Preventive Maintenance Plan

Washington Compressor Station
SOLAR Mars Turbines

Prepared for:
Vector Pipeline, LP

Project No. 190053
February 2019




Fishbeck, Thompson, Carr & Huber, Inc.
engineers | scientists | architects | constructors

ftc&h

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List of Abbreviations/Acronyms

ADAS	Automated Data Acquisition System
BTU	British thermal unit(s)
CFR	Code of Federal Regulations
CO	carbon monoxide
°F	degrees Fahrenheit
FTCH	Fishbeck, Thompson, Carr & Huber, Inc.
gr/scf	grains per standard cubic foot
HC	hydrocarbon
HP	horsepower
lb/hr	pound(s) per hour
lb/MMBtu	pound(s) per million Btus
MDEQ	Michigan Department of Environmental Quality
MMBtu/her	million Btus per hour
NGP	Natural Gas Producer Speed (expressed as percent RPM)
NO_X	nitrogen oxides
NSPS	New Source Performance Standard
O_2	oxygen
O&M	operation and maintenance
PMP	Preventive Maintenance Plan
ppm	parts per million
PSD	Prevention of Significant Deterioration
PTI	Permit-to-Install
ROP	Renewable Operating Permit
RPM	Revolutions per Minute
SO_2	sulfur dioxide
Subpart KKKK	40 CFR 60.4320(a), Subpart KKKK
tpy	tons per year
Vector	Vector Pipeline, LP

1.0 Introduction

Vector Pipeline LP (Vector) operates a natural gas compressor station in Macomb County, Michigan, which operates under a Michigan Title V Renewable Operating Permit MI-ROP-N7624 (ROP). The Washington Compressor Station includes two natural gas-fired turbines used to transport gas along Vector's 348-mile pipeline which extends from Joliet, Illinois to parts of Indiana and Michigan and into Ontario, Canada. Natural gas transported along this pipeline is used to heat homes in the winter as well as providing natural gas for power generation. The purpose of this document is to outline the Preventive Maintenance Plan (PMP) required by the ROP for the two SOLAR® Mars turbines. Following the PMP will ensure that emissions from the two turbines will continue to comply with applicable regulations and emission limits by operating within acceptable operating limits.

2.0 Process Description

The Washington Compressor Station is a part of Vector's pipeline transportation system. The two natural gas-fired turbines are used to maintain the pressure and velocity of the natural gas as it moves through the system. The turbines are SOLAR Mars Model 100 natural gas-fired turbines with a maximum heat input of approximately 120 MMBtu/hr and a rating of approximately 15,000 HP. A catalog cut sheet for the turbines is included in Appendix 1. In general, natural gas and combustion air are compressed and charged to the turbine combustor. The exhaust gases from the combustor pass through the power turbine. The single shaft through the power turbine section of the unit also drives the compressors.

The Washington turbines are equipped with Solar's $SoLoNO_X$ dry low NO_X control system. The emission control is a lean premix combustion technology which is passive in nature and is effective, provided that the turbine operating load and fuel/air mixture ratio are sufficient for the turbine to operate in $SoLoNO_X$ mode and ambient temperatures are above 0°F. Excess air is added to cool the combustion flame, which reduces peak flame temperature, reducing the rate of thermal NO_X formation. Sometimes shortening the time at the higher temperatures results in an increase in CO and HC emissions. Design changes have been made to SOLAR turbines with $SoLoNO_X$ to promote turbulence, which also reduces the formation of CO and HC emissions. Proper operation of the turbine in $SoLoNO_X$ mode is necessary to ensure compliance with emission limits for NO_X as well as CO and HC.

3.0 Defining Malfunctions

Michigan Air Pollution Control Rule R 336.1113(a) [Rule 113(a)] defines a **malfunction** as:

> *…any sudden, infrequent and not reasonably preventable failure of a source, process, process equipment, or air pollution control equipment to operate in a normal or usual manner. Failures that are caused in part by poor maintenance or careless operation are not malfunctions.*

A true malfunction must have a reasonable potential to cause:

- An operating parameter to stray from an acceptable range or value that has been established to indicate compliance with an emission limit or
- An exceedance in an established emission rate

The following emission limits apply to the two turbines:

Table 1 – Turbine Emissions Information

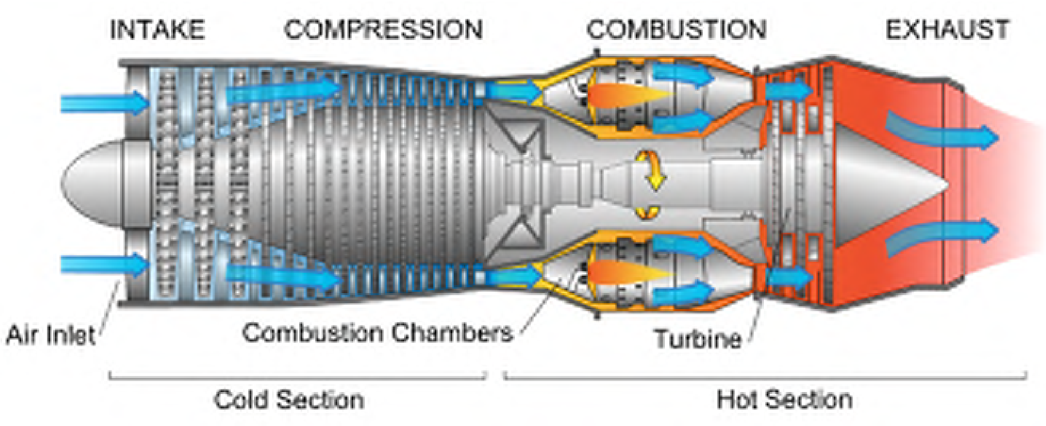
Pollutant	Emission Limit (w/averaging time)	Underlying Applicable Requirement	Comments
CO	18.8 lb/hr	Rule 205(1)(a)	Applies in the normal operating range
CO	800 lb/hr	Rule 205(1)(a)	Applies between 87 and 92% NGP
NO_X	25 ppm @15% O_2	40 CFR 60.4320(a)	Applies in normal operating range – Subpart KKKK includes alternative limits for sub-zero operation
SO_2	0.06 lb/MMBtu	40 CFR 60.4330 40 CFR 60.4335	Equivalent to 20 gr sulfur/100 scf natural gas-compliance demonstrated through fuel monitoring

The control equipment is an integral part of the turbine, though $SoLoNO_X$ only lowers NO_X emissions when ambient air (or inlet temperature) is greater than 0°F and at loads above 50%. Emissions are also higher during start-up and shutdown, though none of these operating conditions would be considered a *malfunction* as they are expected methods of operation that were anticipated in the original permitting. However, turbine operation must be returned to *$SoLoNO_X$-ON* mode as soon as possible to maintain maximum emission control.

4.0 $SoLoNO_X$ Operation

Both turbines are simple-cycle turbines equipped with SOLAR's $SoLoNO_X$ system to lower emissions. To lower NO_X emissions, fuel is injected through injection spokes, where it mixes with swirling inlet air to create a homogeneous air/fuel mixture which is then injected into the combustion chamber. The injector also includes a pilot fuel circuit which enables a portion of the fuel to be burned in the combustor with a diffusion flame. This power circuit, which is not a lean air/fuel mixture, is used for start-up and low power operation and can provide stable combustion when lean premix combustion is not sustainable. Air bleed valves are used to control air to each of the fuel injectors to control emissions. When the injector premix duct leans out to a point where CO approaches the limit during engine turn down, the bleed valve opens to restore the correct air/fuel ratio to control emissions.

Figure 1 – Turbine Combustion System



The Mars turbine includes a full annular combustor and 14 injectors. Approximately 60% of the combustion air is fed through the injectors; the remaining 40% is used to cool the combustor walls.

The turbine starts in a high pilot fuel transient mode, in which the bleed valve is nominally closed and 30% of the fuel flows through the pilot circuit to provide high combustion stability. The turbine then accelerates to the low emissions (or *normal*) mode of operation, which is above 86% NGP. At 88% NGP the bleed valve ramps open to raise the primary zone air-to-fuel ratio to the required conditions for low emissions. As engine speed increases, the bleed valve starts to close in response to the premixed flow becoming richer. Once the bleed valve has closed, the engine will operate in its low emission mode. The normal operating range for the turbine is between 92 and 103.6% NGP, or 50 to 100% load, during which emissions will always fall below the required limits.

Unfortunately, under certain operating conditions, the lean premix annular combustors have pressure pulsations, which can cause combustion instability and vibration. In these cases, pilot fuel flow is increased to stabilize combustion. CO and NO_X increase under these conditions, though combustion is quickly stabilized and the turbine can return to its low emission operating condition.

