APPENDIX B. EMISSION SPECIFICATION SHEETS (CONFIDENTIAL)

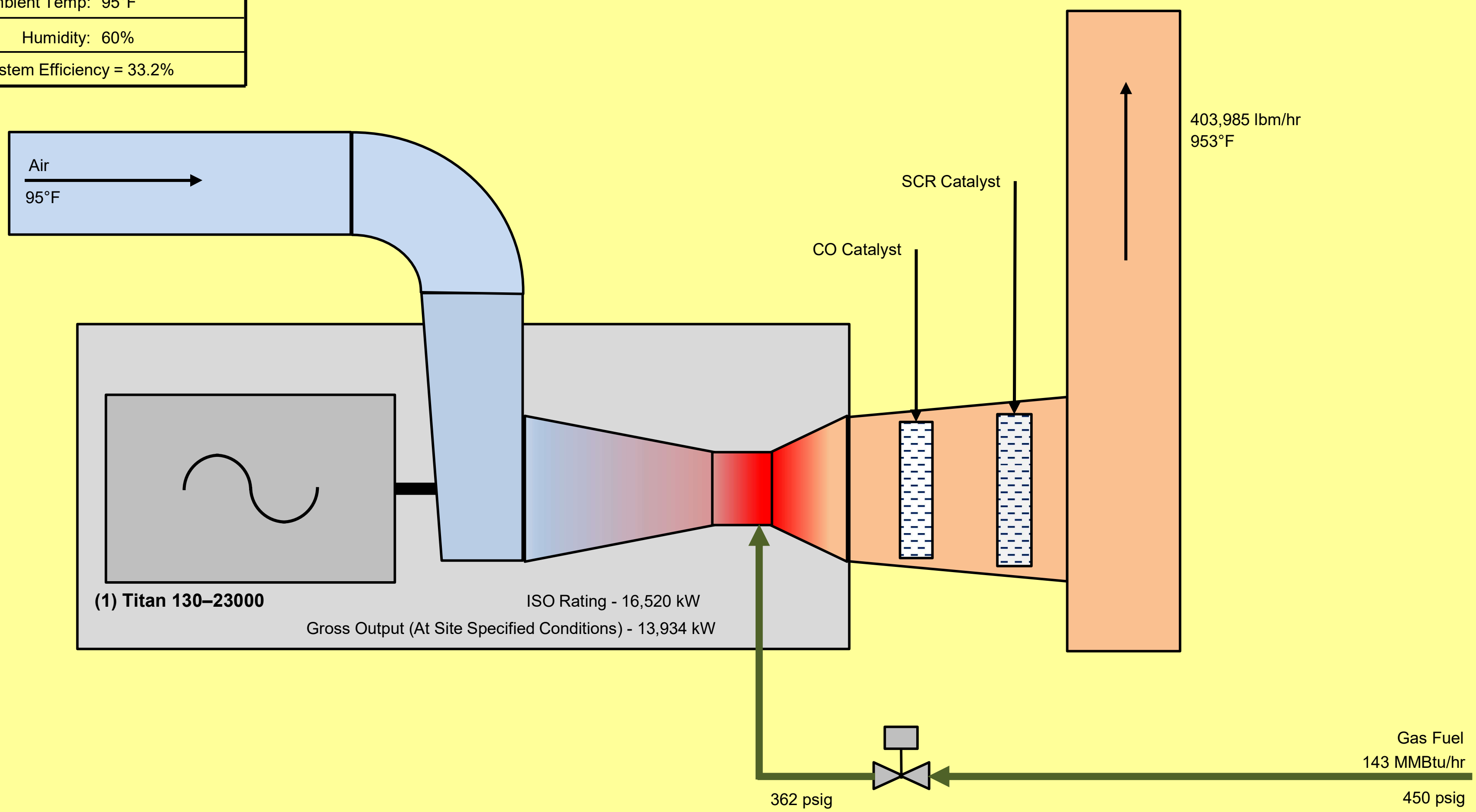
Solar Turbines
A Caterpillar Company

Pacifico Power

Specified Site Conditions
Elevation: 0 feet
Ambient Temp: 95°F
Humidity: 60%
System Efficiency = 33.2%

Predicted Stack Emissions

	ppm@15%O2	short tons/yr
NOx	2.0	5.0
CO	3.0	4.6
UHC	15	13.2



Fuel Flow(s) based on Lower Heating Value

Note: For Estimating Purposes only. For Guaranteed Performance, see your Solar Turbines Representative.

January 7, 2025

CEP Version 2501

Off Design Performance Worksheet

Pacifico Power

January 7, 2025

Prepared by Mark Hughes

Titan 130-23001S Axial
Natural Gas

	As-Designed Values						
Site Elevation	**0**						
Barometric Pressure	**29.92**						
Inlet Duct Loss	**4.0**						
Exhaust Duct Loss	**7.0**						
# of Turbines in Service	**1**	**1**	**1**	**1**	**1**	**1**	
Ambient Temperature (T1)	**95.0**	**95.0**	**95.0**	**32.0**	**32.0**	**32.0**	**°F**
Relative Humidity	**60.0**	**60.0**	**60.0**	**60.0**	**60.0**	**60.0**	**%**
Part Power (kW), % Load, or 0 for Max	**0**	**0.8**	**0.5**	**0.5**	**0.8**	**0.0**	**kW**
Engine Inlet Air Temperature (T1)	**95.0**	**95.0**	**95.0**	**32.0**	**32.0**	**32.0**	**°F**
Nominal Output Power @ Terminals	**13,934**	**10,450**	**6,967**	**8,560**	**12,840**	**17,120**	**kW**
Fuel Flow (LHV)	**142.6**	**115.1**	**93.7**	**108.0**	**134.0**	**166.2**	**MMBtu/hr**
Inlet Air Flow	**397,067**	**334,442**	**259,391**	**285,837**	**371,229**	**448,384**	**lbm/hr**
Exhaust Gas Temperature (T7)	**953**	**951**	**1,050**	**1,024**	**922**	**909**	**°F**
Exhaust Gas Mass Flow	**403,985**	**340,028**	**263,936**	**291,077**	**377,732**	**456,447**	**lbm/hr**
Exhaust Gas Volumetric Flow	**92,754**	**77,983**	**60,609**	**66,925**	**86,740**	**104,890**	**SCFM**
Nominal Electrical Efficiency @ Terminals	**33.4**	**31.0**	**25.4**	**27.1**	**32.7**	**35.2**	**%**
Nominal Electrical Heat Rate @ Terminals	**10,233**	**11,017**	**13,446**	**12,617**	**10,438**	**9,707**	**Btu/kWHR**
Exhaust Heat Captured	**67.6**	**56.1**	**50.4**	**53.6**	**59.5**	**70.3**	**MMBtu/hr**
% Argon, wet	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	
% CO2, wet	**2.9**	**2.8**	**3.0**	**3.1**	**3.0**	**3.0**	
% H2O, wet	**9.1**	**8.8**	**9.1**	**9.3**	**9.1**	**9.2**	
% N2, wet	**73.3**	**73.4**	**73.3**	**73.2**	**73.3**	**73.2**	
% Oxygen, wet	**13.8**	**14.1**	**13.8**	**13.5**	**13.8**	**13.6**	
	33.2	**Net Electrical Efficiency**				**35.0**	**%**

