

# PROPOSAL

Presented To:

## PDVSA

For

### TM 2500 Equipment Only

*Prepared By*



DERWICK ASSOCIATES S.A.



Proposal No. 709-2907

November 17, 2009

**This document is privileged and contains confidential information intended for use only by  
PDVSA**

## **1.0 Introduction**

Derwick Associates ("Derwick") is pleased to provide this proposal to PDVSA for Three (3) TM2500.

## **2.0 Gas Turbine Generator Set Scope Of Supply**

We are offering three (3) Mobile GE TM2500PE gas turbines generator set ISO Rated at 22 MW which includes the following scope of supply:

- TM2500PE gas turbine configured for both natural gas and liquid fuel operation
- Mobile 4-Trailer assembly
- Air cooled Brush 2 Pole generator w/brushless excitation.
- Dual Fuel Capacity
- Dual frequency-quick converted from 50 to 60 Hertz-no reduction Gear.
- Coupling for direct drive at 3600 rpm, for a 60 Hz operation if required.
- Weatherproof acoustic enclosure for gas turbine and electric generator
- Low emission with Demineralized water injection.
- Quick set up in less than 5 days. (When all the BOP and landscape are ready for the installation).
- Woodward/Netcom 5000 control system."Single lift" I bean base plate
- Minimal foundation requirements.

## **3.0 Pricing of Equipment**

### **A. Firm Price**

The price quoted is not subject to escalation or adjustment if a purchase commitment is received and accepted by Derwick Associates prior to December 17, 2009. Equipment is subject to prior sale.



E. SCHEDULE

Derwick Associates expects to prepare the equipment for shipment to site: November 30, 2009

F. GENERAL TERMS AND CONDITIONS OF SALE

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

G. WARRANTY

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

H. SITE SERVICES

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

Derwick Associates can also provide an experienced service representative to assist the operating personnel during the first (2) months after the Equipment goes online.

I. EXCLUSIONS

Derwick Associates has excluded these items listed below from our offering. Any other equipment or service not described in our written proposal is also excluded.

- Absorption chiller and chilled water supply system
- Balance of plant and energy optimization controls
- Boiler feed pump and auto level control assembly
- Building, foundations, anchor bolts, embedment and grouting
- Bus bars and bus duct beyond generator lineside and neutral enclosures
- Cooling tower and circulating water system
- Deaeration and chemical injection equipment

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- Desuperheater equipment
  - Distributed plant control
  - Filter house support structure, other than standard
  - Field Supervision
  - Fuel, fluids and chemicals
  - Fuel storage tanks, forwarding equipment and primary fuel filter
  - Gas compression, filtration, and separation or regulation equipment
  - Heat recovery boiler and blow down controls
  - High voltage transformer(s), cables, switchgear and associated equipment
  - Interconnecting piping, conduit, and wiring between equipment modules (site layout is unknown at this time)
  - Plant utilities
  - Power plant calibration tools and ordinary hand tools
  - Spare parts (quoted separately)
  - Steam filtration and purification equipment
  - Steam turbine condenser and condensate pumping equipment
  - All transportation to job site loading and off loading of equipment
  - Water injection pressurization equipment
  - Water treatment and purification equipment
  - Yard light and fences

#### **4.0 Follow Up**

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

Pedro Trebbau

Director

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Celular: +58 (412)3007470

## **BASIC (Typical) SCOPE OF SUPPLY**

### **TM 2500 MOBILE Gas Turbine Generator**

The TM2500 consist of four trailers describe below. The trailers include the main trailer, auxiliary trailer, air filter trailer and exhaust trailer. The scope of each of these trailers will be described in detail.

#### **Main Trailer**

The main Trailer consists of the following components:

#### **Main Trailer and Jeep**

A six-axle, air ride suspension trailer (3+ $\#$ ) and a 3 axle jeep are used to transport the main trailer components. The trailer and jeep combination is approximately 108" (32.9m) long (less tractor) during transport and weighs approximately 210,000 pounds (95,254 Kg) fully loaded. At the jobsite, the jeep and trailer gooseneck are remove as well as the 3 rear axles of the trailer. With these pieces removed, the main trailer is approximately 58" (17.7m) long during operation. Ten landing legs are provided to support and level the equipment at the jobsite.

#### **Gas Turbine**

General Electric LM2500 - PE-MG gas turbine, ISO rated at 30,563 HP for continuous duty, with a heat rate of 6772 Btu/HP-hr (LHV). Suitable for base load or peaking, designed for simple cycle, combined cycle or cogeneration service. Turbine is shock mounted and shipped in position, ready to run. Turbine is complete with "last chance" inlet screen and bellmouth seal for protection against foreign object damage.

#### **Generator**

Air-cooled open air, 2 pole generator capable of handling the full continuous power of the gas turbine at any ambient temperature throughout the operation range. Filtered air from the inlet air filter is used to cool the generator. 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 and voltage regulator are also included. The generator is hard mounted to a base on the main trailer. Generator air inlet filtering and air silencing is provided.

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## Unit Enclosure

The basic equipment package is supplied with waterproof acoustic enclosure for the turbine. The enclosure is completely assembled and mounted over the equipment prior to testing and shipment. Both turbine and generator compartments are fully ventilated with redundant fans (3 x 50% provided on the air filter trailer). Provision for turbine removal and personal access are included.

## Gas Turbine Baseplate

A steel baseplate is provided for gas turbine support. The baseplate will be designed to provide suitable strength and all the necessary installation provision. A 3 point mount system between the baseplate and the trailer provide engine and enclosure isolation from main trailer movement during transport.

## Turbine Exhaust

The basic equipment package is supplied with a rectangular, RH horizontal (aft looking forward) exhaust outlet with connection flange to facilitate in-line mounting of the simple cycle exhaust trailer.

## Fuel System

The basic equipment package is supplied in a dual configuration. The package is supplied with a natural gas fuel system using an electronically controlled fuel-metering valve. For full-load operation, the gaseous fuel must be supplied to the auxiliary trailer skid at 375 psig  $\pm$  20 psig All necessary shutoff valves, piping and instruments between the auxiliary trailer skid connection and the engine are included. Gas fuel must meet General Electric specification MID-TD-0000-1.

The package is also equipped with a liquid fuel system. Typical liquid fuels include DF1, DF2 or JP4. Customer must supply liquid fuel to the connection at the auxiliary trailer skid at 20-10 psig (138-276kpag) and at least 20 degree F (11 C) above the wax point temperature. Customer supplied fuel must be clean filtered and meet the GE fuel Specification MID-TD-0000-2. All necessary shutoff valves, flow meter, piping and instruments between the auxiliary Trailer Skid connection and the engine are included. Customer must provide and supply piping only.