When originally permitted, Vector was able to foresee operation outside of $SoLoNO_X$ mode; in the application for PTI 182-06A, this was described as an *alternative operating scenario*.

5.0 Applicable Regulatory Requirements

The two SOLAR Mars turbines, each rated at approximately 15,000 HP, were installed in 2007 making them subject to several specific environmental regulations. Information on these applicable requirements follows.

5.1 ROP Turbine Emission Limits

The ROP contains emission limits for the turbines as outlined in Table 2.

5.2 Federal New Source Performance Standards

The ROP also contains specific requirements associated with the NSPS for turbines. New stationary combustion turbines that commence construction after February 18, 2005, are subject NSPS Subpart KKKK: *Standards of Performance for Stationary Combustion Turbines*. The standard includes NO_X and SO_2 emission limits, performance test requirements, and monitoring. Other requirements in the rule include record keeping and notifications.

The emission limits in Table 2 stem from the NSPS and apply to the turbines at Washington Compressor Station:

Table 2 – NSPS Turbine Emission Limits and Requirements

Pollutant	Limit	Monitoring and Test Method
NO_X	25 ppm@15 % ppm O_2	Annual performance test, unless <75% of permit limit, then testing can be reduced to every two years
NO_X	150 ppm@15 % O_2, at temps less than 0°C	Manufacturer's information
SO_2	0.060 lb/MMBtu	Fuel quality (tariff)

5.3 Prevention of Significant Deterioration

This facility could be a major source of CO and NO_X emissions without accepting the federally enforceable permit limits included in of the ROP as outlined below. The PSD thresholds and the project emissions are summarized in Table 3:

Table 3 – Emissions Summary and PSD Threshold Comparison

Pollutant	PSD Major Modification Threshold (tpy)	Permitted Emissions (tpy)
NO_X	250	81.34
CO	250	219.18

To ensure compliance with limits outlined in the ROP, and included in Table 3, Vector operates the $SoLoNO_X$ system on each turbine based on data gathered during stack testing of the turbines. Stack testing has been conducted for NO_X and CO above 93% NGP; emission factors were developed based on this information. Using the emission factors developed during stack testing, hourly emissions are calculated based on whether the unit is operating in $SoLoNO_X$ or outside of $SoLoNO_X$ mode.

6.0 Operation and Maintenance Requirements

The ROP requires a Preventive Maintenance Plan:

> ***IX. Other Requirements***
>
> 3. *Permittee shall maintain on site and implement a preventative maintenance plan (PMP) that ensures FGTURBINES can operate in compliance with the above emission limits. (R 336.1213(3)(a)*

Vector has adopted these O&M requirements to ensure proper operation of the turbines and compliance with emission limits.

6.1 Maintenance Activities

To ensure proper operation and acceptable emissions, maintenance activities associated with ensuring compliant emissions must be performed. Vector has developed a maintenance program in conjunction with SOLAR, the turbine manufacturer. Examples of the maintenance activities are:

- Periodic inspections of air intake and exhaust, accessory drive, fuel control systems and fuel injectors
- Test and calibrate switches, speed and temperature topping system, safety warning and shutdown devices
- Sample lube oil, analyze and replace as oil shows evidence of degradation

On any given day, the process operator(s) or maintenance personnel will conduct inspections during their normal course of facility operation. Table 4 summarizes the individuals responsible for inspecting, maintaining, and repairing the emission sources and emission controls.

Table 4 – Personnel Responsible for Maintenance

Title/Position	Contact No.
Operations Manager	269.729.4419
Technical Maintenance Coordinator	219.778.8116
O&M Technician	586.336.5086

Replacement of internal turbine components is not normally performed by staff onsite; spare parts are not generally maintained onsite. Technicians maintain some consumables onsite for making repairs and performing equipment calibration or testing (e.g., fuel filters, oil filters, and electronics). Vector relies primarily on an outside contractor to conduct periodic inspections and engine overhauls to ensure that the turbines operate optimally (SOLAR, one of their affiliates, or a similar company). In accordance with the manufacturer's scheduled maintenance requirements, the turbine is overhauled on a periodic basis (typically at/near every 30,000 hours).