Fuel Flow(s) based on Lower Heating Value

Estimated Power Island Emissions

Pacifico Power

Estimated using data available as of January 7, 2025

(1) Titan 130-23001S Axial with WHRUs and CO Catalyst Emission Control Systems		Plant Total
Ambient Temperature	°F	95.0
Gross Power Output	kW	13,934
Fuel Type		Natural Gas
Assumed Fuel Sulfur Content	lbm/MMBtu*	0.000162
Gas Turbine Exhaust Flow	lbm/hr	404,000
Stack Exhaust Flow	lbm/hr	404,000
Flue Gas Temperature Leaving Gas Turbine	°F	953
Flue Gas Temperature At Stack	°F	450
Heat Input to Gas Turbine	MMBtu/hr*	158.0
PM10/PM2.5 Particulates from Gas Turbine	lbm/MMBtu*	0.01
Turbine Exhaust Gas Analysis		
H2O, assumes 60% relative humidity	% vol	9.1%
N_2	% vol	73.3%
CO_2	% vol	2.9%
O_2	% vol	13.8%
SO_2	% vol	0.0%
Argon	% vol	0.9%
Gas Turbine Exhaust Emissions		
NOx	ppm@15%O2	9.0
	lbm/hr	5.18
CO	ppm@15%O2	15.0
	lbm/hr	5.26
UHC	ppm@15%O2	15.0
	lbm/hr	3
$PM_{10}/PM_{2.5}$	lbm/hr	1.58
SO_2	lbm/hr	0.0257
CO_2	lbm/hr	18,500
Exhaust Emissions At Stack		
NOx (assumes 78% reduction SCR)	ppm@15%O2	2.0
	lbm/MMBtu*	0.00728
	lbm/hr	1.15
	short tons/yr	5.04
CO (assumes 80% reduction CO catalyst)	ppm@15%O2	3.0
	lbm/MMBtu*	0.00664
	lbm/hr	1.05
	short tons/yr	4.6
UHC	ppm@15%O2	15.0
	lbm/MMBtu*	0.019
	lbm/hr	3
	short tons/yr	13.2
VOC	ppm@15%O2	2.0
	lbm/MMBtu*	0.0038
	lbm/hr	0.601
	short tons/yr	2.63
$PM_{10}/PM_{2.5}$	lbm/hr	1.58
	lbm/MMBtu*	0.01
	short tons/yr	6.93
SO_2	lbm/hr	0.0257
	lbm/MMBtu*	0.0002
	short tons/yr	0.11
SCR Ammonia Slip	ppm@15%O2	5
SCR Reduction Efficiency	%	78%
CO Catalyst Reduction Efficiency	%	80%
VOC Catalyst Reduction Efficiency	%	0%
	lbm/MMBtu*	118

(1) Titan 130-23001S Axial with WHRUs and CO Catalyst Emission Control Systems		Plant Total
CO_2	lbm/hr	18,700
	short tons/yr	81,900
	tonne/year	74,300

*HHV

(1) Titan 130-23001S Axial with WHRUs and CO Catalyst Emission Control Systems **Plant Total**

Emissions Notes:

1. This document is for initial emissions estimates only. For air permit applications, Solar can provide appropriate site-specific turbine emissions documentation.

2. Fuels must comply with Solar specification ES 9-98. Actual emissions may vary due to site fuel characteristics. Zero fuel bound nitrogen is assumed for gaseous fuels, and less than 0.02% for liquid fuels.

3. Turbine "ppm" values are applicable for operation at ambient temperatures between -4 and 120°F.

4. The table below gives the load ranges to which the turbine ppm emissions listed above apply. Mass based estimates are valid at ambient temperature and operating load noted.

Pollutant	Load Range
NOx	50 to 100%
CO	50 to 100%
UHC	50 to 100%

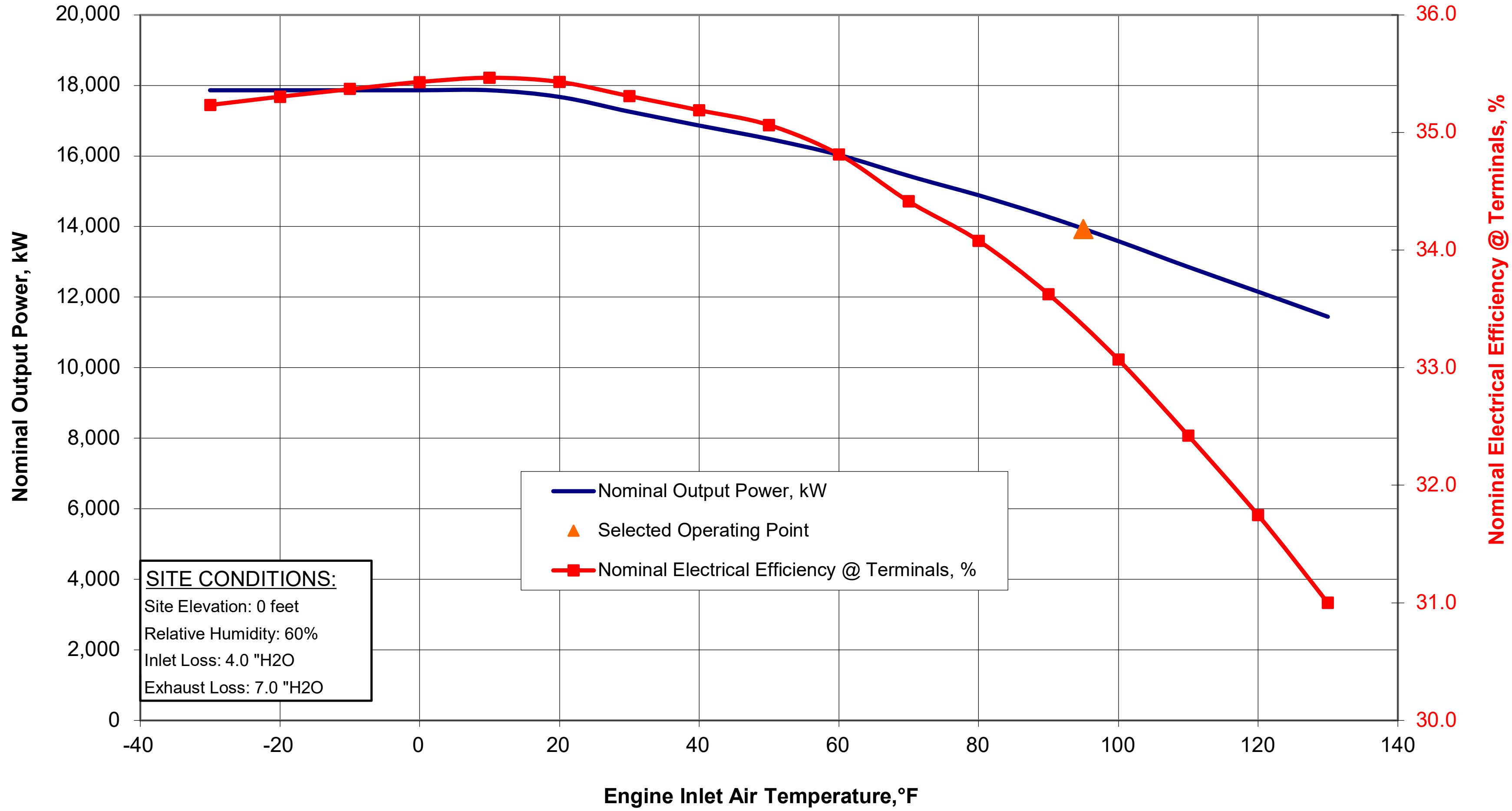
5. SO2 emissions depend upon the fuel's sulfur content. The SO2 estimate is based upon EPA's AP-42 document (Tables 3.1-2a. and 3.1-2b. April 2000).