## **Water Injection System**

The basic equipment package is supplied with a water injection system for Nox reduction. The system is complete with inlet strainer, pump, valves, flow meter, piping and controls. Customer must provide a supply of purified water per GE Water Specification MID-TD-0000-3 to the Auxiliary Trailer Skid at 20-40 psig (138-276 kPag).

## **Lube Oil Systems**

The basic equipment package is supplied with two separate lube oil system; one for the gas turbine and one for the generator. The oil reservoirs and piping are all stainless steel and the lube oil system valves have stainless steel trim. Each lube oil system has a pump, simplex filters, necessary valving and instrumentation, and thermostatic-controlled electric heaters. A dual fan, single core fin-fan cooler is provided to cool the turbine, generator lube oil and hydraulic oil. The cooler is mounted on the auxiliary trailer and the rest of the lube oil systems are mounted on the main trailer.

## **Switchgear**

The basic equipment package is supplied with a 3 NEMA 3R switchgear enclosure. The switchgear includes a set of generator circuit breaker equipment, 2 sets of incoming line voltage monitoring equipment, a marshalling cabinet and a set of switchgear accessories. Permanent cable terminations from the neutral and lineside of the generator are also included. The customer is only required to connect the 11kV power cables at site.

## **Auxiliary Trailer**

The auxiliary trailer is approximately 48' (14.6m) long and 8'-6" (2.6m) wide and weighs approximately 46,000 pounds (20,865kg) fully loaded. The trailer is provided with a tandem air ride suspension and includes the equipment listed below. Four landing legs are provide to support and level the trailer at side.

## **Auxiliary Trailer Skid**

The auxiliary trailer skid includes the two fuel and water injection system components not mounted on the main trailer. The pumps, filters and necessary instrumentation are connected to the main trailer components at site with interconnected hoses. The auxiliary Equipment module and the main baseplate are also furnished.

## **Electro-Hydraulic Starting Module**

The basic equipment package is supplied with a hydraulic starting which includes an electric motor driven hydraulic pump assembly, filters, coolers and controls, mounted on the auxiliary equipment module. A hydraulic motor is also mounted on the gas turbine accessory gearbox to turn the gas generator shaft. All piping and fitting on the baseplate, plus hydraulic connections between the auxiliary equipment module and the main baseplate are also furnished.

## **"Off Line" Soak Wash System**

The basic equipment package is supplied with an "off line" cleaning system, with a water wash reservoir and all necessary filters and instrumentation supplied. Customer is required to provide purified water to the standards listed in the water injection system..

## **Fire Protection System**

The basic equipment package is supplied with an installed fire and gas detection and extinguishing system includes hydrocarbon sensing and thermal detectors; complete with piping and nozzles in the engine compartments. The fire protection system includes cylinders of CO<sub>2</sub> extinguishant mounted on the auxiliary trailer. Proenergy furnishes a dedicated 24V DC battery and charger to power the fire protection system. Fire system alarms and shutdowns are annunciated at the turbine control panel. An alarm sounds at the turbine enclosure and unit control panel if the gas detectors sense high gas levels, or if the system is preparing to release the CO<sub>2</sub>. When activated, the primary CO<sub>2</sub> cylinders discharge into the turbine compartments via multiple nozzles, and ventilation dampers close automatically. After a time delay, the reserve supply of CO<sub>2</sub> is discharged, if required.

## **Fin Fan Cooler**

The basic equipment package is supplied with a 100% redundant dual fan, single core cooler with separate coils for the turbine, generator lube oil and hydraulic oil. The cooler is equipped with all interconnect piping and instrumentation necessary for the three circuits.

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## **Turbine Ventilation Silencer**

A Turbine ventilation silencer is provided with the package and is mounted on a rail system to slide into position at the jobsite. The silencer is bolted to the side of the turbine opposite the exhaust collector and expansion joint and fire damper are provided.

## **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 electronic fuel management system with a PLC based programmable sequencer, vibration monitor, fire system monitor, digital meter, and a digital generator protective relay module. A desk top PC with separate workstation and chair is provided for HMI 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 customer's distributed control system. An optional printer can be furnished to provide hard copy records. Power for the control panel is provided by a dedicated 24V DC battery system with dual 100% capacity chargers.

## **Generator Protective Relays**

The basic equipment package is supplied with a microprocessor based generator protective relay module, mounted in the turbine control panel. Protective relay system includes all functions necessary for protection of the generator.

## **Unit Motor Control Center**

A free standing lineup of motor controls for all motors furnished by GE is supplied. The motor control center is installed in the control house and also includes a 30kVA lighting and distribution transformer.

## **Battery and Charger System**

The basic equipment package is supplied with a 24 VDC control system battery system and charger, a 24VDC fire system battery system and charger, and a 125 VDC switchgear and backup generator lube pump motor battery system and charger. The battery systems are fully wired and mounted in racks and are installed in the control house along with the wall mounted chargers.

## **Air Filter Trailer**

The air filter trailer is approximately 48' (14.6m) long and 8'-6" (2.6,) wide and weighs approximately 46,000 pounds (20,865kg) fully loaded. The trailer is provided with a tandem air ride suspension and includes the equipment listed below. Four landing legs are provided to support and level the trailer at the jobsite.

The trailer is equipped with a two stage filtration system for both ventilation and combustion air, with panel type pre-filters housed in hinged doors and high efficiency bag barrier filters. Vane separators are installed in front of and behind the filtration system and inlet silencers are provided. A heating/cooling coil is provided with flanged customer connections for heating and chilling capability. An inlet plenum with access door is provided for access to the FOD screen and commissioning screen.

Ventilation fans for the turbine enclosure are installed on the air filter trailer. Three 50% fans are installed and are equipped with back draft dampers. All of the items listed are housed in the filter house that is complete with access door and lighting for maintenance, separate air paths and turning vanes and the necessary instrumentation. For connection to the main trailer, a flex connection for the combustion inlet to the engine bellmouth and a trailer flex connection are provided.

## **Exhaust Trailer**

The exhaust trailer is approximately 48' (14.6m) long and 8'-6" (2.6,) wide and weighs approximately 40,000 pounds (18,144kg) fully loaded. The trailer is provided with a tandem air ride suspension and includes the equipment listed below. Four landing legs are provided to support and level the trailer at the jobsite.

The exhaust trailer is equipped with an expansion joint for trailer connection to the main trailer exhaust collector flange. An exhaust trailer is equipped with an expansion joint for trailer connection to the main trailer exhaust collector flange. An exhaust transition with access hatch, a horizontal exhaust silencer, a 90 degree exhaust elbow, and a vertical stack are also included. The stack is lifted into position at the job site. The exhaust trailer is 13'-6" (4.1m) tall for roading purposes and is 20' (6.1M) tall with the stack in position at site.

## **Training (Optional)**

Hands-on training for 10 customer's operators and supervisors. Experienced instructors, using specially developed training materials, provide a firm groundwork of basic theory, plus advanced concepts with classroom and hands-on training.