6.2 Process or Operational Restrictions

The Washington turbines use $SoLoNO_X$ control technology to limit both CO and NO_X emissions. $SoLoNO_X$ technology is only available for use when loads are greater than 50%, which corresponds to an operating range of greater than 92% of NGP. **NGP** is defined as *the rotational speed [measured in percent revolutions per minute (RPM)] of the gas producer*. The turbines produce 103.6% NGP at 10,780 RPM. The optimum NGP was identified during initial stack testing; though it can be refined (i.e., expanded or limited) through additional stack testing.

To allow the capability of the operation outside of $SoLoNO_X$ mode, **operation outside of $SoLoNO_X$** was identified as an *alternative operating scenario* in the initial permit application. The parameter monitoring system on each of the turbines tracks time *in $SoLoNO_X$ mode* and *outside of $SoLoNO_X$ mode* so emissions can be estimated. Additional time outside of $SoLoNO_X$ mode will not constitute an emission exceedance; however, operating hours on each of the units may be restricted to ensure that total annual emission limits are not exceeded.

The parameter tracking associated with turbine operation must be maintained to allow proper operation of its emission monitoring system:

- Continuous monitoring of NGP to allow tracking time in $SoLoNO_X$ and outside of $SoLoNO_X$ mode, allowing compilation of hours in each mode of operation be gathered on a monthly basis.
- Continuous monitoring of NGP, based on an hourly average, to allow compilation of monthly NO_X and CO emissions.

6.3 Start-up and Shutdown

The Washington turbines are operated in a way that limits emissions during start-up, shutdown, or malfunction. As explained in the application, there may be times when the turbines must be operated outside of $SoLoNO_X$ mode; although, in general, operation outside of $SoLoNO_X$ mode is limited. Turbines have a start-up routine that is followed which ensures that the turbine will start and advance to $SoLoNO_X$ mode, where it will operate until shutdown. Shutdown also follows a specific routine to ensure the engine spends a limited time outside of $SoLoNO_X$ mode as it shuts down**. Start-u**p is defined as *the period of time from first ignition to when the turbine reaches 85% of NGP*. **Shutdown** is defined as *that period of time from the initial lowering of the turbine's speed to below 85% of NGP, with the intent to shut down*.

7.0 Record Keeping Requirements

7.1 Required Permit Records

To ensure compliance with permit emission limits, turbine operating parameters are recorded. The turbine operating mode and monitoring basis are:

- In $SoLoNO_X$ or outside of $SoLoNO_X$, for each operating hour based on %NGP
- NGP for each operating hour
- Number of startups and shutdowns, daily basis
- Natural gas consumption, daily basis
- Operating hours, daily basis

A current and valid Federal Energy Regulatory Commission Gas Tariff sheet must also be available for the natural gas burned in the turbines. This is used to show compliance with the SO_2 emission limit. A copy is included as Appendix 2.

Once operating information is collected, it is used to estimate emissions from each of the turbines on a 12-month rolling basis. This emission estimate is used to demonstrate compliance with FGFACILITY emission limits (which include emissions from the emergency generator) outlined below:

- NO_X emissions: 81.34 tpy (based on a 12-month rolling total)
- CO emissions: 219 tpy (based on a 12-month rolling total)

The permit requires use of an Automated Data Acquisition System (or ADAS) to track NGP as a percentage of maximum design producer speed. NGP of the gas turbines will be logged at least hourly. The 12-month rolling time period CO and NO_X emissions associated with FGFACILITY will be calculated. The 12-month rolling time period sum also includes those emissions associated with start-up and shutdown of the turbines.

Manufacturer's information was used to differentiate between *SoLoNO$_X$-ON* mode and *SoLoNO$_X$-OFF* mode for the two turbines. Additional testing has been performed that confirms these ranges. Based on this testing, the two turbines are assumed to be in SoLoNO$_X$-ON mode at turbine speeds of 92% or greater NGP; at an NGP of less than 92%, the turbines are assumed to be in SoLoNO$_X$-OFF mode. When operating below 85% NGP, turbines are assumed to be in either start-up or shutdown. In the event that additional stack testing is performed, the results of that stack testing can be used to establish new emission factors – upon review and approval of the MDEQ inspector.

Using the NGP and emission factor, hourly emissions are calculated and recorded from each turbine. Records required include total calculated emissions of CO and NO_X for each hour, hourly NGP, and whether the applicable turbine is operating in SoLoNO$_X$-ON or SoLoNO$_X$-OFF mode for the recorded hour. Using the most recent stack testing, a CO emission rate of 9.4 lb/hr for each turbine for SoLoNO$_X$-ON mode (92% NGP and above) and a CO emission rate of 400 lb/hr per turbine for SoLoNO$_X$-OFF mode (less than 92% NGP) will be used.