6. Annual estimates shown above assume 8760 hours/year operation.

Contact: Mark Hughes, 858-245-8028, hughes_mark_x@solarturbines.com
 CEP Version 2501

Titan 130-23001S Axial (Natural Gas)

FULL LOAD PERFORMANCE



Caterpillar Confidential: Do not disclose without Solar's approval CEP Version 2501

Estimated Power Island Emissions

Pacifico Power

Estimated using data available as of May 21, 2025

(1) Titan 130-23001S Axial w ith WHRUs and CO Catalyst Emission Control Systems		Plant Total
Ambient Temperature	°F	95.0
Gross Pow er Output	kW	13,629
Fuel Type		Natural Gas
Assumed Fuel Sulfur Content	lbm/MMBtu*	0.000162
Gas Turbine Exhaust Flow	lbm/hr	395,600
Stack Exhaust Flow	lbm/hr	395,600
Flue Gas Temperature Leaving Gas Turbine	°F	953
Flue Gas Temperature At Stack	°F	450
Heat Input to Gas Turbine	MMBtu/hr*	155.0
PM10/PM2.5 Particulates from Gas Turbine	lbm/MMBtu*	0.01
Turbine Exhaust Gas Analysis		
H2O, assumes 60% relative humidity	% vol	9.1%
N_2	% vol	73.2%
CO_2	% vol	2.9%
O_2	% vol	13.8%
SO_2	% vol	0.0%
Argon	% vol	0.9%
Gas Turbine Exhaust Emissions		
NOx	ppm@15%O2	9.0
	lbm/hr	5.07
CO	ppm@15%O2	15.0
	lbm/hr	5.15
UHC	ppm@15%O2	15.0
	lbm/hr	2.94
$PM_{10}/PM_{2.5}$	lbm/hr	1.55
SO_2	lbm/hr	0.0251
CO_2	lbm/hr	18,100
Exhaust Emissions At Stack		
NOx (assumes 78% reduction SCR)	ppm@15%O2	2.0
	lbm/MMBtu*	0.00728
	lbm/hr	1.13
	short tons/yr	4.94
CO (assumes 80% reduction CO catalyst)	ppm@15%O2	3.0
	lbm/MMBtu*	0.00664
	lbm/hr	1.03
	short tons/yr	4.51
UHC	ppm@15%O2	15.0
	lbm/MMBtu*	0.019
	lbm/hr	2.94
	short tons/yr	12.9
VOC	ppm@15%O2	2.0
	lbm/MMBtu*	0.0038
	lbm/hr	0.588
	short tons/yr	2.58
$PM_{10}/PM_{2.5}$	lbm/hr	1.55
	lbm/MMBtu*	0.01
	short tons/yr	6.79
SO_2	lbm/hr	0.0251
	lbm/MMBtu*	0.0002
	short tons/yr	0.11
SCR Ammonia Slip	ppm@15%O2	5
SCR Reduction Efficiency	%	78%
CO Catalyst Reduction Efficiency	%	80%
VOC Catalyst Reduction Efficiency	%	0%
CO2	lbm/MMBtu*	118
	lbm/hr	18,300
	short tons/yr	80,200
	tonne/year	72,800

*HHV

Emissions Notes:

1. This document is for initial emissions estimates only. For air permit applications, Solar can provide appropriate site-specific turbine emissions documentation.

2. Fuels must comply w ith Solar specification ES 9-98. Actual emissions may vary due to site fuel characteristics. Zero fuel bound nitrogen is assumed for gaseous fuels, and less than 0.02% for liquid fuels.

3. Turbine "ppm" values are applicable for operation at ambient temperatures betw een -4 and 120°F.

4. The table below gives the load ranges to w hich the turbine ppm emissions listed above apply. Mass based estimates are valid at ambient temperature and operating load noted.

Pollutant	Load Range
NOx	50 to 100%
CO	50 to 100%
UHC	50 to 100%

5. SO2 emissions depend upon the fuel's sulfur content. The SO2 estimate is based upon EPA's AP-42 document (Tables 3.1-2a. and 3.1-2b. April 2000).

