APPENDIX B

Emissions Calculations and Sample Calculation

Table B.1 Stoichiometric Combustion

Fuel Components	Fuel Composition			Air (lb)/Fuel (lb)		Total Air Required per 100 mol fuel (lb)	Combined Products (lb)/ Fuel (lb)			Total Combined Products (lb)/ mol Fuel	Average Molecular Weight of Products
	lb/mol	mol %	lb/100 mol fuel	O_2	N2a		CO_2	H_2O	N2a		
Methane	16.04	92.79	1488.61	3.99	13.25	25656.22	2.74	2.25	13.25	27144.83	27.74
Ethane	30.07	4.16	125.09	3.72	12.37	2012.82	2.93	1.80	12.37	2137.91	28.23
Propane	44.10	0.84	37.04	3.63	12.05	580.62	2.99	1.63	12.05	617.66	28.43
n-Butane	58.12	0.18	10.46	3.58	11.88	161.75	3.03	1.55	11.88	172.22	28.54
n-Pentane	72.15	0.04	2.89	3.55	11.78	44.24	3.05	1.50	11.78	47.13	28.61
Hexane	86.18	0.04	3.45	3.53	11.71	52.53	3.06	1.46	11.71	55.98	28.65
CO_2	44.01	0.44	19.36				1.00			19.36	44.01
H_2S	34.08	0.00	0.00	1.41	4.68	0.02	1.88	0.53	4.68	0.02	29.75
N_2	28.01	1.51	42.30						1.00	42.30	28.16
Total		100.00	1729.21			28508.20				30237.42	27.80

Table B.2 Flow Parameters for Modeling

Temperature	T = 40 °F			T = 0 °F		
	% load			% load		
Parameters	**100**	**75**	**50**	**100**	**75**	**50**
Exit Temperature (°F)	924	885	888	867	845	833
Exit Temperature (°C)	496	474	476	464	452	445
Exit Temperature (K)	769	747	749	737	725	718
Exit flow (lb/hr)	150,581	139,798	126,211	161,294	152,958	139,444
Fuel Flow (MMBtu/hr, LHV)	52.23	43.86	36.63	54.56	47.19	39.23
Fuel Flow (cf/hr @ 60 °F)	55,611	46,699	39,001	58,092	50,245	41,770
Fuel Flow (lb/hr)	2,534	2,128	1,777	2,647	2,290	1,903
Stoichiometric Air Demand (lb/hr)	41,779	35,084	29,300	43,642	37,747	31,380
Exhaust from Stoichiometric Combustion (lb/hr)	44,313	37,212	31,078	46,290	40,037	33,283
Air flow into turbine (lb/hr)	148,047	137,670	124,434	158,647	150,668	137,541
Average MW of exhaust	28.61	28.65	28.67	28.62	28.65	28.68
Exhaust air flow (acfm)	88,588	79,834	72,176	90,955	84,736	76,466
Stack Diameter (in)	72.0	72.0	72.0	72.0	72.0	72.0
Stack Diameter (m)	1.83	1.83	1.83	1.83	1.83	1.83
Exit Velocity (ft/s)	52.22	47.06	42.54	53.61	49.95	45.07
Exit Velocity (m/s)	15.92	14.34	12.97	16.34	15.22	13.74

Notes: Gas heat input: 939.2 Btu/scf (LHV)
Specific Gravity: 0.597
Molar volume of gas at T= 60°F and P = 14.696 psia: 379.5 cf/lb-mol
Molecular weight of air: 28.966

Table B.3 Emissions from the Proposed New Turbine (Centaur 50-6200LS) under Normal Operation, Ambient T > 0 °F