A 12-month rolling time period sum of CO and NO_X emissions for FGFACILITY is calculated for the previous 12-month period for comparison to annual emission limits. These records will be retained for a period of 5 years.

7.2 Emissions Tracking

Emissions are tracked to demonstrate compliance as follows.

Monthly CO emissions for Turbines 1 and 2, combined, are calculated using the following equation:

$$COMX = [(EFNGP > 92\% \times HRNgP > 92\%) + (EFNGP < 92\% \times HRNgG < 92\%)] \times 1/2{,}000\ (lb/ton)$$

Where:

COMX = CO emissions from the month (tons/month)
EFNGP>92% = Emission factor when the NGP speed is greater than 92% full load (lb CO/hr)
HRNPG>92% = Operating hours for the month, as obtained from the ADAS, when the NGP speed is greater than 92% of full load.
EFNGP<92% = Emission factor when the NGP speed is less than 92% full load (lb CO/hr)
HRNPG<92% = Operating hours for the month, as obtained from the ADAS, when the NGP speed is less than 92% of full load.

Monthly NO_X emissions for Turbines 1 and 2, combined, using the following equation:

$$NO_XMX = [(EFNO_X \times HR) + (\mathrm{EFNGP} < 92\%\ \mathrm{x}\ \mathrm{HRNgG} < 92\%)] \times 1/2{,}000\ (lb/ton)$$

Where:

NO_XMX = NO_X emissions from the month (tons/month)
$EFNO_X$ = Emission factor (lb NO_X/hr)
HR = Hours of operation for the month, as obtained from the ADAS.

The emission factors used for CO and NO_X emissions shall be the following:

1. $EF_{NGP>92\%}$ = 13.43 lb CO/hr
2. $EF_{NGP<92\%}$ = 400 lb CO/hr
3. EF_{NOx} = 20.0 lb NO_X/hr

Emissions from the most recent stack test can be substituted for the emissions listed above. The most recent stack testing was conducted in 2017 and includes:

Table 5 – 2017 Stack Testing Results

	NO_X		CO	
Turbine 1	93% NGP	4.6 ppm (1.4 lb/hr)	93% NGP	0.3 lb/hr
	103% NGP	6.3 ppm (2.7 lb/hr)	103% NGP	0.4 lb/hr
Turbine 2	93% NGP	9.2 ppm (2.9 lb/hr)	93% NGP	0.3 lb/hr
	103% NGP	10.6 ppm (4.7 lb/hr)	103% NGP	0.4 lb/hr

