oils listed on QPL-23699 and QPL-7808, (Qualified Products List), the following lubricating oils are approved for use in GE Aero Derivative gas turbines and gas generators:

1. None at this time.

ATTACHMENT E
COMPRESSOR WASH DETERGENT SPECIFICATION

Liquid Detergent for Compressor Cleaning for GE Aircraft Derivative Gas Turbines

This specification establishes the requirements for liquid detergent products used to prepare cleaning solutions for cleaning the compressors of gas turbine engines, where the intent is to restore performance by removing the build-up of deposits on compressor components. Such deposits include salt, soils or oils that may be ingested from the atmosphere.

The cleaning process shall be carried out by spraying the cleaning solution into the bellmouth of the engine while the engine is running at power (on-line cleaning) or while the engine is being cranked (crank soak cleaning).

For the purposes of this specification, the following definitions shall apply:

Liquid Detergent - A concentrated solution of water soluble surface active agents and emulsifiable solvents.

Cleaning Solution - A solution or emulsion of liquid detergent in water or a water and antifreeze mixture for direct engine application. The recommended dilution of liquid detergent and water shall be determined by the liquid detergent manufacturer.

1. Applicable Documents

The following documents shall form a part of this specification to the extent specified herein. Unless a specific issue is specified, the latest revision shall apply.

ASTM D88 Standard Test Method For Saybolt Viscosity

ARP 1795 Stress-Corrosion of Titanium Alloys, Effect of Cleaning Agents on Aircraft Engine Materials

AMS 1424 Deicing/Anti-icing Fluid, Aircraft (Newtonian-SAE Type 1)

2. Detergent Properties

2.1 Composition

The chemical composition of the detergent is not limited, other than as specified herein.

2.2 Biodegradability

Use of the liquid detergent/cleaning solution shall conform to local regulations for water pollution. Use of biodegradable ingredients is recommended.

2.3 Toxicity

Use of the liquid detergent/cleaning solution shall conform to local regulations for industrial hygiene and air pollution. Use of nontoxic ingredients is recommended.

2.4 Health and Safety Information

The liquid detergent manufacturer shall make available health and safety information for the liquid detergent as required by applicable local, state and federal regulations.

2.5 Solids

The liquid detergent shall contain no particles larger than 20 micron.

2.6 Physical and Chemical Properties

The liquid detergent shall meet the test requirements.

3. Test Requirements

3.1 Liquid Detergent

3.1.1 Residue or Ash Content

Residue or ash content shall not exceed 0.01 percent when tested in accordance with paragraph 4.1.

3.1.2 Low Temperature Stability

The liquid detergent shall show no evidence of separation of component parts when maintained at $40^{\circ}\text{F} \pm 3$ ($5^{\circ}\text{C} \pm 2$). It is highly desirable although not mandatory that the fluid shall remain liquid below 32°F (0°C).

3.1.3 Cold Weather Solution Compatibility

The liquid detergent shall show no separation, layering or precipitation when mixed to the liquid detergent manufacturer's recommended dilution in one or more of the following antifreeze solutions after 2 hours at $10^{\circ}\text{F} \pm 3$ ($-12^{\circ}\text{C} \pm 2$):

- Isopropyl Alcohol
- Monopropylene glycol (PG)
- Acetone

See paragraph 6.1 for more information regarding liquid detergent and antifreeze mixtures.

3.1.4 Hard Water Compatibility

The liquid detergent shall show no separation or layering when mixed with synthetic hard water prepared in accordance with paragraph 4.2.

3.1.5 Acid and Alkali Acceptance

The liquid detergent shall show no separation, layering or precipitation when tested in acidic or alkali media in accordance with paragraph 4.3.

3.1.6 Salt Water Tolerance

The liquid detergent shall show no separation or gelling when mixed with 3.5 percent salt water in accordance with paragraph 4.4.

3.1.7 Viscosity

The liquid detergent shall have a viscosity of 50 to 200 SUS at 77°F (25°C) when tested in accordance with ASTM D88.

3.1.8 pH

The pH of the liquid detergent as received shall be from 6.5 to 8.5 when measured with a suitable pH meter employing a glass electrode.

3.2 Cleaning Solution

3.2.1 Corrosive Elements

Maximum levels of elements in the cleaning solution which may promote various types of corrosion, shall be no greater than as shown in Table 1, when analyzed by methods in paragraph 4.5.