## STANDARD 60Hz TM2500 GENERATOR PACKAGE

### Gas Turbine

16 Stage Axial Compressor

- 1st 6 stages have variable station
- Horizontal Split Casing
- 20:1 Compression Ratio
- 150 lb/s Nominal Inlet Mass Flow

Annular Combustor

- 30 Nozzles Gas Fuel, Water Injection for NOx Control

6 Stage Power Turbine

### Generator

Continuous Duty 13.8kV, 0.85 PF

2 Pole, 3 Phase Brushless Exciter

WPII Weather Protected

Voltage Regulator/Neutral Side Protection CT's

NEMA Class F Insulation & B Temperature Rise

### Package

24V and 125V DC Batteries

90dBA Near Field Design

Barrier Inlet Air Filters

Electro-Hydraulic Start System

Class I Div 2 Group D Class Electrical System

Digital Control System with a Human Machine Interface (HMI)

Turbine and Generator Lube Oil System with Simplex Shell and Tube Coolers

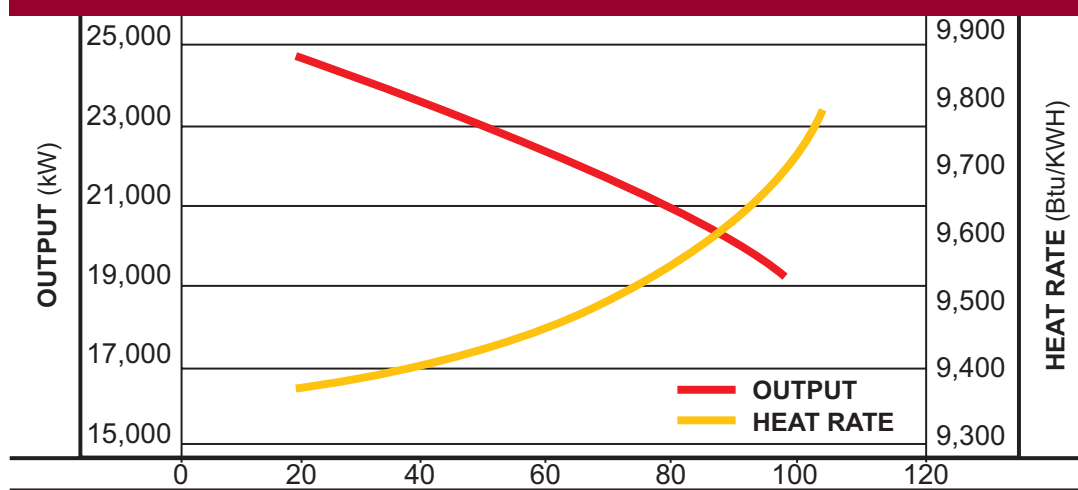
On/Off-line Water Wash





## TM2500 FACT SHEET

### TM2500 60Hz Output and Heat Rate

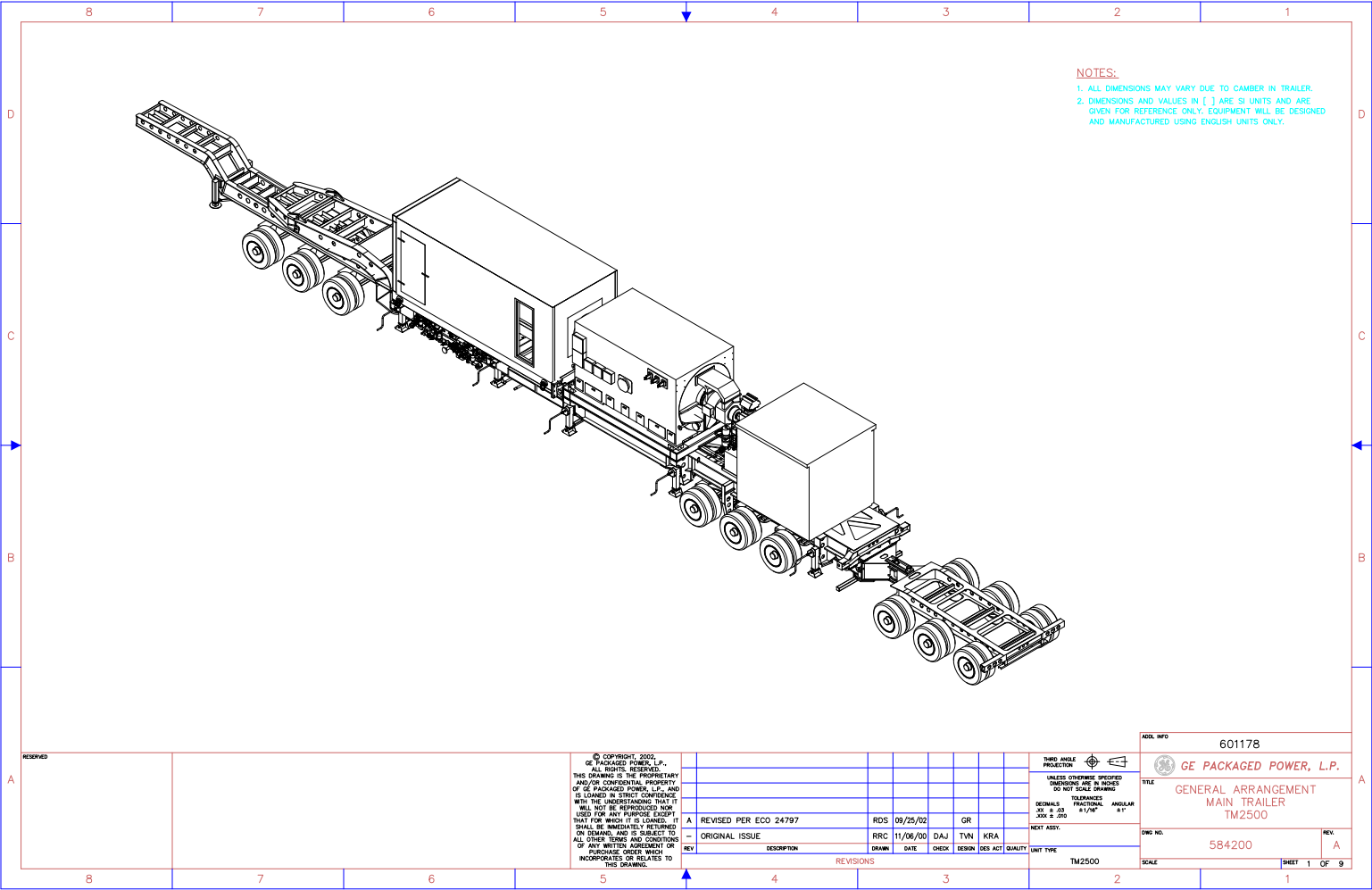


0 ft. 60% RH, 4/6 in H<sub>2</sub>O inlet/exhaust loss on natural gas with water injection to 25ppmvd NO<sub>x</sub> water inj.