6. Annual estimates show n above assume 8760 hours/year operation.

Contact: , ,

 CEP Version 2501

Estimated Power Island Emissions

Pacifico Power

Estimated using data available as of May 21, 2025

(1) Titan 350-52500S 60 Hz with WHRUs and CO Catalyst Emission Control Systems		Plant Total
Ambient Temperature	°F	95.0
Gross Power Output	kW	30,346
Fuel Type		Natural Gas
Assumed Fuel Sulfur Content	lbm/MMBtu*	0.000162
Gas Turbine Exhaust Flow	lbm/hr	732,800
Stack Exhaust Flow	lbm/hr	732,800
Flue Gas Temperature Leaving Gas Turbine	°F	961
Flue Gas Temperature At Stack	°F	450
Heat Input to Gas Turbine	MMBtu/hr*	308.0
PM10/PM2.5 Particulates from Gas Turbine	lbm/MMBtu*	0.01
Turbine Exhaust Gas Analysis		
H2O, assumes 60% relative humidity	% vol	9.5%
N_2	% vol	73.1%
CO_2	% vol	3.2%
O_2	% vol	13.4%
SO_2	% vol	0.0%
Argon	% vol	0.9%
Gas Turbine Exhaust Emissions		
NOx	ppm@15%O2	15.0
	lbm/hr	16.8
CO	ppm@15%O2	25.0
	lbm/hr	17.1
UHC	ppm@15%O2	25.0
	lbm/hr	9.75
$PM_{10}/PM_{2.5}$	lbm/hr	3.08
SO_2	lbm/hr	0.0499
CO_2	lbm/hr	36,000
Exhaust Emissions At Stack		
NOx (assumes 87% reduction SCR)	ppm@15%O2	2.0
	lbm/MMBtu*	0.00728
	lbm/hr	2.24
	short tons/yr	9.82
CO (assumes 80% reduction CO catalyst)	ppm@15%O2	5.0
	lbm/MMBtu*	0.0111
	lbm/hr	3.41
	short tons/yr	14.9
UHC	ppm@15%O2	25.0
	lbm/MMBtu*	0.0317
	lbm/hr	9.75
	short tons/yr	42.7
VOC	ppm@15%O2	2.0
	lbm/MMBtu*	0.00633
	lbm/hr	1.95
	short tons/yr	8.54
$PM_{10}/PM_{2.5}$	lbm/hr	3.08
	lbm/MMBtu*	0.01
	short tons/yr	13.5
SO_2	lbm/hr	0.0499
	lbm/MMBtu*	0.0002
	short tons/yr	0.22
SCR Ammonia Slip	ppm@15%O2	5
SCR Reduction Efficiency	%	87%
CO Catalyst Reduction Efficiency	%	80%
VOC Catalyst Reduction Efficiency	%	0%
CO2	lbm/MMBtu*	118
	lbm/hr	36,400
	short tons/yr	159,000
	tonne/year	145,000

*HHV

Emissions Notes:

1. This document is for initial emissions estimates only. For air permit applications, Solar can provide appropriate site-specific turbine emissions documentation.
2. Fuels must comply with Solar specification ES 9-98. Actual emissions may vary due to site fuel characteristics. Zero fuel bound nitrogen is assumed for gaseous fuels, and less than 0.02% for liquid fuels.
3. Turbine "ppm" values are applicable for operation at ambient temperatures between -4 and 120°F.
4. The table below gives the load ranges to which the turbine ppm emissions listed above apply. Mass based estimates are valid at ambient temperature and operating load noted.

Pollutant	Load Range
NOx	50 to 100%
CO	50 to 100%
UHC	50 to 100%

5. SO2 emissions depend upon the fuel's sulfur content. The SO2 estimate is based upon EPA's AP-42 document (Tables 3.1-2a. and 3.1-2b. April 2000).
6. Annual estimates shown above assume 8760 hours/year operation.

Contact: , ,

 CEP Version 2501

Solar Turbines
A Caterpillar Company

IC Thomasson

Solar Turbines Engine Performance Program v.2407

Customer Name	IC Thomasson
Project Name	Pacifico Energy
Project Location	Bynum, TX
Project Filename	None - program reset to defaults or entries not saved

Project Case Name	No project case loaded

Turbine Selected/Modeled	Titan 350-52500S 60 Hz
ISO Rating	37,914 kW
Fuel Type	Natural Gas
Dual Fuel or Single Fuel?	Gas Only

Use STEPP TOOLS tab to select engine, reset selections, and access other program features

	Display selected column's results in other sheets>>>		1 ○	2 ○	3 ○	4 ○	5 ○	6 ◉
SITE CONDITIONS	Site Elevation	feet	560	560	560	560	560	560
	Ambient Temperature (T1)	°F	9	32	59	80	100	113
	Relative Humidity	%	60	60	60	60	60	60
	Barometric Pressure	"Hg	29.3	29.3	29.3	29.3	29.3	29.3
	Inlet Duct Loss	"H2O	4.0	4.0	4.0	4.0	4.0	4.0
	Exhaust Duct Loss	"H2O	7.0	7.0	7.0	7.0	7.0	7.0
	Site Fuel Gas Pressure	psig	400	400	400	400	400	400
	Process Steam Pressure	psig	150	150	150	150	150	150
	Steam Saturation Temperature	°F	366	366	366	366	366	366
	Process Steam Temperature	°F	0	0	0	0	0	0
	Steam Flow to Process	lbm/hr	1	1	1	1	1	1
	Condensate Temperature	°F	227	227	227	227	227	227
	Condensate Return	%	100	100	100	100	100	100
	Makeup Water Temperature	°F	60	60	60	60	60	60
Balance of Plant Equipment	Evap. Cooler		☐	☐	☐	☐	☐	☐
	Inlet Chiller Coil		☐	☐	☐	☐	☐	☐
	Inlet Chiller Outlet Temperature	°F	59	59	59	59	59	50
	HRSG		☐	☐	☐	☐	☐	☐
	fired HRSG		☐	☐	☐	☐	☐	☐
	Duct Burner NOx Emissions	lbm/MMBtu	0.06	0.06	0.06	0.06	0.06	0.06
	HRSG Pinch (Unfired)	°F	27.0	27.0	27.0	27.0	27.0	27.0
	HRSG Approach (Unfired)	°F	18.0	18.0	18.0	18.0	18.0	18.0
	Deaerator Pressure	psig	5.0	5.0	5.0	5.0	5.0	5.0
	Diverter Valve		☐	☐	☐	☐	☐	☐
	DA Heat Exchanger		☐	☐	☐	☐	☐	☐
	SCR		☑	☑	☑	☑	☑	☑
	CO Catalyst		☑	☑	☑	☑	☑	☑
Total Auxiliary Power Consumption	Turbine Auxiliary Power	kW	41	41	41	41	41	41
	Required Gas Fuel Pressure	psig	492	467	436	411	385	369
	Gas Compressor Power	kW	70	45	17	0	0	0
	Condensate Pump Power	kW						
	Boiler Feed Pump Power	kW						
	Total Auxiliary Power Consumption	kW	111	86	58	41	41	41
	Net Gas Turbine Power Production	kW	42,703	39,708	36,002	32,667	29,534	27,700