Appendix 1

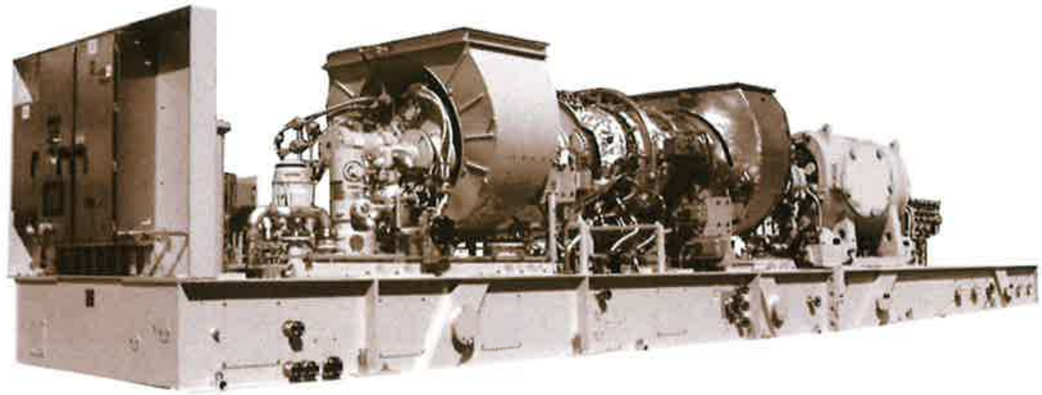
Solar Turbines

A Caterpillar Company

MARS 100

Gas Turbine Compressor Set

Oil & Gas Applications



General Specifications

Mars® 100 Gas Turbine

- Industrial, Two-Shaft
- Axial Compressor
  - 15-Stage
  - Variable Inlet Guide Vanes and Stators
  - Pressure Ratio: 17:1
  - Inlet Airflow: 41.6 kg/sec (91.8 lb/sec)
  - Max. Speed: 11,170 rpm
  - Vertically Split Case
- Combustion Chamber
  - Annular-Type
  - Conventional or Lean-Premixed, Dry, Low Emission (*SoLoNOx*™)
  - 21 Fuel Injectors (Conventional)
  - 14 Fuel Injectors (*SoLoNOx*)
  - Torch Ignitor System
- Gas Producer Turbine
  - 2-Stage, Reaction
  - Max. Speed: 11,170 rpm
  - Thrust Bearing, Active: Tilting-Pad
  - Thrust Bearing, Inactive: Fixed Tapered Land
- Power Turbine
  - 2-Stage, Axial
  - Max. Speed: 9500 rpm
  - Full Tilting-Pad Thrust Bearing
- Journal Bearings
  - Tilting-Pad
- Coatings
  - Compressor: Inorganic Aluminum
  - Turbine and Nozzle Blades: Platinum Aluminide
- Vibration Transducer Type
  - Proximity Probes
  - Velocity Pick-up

Solar® Gas Compressors

- Single Body or Tandem
- Gearbox (if required)
- Dry Gas Seal System
- Driven Equipment Monitoring

Key Package Features

- Driver and Driven Skid with Drip Pans
- 316L Stainless Steel Piping ≤4"
- Compression-Type Tube Fittings
- Digital Display Panel
- Electrical System Options
  - NEC, Class I, Group D, Div 1
  - ATEX, Zone 2
  - CENELEC, Zone 1
- *Turbotronic*™ Microprocessor Control System
  - Onskid Control System (Div 2 or ATEX, Zone 2)
  - Freestanding Control Console
  - Color Video Display
  - Vibration Monitoring
- Control Options
  - 120-Vdc Battery Charger System
  - Gas Turbine and Package Temperature Monitoring
  - Serial Link Supervisory Interface
  - Turbine Performance Map
  - Compressor Performance Map
  - Historical Displays
  - Remote Monitoring and Diagnostic Option
  - Printer/Logger
  - Process Controls
  - Compressor Anti-Surge Control
  - Field Programming
  - Predictive Emissions Monitoring
- Start Systems
  - Pneumatic
  - Direct Drive AC
- Fuel System
  - Natural Gas
- Integrated Lube Oil System
  - Turbine-Driven Accessories
  - AC Motor-Driven Accessories
- Oil System Options
  - Oil Cooler
  - Oil Heater
  - Tank Vent Separator
  - Flame Trap
- Package Skid Design
  - Accommodates *Mars* and *Titan*™ Gas Turbines
  - Optional Modifications for Floating Production Applications
  - Drop-In Lube Oil Tank
  - Modularized System Design
- Axial Compressor Cleaning Systems
  - On-Crank
  - On-Crank/On-Line
  - Portable Cleaning Tank
- Gearbox (if applicable)
  - Speed Increaser
  - Speed Decreaser
- Air Inlet and Exhaust System Options (Carbon or Stainless Steel)
- Enclosure and Associated Options
- Factory Testing of Turbine and Package
- Documentation
  - Drawings
  - Quality Control Data Book
  - Inspection and Test Plan
  - Test Reports
  - Operation and Maintenance Manuals

Solar Turbines

A Caterpillar Company

MARS 100

Gas Turbine Compressor Set

Oil & Gas Applications

Performance

Output Power	11 860 kW (15,900 hp)
Heat Rate	10 465 kJ/kW-hr (7395 Btu/hp-hr)
Exhaust Flow	153 245 kg/hr (337,850 lb/hr)
Exhaust Temp.	485°C (905°F)

