

Applications accepted through November 30, 2016 at 5:00 PM Eastern Time*

New York State Energy Research and Development Authority (NYSERDA) is accepting applications from vendors of packaged Combined Heat and Power (CHP) systems in order to pre-qualify systems that will be eligible for incentives under PON 2568 - CHP Acceleration Program. Packaged CHP systems may consist of one or more prime movers and can be from 50kW to 1.3 MW in size. Vendors must submit a separate application for each system design or system size. When issued (anticipated in early Q4 of 2012), PON 2568 will offer approximately \$20 million in incentive funds which will be available through 2016. Customers will be able to access these funds only for purchase and installation of the pre-qualified/conditionally-qualified equipment.

NYSERDA is seeking to pre-qualify CHP systems that have been completely pre-engineered and pre-tested with a single point of responsibility for design, installation, service and warranty including all system components. Pre-qualified systems must be capable of acquiring proper air permits, transitioning from grid interconnected to grid islanding mode, and capable of interconnecting to New York State electric utilities using radial distribution systems, secondary network distribution systems and/or spot network distribution systems. Systems that cannot pre-qualify because they do not meet the pre-tested requirement for pre-qualification will be considered for conditional-qualification provided performance test data is available for the major components and acceptable calculations showing interconnecting piping, ductwork or other interconnecting apparatus is provided.

Applications may be submitted at any time up to 5 PM Eastern Time, November 30, 2016, however, vendors interested in having their applications evaluated prior to the initial availability of PON 2568 must submit a complete application prior to 5 PM Eastern Time, July 27, 2012.

Application Submission: Applicants must submit one (1) hard copy and one (1) digital copy on CD-ROM of the application and supporting documentation, including a completed Application Cover Sheet (Attachment A). Applications must be clearly labeled and submitted to:

Edward Kear, RFI 2568 NYS Energy Research and Development Authority 17 Columbia Circle Albany, NY 12203-6399

If you have questions concerning this solicitation, contact Edward Kear at (518) 862-1090, ext. 3269 or ebk@nyserda.org.

*Late applications will be returned. Faxed or emailed applications will not be accepted. Applications will not be accepted at any other NYSERDA location other than the address above. If changes are made to this solicitation, notification will be posted on NYSERDA's web site at www.nyserda.ny.gov.



Introduction

NYSERDA's CHP Acceleration Program (PON 2568) provides incentives for the installation of appropriately sized, packaged CHP systems that meet specified criteria in terms of system design and component integration; capability to meet a threshold of performance; and sales, installation and service support. Only CHP installations using pre-qualified, or conditionally qualified, packaged CHP systems will be eligible for incentives under PON 2568. The purpose of this RFI is to invite applications to pre-qualify/conditionally-qualify packaged CHP systems.

The term "packaged" is not necessarily limited to, or defined as, a physically integrated prime mover, heat recovery and controls product on a single skid, but more broadly defined to include:

- An integrated CHP system design that includes one or more prime mover/generator(s) and matched heat recovery, interconnection, controls, and monitoring components with demonstrated performance,
- The system is pre-engineered and major components and assemblies are factory pre-tested (including controls) prior to shipment to the site,
- A single point of responsibility for installation, service and warranty, and
- A single warranty for the system including all system components.

Two categories of CHP system qualification will be used based on the level of documented system performance:

- Pre-qualified CHP systems pre-engineered, pre-tested systems with a single point of responsibility for installation, service and warranty, and demonstrated performance as an integrated system based on one of the three ASERTTI CHP Testing Protocols or equivalent.
- Conditionally-qualified CHP systems pre-engineered systems of matched components and a single
 point of responsibility for installation service and warranty. Components and subsystems have been
 individually performance tested and the complete system has been designed and performance
 rated using accepted engineering methods. Conditionally qualified systems can be upgraded to prequalified status once integrated system performance is demonstrated and documented to NYSERDA's
 satisfaction.

Program Requirements

Applicants (i.e., Respondents to this RFI) must be fully responsible for all aspects of vending/installing/maintaining/warranting the package and may be an original equipment manufacturer, a system integrator, or any other entity that offers to install packaged CHP systems at sites in New York State.

