MEASUREMENT AND VERIFICATION PLAN

FOR

DG/CHP SYSTEM AT 15 W 43RD ST. – PRINCETON CLUB

May 2012

Submitted to:

New York State Energy Research and Development Authority
17 Columbia Circle
Albany, NY 12203-6399

Submitted by:

CDH Energy Corp.
PO Box 641
2695 Bingley Rd
Cazenovia, NY 13035
(315) 655-1063
www.cdhenergy.com

Project Team:

NYSERDA Project Manager:

Joanna A. Moore
518-862-1090 ext 3220
jm1@nyserda.org

Developer/Applicant:

Larry Hines
Princeton Club of New York
15 W 43rd Street
New York, NY 10036
Phone: (212) 596-1269
Fax: (212) 596-1398
hines@princetonclub.com

John Brogan
Endurant Energy
One Penn Plaza, Suite 4512
New York, NY 10119
Phone: (646) 786-1260
john.brogan@endurantenergy.com

Bob Schultz
Automated Logic New York/New Jersey
100 Delawanna Ave.
Clifton, NJ 07014
862-377-5575 mobile
bschultz@alcnynj.com

NYSERDA QC Contractor:

Dennis R. Landsberg
L&S Energy Services, Inc.
58 Clifton Country Road Suite 203
Clifton Park, NY 12065
Phone: (518) 383-9405
Fax: (518) 383-9406
Email: dlandsberg@LS-Energy.com

NYSERDA M&V Contractor:

Hugh Henderson, CDH Energy
PO Box 641
2695 Bingley Rd
Cazenovia, NY 13035
315-655-1063
hugh@cdhenergy.com

1. Introduction

The CHP system at 15 W 43rd Street consists of three (3) 100-kW, InVerde100 engine units from Tecogen that use permanent magnet generators with 480 VAC inverter power output. The engines are capable of providing 125 kW peak and 100 kW continuous. The inverters, generator and associated electronics have their own cooling loop. A heat recovery loop from the engine jacket and exhaust heat recovery heat exchanger is the primary heat source.

The three engines are arranged in parallel to provide heat recovery for a hot-water-driven absorption chiller as well as various heating loads in the building. A heat exchanger can also dump heat to the building cooling tower system if required.

The system also has 2,000 gallons (approx. 3 hrs worth) of hot water storage.

Heat from the engines is used to meet thermal loads in the facility for various loads:

- Heat exchanger HX 1 can supply heat for spacing heating loads (seasonal)
- HX 4 and HX 5 can supply heat for the high and low domestic water system (year round),
- The absorption chiller uses high grade heat to provide 120 tons of chilled water capacity (summer). The chiller also has a gas-fired burner that can increase the chiller capacity to 245 tons.

At full load the generators will consume approximately 3,900 std cubic feet of natural gas per hour (1300 cf/h each).