Pollutants	Vendor Guarantees (1)		Emission Factors (2) (lb/MMBtu, HHV)		Load = 100% Hourly Emissions (lb/hr)		Load = 75% Hourly Emissions (lb/hr)		Load = 50% Hourly Emissions (lb/hr)	
					T = 0 °F	T = 40 °F	T = 0 °F	T = 40 °F	T = 0 °F	T = 40 °F
				MMBtu/hr	54.5	52.2	47.19	43.86	39.23	36.63
				MMBtu/hr	60.5	57.9	52.38	48.68	43.55	40.66
NOx	25.00	ppmvd @ 15% O_2	0.092		5.57	5.34	4.82	4.48	4.01	3.74
CO	50.00	ppmvd @ 15% O_2	0.112		6.79	6.50	5.87	5.46	4.88	4.56
UHC (3)	25.00	ppmvd @ 15% O_2	0.032		1.94	1.86	1.68	1.56	1.39	1.30
PM_{10} (4)	N/A									
Filterable			0.0047		0.28	0.27	0.25	0.23	0.20	0.19
Condensible			0.0019		0.11	0.11	0.10	0.09	0.08	0.08
Total			0.0066		0.40	0.38	0.35	0.32	0.29	0.27
SO_2 (4)	N/A		0.0034		0.21	0.20	0.18	0.17	0.15	0.14
Total HAP (5)	N/A		0.00305		0.18	0.18	0.16	0.15	0.13	0.12
Formaldehyde (5)	N/A		0.00288		0.17	0.17	0.15	0.14	0.13	0.12
CO_2 (4)	N/A		110		6,658	6,373	5,762	5,355	4,790	4,473

Notes: (1) From Solar Turbines Engine Performance Sheet - Centaur 50-6200LS
(2) ppmvd @ 15% O2 converted to lb/MMBtu using Fd factor of 8710 dscf/MMBtu (HHV) (EPA default)
(3) UHC is a conservative estimate for VOC; Solar suggests assuming VOC = 10-20% of UHC emissions (see PIL 168, included in Appendix B)
(4) Source for Emission Factor = AP-42, Table 3.1-2a, dated 4/00.
(5) Solar Turbines Product Information Literature 168 (included in Appendix B), 95% Upper Confidence of Data emission factors.

Table B.4 Emissions from Centaur 50-6200LS under Normal Operation, Ambient T = 0 to -20°F

Pollutants	Exhaust Concentrations (ppm) (6)
NOx[4]	42
CO[4]	100
VOC (=UHC)[4]	50

Notes: (6) Solar Turbines Product Information Literature 167.

Table B.5 Emissions from Centaur 50-6200LS during Startup and Shutdown Events

Pollutants	Emissions (lb/event) (7)
NOx	1.1
CO	23
VOC (=UHC)	1.9

Notes: Event = 1 startup + 1 shutdown, total duration = 14 minutes
(1) Solar Turbines Product Information Literature 170

Table B.6 Annual Emissions for the Centaur 50-6200LS Turbine under 50, 75, and 100% Loads

	Load = 100%				Load = 75%				Load = 50%			
	8760 @ Normal (tons/year)	Corr. for 0-20 °F (tons/year)	Corr. for Startups/ Shutdowns (tons/year)	Total (tons/year)	8760 @ Normal (tons/year)	Corr. for 0-20 °F (tons/year)	Corr. for Startups/ Shutdowns (tons/year)	Total (tons/year)	8760 @ Normal (tons/year)	Corr. for 0-20 °F (tons/year)	Corr. for Startups/ Shutdowns (tons/year)	Total (tons/year)
NO_x	23.4	0.5	0.00	**23.9**	19.6	0.5	0.01	**20.1**	16.4	0.4	0.03	**16.8**
CO	28.5	1.0	2.69	**32.1**	23.9	0.8	2.72	**27.4**	20.0	0.7	2.74	**23.4**
UHC	8.1	0.3	0.18	**8.6**	6.8	0.2	0.19	**7.3**	5.7	0.2	0.20	**6.1**
PM_{10}												
Combustion	1.2			**1.2**	1.0			**1.0**	0.8			**0.8**
Sulfates	0.5			**0.5**	0.4			**0.4**	0.3			**0.3**
Total	1.7			**1.7**	1.4			**1.4**	1.2			**1.2**
SO_2	0.9			**0.9**	0.7			**0.7**	0.6			**0.6**
HAP	0.8			**0.8**	0.7			**0.7**	0.5			**0.5**
Formaldehyde	0.7			**0.7**	0.6			**0.6**	0.5			**0.5**
CO_2	27,913			**27,913**	23,456			**23,456**	19,590			**19,590**