AMBIENT(°F)

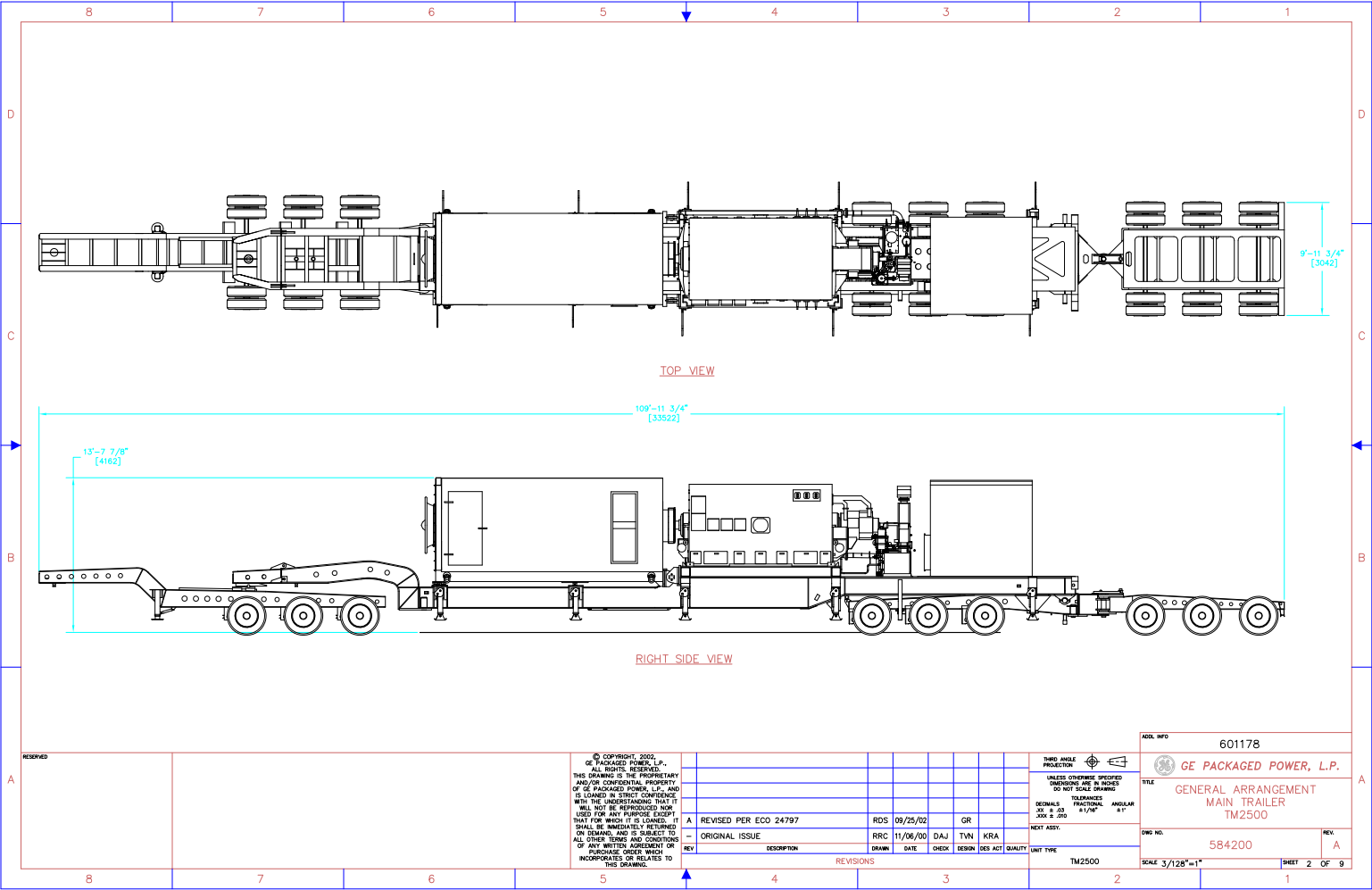
### Turbine

	TM2500
Power Output (kWe)	18,400
Heat Rate LHV (Btu/kWe-Hr)	9,900
Exhaust Flow (lbs/sec)	143
Exhaust Temperature (°F)	860
Emissions (ppmvd)	NO <sub>x</sub> /CO
Gas-DLE	25/25
Gas or Liquid-Water	25/75, 42/55
Gas-Steam	25/74
Power Turbine Speed (rpm)	3,600
No. of Compressor Stages	16
No. of Turbine Stages	6