CONFIDENTIAL

Solar Turbines
A Caterpillar Company

IC Thomasson

Solar Turbines Engine Performance Program v.2407

Customer Name	IC Thomasson
Project Name	Pacifico Energy
Project Location	Bynum, TX
Project Filename	None - program reset to defaults or entries not saved
Project Case Name	No project case loaded
Turbine Selected/Modeled	Titan 350-52500S 60 Hz
ISO Rating	37,914 kW
Fuel Type	Natural Gas
Dual Fuel or Single Fuel?	Gas Only

Use STEPP TOOLS tab to select engine, reset selections, and access other program features

Section	Display selected column's results in other sheets>>>	Unit	1 ○	2 ○	3 ○	4 ○	5 ○	6 ◉
Gas Turbine	Inlet Chiller Load	RT						
	# of Turbines in Service		1	1	1	1	1	1
	Engine Inlet Air Temperature (T1)	°F	9	32	59	80	100	113
	Part Power (kW), % Load, or 0 for Max	kW	0	0	0	0	0	0
	Nominal Output Power @ Terminals	kW	42,814	39,794	36,060	32,708	29,575	27,741
	Fuel Flow (LHV)	MMBtu/hr	360.4	339.0	314.0	292.1	272.8	262.5
	Inlet Air Flow	lbm/hr	909,644	865,748	811,150	757,840	706,665	675,583
	Exhaust Gas Temperature (T7)	°F	876	893	917	941	968	989
	Exhaust Gas Mass Flow	lbm/hr	927,131	882,198	826,384	772,013	719,903	688,321
	Exhaust Gas Volumetric Flow	SCFM	213,890	203,732	191,483	179,971	169,663	164,067
	Nominal Electrical Efficiency @ Terminals	%	40.5	40.1	39.2	38.2	37.0	36.1
	Nominal Electrical Heat Rate @ Terminals	Btu/kWHR	8,418	8,520	8,707	8,930	9,225	9,464
	Exhaust Heat Captured	MMBtu/hr						
Turbine Exhaust Gas Analysis	% Argon, wet	%	0.9	0.9	0.9	0.9	0.9	0.8
	% CO2, wet	%	3.3	3.2	3.2	3.2	3.2	3.1
	% H2O, wet	%	6.4	6.6	7.2	8.2	10.1	12.1
	% N2, wet	%	75.6	75.4	74.9	74.1	72.6	71.0
	% Oxygen, wet	%	13.8	13.8	13.8	13.6	13.3	12.8
HRSG Performance	Unfired Steam Flow	lbm/hr						
	Fired Steam Flow	lbm/hr						
	Pegging Steam	lbm/hr						
	Steam Flow to Process	lbm/hr						
	Process Steam Temperature	°F						
	Firing Temperature	°F						
	Duct Burner Fuel Flow*	MMBtu/hr						
	Blowdown	lbm/hr						
	Feedwater Flow	lbm/hr						
	Feedwater Temperature	°F						
	Stack Exhaust Flow	lbm/hr						
	Flue Gas Temperature At Stack	°F						
Stack Gas Analysis	% Argon, wet	%	0.9	0.9	0.9	0.9	0.9	0.8
	% CO2, wet	%	3.3	3.2	3.2	3.2	3.2	3.1
	% H2O, wet	%	6.4	6.6	7.2	8.2	10.1	12.1
	% N2, wet	%	75.6	75.4	74.9	74.1	72.6	71.0
	% Oxygen, wet	%	13.8	13.8	13.8	13.6	13.3	12.8
Results	Net CHP System Efficiency*	%	40.4	40.0	39.1	38.2	36.9	36.0
	Plant Heat Rate, Btu/kWhr*	Btu/kWHR	8,440	8,538	8,721	8,942	9,238	9,478
	Net Gas Turbine Heat Rate, LHV	Btu/kWHR	8,440	8,538	8,721	8,942	9,238	9,478
	Net Gas Turbine Heat Rate, HHV	Btu/kWHR	9,364	9,473	9,675	9,921	10,249	10,516

*Fuel Flow(s) based on Lower Heating Value

CONFIDENTIAL

TITAN 350-52500S
GSC 60 Hz
59F MATCH
GAS
REV. 1.0

Fuel Type	SD NATURAL GAS						
Facility Total Demand	432000 kW						
Elevation	feet	560					
Inlet Loss	in H2O	4					
Exhaust Loss	in H2O	7					
Accessory on GP Shaft	kW	41					
Engine Inlet Temp.**	deg F	8.6	32	59	80	100	112.9
Relative Humidity	%	60	60	60	60	60	60
Based On 1.0 Power Factor							
Specified Load*	kW	FULL	FULL	FULL	FULL	FULL	FULL
NO INLET COOLING							
Turbines Running		11	12	13	15	16	18
Turbines Required		10.71	11.56	12.84	14.25	15.89	17.04
Total Output Power	kW	443,883	448,296	437,476	454,755	434,944	456,300
BOP Aux Load	kW	2,000	2,000	2,000	2,000	2,000	2,000
Turbine Aux Load	kW	41	41	41	41	41	41
Fuel Gas Heater Load per Turbine	kW	350	350	350	350	350	350
Fuel Gas Compressor Load	kW	70	45	17	-	-	-
Compressed Air System Load	kW						
Net Output Power*	kW	40,353	37,358	33,652	30,317	27,184	25,350
Fuel Flow	mmBtu/hr	360	339	314	292	273	263
Nom Net Output Power*	kW	42,814	39,794	36,060	32,708	29,575	27,741
Nom Fuel Flow	mmBtu/hr	360	339	314	292	273	263
Inlet Air Flow	lbm/hr	909,644	865,748	811,150	757,840	706,665	675,583
Engine Exhaust Flow	lbm/hr	927,131	882,198	826,384	772,013	719,903	688,321
Exhaust Temperature	deg F	876	893	917	941	968	989

Solar Turbines
A Caterpillar Company

PIL 170
Product Information Letter

Emission Estimates at Start-up, Shutdown, and Commissioning for SoLoNOx™ Combustion Products

Leslie Witherspoon

PURPOSE

The purpose of this Product Information Letter (PIL) is to provide emission estimates for start-up and shutdown events for Solar® gas turbines with SoLoNOx™ dry low emissions combustion systems.[1] For start-up and shutdown emissions estimates for conventional combustion turbines, landfill gas, digester gas, or other alternative fuel applications, contact Solar's Environmental Programs team.

INTRODUCTION

The information presented in this document is representative for both generator set (GS) and compressor set/mechanical drive (CS/MD) SoLoNOx combustion turbine applications. Operation of duct burners and/or any add-on control equipment is not accounted for in the emissions estimates. Emissions estimates related to the start-up, shutdown, and commissioning of combustion turbines will not be warranted. The estimates in this document are based on limited engine testing and analysis. The engine testing was conducted at idle and other non-SoLoNOx mode load points. An actual start-up/shutdown event was not measured.