Notes: Based on 8760 hour/total operation including 300 hr/year at 0-20 °F and 250 startups/shutdown events/year

Table B.7 Emissions from Normal Operation of Proposed Emergency Engine, Ambient T > 0 °F

Pollutants	NSPS Exhaust Emission Limits (1) (g/bhp-hr)	Emission Factor (lb/MMBtu, HHV)	Hourly Emissions (lb/hr) 4.21 MMBtu/hr (LHV)	Hourly Emissions (lb/hr) 4.68 MMBtu/hr (HHV)(2)
NOx	2.00	0.401		1.87
CO	4.00	0.802		3.75
VOC	1.00	0.200		0.94
PM_{10} (3)				
Filterable	N/A	0.0001		0.0004
Condensible		0.0099		0.046
Total		0.0100		0.047
SO_2 (3)	N/A	5.88E-04		0.003
CO_2 (3)	N/A	110		514

Notes: Gas Characteristics: LHV: 939.2 Btu/scf
HHV: 1042.5 Btu/scf

(1) From New Source Performance Standards (NSPS) exhaust emission limits for emergency engines greater than or equal to 130 hp, manufactured after January 1, 2009.
(2) The potential fuel heat input was calculated using a conservative estimate of 11,000 Btu/hp-hr (HHV) for fuel efficiency
(3) Source for Emission Factor = AP-42, Table 3.2-2, dated 7/00.

Table B.8 Annual Emissions for the Proposed Emergency Engine (Based on 500 hr/year Total Operation)

Pollutants	Annual Emissions under Normal Operating Conditions (tons/year)
NO_x	0.47
CO	0.94
VOC	0.23
PM_{10}	
Combustion	0.0001
Sulfates	0.0116
Total	0.0117
SO_2	0.0007
HAP	N/A
Formaldehyde	N/A
CO_2	128.6

Table B.9 Emissions from Fuel Gas Heater, Space Heater, and Water Heater under Normal Operating Conditions

Pollutants	Emission Factors lb/10^6 scf	Emission Factors (lb/MMBtu)(3)	Hourly Emissions (lb/hr)
NOx(1)	100	0.098	0.39
CO(1)	84	0.082	0.33
VOC(2)	5.5	0.005	0.022
PM_{10} (2)			
Filterable	1.9	0.002	0.0075
Condensible	5.7	0.006	0.022
Total	7.6	0.007	0.030
SO_2 (2)	0.6	0.001	0.0024
CO_2 (2)	120,000	118	471

Notes: Heat Input: 4.0 MMBtu/hr

(1) Source for Emission Factor = AP-42, Table 1.4-1, dated 7/98, for uncontrolled small (<100 MMBtu/hr) burners.

(2) Source for Emission Factor = AP-42, Table 1.4-2 dated 7/98.

(3) Source for Conversion Factor = AP-42, Table 1.4-2, dated 7/98.

Table B.10 Annual from Fuel Gas Heater, Space Heater, and Water Heater (Based on 8760 hr/year Total Operation)

Pollutants	Annual Emissions under Normal Oper .ting Conditions (tons/year)
NO_x	0.429
CO	0.361
UHC	0.024
PM_{10}	
Combustion	0.008
Sulfates	0.024
Total	0.033
SO_2	0.003
HAP	N/A
Formaldehyde	N/A
CO_2	515.29

Table B.11 Summary of Annual Potential Emissions Calculations - TGP Concord Compressor Expansion Project