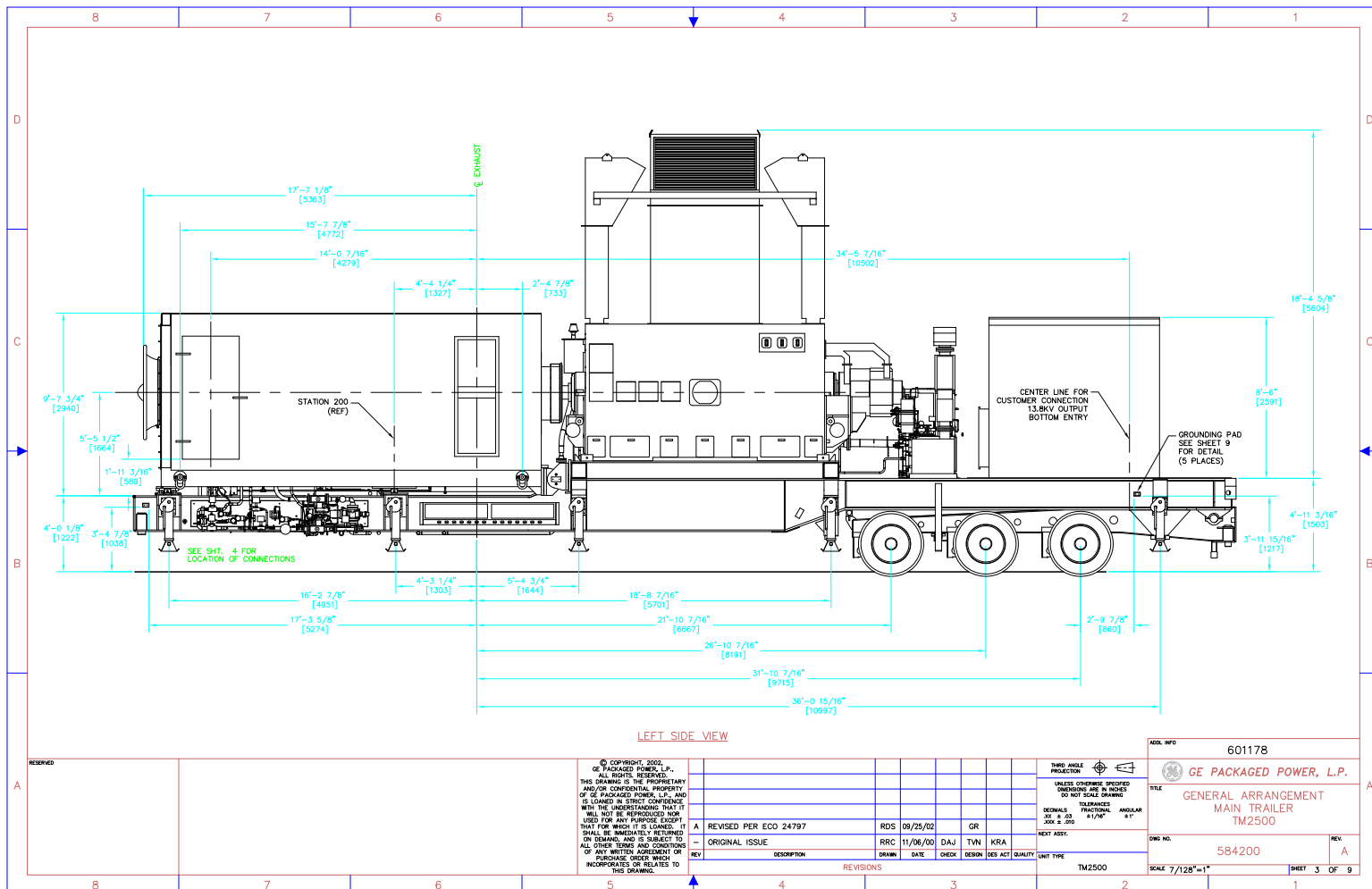


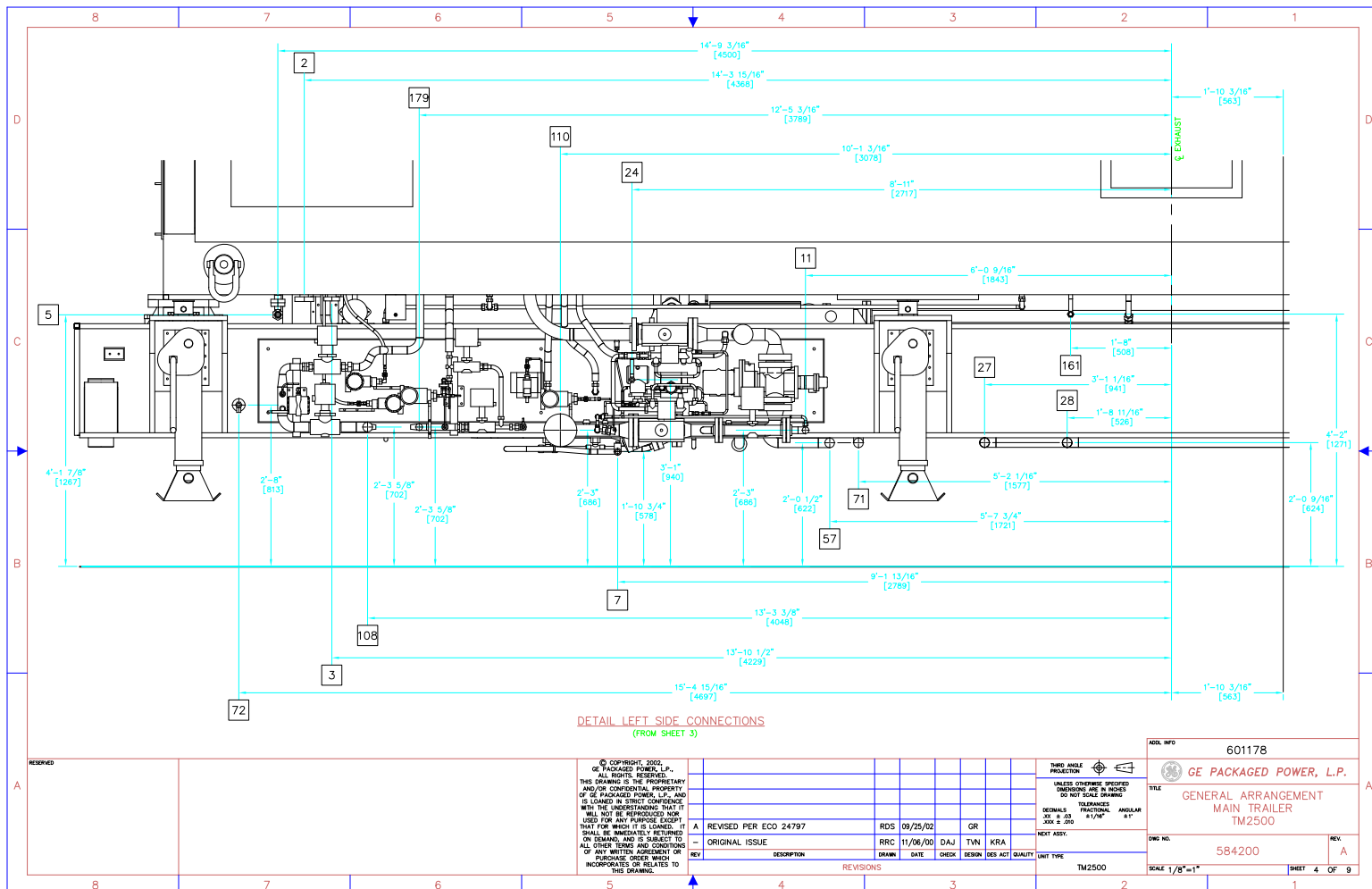
NOTES:  
1. ALL DIMENSIONS MAY VARY DUE TO CAMBER IN TRAILER.  
2. DIMENSIONS AND VALUES IN ( ) ARE SI UNITS AND ARE GIVEN FOR REFERENCE ONLY. EQUIPMENT WILL BE DESIGNED AND MANUFACTURED USING ENGLISH UNITS ONLY.