The Applicant must provide a single point of responsibility for site integration, installation, and all warranty (defect and performance), maintenance and service activities related to packaged CHP system offered by the Applicant (including all components) for a period of not less than five (5) years from the date of electric grid interconnection approval. The Applicant can use subcontracted teams to fulfill these obligations, however, regardless of the teaming arrangement; the Applicant remains fully responsible for all aspects.

The aggregate generator nameplate electric output rating of the packaged CHP system must not be less than 50 kW or greater than 1.3 MW. Furthermore, all generators within the packaged CHP system must have a nameplate electric output rating not less than 50 kW or greater than 1.3 MW.

Packaged CHP systems that utilize thermal energy to power the prime move are eligible. For those CHP systems that utilize a fuel to power the prime mover, only pipeline natural gas fueled prime movers are eligible. Fuel cell systems are not eligible.

Eligible packaged CHP systems must be capable of operating in parallel with the utility electric grid and also must be capable of operating in stand-alone mode during a grid outage.

Eligible packaged CHP systems may be configured to provide hot water, steam, chilled water, or any combination as thermal outputs.



Packages selected for admittance into the Program will be listed in catalog-format by NYSERDA in PON 2568 when it is issued/updated. Excerpts from the materials submitted by the Applicant in response to this RFI will be used to create the "catalog entry" and thus the Applicant must work in good faith with NYSERDA to distinguish between confidential/proprietary materials which the Applicant may submit in order to convince NYSERDA of the merits of their packages, versus materials which NYSERDA would be allowed to publish in order to create a catalog that adequately describes the package.

Each CHP system installed at a customer's site via PON 2568 will be subject to an exercise to re-commission the system, at NYSERDA's sole expense, during the system's sophomore-year of operation. The Applicant will be expected to facilitate NYSERDA's re-commissioning agent's access to the site, the CHP system, and information regarding its legacy of performance. Additionally, the Applicant is expected to thoughtfully consider the merits of any recommendations for improvement of the CHP System and/or its operational dispatch that may result from such re-commissioning effort.

The packaged CHP system must include a performance monitoring system that, at a minimum, conforms to NYSERDA's Monitoring and Data Collection Standard (Attachment C).

All conditionally-qualified CHP systems and the first unit of a pre-qualified CHP system supported under PON 2568 must be factory witness tested prior to shipment to the site. The witness test must be conducted with the system fully assembled. Testing of a disaggregation of individual subsystems will not satisfy this requirement. The witnesses shall include NYSERDA staff or designated representative. If the witness testing of the first pre-qualified unit proves acceptable then NYSERDA may allow subsequent units to be factory tested as a disaggregation of individual subsystems so as to assess the quality of workmanship.



Qualification Requirements

Qualification Table				
Category	Minimum Requirements	Required Documentation		
CHP System submitted for prequalification	Completed	CHP Acceleration Program – CHP System Qualification Data Form (Attachment B)		
Dverall CHP efficiency Overall CHP Efficiency = (Net CHP Electric Output + CHP Thermal Output Available @ Temperature)/CHP Fuel Input; all calculated in Higher Heating Value (HHV). Operating conditions must be stated that annual efficiencies in the fiel the 60% minimum requirement. Pre-qualified: Third party laborate based on one of the three ASER Testing Protocols or Equivalent. tested data such as data at chp.nyserda.org may be accepted Conditionally-qualified: Overall C Efficiency (HHV) based on accepted.		Pre-qualified: Third party laboratory results based on one of the three ASERTTI CHP Testing Protocols or Equivalent. Field		
NOx Emissions (Expressed as generator-out emissions, engine-out calculation should be based on 95% efficient generator)	Less than 1.6 lb/MWhe	Certified third party emissions measurements in accordance with latest EPA test requirements. Emissions data provided for full and part load.		
Warranty/Service	Five year parts and labor for the complete CHP system ¹	Written warranty language and description of warranty/service plan.		
Performance Monitoring System	Conforming to NYSERDA Data Monitoring Standard	Written compliance		
Installation and Commissioning Manual	Complete CHP	Written manual		
Operating Manual Maintenance and Repair Manual	system including heat recovery	Written manual Written manual		
Certifications	IEEE 1547 compliant UL 1741 certification	Written compliance with IEEE 1547 Written UL 1741certification (if applicable)		
Dispatch: Grid-parallel & stand- alone	Capable of operation in both grid-parallel and stand-alone configurations	Written description of capability and operational transition sequence from grid-parallel to stand-alone, and then back to grid-parallel		
Interconnection A – Radial B – Secondary network C- Spot network		Description of interconnection and protective equipment and demonstrated compliance with minimum specifications for each type of interconnection where qualification is requested.		