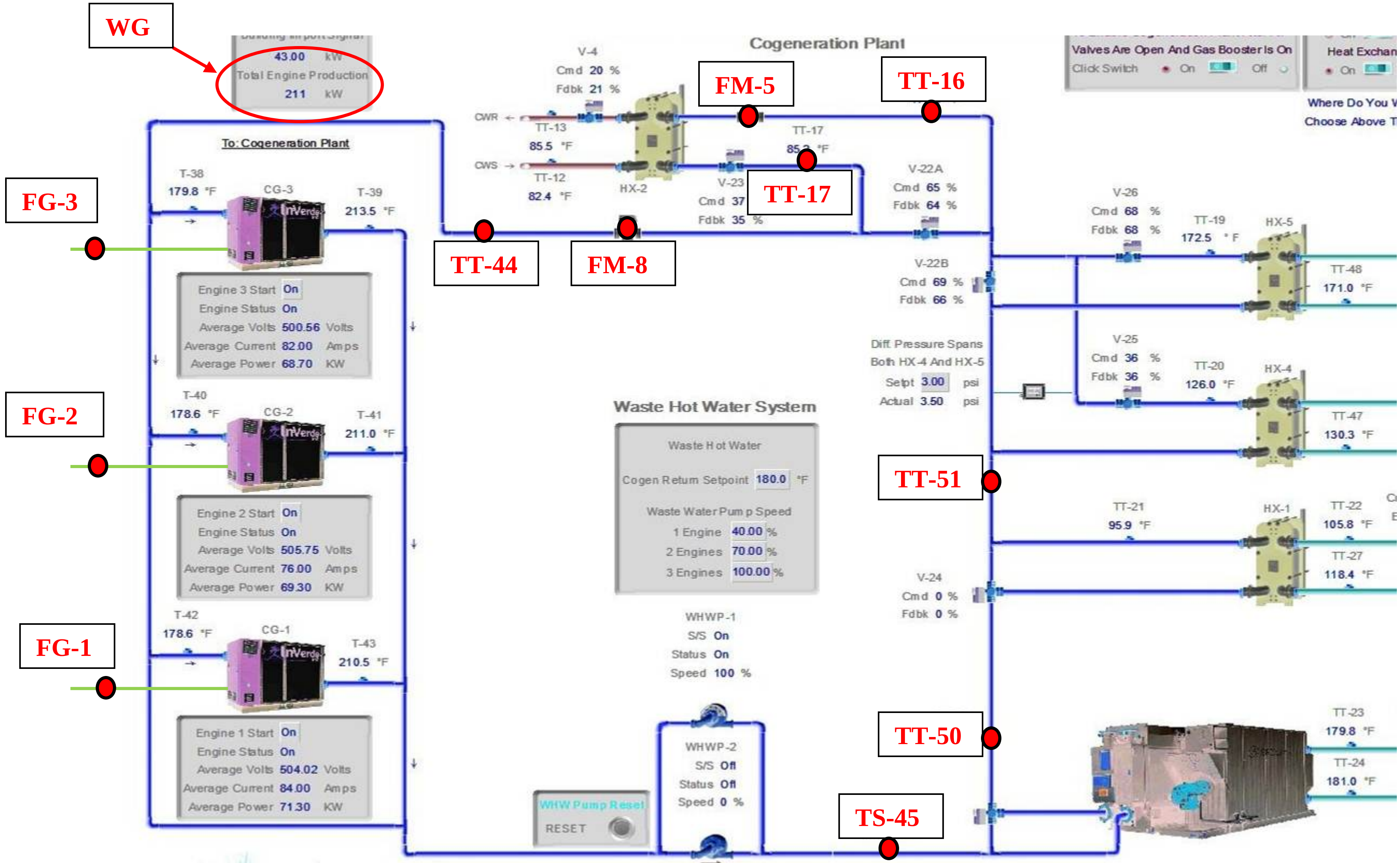
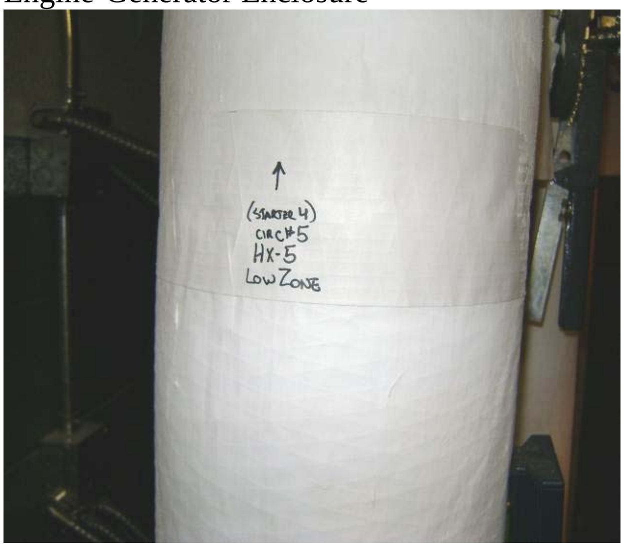


