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MEASUREMENT AND VERIFICATION PLAN

FOR

COOP CITY – RIVERBAY CORP.

Revised

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Submitted to:

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1. Introduction

Riverbay Corporation manages the Co-op City Complex located in the Bronx that includes 15,372 units and about 60,000 residents. The physical plant complex for complex is located on the corner of Bartow Ave and Co-op City Blvd (Figure 1). Riverbay has submitted an application to the NYSERDA CIPP program to install a 38 MW Combined Cycle CHP system at their campus in the Bronx, New York. The Plant will include two 12.5 MW Siemens Combustion Turbines (CTs), two Once-Through Steam Generators (OTSGs) to generate 850 psig steam, and a 13 MW steam turbine generator. The steam exiting the turbine at 150 psig will be used to meet campus heating loads in the winter and to drive steam-turbine centrifugal chillers in the summer. The combustion turbines can operate on natural gas or fuel oil. A Siemens T-3000 digital control system is being installed to operate and monitor plant performance.

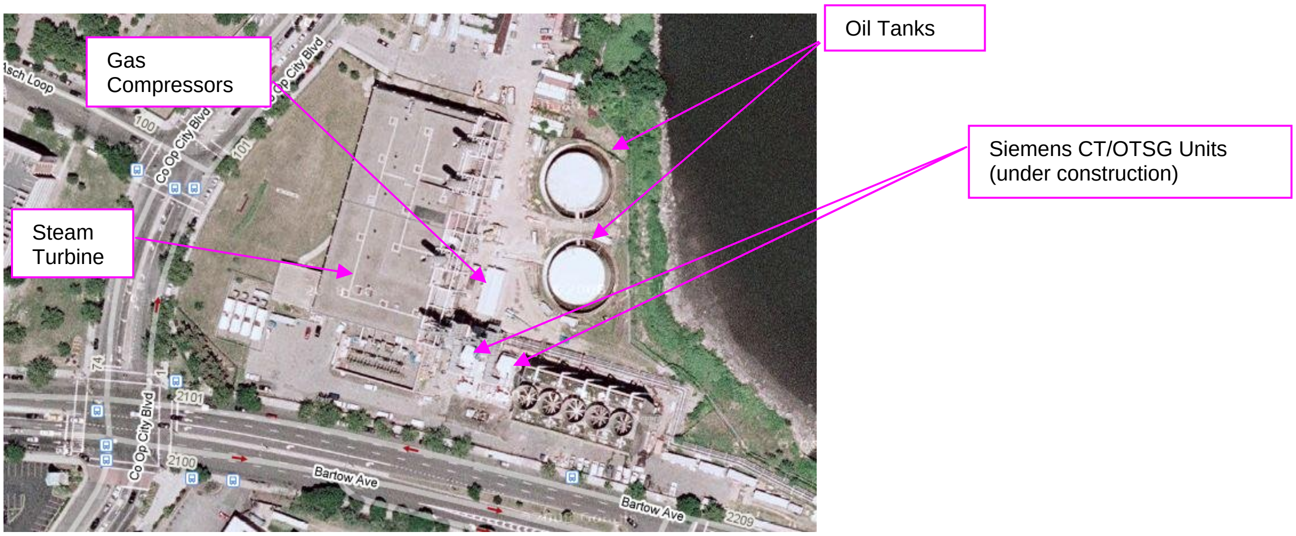

Figure 1. Satellite Photo of Physical Plant at Co-op City

The power output, steam output, and steam consumption for each of the major system components is summarized in the table below. The four chillers combined require nearly 200,000 lb/h of 150 psig steam to produce 20,000 tons of cooling. CT#2 with the HP boiler can operate the steam turbine and drive the four chillers.