¹ A critical factor in qualification is single point responsibility for the entire system. This includes a single warranty covering all elements that make the CHP system function including prime mover, generator, waste heat recovery system, heat dump radiator (if required), supplemental heating (if required), valves, dampers, piping, ductwork, controls, monitoring and data export, etc. Single point responsibility also includes CHP system level drawings, part lists, installation, operation and maintenance manuals, and service and maintenance program.



Application Requirements

Applicants must submit a separate application under this RFI for each different packaged CHP system design where qualification is requested.

Pre-qualified CHP systems

These systems are pre-engineered, pre-tested with single or multiple integrated prime movers, or matched components that have been previously integrated and performance tested as a complete system including controls, monitoring system, any interconnecting piping, ductwork and/or wiring as supplied by the manufacturer/developer.

Applicants seeking Pre-qualification of their packages are required to submit the following materials:

- System piping and instrumentation drawing (P&ID).
- System layout (configuration) drawing.
- Single line wiring diagram.
- Complete bill of materials that includes major system components, controls and piping, ductwork and wiring integral to the system.
- System performance test documentation including: net electric output, useful thermal output(s)
 (form, flows, temperature, pressure, and energy see data form for details), fuel requirements
 (flow, temperature, pressure and energy in HHV), as well as testing entity, the method of testing
 utilized and uncertainty analysis.
- All system performance and emissions data must be provided at full and part load conditions; Part load is defined as 75%, 50% and 25% of full load capacity.
- System monitoring and data export configuration and mechanisms.
- System performance guarantees including net power and thermal outputs (temperature and energy) shall be provided at part and full loads.
- System installation and commissioning requirements to maintain system warranty including (as applicable)
 qualification requirements to be used to select subcontractors that will act as installers and associated
 quality control measures, training and responsibilities.
- System operation requirements including services provided and responsibilities.
- System warranty and service plan including information on parts and labor coverage, length of coverage, and warranty/service providers (Five year term is mandatory, ten year term is optional).
- System service requirements including parts, labor and maintenance requirements during the first ten years of operation.
- Factory test protocols for each major component and assembly, and the complete system.
- Description of the operational transition from grid-parallel to stand-alone, and then back to grid-parallel.
- List (with photos) of existing installations of the packaged CHP system.
- A completed CHP System Qualification Data Form.

Conditionally-qualified CHP systems

This category includes pre-engineered systems comprised of matched components and subsystems that have been individually tested. The complete systems including interconnecting piping, ductwork and or wiring which have been designed by the manufacturer/developer. Individual components and subsystems have been performance tested, and the complete system including all interconnecting equipment has been engineered, designed and performance rated using accepted engineering methods.

Applicants seeking Conditional-qualification of their packages are required to submit the following materials:

- System piping and instrumentation drawing (P&ID).
- System layout (configuration) drawing.
- Single line wiring diagram.
- Complete bill of materials that includes major system components, controls and piping, ductwork and wiring integral to the system.
- System component and subsystems performance test documentation, and calculations combining
 the components and subsystems into a complete CHP system including: net electric output, useful
 thermal output(s) (form, flows, temperature, pressure, and energy see data form for details), fuel



requirements (flow, temperature, pressure, and energy in HHV), as well as the method of testing utilized and uncertainty analysis.

- All system performance and emissions data must be provided at full and part load conditions; part load is defined as 75%, 50% and 25% of full load capacity.
- System monitoring and data export configuration and mechanisms.
- System performance guarantee including net power and thermal outputs (temperature and energy) shall be provided at part and full loads.
- System installation and commissioning requirements to maintain warranty including (as applicable)
 qualification requirements to be used to select subcontractors that will act as installers and associated
 quality control measures, training and responsibilities.
- System operation requirements including services provided and responsibilities.
- System warranty and service plan including information on parts and labor coverage, length of coverage, and warranty/service providers (Five year term is mandatory, ten year term is optional).
- System service requirements including parts, labor and maintenance requirements during the first ten years of operation.
- Factory test protocols for each major component and assembly, and the complete system.
- Description of the operational transition from grid-parallel to stand-alone, and then back to grid-parallel.
- List (with photos) of existing installations utilizing the various major components/sub-systems.
- A completed CHP System Qualification Data Form.