Figure 1. Schematic of CHP System

Engine-Generator Enclosure


Main Loop Pumps



HX#5 - Plumbing Low Zone


HX#1 - Space Heating Loads

Figure 2. Photos of CHP System

2. Monitoring System

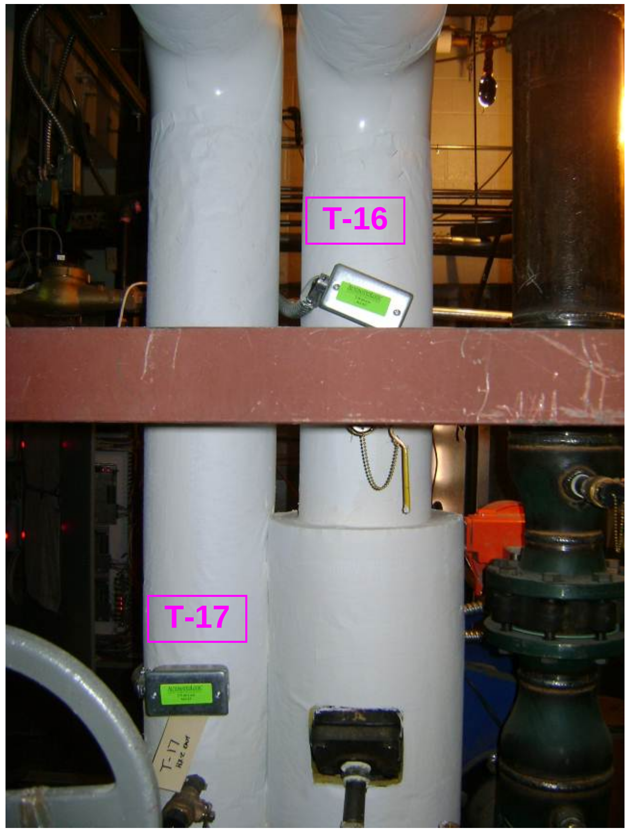
Table 1 lists the monitored points required to characterize the performance of the CHP system.

Table 1. Monitored Data Point List

No.	Actual Tag Name (see pics)	Manufacturer / Model #	Description	CDH Point Name	Eng Units
1	WG	Veris H8053-0800-4 (pulse)	Gross Generator Power (all 3)	WG	kW
2	-	InVerde 100	Gross Generator #1 Power	WG1	kW
3	-	InVerde 100	Gross Generator #2 Power	WG2	kW
4	-	InVerde 100	Gross Generator #3 Power	WG3	kW
5	FG-1	Sage SIP-150	Engine 1 Gas Input	FG1	cf/h
6	FG-2	Sage SIP-150	Engine 2 Gas Input	FG2	cf/h
7	FG-3	Sage SIP-150	Engine 3 Gas Input	FG3	cf/h
8	FM-8	Flexim / FSM-NNNTS-000	Heat Recovery Loop Flowrate	FM8	gpm
9	T-45	BAPI / ALC M304	HR Loop High Supply Temp	T45	ºF
10	T-44	BAPI / ALC M304	HR Loop High Return Temp	T44	ºF
11	T-50	BAPI / ALC M304	HR Loop Temp - After Abs. Chiller	T50	ºF
12	T-51	BAPI / ALC M304	HR Loop Temp - After HX-1	T51	ºF
13	FM-5	Flexim / FSM-NNNTS-000	Dump/HX2 Flowrate	FM5	gpm
14	T-16	BAPI / ALC M304	Dump/HX2 Supply Temp	T16	ºF
15	T-17	BAPI / ALC M304	Dump/HX2 Return Temp	T17	ºF
16	-	Calculated	Total Heat Recovery	QT	MBTU/hr
17	-	Calculated	Rejected Heat Recovery	QR	MBTU/hr
18	-	Calculated	Useful Heat Recovery	QU	MBTU/hr

<u>Temperature Sensors (T-16, T-17, T-44, T-45, T-50, T-51)</u>

The temperature sensors (thermistors) are manufactured by BAPI and are 2 inch Series 304 Stainless Steel in 2-inch thermowells. Each sensor is installed in a 3 inch diameter pipe.