Table 1. Specifications for Major CHP Equipment at the Site

	Power Output (MW)	High Pressure Steam (850 psig)		Low Pressure Steam (150 psig)	
		Input (lb/h)	Output (lb/h)	Input (lb/h)	Output (lb/h)
High Pressure Boiler			150,000		
CT / OTSG#1	12.5		86,000		
CT / OTSG#2	12.5		43,000		
Steam Turbine	13	268,000			195,000
Steam-driven Chiller #1				47,500	
Steam-driven Chiller #2				47,500	
Steam-driven Chiller #3				47,500	
Steam-driven Chiller #4				47,500	

Chillers are 5,000 ton, steam-turbine driven, R134a centrifugal, 9.5 #/ton-hr
CT – Combustion Turbine, OTSG – Once Through Steam Generator

The system has several large parasitic loads. The two most important parasitic loads are the natural gas compressors, the high pressure (1000 psig) feedwater pumps and the boiler draft fan. These parasitic loads represent about 5% of the maximum power output.

Table 2. Shaft and Electrical Power for Major Parasitic Loads in CHP System

	Full Load Shaft Power (HP)	**Estimated Full Load Electric Power (kW)**
Three Glauber Gas Compressors, 400 HP each, 2300 volt	800 (two at once)	660
Feedwater Pumps – OTSG 300 HP each, 2300 volt	300 x 2	500
Feedwater Pump - HP Boiler 350 HP, 2300 volt	350	290
Draft Fan - HP Boiler 450 HP, 2300 volt	450	370
Total	2,200	1,530 (4.7% of power output)

2. Instrumentation

The Siemens T-3000 control system includes many instruments and meters to measure and track the performance of the system. The data points required to quantify the performance of the system for the NYSERDA website are shown in Figure 2 and listed in Table 3. Each data points is shown on the schematic as a grey box with red text. The corresponding data point name is listed in the table, which also includes the “tag name” assigned to it in the Siemens system. These data points quantify the fuel inputs, power outputs, and steam flows within the system. Inputs and outputs are also measured for duct burners and boilers which must be factored into the overall calculations of CHP efficiency (see section 3). Utility power is provided to the facility via four feeders than each have their own power meters (**WT1** through **WT4**) on a ring network (i.e., all four feeders provide power at the same time). The generated power from the combustion turbines (**WCT1** & **WCT2**) and steam turbine (**WST**) all feed into the 13.2 kV network bus. kVA and power factor data will also be collected from each power meter to understand the overall power quality of the system.

Table 3. List of Monitoring Points from Siemens T-3000 Control System

No	CDH Name	Siemens Tag (from drawings)	Description	Eng, Units	file	channel
1	WCT1	GT1_PM130_Kw_Total	Combustion Turbine #1 Power	kW	1	2
2	WCT1_kVA	GT1_PM130_KVA_Total	Combustion Turbine #1 kVA	VA		1
3	WCT2	GT2_PM130_Kw_Total	Combustion Turbine #2 Power	kW		4
4	WCT2_kVA	GT2_PM130_KVA_Total	Combustion Turbine #2 kVA	kVA		3
5	WST	ST486??	Steam Turbine Power	MW		5
6	WT1_kW	TX1-62 P	Secondary Breaker #1 7x27 Power	MW		7
7	WT1_PF	TX1-62 PF	Secondary Breaker #1 7x27 PF	na		6
8	WT2_kW	TX2-122 P	Secondary Breaker #2 7x26 Power	MW	2	2
9	WT2_PF	TX2-122 PF	Secondary Breaker #2 7x26 PF	na		1
10	WT3_kW	TX3-202 P	Secondary Breaker #3 7x25 Power	MW		4
11	WT3_PF	TX3-202 PF	Secondary Breaker #3 7x25 PF	na		3
12	WT4_kW	TX4-262 P	Secondary Breaker #4 7x24 Power	MW		6
13	WT4_PF	TX4-262 PF	Secondary Breaker #4 7x24 PF	na		5
14	FG1	01FIT2336	CT1 Natural Gas Input	lb/h	3	1
15	FO1	01FIT2436	CT1 Fuel Oil Input	gpm		2
16	TIN1	01TY0922	CT1 Air Inlet Temperature	F		3
17	FG2	02FIT2336	CT2 Natural Gas Input	lb/h		4
18	FO2	02FIT2436	CT2 Fuel Oil Input	gpm		5
19	TIN2	02TY0922	CT2 Air Inlet Temperature	F		6
20	FGDB1	01FIT2317	Duct Brnr 1 Natural Gas Input	lb/h	4	3
21	FGDB2	02FIT2317	Duct Brnr 2 Natural Gas Input	lb/h		5
22	FS1	01FIT2731	OTSG #1 Steam Output	lb/h		2
23	FS2	02FIT2731	OTSG #2 Steam Output	lb/h		4
24	FSB	00FY3073	HP Boiler Steam Output	Mlb/h		1
25	FGB	00FT2516	HP Boiler Natural Gas Input	Mcf/h		7
26	FOB	00FT2415	HP Boiler Fuel Oil Input	gpm		6
27	FSPRA	00FT3510A	Pressure Reducing Station A Steam Flow	Mlb/h	5	3
28	FSPRB	00FT3510B	Pressure Reducing Station B Steam Flow	Mlb/h		4
29	FST	00FT3081	Steam Turbine Inlet Steam Flow	Mlb/h		2
30	PST	00PIT3081	Steam Turbine Inlet Pressure	psig		5
31	PSL	00PT3510	LP Steam Pressure	psig		6
32	FSL	00FT3505	Steam Turbine Outlet Steam Flow	in WC		1
33	PGT	00PT2335	Gas Compressor Output	psig	6	2
34	PGDB	00PT2313	Duct Burner Input	psig		1
35	Fg1a	GT1_FFDEM_GAS	CT#1 Gas Consumption	kW		3
36	FO1a	GT1_FFDEM_LIQ	CT#1 Liquid Fuel Consumption	kW		4
37	FG2a	GT2_FFDEM_GAS	CT#2 Gas Consumption	kW		5
38	FO2a	GT2_FFDEM_LIQ	CT#2 Liquid Fuel Consumption	kW		6