Table 1. Maximum Corrosives Limit

Total alkali metals (sodium + potassium + lithium, etc.)	25 ppm max.
Magnesium + calcium	5 ppm max.
Vanadium	0.1 ppm max.
Lead	0.1 ppm max.
Tin + Copper	10 ppm max.
Sulfur	50 ppm max.
Chlorine	40 ppm max.

3.2.2 pH

The pH of the cleaning solution shall be from 6.5 to 8.5 when measured with a suitable pH meter employing a glass electrode.

4. Test Methods**4.1 Residue or Ash Content**

Weigh 10 ± 0.1 gram sample of liquid detergent in a weighed 30 ml porcelain crucible. Heat gently to volatilize any water or solvents. (Crucible may be placed in air oven at $105^{\circ}\text{C} \pm 2$ for 24 hours, followed by $240^{\circ}\text{C} \pm 2$ for 24 hours to insure all volatile matter is evaporated.) Finally, ignite contents over Bunsen Burner, first at low temperature under good oxidizing conditions until all ignitable material is consumed, then place a crucible in a muffle furnace at 1040 to 1100°C for 2 hours. Cool in desiccator, and weigh.

Percent residue or ash = $(100 \times A)/W$

Where: A = grams of residue

W = grams of sample

4.2 Hard Water Compatibility**4.2.1 Preparation of Synthetic Hard Water**

A hard water solution is prepared by dissolving the following in one liter of just boiled and cooled distilled water:

- 0.20 ± 0.005 gram Calcium Acetate, reagent grade $\text{Ca}(\text{C}_2\text{H}_3\text{O}_2)_2 \bullet \text{H}_2\text{O}$
- 0.15 ± 0.005 gram Magnesium Sulfate, reagent grade $\text{MgSO}_4 \bullet 7 \text{H}_2\text{O}$

4.2.2 Hard Water Test

5 ml of liquid detergent shall be added to a clean 50 ml cylinder. 45 ml of synthetic hard water shall be added and mixed well. The solution shall be examined for compatibility after 16 hours at $77^{\circ}\text{F} \pm 5$ ($25^{\circ}\text{C} \pm 3$).

4.3 Acid and Alkali Acceptance

The liquid detergent shall be mixed with distilled water in accordance with the liquid detergent manufacturer's recommended dilution. To 50 ml of the solution, add 1 ml of 75 percent phosphoric acid. To another 50 ml of the solution, add 5 ml of 75 percent phosphoric acid. To another 50 ml of the solution, add 1 ml of 50 percent potassium hydroxide. Let all three mixtures stand for one hour at $77^{\circ}\text{F} \pm 5$ ($25^{\circ}\text{C} \pm 3$), and then examine for acid or alkali acceptance.

4.4 Salt Water Tolerance

Prepare a 3.5 percent by weight solution of sodium chloride in distilled water. Add 15 ml of salt solution to 35 ml of liquid detergent and let stand for 1 hour at $77^{\circ}\text{F} \pm 5$ ($25^{\circ}\text{C} \pm 3$). Examine for salt water tolerance.

4.5 Elemental Content

Elemental content shall be determined using the following methods:

Element	Method
Sulfur, Phosphorous	Inductivity Coupled Plasma Spectroscopy - Atomic Emission Spectroscopy (ICP-AES)
Chlorine	Microcoulometric filtration
Sodium, Potassium	Atomic Absorption (AA)
Other metals	ICP-AES or AA

5. Material Compatibility

5.1 Compatibility with Engine Materials

Use of the detergent gas turbine cleaner shall not have adverse effects on engine system materials such as titanium stress corrosion, hot corrosion of turbine components or damage to lubrication system components.

5.2 Titanium Stress Corrosion

A titanium stress corrosion test in accordance with ARP 1795 or equivalent may be run on the liquid detergent at the discretion of GE.

6.1 Cold Weather Usage

In cold weather, liquid detergent must be added to antifreeze mixture rather than to water alone. At present, the only acceptable antifreeze solutions are:

- Isopropyl Alcohol
- Monopropylene glycol (PG)
- Acetone

Monopropylene glycol (PG) must be per AMS 1424 and may be used down to 20°F (-7°C)

Antifreeze mixtures are shown in Table 2. The liquid detergent manufacturer must specify which, if any, of the antifreezes specified above is not compatible with the liquid detergent.

The use of non-isopropyl alcohol, ethylene glycol or additives containing chlorine, sodium or potassium are not permitted since they may attack the titanium and other metals in the gas turbine.