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				A REVISED PER ECO 24797				RDS 09/25/02				GE PACKAGED POWER, L.P.			
				-- ORIGINAL ISSUE				RRC 11/06/00				TITLE			
				REV DESCRIPTION				DAJ TVN KRA				GENERAL ARRANGEMENT			
								DRAWN DATE CHECK DESIGN DES ACT QUALITY UNIT TYPE				MAIN TRAILER			
												TM2500			
												DRAWING NO. 584200			
												SCALE			
												SHEET 1 OF 9			









ITEM #	LOCATION	DESCRIPTION	PART #	QUANTITY	NOTE
<b>MAIN TRAILER</b>					
1	GENERATOR LUBE OIL FILTER	FILTER ELEMENT	PH518-12-CG	1	
2	TURBINE LUBE OIL FILTERS	FILTER ELEMENT	PH414-12-CG	2	
3	TURBINE MODULE CLEVIS	PIN SHM	554618	1	⊙
		1-CLEVIS SHM	554614	1	⊙
		0-CLEVIS SHM	554618	1	⊙
		1-BUNG X 3 1/2" BOLT	401271	4	+
		1" LOCK WASHER	J00631	4	+
		1" FLAT WASHER	J00625	4	+
4	TURBINE MODULE SUPPORT PAD	JACKING PAD	LL-22	4	+
		SHM	554695	4	+
		1-BUNG X 6 1/2" BOLT	J03283	2	+
		1-BUNG X 9" BOLT	J05499	2	+
		1" FLAT WASHER	J00625	8	+
		1" LOCK WASHER	J00631	4	+
5	GENERATOR	COUPLING GUARD	W/ ENCLOSURE	1	+
		GENERATOR COUPLING GUARD FLANGE & HARDWARE	SUPPLIED BY BRUSH		+
		FILTER/SILENCER BOX & HARDWARE			
		GASKET			
		FILTER ELEMENT			
6	VENTILATION EXHAUST SILENCER	3/4"-16UNC X 1 1/4" BOLT	J00248	36	
		3/8" FLAT WASHER	J00399	72	
		3/8" LOCK WASHER	J00408	36	
		3/8"-16UNC NUT	J00473	36	
7	TURBINE EXHAUST SILENCER	1/8" T X 2" W NEOPRENE GASKET	J04069	20	
		1/2"-13UNC X 1 1/2" ASTM-A 193 BOLT OR SS	J04769	48	+
		1/2" FLAT WASHER	J00399	96	+
		1/2" LOCK WASHER	J00405	48	+
		1/2" NUT ASTM-A 194 OR SS	J02353	48	+
		1/8" T X 3" W FIBERGLASS GASKET	EXH04T18X3	50	+
8	COMBUSTION AIR INLET INTERFACE	3/8"-16UNC X 1 1/4" BOLT	J00248	60	+
		3/8"-16UNC NUT	J00473	60	+
		3/8" FLAT WASHER	J00399	120	+
		3/8" LOCK WASHER	J00408	60	+
		SILICON SEALANT		5	TUBES
9	VENTILATION AIR INLET INTERFACE	3/8"-16UNC NUT	J00473	36	+
		3/8" FLAT WASHER	J00399	72	+
		3/8" LOCK WASHER	J00408	36	+
10	AIR FILTER DOCKING STATION	5/8"-11UNC X 1 1/2"	J00279	6	
		5/8" WASHER LOCK	J00410	6	
		5/8" WASHER FLAT	J00401	12	
11	EXHAUST DOCKING STATION	3/4"-10UNC X 4" STUD	96991	16	
		3/4"-10UNC HEAVY HEX NUT	92318	32	
12	MAIN DRIVE COUPLING	SPOOL	DB-412R22	1	+
13	LANDING GEAR SUPPORT	SUPPORT BLOCK	584675	10	+
14	QUICK DISCONNECT CABLES	CABLE			AS REQ'D
<b>AUXILIARY TRAILER</b>					
1	GAS FUEL SHUT OFF VALVE	3" BALL VALVE	J00123	1	+
2	GAS FUEL HOSE INTERCONNECT	5/8" STUD X 3 1/2" LG.	92307	8	
		3/8"-11UNC HEAVY HEX NUT	92317	16	
		3"-300# GASKET	CG-3J	1	
<b>EXHAUST SILENCER TRAILER</b>					
		CABLE			AS REQ'D
1	EXTENSION DUCT	1/2"-13UNC X 1" ASTM-A 193 BOLT OR SS	J02664	80	+
		1/2" FLAT WASHER	J00395	80	+
		1/2" LOCK WASHER	J00405	80	+
<b>AIR FILTER TRAILER</b>					
1	QUICK DISCONNECT CABLES	CABLE			AS REQ'D
<b>MISCELLANEOUS TOOLS</b>					
1	ROTALIGN LASER EQUIPMENT	COMPUTER KIT	AL3501	1	#
		BOLT HOLE BRACKET	AL3106	1	#
		5 METERS RECEIVER CABLE	AL3581-5	1	#
		MAGNETIC BRACKET SET	AL3112	1	#
2	JACKING OIL PUMP	POWER PACK	CWP-1M2XXX	1	#
3	GENERAC HYD PUMP	115 VAC ECONOMY HYD PUMP W/ CONTAINER	PUJ-1201B	1	#
4	GENERAC HYD JACK	50 TON CAPACITY CYLINDER (5/8" TRAVEL LENGTH)	RSM-500	2	#
5	GENERAC HYD JACK	50 TON CAPACITY CYLINDER (6 1/4" TRAVEL LENGTH)	RC-500	2	#

⊙ ALL SHIMS MUST BE MARKED TO INDICATE LOCATION WHEN REMOVED FROM UNIT

\* PARTS ARE ALREADY ORDERED. NEED TO PULL AND VERIFY ITEMS ARE SHIPPED W/ UNIT

# TOTAL OF 4 SETS WERE ORDERED FOR 20 UNITS

REVIEWS

DATE

BY

CHKD

DES

APP

QUALITY

05/18/01

DAJ

TVN

LMP

601178

TM2500

WORLD ANGLE PRODUCTION

UNLESS OTHERWISE SPECIFIED

DIMENSIONS ARE IN INCHES

DO NOT SCALE DRAWING

TELEPHONE

DEONALS

303 X 203

303 X 203

GE PACKAGED POWER, L.P.

SHIPPING DATA

SIZE FROM NO. D

DWG NO. 584226

SHEET 1 OF 1

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## Liquid Fuel Requirements for GE AeroDerivative Gas Turbines

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This document lists specifications and describes application guidelines for liquid fuels that can be fired satisfactorily in GE AeroDerivative gas turbines. It is recommended that a complete specification analysis of all liquid fuels proposed for use in GE AeroDerivative gas turbines be reviewed by GE prior to use.

### 1.0 Fuel Specifications

Fuels conforming to the following military and industry specifications are acceptable for use in GE gas turbines in industrial and shipboard applications, except as noted below, and provided they also meet the additional criteria described in 2.0. However, their use should be reviewed against applicable safety and regulatory requirements.