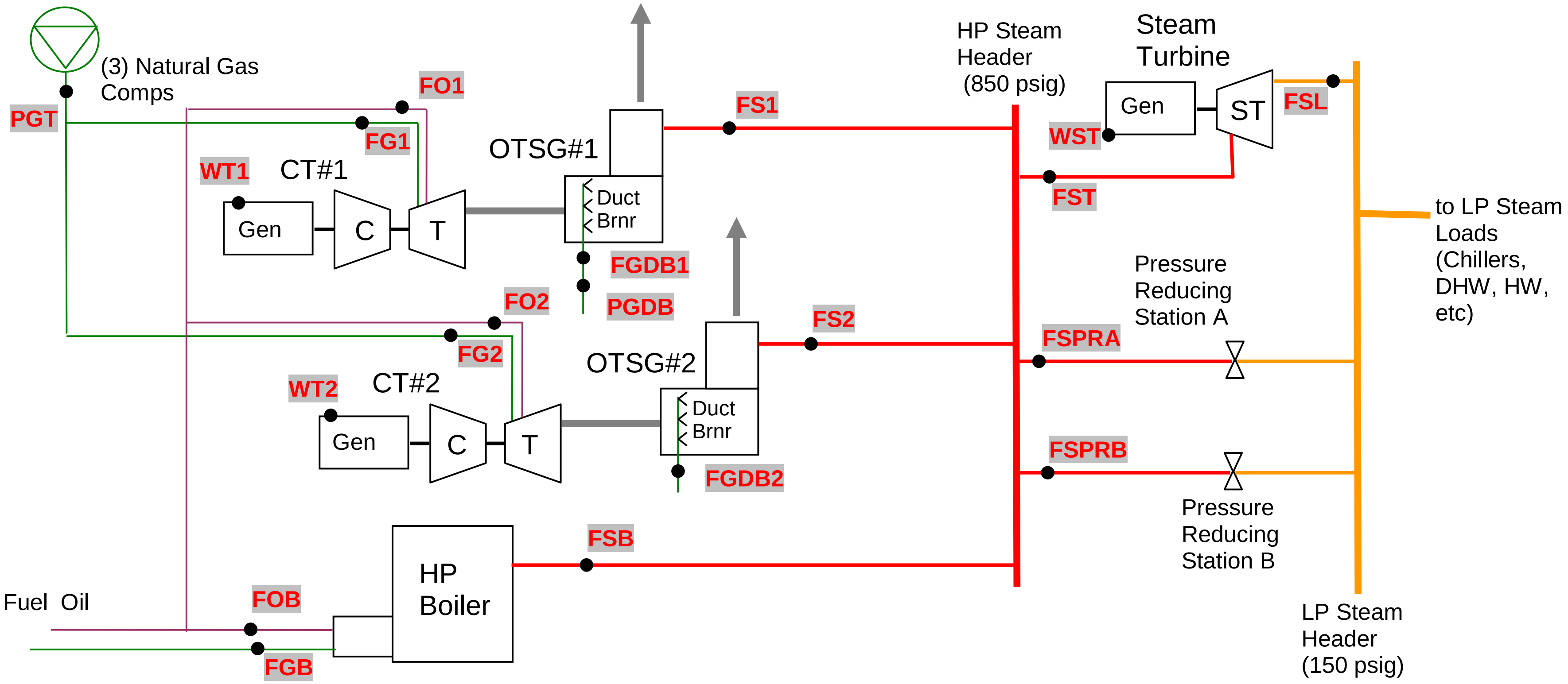

Figure 2. Schematic of CHP System with Monitored Data Points Shown

Parasitic Power

The power consumption of parasitic loads on the CHP system are not directly measured by the Siemens system. The largest loads (feedwater pumps, gas compressors, etc.) are listed in Table 2, and these are estimated be about 4.7% of the gross generator output. We will start with these as main list of parasitic loads and refine this list (and the estimated power) when more information is available.

Data Collection Process

The Siemens T-3000 control system will be programmed to record the data values listed in Table 3. These data points will to be automatically logged to multiple files at 15-minute intervals[1]. Each 15-minute record will be time and date stamped. The file will be a row-oriented ASCII, text, or comma separated values (CSV) file with sufficient resolution to represent each reading. Once per day the file will be automatically transferred to CDH Energy (the NYSERDA web site contractor) by a daily email with the files attached.

Each night an operator collects the files and manually emails the data files. CDH periodically requests data for days that were not previously received.

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[1] If the data values are averaged or totalized over the interval, then 15-minute data are acceptable. If the data are sampled, then 5-minute data will be required.