The start-up and shutdown estimates are most commonly used for potential to emit calculations to determine air permitting status. **Solar discourages customers from accepting the estimates in this document as permit limits, with or without source testing requirements.** Accurately measuring emissions during a – non-steady state – start-up or shutdown event with steady state source test methods may prove to be very challenging. In the event customers take permit limits and accept compliance testing permit conditions, Solar recommends adding significant margin to the estimates in this document.

START-UP PROCESS

The duration of a nominal start-up is the same for a cold start, warm start, or hot start (e.g., a Solar Turbine is programmed to start-up in "x" minutes whether it's a cold, warm, or hot start).

The start-up and shutdown time for a Solar turbine in a simple-cycle or combine heat and power application is the same. Heat recovery steam generator (HRSG) steam pressure is usually 250 psig or less. At 250 psig or less, thermal stress within the HRSG is minimized and, therefore, firing ramp-up/ramp-down is not limited. However, some combined heat and power plant applications will desire or dictate longer start-up/shutdown times due to external requirements.

The start-up sequence and attaining SoLoNOx combustion mode takes three steps:

1. Purge-crank
2. Ignition and acceleration to idle
3. Loading/thermal stabilization

---

[1]Start-up and shutdown emissions for the Mercury™50 engine are found in PIL 205

During the “purge-crank” step, rotation of the turbine shaft is accomplished with a starter motor to remove any residual fuel gas in the engine flow path and exhaust. During “ignition and acceleration to idle,” fuel is introduced into the combustor and ignited in a diffusion flame mode and the engine rotor is accelerated to idle speed.

The third step consists of applying up to 50% load[2] while allowing the combustion flame to transition and stabilize. Once 50% load is achieved, the turbine transitions to SoLoNOx combustion mode and the engine control system begins to maintain the combustion primary zone temperature and limit pilot fuel to achieve the targeted nitrogen oxides (NOx), carbon monoxide (CO), and unburned hydrocarbons (UHC) emission levels.

SHUTDOWN PROCESS

Normal, planned cool down/shutdown duration varies by engine model. Once the shutdown process starts the engine unloads and moves into a cooldown mode.

START-UP AND SHUTDOWN EMISSIONS ESTIMATES

Tables 1 through 5 summarize the estimated pounds of emissions per start-up and shutdown event for SoLoNOx products. The mass emissions estimates are calculated using exhaust characteristics at ISO conditions in conjunction with ppm emissions estimates at various load points. The estimates in Tables 1 and 2 are representative of new production units ordered from 2006 up until the implementation of Enhanced Emissions Control (EEC). Tables 3 and 4 summarize emissions estimates for turbine models and ratings equipped with EEC. Enhanced Emission Control is a control regime that will result in lower CO and UHC values at lower loads thus reducing the estimated emissions per start-up and shutdown sequence. The Titan™ 250 and the Titan 130 23001/23502 (and 22401/22402) ratings have always been equipped with EEC. As testing is completed and other models/ratings are qualified and able to be equipped with the updated controls PIL170 will be updated. Reference PIL 220, specifically pages 7 and 8, for additional information about Enhanced Emission Control. Table 5 summarizes start-up and shutdown emissions estimates for liquid fuel applications.

Please contact Solar Environmental Programs, Leslie Witherspoon (858.694.6609) or Anthony Pocengal (858.505.8554) for support.

COMMISSIONING EMISSIONS

Commissioning generally takes place over a two-week period. Static testing, where no combustion occurs, usually requires one week and no emissions are expected. Dynamic testing, where combustion will occur, typically includes a number of engine start and shutdown cycles and a variety of loads will be placed on the system. It is impossible to predict how long the turbine will run and in what combustion/emissions mode it will be running. The dynamic testing period is generally followed by one to two days of final commissioning during which the turbine is running at various loads.

[2] 40% load for the Titan 250 Engine on natural gas. 65% load for all engines on liquid fuel (except 80% load for the Centaur™ 40).

Table 1: Estimation of Start-up and Shutdown Emissions (lbs/event) for SoLoNOx Generator Set Applications

Nominal Start-up and Shutdown, Natural Gas Fuel

Production Units from 2006 and without Enhanced Emissions Control

Emissions estimates will NOT be warranted.

Engine	Total Emissions Per Start (lbs)					Total Emissions Per Shutdown (lbs)				
	NOx	CO	UHC	VOC	CO2	NOx	CO	UHC	VOC	CO2
Centaur 40 4701S	1	66	62	12	247	1	67	67	13	228
Centaur 50 6201S	1	67	84	17	333	1	67	88	18	316
Taurus™ 60 7901S	1	86	110	22	338	1	89	119	24	311
Taurus 65 8701S	1	74	67	13	376	1	75	74	15	347
Taurus 70 10801S	1	78	67	13	544	1	58	52	10	411
Mars™ 90 13000S GSC	1	84	41	8	640	1	80	44	9	605
Mars 100 15000S/16000S GSC	1	81	39	8	669	1	76	42	8	616
Titan 130 20501S	3	172	138	28	832	3	174	151	30	768

Assumes ISO conditions: 59°F, 60% RH, sea level, no losses.

Assumes unit is operating at >50% load prior to shutdown.

Assumes natural gas fuel; ES 9-98 (Fuel Air and Water or Steam for Solar Gas Turbine Engines) compliant.

Table 2: Estimation of Start-up and Shutdown Emissions (lbs/event) for SoLoNOx CS/MD Applications

Nominal Start-up and Shutdown, Natural Gas Fuel

Production Units from 2006 and without Enhanced Emissions Control

Emissions estimates will NOT be warranted.

Engine	Total Emissions Per Start (lbs)					Total Emissions Per Shutdown (lbs)				
	NOx	CO	UHC	VOC	CO2	NOx	CO	UHC	VOC	CO2
Centaur 40 4702S	1	21	17	3	188	1	19	18	4	194
Centaur 50 6102S	1	21	17	3	184	1	20	19	4	169
Taurus 60 7802S	1	22	17	3	180	1	20	18	4	161
Taurus 70 10802S	1	88	88	18	381	1	78	83	17	295
Mars 90 13000S CS/MD	1	45	20	4	437	1	56	28	6	590
Mars 100 15000S/16000S CS/MD	1	46	20	4	385	1	58	28	6	490
Titan 130 20502S	1	55	37	7	662	1	61	43	9	751

Assumes ISO conditions: 59°F, 60% RH, sea level, no losses.

Assumes unit is operating at >50% load prior to shutdown.

Assumes natural gas fuel; ES 9-98 (Fuel Air and Water or Steam for Solar Gas Turbine Engines) compliant.