**D50TF2** - GEAE Aviation Fuel Specification

**ISO 8217** - ISO-F-DMA (MGO)

**MIL-DTL-5624** - Grades JP-4<sup>1</sup>, JP-5 (NATO F-40, 44)

**MIL-DTL-83133** - Grade JP-8 (NATO F34/F35)

**ASTM D975** - Diesel Fuel Oil, Grades 1-D, 2-D, 1-D Low Sulfur, and 2-D Low Sulfur

**ASTM D1655** - Aviation Turbine Fuels (Jet-A, Jet-A1, and Jet-B<sup>1</sup>)

**MIL-F-16884** - Fuel Oil - Diesel Marine

(NATO F-75, F-76)

**VV-F-800** - Fuel Oil - Diesel, Grades DF-A, DF-1, and DF-2 (NATO F-54)

**ASTM D396** - Grades No. 1, 2, 4, and 4 (Light)

**ASTM D2880** - Gas Turbine Fuel Oils, Grades No. 0-GT<sup>1,2</sup>, No. 1-GT, No. 2-GT

Other:

The pure hydrocarbon combustibles<sup>2</sup> [e.g. propane (C<sub>2</sub>H<sub>8</sub>) and butane (C<sub>4</sub>H<sub>10</sub>), both normal and iso], are acceptable either alone or in various mixtures with other liquid fuels, providing that fuel manifold pressures are sufficient to maintain the fuel in the liquid state. Alternate fuels may be required for starting and low-power operation. Contact GE for specific applications.

Light distillate fuels<sup>2</sup>, such as Naphtha (C10 down to C4 hydrocarbons), gasoline (C7 to C5 hydrocarbons) and D2880 Grade No. 0-GT, are acceptable as fuels in GE AeroDerivative gas turbines provided fuel manifold pressures are sufficient to maintain fuel as a liquid, especially in hot climates. Alternative fuels may be necessary for starting the engines and low power operation. Contact GE for specific applications.

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<sup>1</sup> Highly volatile wide-cut fuels (such as MIL-DTL-5624 JP-4, ASTM D1665 Jet-B, and ASTM D2880 Grade No. 0-GT) are generally acceptable for industrial, but not shipboard applications.

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<sup>2</sup> Liquefied gas fuels, light distillates, and alcohols may have inadequate *lubricity*, requiring the use of a fuel pump/system specifically designed to handle these types of fuels. See paragraph 2.3.

Various alcohols<sup>2</sup>, [e.g. hydroxyl derivatives of hydrocarbons, such as methanol (CH<sub>3</sub>OH) and ethanol (C<sub>2</sub>H<sub>5</sub>OH)], can burn in GE aero-derivative gas turbines. Contact GE for specific applications.

## 2.0 Additional Requirements

The following requirements supplement and supersede, where there is a conflict, the specifications listed in 1.0. However, if the specification requirement is more restrictive, it applies.

### 2.1 Composition

The fuel shall consist of hydrocarbon compounds only and must be compatible between brands and batches.

While there is no specific requirement or limit on the amount of fuel-bound nitrogen (FBN) contained in a liquid fuel, it is recommended that the amount of liquid fuel FBN be understood for those applications that are sensitive to levels of oxides of nitrogen (NO<sub>x</sub>) in the gas turbine exhaust. FBN is the amount of nitrogen in the fuel that is chemically bound. During the combustion process, the FBN is converted, at least partially, to NO<sub>x</sub> (called organic NO<sub>x</sub>) and adds to the total amount of NO<sub>x</sub> that is contained in the gas turbine exhaust. GE emissions data provided for liquid fuels assumes a FBN content of less than 0.015 percent by weight unless otherwise noted.

### 2.2 Additives

The use of any dyes or additives requires approval of GE, unless such additives are specifically approved in the fuel specifications (1.0) or, they conform to MIL-S-53021A.

The purchaser may refer to the Qualified Parts List (QPL-53021) for a summary of approved stabilizer additives used in the long-term storage of diesel and distillate fuels. This publication is periodically revised, and is available from the U.S. Government Printing Office.

### 2.3 Viscosity

The viscosity of the fuel as supplied to the inlet connection on the gas turbine shall be a minimum of 0.5 centistokes<sup>3</sup> and shall be up to 6.0 centistokes maximum for starting and 12.0 centistokes maximum during operation. The fuel may be heated to meet this requirement.

### 2.4 Wax

Wax can be present in fuel oil, especially the distillates with higher pour points. It may be necessary to determine the percent of wax and its melting point and to provide a suitable method to keep the wax dissolved at all times.

### 2.5 Fuel Temperature Requirements

The minimum temperature of liquid fuel supplied to the gas turbine shall be the greater of:

- (a) 20°F (11°C) above the wax point temperature of the fuel.

or

- (b) The temperature required to remain within maximum fuel viscosity requirements, or 35°F (2°C).

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<sup>3</sup> Required for adequate GE aeroderivative gas turbine fuel pump lubrication and to prevent pump cavitation when using light fuels.

The maximum temperature of liquid fuel supplied to the gas turbine should not exceed 150°F (65.6°C). For liquid fuels with high vapor pressure constituents (naphtha, NGL, etc.) the fuel temperature in the manifold should be at least 100°F (55.6°C) below the bubble point temperature of the lightest component at high pressure compressor discharge static pressure (PS3).

### 3.0 Property Requirements

Property requirements are listed in Table 1. Contaminant limits apply to fuel samples taken at the gas turbine fuel manifold flange. It cannot be assumed that specification fuel supplied by a refinery still meets those specifications once it is delivered to the gas turbine.

### 4.0 Fuel Handling

True distillate fuel as refined has low water, dirt, and trace metal contaminant levels that can be maintained with careful transportation, handling, and storage methods. Most contamination occurs during transportation of fuel.

Since fuel can be contaminated during transportation from the refinery to the site, auxiliary fuel cleanup equipment should be available to restore the fuel quality. Available purification equipment includes centrifuges and electrostatic dehydrators. In addition to potential hot corrosion from salt in the water, water accumulated in the bottom of a storage tank can also cause problems. Microorganisms tend to grow at the water/fuel interface, generating both chemicals corrosive to metals in the fuel system and also slime that can plug fuel filters. In marine applications, shipboard systems that allow recycling fuel from the service tanks through the centrifugal purifiers are recommended.

bulk modes of transportation, it should be pumped directly into raw fuel storage tanks, and must be conditioned/treated before being placed in one of two clean fuel day storage tanks from which gas turbine will be supplied. Redundant, clean day fuel storage tanks are recommended to provide a primary *settled* fuel supply and to allow tank repair and/or cleaning with minimum downtime. Storage tanks must be constructed of corrosion-resistant materials or appropriately lined to minimize internally formed contaminants. Fuel shall not be transported, stored, or handled in system components containing copper, e.g. ships that have copper heating coils, or storage tanks coated with zinc. Neither copper or zinc are normally found in refined fuels such as diesel and naphtha, but should they be present, they can cause fuel degradation and additional engine maintenance. No fuel should be used that contains detectable amounts of copper or zinc.

Duplex, primary strainers (150-200 microns absolute) should be located between the off-loading facility and the raw fuel storage tanks. Duplex, secondary filters (50-100 microns absolute) should be located between the raw fuel storage tanks and the final fuel treatment system. All fuel storage tanks must have inlets at the bottom of the tank. All fuel day storage tanks should be provided with a floating suction. The distance between the inlet and outlet should be maximized.