3. Data Analysis Procedures

The total gross power output from the three generators is determined from the equation below. The power output from the combustion turbines in ‘kW’ while the steam turbine output is in ‘MW’. The parasitic power **WP** will be determined by on-time power readings as described above.

$$\mathbf{WG} = \mathbf{WCT1} + \mathbf{WCT2} + \mathbf{WST} \times 1000$$

and

$$\mathbf{WNET} = \mathbf{WG} - \mathbf{WP}$$

The fuel input for the overall system (in Btu/h)

$$\mathbf{FG_{ct/otsg}} = (\mathbf{FG1} + \mathbf{FG2} + \mathbf{FGDB1} + \mathbf{FGDB2}) \times K_{fuel\text{-}lb}$$

$$\mathbf{FG_{overall}} = (\mathbf{FG1} + \mathbf{FG2} + \mathbf{FGDB1} + \mathbf{FGDB2}) \times K_{fuel\text{-}lb} + \mathbf{FGB} \times 1000 \times K_{fuel\text{-}cf}$$

Where the fuel flowrates are in ‘lb/h’ for the turbines and duct burners and ‘MCF/h’ for the boiler, and the calculation factors are:

$K_{fuel\text{-}cf}$ = 927 Btu/ std ft^3 for Natural Gas, lower heating value (LHV)

$K_{fuel\text{-}lb}$ = 20,950 Btu/lb for Natural Gas, lower heating value (LHV)
(which is equivalent to 927 Btu per std ft^3, at 0.044248 lb per std ft^3)

The energy content of the high pressure steam is taken from the test report for the high pressure boiler (HPB). The OTSG’s are assumed to operate at the same condition.