Table 3: Estimation of Start-up and Shutdown Emissions (lbs/event) for SoLoNOx Generator Set Applications

Nominal Start-up and Shutdown, Natural Gas Fuel

Production Units with Enhanced Emissions Control

Emissions estimates will NOT be warranted.

Engine	Total Emissions Per Start (lbs)					Total Emissions Per Shutdown (lbs)				
	NOx	CO	UHC	VOC	CO2	NOx	CO	UHC	VOC	CO2
Taurus 60 7901S GSC (Post 9/2020 Orders)	1	42	24	5	368	1	50	28	6	345
Taurus 70 10801S GSC (Post 2/2018 Orders)	1	21	26	5	552	1	16	21	4	419
Taurus 70 11101S GSC (Post 2/2018 Orders)	1	21	27	5	563	1	17	22	4	427
Mars 90 13000S GSC (Post 9/2020 Orders)	1	23	20	4	727	1	25	20	4	682
Mars 100 15000S GSC (Post 9/2020 Orders)	1	40	34	7	760	1	44	36	7	710
Mars 100 16000S GSC (Post 8/2017 Orders)	1	32	26	5	789	1	35	27	5	733
Titan 130 19501S (Post 9/2020 Orders)	1	15	17	3	842	1	15	17	3	795
Titan 130 20501S (Post 2/2018 Orders)	1	18	21	4	839	1	19	22	4	782
Titan 130 23001S (All Units)	1	24	28	6	943	1	26	30	6	885
Titan 250 30000S GSC (All Units)	2	42	22	4	1502	2	33	17	3	1159
Titan 250 31900S GSC (All Units)	2	32	18	4	1280	2	26	14	3	975

Assumes ISO conditions: 59°F, 60% RH, sea level, no losses.

Assumes unit is operating at >50% load prior to shutdown.

Assumes natural gas fuel; ES 9-98 (Fuel Air and Water or Steam for Solar Gas Turbine Engines) compliant.

Table 4: Estimation of Start-up and Shutdown Emissions (lbs/event) for SoLoNOx CS/MD Applications

Nominal Start-up and Shutdown, Natural Gas Fuel

Production Units with Enhanced Emissions Control

Emissions estimates will NOT be warranted.

Engine	Total Emissions Per Start (lbs)					Total Emissions Per Shutdown (lbs)				
	NOx	CO	UHC	VOC	CO2	NOx	CO	UHC	VOC	CO2
Taurus 60 7802S (Post 9/2020 Orders)	1	6	5	1	247	1	7	6	1	235
Taurus 70 10802S (Post 2/2018 Orders)	1	20	28	6	381	1	19	27	5	295
Mars 90 13000S CS/MD (Post 9/2020 Orders)	1	17	12	2	437	1	24	18	4	564
Mars 100 15000S CS/MD (Post 9/2020 Orders)	1	20	13	3	474	1	30	18	4	612
Mars 100 16000S CS/MD (Post 8/2017 Orders)	1	19	13	3	496	1	28	19	4	642
Titan 130 20502S (Post 9/2020 Orders)	1	11	6	1	682	1	14	8	2	762
Titan 130 22402S (All Units)	1	13	15	3	690	1	15	17	3	775
Titan 130 23502S (All Units)	1	17	19	4	767	1	20	23	5	869
Titan 250 30000S CS/MD (All Units)	2	33	13	3	1172	2	28	11	2	1036
Titan 250 31900S CS/MD (All Units)	1	21	8	2	987	1	18	7	1	880

Assumes ISO conditions: 59°F, 60% RH, sea level, no losses.

Assumes unit is operating at >50% load prior to shutdown.

Assumes natural gas fuel; ES 9-98 (Fuel Air and Water or Steam for Solar Gas Turbine Engines) compliant.

Table 5: Estimation of Start-up and Shutdown Emissions (lbs/event) for SoLoNOx Generator Set Applications

Nominal Start-up and Shutdown, Liquid Fuel (Diesel #2)

Emissions estimates will NOT be warranted.

Engine	Total Emissions per Start (lbs)					Total Emissions per Shutdown (lbs)				
	NOx	CO	UHC	VOC	CO2	NOx	CO	UHC	VOC	CO2
Centaur 40 4701S	1	11	1	1	420	1	12	1	1	388
Centaur 50 6201S	1	15	1	1	471	1	17	1	1	439
Taurus 60 7901S	1	14	1	1	510	1	16	1	1	467
Taurus 70 10801S	2	27	2	2	754	1	22	1	1	568
Mars 100 16000S GSC	2	19	1	1	821	2	25	2	2	804
Titan 130 20501S	2	32	2	2	1189	2	35	2	2	1106
Titan 130 23001S	2	27	2	2	1231	2	29	2	2	1132
Titan 250 30000S GSC	5	7	1	1	2188	4	6	1	1	1656
Titan 250 31900S GSC	4	5	1	1	2172	3	4	1	0	1643

Assumes ISO conditions: 59°F, 60% RH, sea level, no losses.

Assumes unit is operating at >50% load prior to shutdown.

Assumes natural gas fuel; ES 9-98 (Fuel Air and Water or Steam for Solar Gas Turbine Engines) compliant.

Volatile Organic Compound, Sulfur Dioxide, and Formaldehyde Emission Estimates

Leslie Witherspoon

PURPOSE

This Product Information Letter (PIL) summarizes emission factors commonly utilized to estimate emissions of volatile organic compounds (VOC), sulfur dioxide (SO_2), and formaldehyde from gas turbines.

Volatile Organic Compounds

Many permitting agencies require gas turbine users to include emissions of VOC, a subpart of the unburned hydrocarbon (UHC) emissions, during the air permitting process. Volatile organic compounds, non-methane hydrocarbons (NMHC), and reactive organic gases (ROG) are different ways of referring to the non-methane (and non-ethane) portion of an "unburned hydrocarbon" emission estimate.

For natural gas fuel, Solar's customers often use 10-20% of the UHC emission rate to conservatively estimate VOC emissions. Solar can offer a 5 ppm VOC warranty level upon request. For liquid fuel, it is appropriate to estimate that 100% of the UHC estimate is VOC. The emissions estimates are assumed valid for natural gas at ambient temperatures >-4°F (-20C) from 50-100% load (80-100% load for the Saturn® 20 and >-20°F (-29C) and 40-100% for the Titan™ 250) and for liquid fuel from 65-100% load (80-100% for the Saturn 20 and Centaur® 40).

Environmental Protection Agency (EPA's) AP-42[1] document and WebFIRE[2] database also contain VOC emission estimates for gas turbines. These sources are not commonly used by Solar's customers.