Application Format

The format of the qualification submittal is left to the Applicant. However, NYSERDA suggests that the submitted materials be organized in the following order:

- System drawings, schematics and diagrams must be of sufficient detail to fully understand the complete
 system that is being submitted for qualification. With respect to pre-qualification this includes all
 interconnecting piping, ductwork, valves wiring and controls including configuration and dimensions.
 Keep in mind that only the submitted system configuration will be pre-qualified. Conditionally-qualified
 systems must include design and physical limitations with respect to interconnecting piping, ductwork,
 valves wiring and controls including configuration and dimensions.
- The Bill of Materials should be at a level of detail where major components are identified including prime
 mover, generator, heat recovery devices, thermally activated technologies, emissions abatement
 equipment, system level controls, monitoring equipment, interconnection paralleling, transfer and
 protective equipment, interconnecting piping, ductwork and valving.
- System energy and emissions performance documentation as requested above.
- Certifications as requested above.
- The installation manual should include:
 - Safety instructions
 - Principles of operation
 - System description and technical data
 - Installation requirements
 - Thermal system connections
 - o Fuel connections
 - Intake and exhaust information
 - Electric connections
 - Controls
 - Initial operation and commissioning
 - Maintenance
 - Spare parts
- The operating manual should include:
 - Application/Operating modes



- Sub-system descriptions
 - Prime mover
 - Heat recovery systems
 - Controls and monitoring systems
 - Grid interconnection and protective systems
 - Other
- System operation
- Operator interface
- Maintenance
- Troubleshooting
- The maintenance and service manual should include:
 - General overview of maintenance requirements
 - Routine service requirements and procedures
 - Troubleshooting
 - o Service parts list
- The warranty description should include:
 - o Length and limits of coverage
 - Service plans and options

Application Evaluation

Applications that meet Application Requirements will be reviewed using the evaluation criteria below:

- Does the application meet the RFI requirements?
- Does the application contain sufficient information to provide an understanding of how the system was
 engineered and designed, why specific components were selected, how they were integrated into the
 package, and how the integrated package and controls will operate in the field?
- Does the application demonstrate that the equipment and individual components have a history of durability, quality, and reliability?
- Does the application demonstrate that the equipment and individual components are well-matched to work in harmony with each other as a "system"?
- Does the application show single-point responsibility, with adequate resources to engender confidence of the ability to manage the equipment packaging, installation, commissioning, and maintenance, either directly or through subcontracted teaming arrangements? (Regardless of the teaming arrangement, the Applicant remains fully responsible for all aspects).

NYSERDA may utilize outside evaluators to assist in the review of applications. NYSERDA may request supplemental materials as reasonably necessary to facilitate review.



GENERAL CONDITIONS

Proprietary Information - Careful consideration should be given before confidential information is submitted to NYSERDA as part of your application. Review should include whether it is critical for evaluating a application, and whether general, non-confidential information, may be adequate for review purposes. The NYS Freedom of Information Law, Public Officers law, Article 6, provides for public access to information NYSERDA possesses. Public Officers Law, Section 87(2)(d) provides for exceptions to disclosure for records or portions thereof that "are trade secrets or are submitted to an agency by a commercial enterprise or derived from information obtained from a commercial enterprise and which if disclosed would cause <u>substantial injury to the competitive position</u> of the subject enterprise." Information submitted to NYSERDA that the applicant wishes to have treated as proprietary, and confidential trade secret information, should be identified and labeled "Confidential" or "Proprietary" on each page at the time of disclosure. This information should include a written request to exempt it from disclosure, including a written statement of the reasons why the information should be exempted. See Public Officers Law, Section 89(5) and the procedures set forth in 21 NYCRR Part 501 http://nyserda.ny.gov/~/media/Files/About/Contact/NYSERDARegulations.ashx However, NYSERDA cannot guarantee the confidentiality of any information submitted.

Omnibus Procurement Act of 1992 - It is the policy of New York State to maximize opportunities for the participation of New York State business enterprises, including minority- and women-owned business enterprises, as bidders, subcontractors, and suppliers on its procurement Agreements.