Steam Header:	1,365.9 Btu/lb	@ 750ºF and 858 psia
Feedwater:	206.5 Btu/lb	@ 236ºF and 1,091 psia
Steam Enthalpy (K_{steam}):	1,159 Btu/lb	

The energy content of the thermal output (steam) is then calculated by:

$$\mathbf{ST} = (\mathbf{FS1} + \mathbf{FS2} + \mathbf{FSB}) \times K_{steam}$$

The efficiency of the high pressure boiler (based on lower heating value) can be calculated using

$$\eta_{HPB} = \frac{\mathbf{FSB} \times K_{steam}}{\mathbf{FGB} \times 1000 \times K_{fuel\text{-}cf}}$$

The extraction efficiency of the steam back-pressure turbine is equal to

$$\eta_{ST\text{-}ex} = \frac{\mathbf{WST} \times 3413}{(\mathbf{FST} \times K_{steam})}$$

The efficiency of the components and system can be calculated for several different perspectives as shown in the table below. All of these values are on a low heating value basis.

Table 4. Summary of Efficiency Calculations

	Calculation
Turbine Electrical Efficiency (CT1 and CT2)	$\frac{\mathbf{WCT1} \times 3413}{\mathbf{FG1} \times K_{fuel\text{-}lb}}$ and $\frac{\mathbf{WCT2} \times 3413}{\mathbf{FG2} \times K_{fuel\text{-}lb}}$
Total Efficiency for CT/OTSG system	$\frac{(\mathbf{WCT1} + \mathbf{WCT2} - \mathbf{WP}) \times 3413 + (\mathbf{FS1} + \mathbf{FS2}) \times K_{steam}}{(\mathbf{FG1} + \mathbf{FG2} + \mathbf{FGDB1} + \mathbf{FGDB2}) \times K_{fuel\text{-}lb}}$
Total Efficiency for Overall System	$\frac{(\mathbf{WCT1} + \mathbf{WCT2} - \mathbf{WP}) \times 3413 + (\mathbf{FS1} + \mathbf{FS2} + \mathbf{FSB}) \times K_{steam}}{(\mathbf{FG1} + \mathbf{FG2} + \mathbf{FGDB1} + \mathbf{FGDB2}) \times K_{fuel\text{-}lb} + \mathbf{FGB} \times 1000 \times K_{fuel\text{-}cf}}$

The total efficiency of the overall system accounts for all the fuel inputs to the gas turbine and boiler as well as all the power outputs and thermal outputs from the system. The power from the steam turbine (**WST**) is not included in this equation because this energy is ultimately extracted from the energy in the high pressure steam. This approach ignores the mechanical and electrical losses in the turbine generator, though for this size turbine those losses are typically on the order of 3%.

Figure 3 shows the control volume and energy flows used for this approach to determining total overall efficiency.