Sulfur Dioxide

Sulfur dioxide emissions are produced by conversion of any sulfur in the fuel to SO_2. Solar customers usually either use a mass balance calculation or reference AP-42 to estimate SO_2 emissions. Because Solar does not control the amount of sulfur in the fuel, no SO_2 emissions warranty is available.

The mass balance method assumes that any sulfur in the fuel converts to SO_2. For reference, the typical mass balance equation is shown below.

$$\frac{\text{lb SO2}}{\text{hr}} = \left(\frac{\text{wt\% Sulfur}}{100}\right)\left(\frac{\text{lb fuel}}{\text{Btu}}\right)\left(\frac{10^6\ \text{Btu}}{\text{MMBtu}}\right)\left(\frac{\text{MMBtu fuel}}{\text{hr}}\right)\left(\frac{\text{MW SO2}}{\text{MW Sulfur}}\right)$$

Variables: wt% of sulfur in fuel
Btu/lb fuel (LHV)
MMBtu/hr fuel flow (LHV)

As an alternative to the mass balance calculation, EPA's AP-42 document can be used. AP-42 (Table 3.1-2a, April 2000) suggests emission factors of 0.94S lb/MMBtu (HHV) (where S=Sulfur % in fuel) or 0.0034 lb/MMBtu (HHV) for gas fuel and 1.01S lb/MMBtu (HHV) (where S=Sulfur% in fuel) or 0.33 lb/MMBtu (HHV) for liquid fuel.

[1] AP-42 is an EPA document containing a compilation of air pollutant emission factors by source category.
[2] WebFIRE is an EPA electronic based repository and retrieval tool for emission factors.

Formaldehyde

For gas turbines, formaldehyde emissions are a result of incomplete combustion and are unstable in the exhaust stream. In this section, regulatory background, recommended emission factors, and testing considerations are discussed.

Regulatory Background and Emissions Factors – U.S. and EU

In 2004 the U.S. EPA published a Maximum Achievable Control Technology (MACT) standard (40 CFR 63 Subpart YYYY) for natural gas fired combustion turbines with a formaldehyde limit of 91 ppb (15% O2). The standard was stayed a few months later for the natural gas subcategories essentially rendering the regulation "on hold". The stay was lifted on March 9, 2022. After ~18 years of not having to comply with the MACT standard, natural gas fired combustion turbines located **at major sources of hazardous air pollutants** need to comply with the standard. The initial compliance date is September 4, 2022. With the lifting of the stay, four of the eight subcategories outlined in the Subpart YYYY must comply with the MACT standard. They are:

- stationary lean premix combustion turbines when firing gas and when firing oil at sites where all turbines fire oil no more than an aggregate total of 1,000 hours annually
- stationary lean premix combustion turbines when firing oil at sites where all turbines fire oil more than an aggregate total of 1,000 hours annually
- stationary diffusion flame combustion turbines when firing gas and when firing oil at sites where all turbines fire oil no more than an aggregate total of 1,000 hours annually
- stationary diffusion flame combustion turbines when firing oil at sites where all turbines fire oil more than an aggregate total of 1,000 hours annually

For U.S. customers with a combustion turbine that must comply with Subpart YYYY, an emission factor of 91 ppb @ 15% O2 (~0.00021 lb/MMBtu HHV) is recommended.

The formaldehyde emissions estimate of 91 ppb @15%O2 (~0.00021 lb/MMbtu HHV) can be used for all new, current production, SoLoNOx models and ratings when firing pipeline quality natural gas or ultra-low sulfur (ULSD) diesel fuel. The emissions estimate is valid for natural gas from 50-100% load (40-100% load for Titan 250) or for liquid fuel from 65-100% load (80-100% load for the Centaur 40) and at ambient temperatures >-4°F (-20C) [> -20 °F (-29C) for Titan 250].

Alternative emission factors for combustion turbines **not** affected by Subpart YYYY (or non-U.S. based combustion turbines) are from U.S. EPA's AP-42 document and are 0.00071 lb/MMBtu (HHV) for natural gas and 0.00028 lb/MMBtu (HHV) for distillate oil[3]. Note that both of the aforementioned formaldehyde emission factors are higher than the MACT standard. Since ~2003 many gas turbine users have used the emission factors found in an EPA memo <u>Revised HAP Emission Factors for Stationary Combustion Turbines</u>[4] for estimating hazardous air pollutant emissions. The memo presents hazardous air pollutant emission factor data in several categories. While the memo presents several formaldehyde emissions factors, the most common formaldehyde emission factor used to estimate emissions from gas turbines from this document is 0.00288 lb/MMBtu HHV (Table 16). Note that this emission factor is an order of magnitude higher than the MACT standard.

In the EU, Germany has established a formaldehyde limit of 5 mg/Nm3 for combustion turbines (13.BImSchV Section 33). This limit applies for operation at 70-100% load and it is anticipated that something similar will be adopted in other EU member states. The 5 mg/Nm3 limit is equivalent to ~0.0038 kg/GJ or ~3.7 ppm.

Formaldehyde Emissions Testing Considerations

Actual emissions of formaldehyde from Solar's gas turbines, in the SoLoNOx operating range, are predicted to be less than 91 ppb @15%O2. However, **the 91 ppb level can only be verified if the proper testing equipment is utilized.** To properly measure formaldehyde emissions, Fourier Transform Infrared (FTIR) instrumentation with limits of detection well below the standard must be utilized. Most "traditional" FTIR systems have formaldehyde

[3] AP-42, Table 3.1-3 for Natural Gas and Table 3.1-4 for Distillate Oil, 4/00.

[4] Revised HAP Emission Factors for Stationary Combustion Turbines, OAR-2002-0060, IV-B-09,8/22/03.

limits of detection in the 120-150 ppb range and are not suitable to measure formaldehyde from combustion turbines.

Solar recommends the MKS Multi Gas 2030 FTIR with StarBoost™ System, the Spectrum WaveRunIR-EXT or an equivalent system with similar path lengths and detection levels.

EPA Method 320 (or equivalent method for non-U.S. testing) should be used to measure formaldehyde. Testing should include three – 120-minute test runs. To ensure accurate formaldehyde measurements, the testing company, in addition to following the requirements of Method 320 (or equivalent method), should take necessary steps to optimize signal-to-noise, verify the FTIR is fully temperature stabilized and purged, ensure the FTIR signal is optimized before testing by maximizing alignment and cleanliness of optics, minimize sampling line bias by using clean sample lines at 250°F to prevent off-gassing and minimize contamination with other compounds, verify absence of sampling system bias via system zero measurements, measure a source specific moisture spectrum while at the test site using a water/N2 delivery systems at +/-10% of turbine moisture content, and use the source specific water spectrum as an interferent in the analysis.