HR Return Temp (T-44) Back to Engines

Figure 3. Locations of Temperature Sensors

<u>Fluid Flowmeters (FM-5, FM-8)</u>

The flowmeters used are manufactured by Flexim and are Type M clamp-on flow transducers. As see in Figure 4 each pair of flow transducers is attached with a metal strap securely to the 3 inch diameter pipes. Their orientation (on opposing sides and with distance between < d_{pipe}) is set up for diagonal mode with one sound path. They have a range of 0.01 to 25 m/s with an accuracy of ±1.6% with standard calibration and as good as ±0.5% with field calibration.

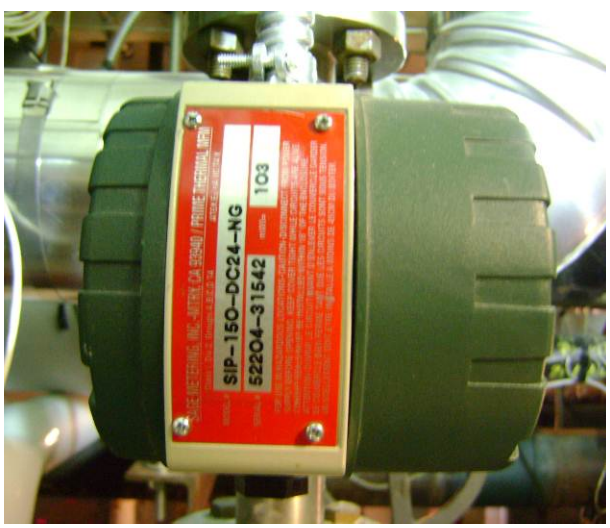
<u>Engine-Generator Gas Input (FG-1, FG-2, FG-3)</u>

There is one Sage gas meter for each of the (3) three engines. This hot-wire device is installed in a spool piece to provide a high accuracy analog reading of mass flow rate.

Heat Recovery Loop Flowrate (FM-8)


Dumped Heat Flowrate (FM-5)

Figure 4. Water Loop Flow Meters



Gas Meter Nameplate

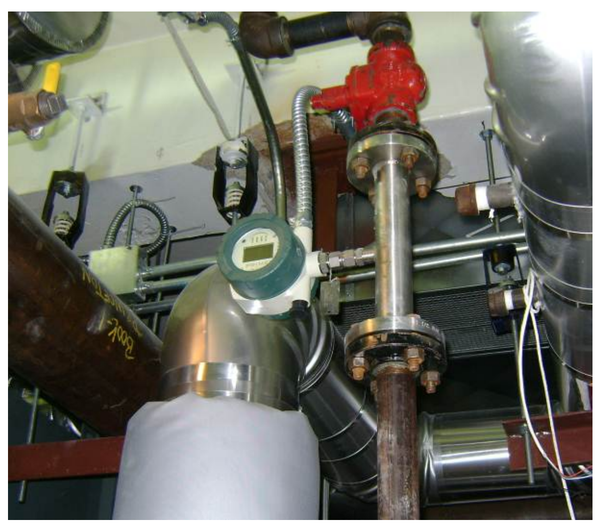

Sage Gas Meter on Engine 1

Figure 5. Gas Meter Locations and Information

Engine-Generator Power Output (WG)

The power output from all three engine-generator units are consolidated into one feed as shown in Figure 6. The gross power produced will measured with a single Veris self-contained power meter. The transducer will be supplied by CDH Energy an installed by the site contractors in either the disconnect or the breaker panel. ALC will add this power transducer into their system.