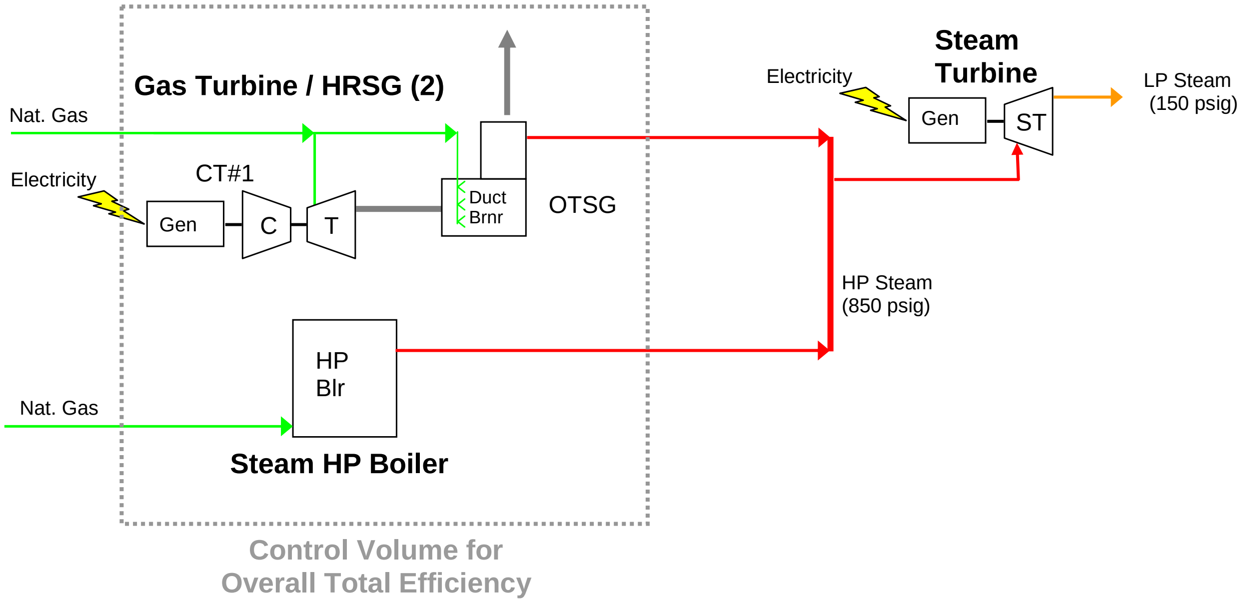

Figure 3. Schematic of Components and Control Volume for Overall Total Efficiency

Table A. Raw data file Map

CDH Name	File and Channel #	File Tag
WCT1_kW	file 1 channel 2	..30_kW_Total.ZQ01||OUT
WCT1_kVA	file 1 channel 1	..0_kVA_Total.ZQ01||OUT
WCT2_kW	file 1 channel 4	..30_kW_Total.ZQ01||OUT
WCT2_kVA	file 1 channel 3	..0_kVA_Total.ZQ01||OUT
WST_kW	file 1 channel 5	MKA10CE001||OUT
WT1_kW	file 1 channel 7	..1-63 P||TX1TotalPower
WT1_PF	file 1 channel 6	TX1-63 PF||OUT
WT2_kW	file 2 channel 2	..-123 P||TX2TotalPower
WT2_PF	file 2 channel 1	TX2-123 PF||OUT
WT3_kW	file 2 channel 4	..-203 P||TX3TotalPower
WT3_PF	file 2 channel 3	TX3-203 PF||OUT
WT4_kW	file 2 channel 6	..-263 P||TX4TotalPower
WT4_PF	file 2 channel 5	TX4-263 PF||OUT
FG1	file 3 channel 1	01FIT2336||ZQ01
FO1	file 3 channel 2	01FIT2436||ZQ01
TIN1	file 3 channel 3	01TY0922||ZQ01
FG2	file 3 channel 4	02FIT2336||ZQ01
FO2	file 3 channel 5	02FIT2436||ZQ01
TIN2	file 3 channel 6	02TY0922||ZQ01
FGDB1	file 4 channel 3	01FT2317|33433|OUT
FGDB2	file 4 channel 5	02FT2317||XQ01
FS1	file 4 channel 2	01FIT2731||ZQ01
FS2	file 4 channel 4	02FIT2731||ZQ01
FSB	file 4 channel 1	00FY3073||XQ01
FGB	file 4 channel 7	FT2516||OUT
FOB	file 4 channel 6	FT2415||OUT
FSPRA	file 5 channel 3	00FT3510A||OUT
FSPRB	file 5 channel 4	00FT3510B||OUT
FST	file 5 channel 2	00FT3081||ZQ01
PST	file 5 channel 5	00PIT3081||XQ01
PSL	file 5 channel 6	00PT3510||OUT
FSL	file 5 channel 1	00FIT3505||XQ01
PGT	file 6 channel 2	00PT2335||XQ01
PGDB	file 6 channel 1	00PIT2313||XQ01
Fg1a	file 6 channel 3	..1_FFDEM_GAS.ZQ01||OUT
FO1a	file 6 channel 4	..EM_LIQ.ZQ01|22299|OUT
FG2a	file 6 channel 5	..2_FFDEM_GAS.ZQ01||OUT
FO2a	file 6 channel 6	..EM_LIQ.ZQ01|22299|OUT