After filling any tank or adding fuel to it, a settling time of 24 hours should be allowed before taking fuel from that tank. Initially, water and sludge should be drained from all storage tanks on a daily basis. After experience is gained with a given fuel and fuel source, the frequency of draining may be adjusted by the customer.

When liquid fuel is supplied by barges or other

## 5.0 Fuel Sampling

A well thought out fuel sampling protocol will ensure that quality fuel is delivered to the engine. For each delivery, fuel samples should be taken and analyzed at the following locations:

- At the refinery before loading
- At the port where the fuel is delivered before unloading
- From the pipeline just upstream of the raw fuel storage tanks as the fuel is being added to the tanks

After the fuel is treated/conditioned, samples should be taken and analyzed at both the inlet and outlet of the fuel treatment system. Fuel exiting the system must meet the fuel specification. This should be confirmed before the fuel is placed in clean fuel day storage tanks. Fuel samples should be taken and analyzed to ensure that the fuel discharged from these

tanks and at a practical location at, or just upstream of, the gas turbine fuel manifold flange meets the specification.

For all fuel sampling, sufficient samples (a minimum of three) must be taken to assure that a representative sample is obtained. Samples should be taken at different levels in large volume tanks and at equally spaced time intervals during fuel delivery or fuel treatment. To avoid contamination, all samples should be obtained in clean plastic bottles. Fuel samples taken should be analyzed to meet all GE liquid fuel requirements. If fuel samples taken after the above recommendations have been implemented indicate that the fuel system does not provide fuel per the requirements, the customer must change his fuel source or modify the fuel treatment system. The end user is responsible for ensuring that the fuel meets the requirements.

**Table 1** Liquid Fuel Property Requirements

Property	Limit	ASTM Method
Ash, %, maximum	0.01	D482
Sulfur, %, maximum	1.0 <sup>a</sup>	D129 <sup>b</sup>
Vanadium, ppm, maximum	0.2	D3605
Sodium, Potassium and Lithium, ppm, maximum	0.2 <sup>c, d</sup>	D3605 <sup>e</sup>
Lead, ppm, maximum	1.0	D3605
Calcium, ppm, maximum	2.0	D3605
Hydrogen content, %, minimum	12.7 <sup>f, k</sup>	D1018, D3701
Demulsification, minutes, maximum	20.0	D1401 and Note 3 therein
Carbon residue, %, maximum (100% sample)	1.0	D524
Carbon residue, %, maximum (10% Ramsbottoms)	0.25	D524
Particulates, mg/gal., maximum	10.0 <sup>g</sup>	D2276
Water and Sediment, volume %, maximum	0.10 <sup>h</sup>	D2709
Flash Point, oF, maximum	See i Below	D93
Copper corrosion, maximum	No. 1 <sup>j</sup>	D130
Asphaltenes, %, maximum	None Detectable	D6560

**Notes**

- a. Fuels with a higher sulfur content can be burned. Impact on HSRI (Hot Section Repair Interval) will be dependent upon alkali metals present in the fuel, inlet air, and injected water and upon engine operating temperature. Consult GE for review of higher sulfur fuels.
- b. The following alternate methods are acceptable: ASTM D1552, ASTM D2622, and ASTM D1266.
- c. This limit is considered to include all alkali metals, e.g. potassium and lithium as well as sodium. Experience, however, has shown that sodium is generally the predominant alkali metal.
- This limit also 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:
- $$\begin{aligned} &\text{ppm Na in Inlet Air} \times \text{Air/Fuel Ratio} \\ &+ \text{ppm Na in Water or Steam} \times \text{Water or Steam/Fuel Ratio} \\ &+ \text{ppm Na in Fuel} \end{aligned}$$
- Total fuel equivalence for sodium from all sources not to exceed 0.2 ppm
- d. For nonmarinized engines (except for LM6000), the total amount of alkali metals from all sources shall not exceed 0.1 ppm.
- e. To achieve the level of sensitivity for detection of sodium to the level required, an atomic absorption spectrometer or a rotating disc spectrometer may be necessary.
- f. Care must be taken with the more viscous fuels to ensure that the minimum hydrogen content is met.
- g. Maximum particle size, 20 micrometers.
- h. For marine gas turbines using a hydromechanical main fuel control, the limit is 40 ppm.
- i. Legal limits and applicable safety regulations must be met; however, it should be noted that use of fuels having a flash point in excess of 200°F (93.3°C) may result in unsatisfactory starting characteristics. Blending for enhancement of spark ignition or use of alternate fuels may be required for starting.
- j. Copper corrosion test conditions are 2 hours at 212°F (100°C).
- k. Fuels with Hydrogen content lower than 12.7% have been approved for use in certain applications with specific restrictions. These fuels require a development test program for the applicable engine model before approval would be considered.



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**GE Energy**

## **Process Specification Fuel Gases For Combustion In AeroDerivative Gas Turbines**

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*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.

<b>TABLE 1</b> <b>FUEL GAS USABILITY</b>						
<b>Fuel Type</b>	<b>LHV Btu/SCF (kJ/NM<sup>3</sup>)</b>	<b>Wobbe Number</b>	<b>Major Components</b>	<b>Operational Comments</b>	<b>Applicability SAC    DLE</b>	
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 <sup>3</sup> ) 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 <sup>3</sup> ) 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 CO<sub>2</sub> content may be acceptable for DLE application. Contact GE.

NM<sup>3</sup> is at 0°C, 101.325kPa (sea level)

**TABLE 2**  
**TEST METHODS FOR GASEOUS FUELS**

<b>PROPERTY</b>	<b>ASTM METHOD</b>
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/NM<sup>3</sup>) (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/NM<sup>3</sup>) (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/NM<sup>3</sup>). The Hydrogen (H<sub>2</sub>) content of these fuels is normally above 30% by volume and have H<sub>2</sub>/CO mole ratio between 0.5 to 0.8. Oxygen blown gasification fuels are often mixed with steam for thermal NO<sub>x</sub> 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/NM<sup>3</sup>) LHV. The Hydrogen (H<sub>2</sub>) content of these fuels can range from 8% to 20% by volume and have a H<sub>2</sub>/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<sub>x</sub> 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 H<sub>2</sub> and H<sub>4</sub>C 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 H<sub>2</sub> 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:

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

This is equivalent to:

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

Where:

- LHV = Lower Heating Value of the Gas Fuel (Btu/scf)
- SG<sub>gas</sub> = Specific Gravity of the Gas Fuel relative to Air
- MW<sub>gas</sub> = 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 <sup>(a)</sup> in gas fuels used with engines having marinized (corrosion-resistant) coatings on the high pressure turbine blading shall not exceed 0.2 ppm <sup>(b)</sup>.

- (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<sub>x</sub> 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.