10th Floor Engine Power Panel

Suggested Location for Power Transducer for Engine Power (**WG**, 3 engines combined)

Figure 6. Engine-Generator Combined Power Panels

Auxiliary or Parasitic Loads

There are two main parasitic loads on the system; recovered heat loop pumps and the gas compressor. The loop pumps (shown in Figure 2) are expected to run continuously and the gas compressor will run when at least one of the cogen units is operating. A onetime power reading, using a Fluke 39 handheld power meter, will be taken.

Data Logging System

CDH will install an Obvius Acqusuite Datalogger with a UPS in its own enclosure underneath the current Auotmated Logic (ALC) panel (see below). The datalogger will communicate with the ALC controller via MODBUS RTU to the extract readings (in Table 1) from the control system. CDH will use the 120 Volt power inside the ALC panel to power the datalogger. Endurant/The Princeton Club will provide internet access to the datalogger by providing a fixed IP-address (accessible from the internet) with a port forwarded to the datalogger's local IP address. The DSL line will be shared with the Broad Chiller.

Figure 7. Location for CDH Panel

The datalogger will sample or scan each data point at one-second intervals. All readings will be averaged, summed or calculated for each 1-minute interval. The datalogger will be able to hold more than 80 days of recorded data if communications are lost. The datalogger will continue to log data for a few hours in the event of a power outage at the site. The data will be downloaded from the datalogger at least once a day via the internet connection and loaded into a database. The data will be checked for validity and posted on the NYSERDA web site.

Data Logger Support

CDH will maintain the data logger over the two-year monitoring period. We will periodically check the CHP web site to ensure the system is operating properly. In the event of a data logger issue, we will be on-site within 48 hours to make a repair. If the problem is with the instrumentation supplied by the site, we will work with them to help correct the problem in a timely manner.

Around the 12th and 24th month of the monitoring period, we will come on site to verify and check the instrumentation and sensors. Temperature sensors will be compared to readings with handheld instruments, power transducer readings will also be compared to handheld power readings. Where feasible, we will check flow readings with ultrasonic flow meters. Based on these measurements we will prepare a verification summary report documenting the findings from each visit. The verification/calibration reports will also be posted on the CHP web site.

3. Data Analysis

Heat Recovery Rates

The heat recovery rates will be calculated in the datalogger at each 1-minute interval.

Total heat recovery (**QT**) = K·FM8·(T45-T44)

Non-Useful or Rejected heat recovery (**QR**) = K·FM5·(T16-T17)

Useful heat recovery (**QU**) = QT – QR or [(K·FM8·(T45-T44)) – (K·FM5·(T16-T17))]

Chiller - K·FM8·(T45-T50)

Space Heating - K·FM8·(T50-T51)

DHW - K·FM8·(T51-T16) **if dump radiator is running*

K·FM8·(T51-T44) * *if dump radiator is not running*

The loop fluid is expected to be a glycol-water mix. The factor K is based on the properties of the loop fluid. (K ~ 500 Btu/h-gpm-°F for pure water; ~480 for 30% glycol). CDH will use a Hygrometer to estimate the glycol concentration if required.

Calculated Quantities

For this site, the net power output from the engine generators is:

WNET = WG – WP

Where WP is the power use of the recovered heat loop pumps (which will be determined with a one-time reading) and the gas compressor. All power data reported on the website is gross generator power. Parasitic loads will still have to be subtracted.

The fuel conversion efficiency of the CHP system, based on the lower heating value of the fuel, will be defined as:

$$FCE = \frac{QU \cdot \Delta t + 3{,}412 \cdot (WNET)}{LHV_{gas} \cdot FG}$$

where:	QU	-	Useful heat recovery (Btu/h)
	WG	-	Generator output (kWh)
	FG	-	Generator gas consumption, sum of 3 meters (Std CF)
	Δt	-	1/60 hour for 1-minute data
	LHV_{gas}	-	Lower heating value for natural gas (~905 Btu per CF)

The FCE can be calculated for any time interval. When converting to daily, monthly, or annual values, each value is summed and then the formula is applied:

$$FCE = \frac{\sum^{N} QU \cdot \Delta t + 3412 \cdot \sum^{N} (WNET)}{LHV_{gas} \cdot \sum^{N} FG}$$

Where N is equal to the number of intervals in the period of interest.