Information on the availability of New York subcontractors and suppliers is available from:

Empire State Development Division For Small Business 30 South Pearl Street Albany, NY 12245

A directory of certified minority- and women-owned business enterprises is available from:

Empire State Development Minority and Women's Business Development Division 30 South Pearl Street Albany, NY 12245

<u>Limitation</u> - This solicitation does not commit NYSERDA to award a contract, pay any costs incurred in preparing an application, or to procure or contract for services or supplies. NYSERDA reserves the right to accept or reject any or all applications received, or to cancel in part or in its entirety the solicitation when it is in NYSERDA's best interest.

<u>Disclosure Requirement</u> - The applicant shall disclose any indictment for any alleged felony, or any conviction for a felony within the past five years, under the laws of the United States or any state or territory of the United States, and shall describe circumstances for each. When an applicant is an association, partnership, corporation, or other organization, this disclosure requirement includes the organization and its officers, partners, and directors or members of any similarly governing body. Applicants must also disclose if they have ever been debarred or suspended by any agency of the U.S. Government or the New York State Department of Labor.

Attachments

Attachment A - Application Cover Sheet

Attachment B - CHP System Qualification Data Form

Attachment C - Monitoring and Data Collection Standard



Attachment A - RFI 2568 Application Cover Sheet

CHP System Model Identifier
Applicant (Company Name)
Contact Person
Address
Phone Number
Thore Number
Email Address



Attachment B - CHP Acce	eleration Program –	CHP System Qualification Data Form
Category	Units	Information Required*
Prime Mover		
Manufacturer		
Model		
Capacity	kW	
Fuel required	scfm	
Fuel pressure	inches water or psia (please indicate)	
Fuel Booster compressor power (if required)	kW	
Exhaust temperature	°F	
Exhaust flow rate	scfm	
Exhaust pressure available for external use (e.g. HRSG if applicable)	psig	
NOx emissions	lb/MWhe	
PM10 emissions	lb/MWhe	
PM2.5 emissions	lb/MWhe	
CO emissions	lb/MWhe	
VOC emissions	lb/MWhe	
Noise	dBA	
Generator/Inverter		☐ Synchronous ☐ Inverter ☐ Other
Manufacturer		
Model		
Power output rating	kW	
Power output rating	kVA	
Rated voltage	V	
Rated efficiency	%	
Rated current	Amps	
Minimum operation frequency/time	Hz/sec.	
Connection		☐ Delta ☐ Wye ☐ Wye grounded
Total system type tested		☐ Yes ☐ No Provide documentation
Equipment type tested (inverter, protection system)		☐ Yes ☐ No Provide documentation
Synchronous		☐ Salient ☐ Non-salient Attach copies of saturation and Vee curves
Rated speed	RPM	
Torque	ft-lbs	
Field amps at rated voltage and current	Amps	



	1	T		
Field power factor over- excited	%			
Type of exciter				
Output power of exciter	W			
Type of voltage regulator				
Locked rotor current	Amps			
Direct-axis synchronous reactance (X _d)	ohms			
Direct-axis transient reactance (X' _d)	ohms			
Direct-axis sub-transient reactance (X" _d)	ohms			
Inverter		☐ Forced com	mutated Line	commutated
Heat Recovery				
Hot Water				
Manufacturer				
Model				
Maximum continuous HW				
supply temperature	°F			
Minimum return HW				
temperature (excluding	°F			
dump radiator heat transfer)				
Maximum energy available	D. "			
at the HW supply	Btu/h			
temperature Maximum energy available				
given the above HW supply	Btu/h			
and return temperatures	Btann			
Chilled Water		□ Exhaust	☐ Hot water	☐ Hybrid
Manufacturer				
Model				
Minimum continuous chilled	°F			
water supply temperature				
Maximum supply/return	°F			
temperature differential				
Maximum energy available	B. "			
at the minimum chilled water	Btu/h			
supply temperature Chiller Coefficient of				
Performance				
Useful thermal energy	D. //			
required from the prime	Btu/h per thermal			
mover to deliver the	stream including required supply			
maximum energy available	temperatures			
at the minimum chilled water	tomporatures			
Steam (HRSG)				
Input (e.g. turbine exhaust at HRSG inlet) temperature	°F			
Input (e.g. turbine exhaust at HRSG inlet) flow rate	scfm			



HRSG pressure drop	psig	
Feedwater inlet temperature	°F	
Steam output pressure	psig	
Steam output flow rate	lb/hr	
Steam output temperature	°F	
Steam output energy	Btu/h	
System Performance		
Net Electric Efficiency ¹ (HHV)	%	
Thermal Energy Available Efficiency ¹ (HHV)	%	
CHP Efficiency ¹ (HHV)	%	

^{*}Note: All system performance and emissions data must be provided at full and part load conditions; Part load is defined as 75%, 50% and 25% of full load capacity. If the CHP System consists of multiple prime mover/generators, complete a data form for the prime mover/generator and for the CHP System as a whole.