Nominal Rating – ISO
At 15°C (59°F), sea level

No inlet/exhaust losses

Relative humidity 60%

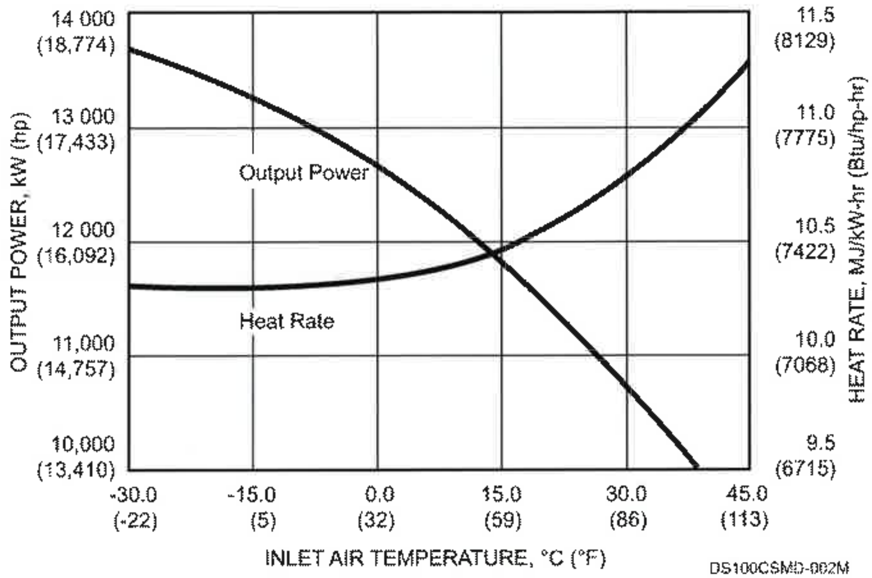
Natural gas fuel with
LHV = 35 MJ/nm³ (940 Btu/scf)

Optimum power turbine speed

AC-driven accessories

Engine efficiency: 34.4%

Available Power



Package Dimensions*

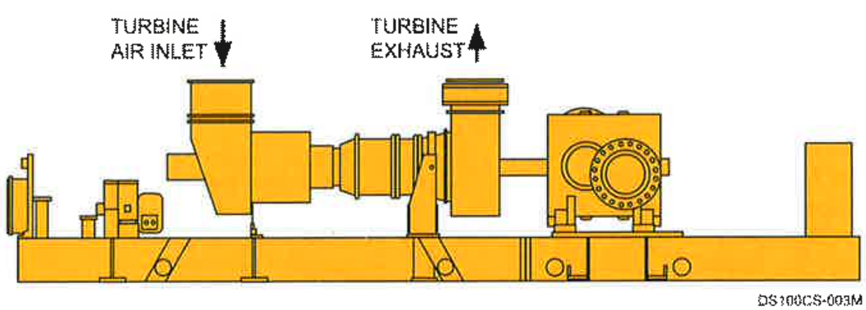
Length: 9.1 m (29' 11")

Width: 2.8 m (9' 2")

Height: 3.4 m (11' 0")

Typical Weight: 33 565 kg (74,000 lb)

**Driver package only*



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P.O. Box 85376
San Diego, CA 92186-5376

FOR MORE INFORMATION

Telephone: (+1) 619-544-5352
Internet: www.solarturbines.com

Appendix 2

2. QUALITY OF GAS

1. The Gas to be received by Transporter from Shipper shall conform to the following specifications:

(a) Shall have a minimum Gross Heating Value of 962 Btus per cubic foot and a maximum Gross Heating Value of 1100 Btus per cubic foot.

(b) Shall be commercially free, at the prevailing pressure and temperature in Transporter's pipeline, from objectionable odors, sand, dust, gums, oils, hydrocarbons liquefiable at temperatures in excess of 14 degrees Fahrenheit at the prevailing operating pressure, impurities, other objectionable substances which may become separated from the Gas, and other solids or liquids which will render it unmerchantable or cause injury to or interference with proper operations of the lines, regulators, meters or other appliances through which it flows; and shall not contain any substance not contained in the Gas at the time the same was produced other than traces of those materials and chemicals necessary for the transportation and delivery of the Gas and which do not cause it to fail to meet any of the quality specifications herein set forth.

(c) Shall contain no more than 1/4 grain of hydrogen sulphide per 100 cubic feet of Gas nor more than 20 grains of total sulphur per 100 cubic feet of Gas as determined by standard methods of testing.

(d) Shall not contain more than 4% by volume of a combined total of carbon dioxide and nitrogen components; provided, however, that the total carbon dioxide content shall not exceed 2% by volume.

(e) Shall have been dehydrated, if necessary, for removal of water present therein in a vapor state, and shall in no event contain more than 4 pounds of entrained water per MMcf of Gas as determined by standard methods of testing.

(f) Shall not exceed a temperature of 120 degrees Fahrenheit.

(g) Shall be as free of oxygen as practicable and shall not in any event contain more than 0.4% by volume of oxygen.

(h) Shall in no event contain any mix of components that will cause the presence of any liquids in the pipeline under normal operating conditions.