It is extremely important that the liquid detergent and antifreeze solution be a homogeneous mixture when sprayed into the bellmouth of the gas turbine. If after 2 hours the liquid detergent and antifreeze solution separates, (see paragraph 3.1.3) agitation of the mixture in the wash water tank is permissible. However, the liquid detergent manufacturer shall specify that agitation is required.

Table 2. Water Wash Antifreeze Mixtures.

Compressor Washing Antifreeze Mixtures						
Outside Air Temp, °F (°C)	Monopropylene glycol (PG) % Vol	H2O % Vol	Acetone % Vol	H2O % Vol	Isopropyl Alcohol % Vol	H2O % Vol
+20 to +50 (-7 to 10)	21	79	25	75	22	78
+10 to +20 (-12 to -7)	N/A	N/A	40	60	34	66
0 to +10 (-18 to -12)	N/A	N/A	53	47	47	53
-10 to 0 (-23 to -18)	N/A	N/A	63	37	72	28
-20 to -10 (-29 to -23)	N/A	N/A	69	31	88	12
-30 to -20 (-34 to -29)	N/A	N/A	75	25	97	3
Compressor Rinsing Antifreeze Mixtures						
Outside Air Temp, °F (°C)	Monopropylene glycol (PG) % Vol	H2O % Vol	Acetone % Vol	H2O % Vol	Isopropyl Alcohol % Vol	H2O % Vol
+20 to +50 (-7 to 10)	14	86	20	80	18	82
+10 to +20 (-12 to -7)	N/A	N/A	33	67	27	73
0 to +10 (-18 to -12)	N/A	N/A	43	57	39	61
-10 to 0 (-23 to -18)	N/A	N/A	50	50	58	42
-20 to -10 (-29 to -23)	N/A	N/A	55	45	70	30
-30 to -20 (-34 to -29)	N/A	N/A	60	40	77	23

ATTACHMENT F
COMPRESSOR WASH WATER PURITY SPECIFICATION

Compressor Cleaning Water Purity

Specification for GE Aircraft Derivative Gas Turbines in Industrial Applications

1.1 Scope

This specification establishes the requirements for purified water for use in cleaning the compressor of gas turbine engines where the intent is to restore performance by removing the build up of deposits on compressor components. The water quality defined in this specification applies to water used in both on-line compressor cleaning and crank-soak compressor cleaning.

1.2 Definitions

For the purpose of this specification, the following definitions shall apply:

On-line Compressor Cleaning - A method of removing the build up of deposits on compressor components while the engine is operating. On-line cleaning as accomplished by spraying cleaning solution into the inlet of the engine while the engine is operating.

Crank-Soak Compressor Cleaning - A method of removing the buildup of deposits on compressor components while the engine is motored by the starter. Crank-soak cleaning is accomplished by spraying cleaning solution into the inlet of the engine while the engine is operating unfired at crank speed.

Liquid Detergent - A concentrated solution of water soluble surface active agents and emulsifiable solvents.

Cleaning Solution - A solution of emulsion of liquid detergent and

water or a water and antifreeze mixture for direct engine application. The recommended dilution of liquid detergent and water shall be specified by the liquid detergent manufacturer.

2. Applicable Documents

2.1 Issue of Documents

The following documents shall form a part of this specification to the extent specified herein. Unless a specific issue is specified, the latest revision shall apply.

2.1.1 American Society of Testing and Materials

Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASTM D1192 Equipment for Sampling and Steam

ASTM D1293 Tests for pH of Water

ASTM D4191 Tests for Sodium in Water by atomic Absorbtion Spectography

ASTM D4192 Tests for Potassium in Water by Atomic Absorbtion Spectography

ASTM D5907 Tests for Filterable and Non-Filterable Matter in Water

ASTM D3370 Practices for Sampling Water

3. Requirements

3.1 Sampling Requirements

The sampling shall be in accordance with ASTM D1192 and ASTM D3370. A

minimum sample of one (1) gallon or four (4) liters shall be supplied.

3.2 Chemical Requirements

The water shall meet the following requirements when tested in accordance with the designated test method.

3.3 Filtration Requirements

The water shall contain no particles larger than 100 microns absolute.

	Limit	Test Method
Total matter, ppm, max	100	ASTM D5907
pH	6.5 - 8.5	ASTM D1293
Sodium + potassium, ppm,max	25	ASTM D4191 & ASTM D4192