Pollutant	Centaur Turbine (tons/yr)	Emergency Engine (tons/yr)	3 Small Sources (tons/yr)	Total Annual Emissions (tons/yr)
NO_x	23.91	0.47	0.43	24.81
CO	32.11	0.94	0.36	33.41
VOC	8.59	0.23	0.024	8.85
PM_{10}				
Filterable	1.19	0.0001	0.008	1.20
Condensible	0.48	0.012	0.024	0.52
Total	1.67	0.012	0.033	1.72
SO_2	0.86	0.0007	0.003	0.87
CO_2	27,913	129	515	28,556

Sample Calculation: Determining NOx Emissions Turbine Centaur 50-6200LS

Given:

Fuel Gas Properties:

Fuel Lower Heating Value: 939.2 Btu/scf (provided by Solar)
Fuel Higher Heating Value: 1,042.5 Btu/scf (Solar value multiplied by 1.1)
Fuel Flow: 52.2 MMBtu/hr (provided by Solar)

Operating Conditions:

- Normal at 100% Load and 40°F
- Annual Operation: 8760 hours/year
- Maximum Concentration of NOx at standard conditions with 15% excess O_2 (volume basis): 25 ppmvd (provided by Solar)

1. Calculating Emission Factor for NOx Using EPA Method 19

US EPA Method 19 contains extensive procedures for calculating emissions for PM, NOx, and SO_2, and for calculating SO_2 removal efficiency for electric utility steam generators. Many regulations prefer PM, SO_2, and NOx emission rates to the heat input to the boiler as pounds/million Btu (lb/MMBtu). In order to calculate these values, the emission rates must be corrected by F factors. The F factor is the ratio of the gas volume of the products of combustion to the heat content of the fuel. F_d includes all components of combustion less water. F_d can be calculated from fuel analysis results. The F_d factor for natural gas is 8,710 dscf/MMBtu.

The emission factor for NOx was calculated using the following equation:

$$EF_x = (C_d \times F_d) * \left[\frac{20.9}{20.9 - \%O_2} \right]$$

Where: EF_x = Emission factor in lb/MMBtu of pollutant X
C_d = Pollutant concentration (lb/dscf)
F_d = F factor (dscf/MMBtu)

First NOx concentration must be converted from ppmvd to lb/dscf using the conversion:

1 ppm NOx = 0.0000001194 lb/dscf, at 0% O_2 (EPA Reference Method 19, Table 19-1)

With the concentration of 25 ppmvd guaranteed by Solar, the conversion would be the following:

25 ppm NOx = 0.000002985 lb/dscf NOx at 0% O_2

Inputting values into the above equation yields:

$$EF_x = (0.000002985 \times 8{,}710) * \left[\frac{20.9}{20.9 - 15}\right] = 0.092\, lb / MMBtu\,(HHV)$$

Therefore the emission factor for NOx is 0.092 lb/MMBtu.

2. Calculating Hourly and Annual NOx Emissions

The fuel flow, 52.2 MMBtu/hr, is adjusted for the gas HHV (below).

$$Fuel\ Flow_{(HHV)} = 52.2\, MMBtu / hr * \left(\frac{1042.5}{939.2}\right) = 57.9\, MMBtu / hr$$

By multiplying the adjusted fuel flow and the calculated NOx emission factor, the hourly NOx emission can be determined (below).

$$EF = \left(\frac{57.9 MMBtu}{hr}\right) \cdot \left(\frac{0.092 lb}{MMBtu}\right) = 5.34\, lb / hr$$

Therefore the hourly NOx emissions are 5.34 lb/hr.

The annual NOx emissions are calculated by assuming operation of 8760 hours/year.

$$\left(\frac{5.34 lb}{hr}\right) \cdot \left(\frac{8760\, hr}{year}\right) \cdot \left(\frac{ton}{2000\, lb}\right) = 23.4\, tons / year$$

The annual NOx emissions generated by the Centaur 50-6200LS Turbine under normal operations at 100% and 40°F are 23.4 tons/year.