Appendix A

Data Sheets

Addendum – Princeton Club

Princeton Club of New York
15 W 43rd Street
New York, NY 10036

Site Contact

Larry Hines – Princeton Club of New York – 212-596-1269

- CDH was on site April 18, 2012 to verify sensor locations and readings

Summary

The facility purchased all metering and had it installed. The controls contractor, Automated Logic, set up data point trending so that CDH can access real time data from the building control system. CDH provided and installed an Obvius data logger to record and send out data.

Networking Information

IP Address:	207.86.191.242
Gateway:	207.86.191.225
Netmask:	255.255.255.224
Primary DNS:	64.7.11.2
Secondary DNS:	66.80.131.5

Monitored Data Points

No.	Actual Tag Name (see pics)	Manufacturer / Model #	Description	CDH Point Name	Eng Units
1	WG	Veris H8053-0800-4 (pulse)	Gross Generator Power (all 3)	WG	kW
2	-	InVerde 100	Gross Generator #1 Power	WG1	kW
3	-	InVerde 100	Gross Generator #2 Power	WG2	kW
4	-	InVerde 100	Gross Generator #3 Power	WG3	kW
5	FG-1	Sage SIP-150	Engine 1 Gas Input	FG1	cf/h
6	FG-2	Sage SIP-150	Engine 2 Gas Input	FG2	cf/h
7	FG-3	Sage SIP-150	Engine 3 Gas Input	FG3	cf/h
8	FM-8	Flexim / FSM-NNNTS-000	Heat Recovery Loop Flowrate	FM8	gpm
9	T-45	BAPI / ALC M304	HR Loop High Supply Temp	T45	ºF
10	T-44	BAPI / ALC M304	HR Loop High Return Temp	T44	ºF
11	T-50	BAPI / ALC M304	HR Loop Temp - After Abs. Chiller	T50	ºF
12	T-51	BAPI / ALC M304	HR Loop Temp - After HX-1	T51	ºF
13	FM-5	Flexim / FSM-NNNTS-000	Dump/HX2 Flowrate	FM5	gpm
14	T-16	BAPI / ALC M304	Dump/HX2 Supply Temp	T16	ºF
15	T-17	BAPI / ALC M304	Dump/HX2 Return Temp	T17	ºF
16	-	Calculated	Total Heat Recovery	QT	MBTU/hr
17	-	Calculated	Rejected Heat Recovery	QR	MBTU/hr
18	-	Calculated	Useful Heat Recovery	QU	MBTU/hr

Procedure

- Power measurements were made with a Fluke 39 handheld meter from phase to phase (p-p) and phase to ground (p-g).
  - Generator power measurements were taken in the 480 switchgear (gross power). The CT's are located in the adjacent disconnect and are measuring the same power.
  - Parasitic loads consist of the cogen loop pumps and gas compressor. One time power measurements were taken of these loads for documentation purposes.

- Temperatures were measured using a Fluke 51-II and either a surface probe or insertion probe.
  - All temperature measurements were taken from the surface of the copper piping.

- Both flows (heat recovery loop and dump radiator flow) were verified using a Portaflow ultrasonic flowmeter, mounted on a straight section of the return piping.

- Natural gas use was verified by comparing the Sage meter display for each engine to the data logger values.

Verification Data – April 18, 2012

Generator Power:

The power measurements taken in the switchgear were compared to the individual generator powers measured by the ALC system. The Veris H8053 was not yet installed at the time of verification.

Fluke 39 (phase to ground)				
	A	**B**	**C**	***Total***
Voltage	284	286	289	-
Amps	285	288	289	-
kW	*81*	*82*	*81*	***244***

ALC (WG)	ALC (WG1+WG2+WG3)
Total (kW)	***Total (kW)***
248	***255.9***

Fluke 39 (phase to phase)			
	A-B (kW)	**C-B (kW)**	***Total (kW)***
Trial 1	133	115	***248***
Trial 2	114	132.5	***246.5***

ALC (WG)
Total(kW)
255.9
252.7

Parasitic Power:

One of the recovered heat loop pumps will always be running. The gas compressor will be running as long as at least one of the cogen units are running.

	Current (A)	**Power (kW)**
WHP1 (off)	0.0	0.0
WHP2	1.4	1.0
Gas Compressor	6.0	4.1
Total:	*7.4*	*5.1*

Temperatures:

TS-45		
Fluke (ºF)	**ALC (ºF)**	**Obvius (ºF)**
211	218.3	-
-	219	221.2

	TT-50	
	Fluke (ºF)	**ALC (ºF)**
	184.6	191.5
	183.7	193.6
	190.9	194
Avg:	*186.4*	*193.0*

	TT-16	
	Fluke (ºF)	**ALC (ºF)**
	172.7	173.5
	171.9	172.8
Avg:	*172.3*	*173.15*

	TT-17	
	Fluke (ºF)	**ALC (ºF)**
	87.9	84.9
	86.5	85
Avg:	*87.2*	*84.95*

	TT-44	
	Fluke (°F)	**ALC (°F)**
	181.4	185.2
	181.8	185.1
	181.5	183.4
	180.8	180.5
	178.8	177.4
	178.1	176.6
	177.5	176.4
	178.3	180.2
	178.6	180.4
	178.5	178.9
	177.9	177.6
Avg:	*179.4*	*180.2*

Flows:

The piping for both loops (recovered heat loop and dump radiator loop) was identical, so the settings used for the ultrasonic flow meter were the same for each measurement.

3" Schedule 40 Steel	
OD (in)	3.5
Wall Thickness (in)	0.216
Sensor Spacing (in)	2.49

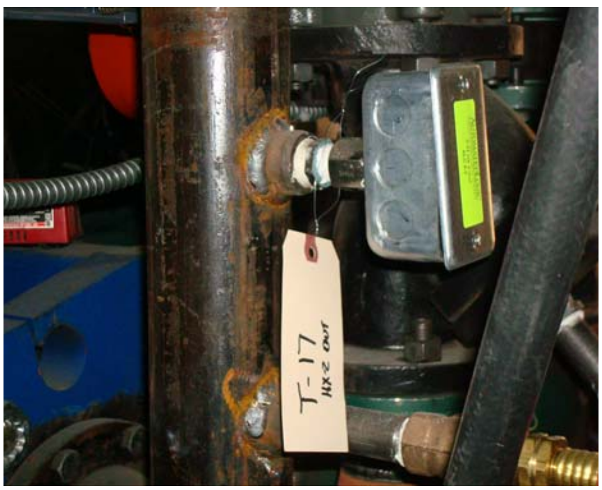
	FM-8	
	Portaflow (gpm)	**ALC (gpm)**
	87.6	88.4
	89.2	88.1
	89.2	88.1
	86.9	88.5
	86	88.9
	90.4	89
	89.3	89
	86.8	89.1
	86.8	88.7
	89.7	89.6
	89.2	90
	89.1	89.5
Avg:	*88.4*	*88.9*

	FM-5	
	Portaflow (gpm)	**ALC (gpm)**
	4.7	5.9
	4.3	5.6
	5.6	6
	4.6	6
	7.2	5.8
	3.2	6.4
	5.3	6.1
	6.9	6.7
	5.7	7.6
	5.5	7.7
	8	7.6
	7.5	7
	5.3	6.1
Avg:	*5.7*	*6.5*

Photos

Cogen unit gas meter (TYP).

InVerde 100 cogen unit (TYP)



Recovered heat loop temperature sensor (TYP)

CGDP-2, 800 A cogen disconnect panel. Location of power verification and Veris power meter future location.