¹ Show complete calculation



Net Electrical Efficiency

Net electrical energy output is a calculated value that indicates the usable electrical power a system (in contrast to a product) delivers and accounts for the energy required in operating the system. The external parasitic loads shall be identified during test plan development prior to testing and included in the test report.

The net electrical output is calculated based on the total electrical energy out of the system, integrated over the test duration, less all external parasitic losses, such as heat transfer fluid pumps and fans that are outside the product boundary, but inside the system boundary. The net electrical energy produced is given by:

$$E_n = E_g - E_a$$

Where:

E_a = total auxiliary electrical energy requirements

E_g = total (gross) electrical energy measured

 E_n = net electrical energy in kW/h

Net electrical efficiency is the indication of fuel to electricity conversion efficiency of the DG product considering internal and external parasitic losses and accounting for the actual fuel required to operate the CHP product and is based on Higher Heating Value (HHV).

$$\eta_{ne} = \frac{E_n x 3412}{Q_i}$$

Where:

 η_{ne} = net electrical efficiency based on HHV Q_i = total fuel into the system (Btu) based on HHV 3,412 = conversion factor from kWe to Btu/hr (Btu/kW·hr)

Thermal Efficiency Hot Water Supply System

Thermal efficiency is a measure of energy utility; that is, the percentage of total fuel input which is captured and put to useful service by conversion to thermal energy and is based on Higher Heating Value (HHV).

$$Q_{hw} = m \times C_p \times \Delta T$$

or,



$$Q_{hw} = F_{hw} \times K \times \Delta T$$

Where:

Q_{hw} = hot water supply in Btu/h

m = mass flow rate of water in lb/h

F_{hw} = hot water flow rate in gpm

ΔT = temperature differential (supply temperature – required return temperature)

K = conversion factor from gpm to lb/h²

 C_p = for water = 1 Btu/lb

$$\eta_{hw} = \frac{Q_{hw}}{Q_i}$$

Where:

 η_{hw} = net thermal hot water efficiency based on HHV

Q_i = total fuel into the system (Btu/h) based on HHV

Chilled Water Supply System

Thermal efficiency is a measure of energy utility; that is, the percentage of total energy input, which is captured and put to useful service by conversion to thermal energy and is based on Higher Heating Value (HHV).

$$Q_{cw} = m \times C_p \times \Delta T$$

or,

$$Q_{cw} = F_{cw} \times K \times K$$

Where:

Q_{cw} = chilled water supply in Btu/hr

m = mass flow rate of chilled water in lb/h

 F_{cw} = chilled water flow rate in gpm

ΔT = temperature differential (supply temperature – required return temperature)

K = conversion factor from gpm to lb/h³

C_p = for water = 1 Btu/lb °F

$$Q_{cwthermal} = \frac{Q_{cw}}{COP}$$

² K is 488 for water at 180 °F, need to adjust accordingly for other fluids

³ K = 500 for chilled water



Where:

 $Q_{cwthermal}$ = the useful thermal energy (Btu/h) from the prime mover required by the chiller to deliver Q_{cw} COP = measured Coefficient of Performance of the chiller (hot water, exhaust gas or hybrid) to deliver the measured Q_{cw}

$$\eta_{cwthermal} = \frac{Q_{cwthermal}}{Q_i}$$

Where:

 $\eta_{cwthermal}$ = net thermal chilled water efficiency based on HHV

 $Q_{cwthermal}$ = the useful thermal energy (Btu/h) from the prime mover required by the chiller to deliver Q_{cw} Q_i = total fuel into the system (Btu/h) based on HHV

Steam Supply System

Thermal efficiency is a measure of energy utility; that is, the percentage of total energy input, which is captured and put to useful service by conversion to thermal energy and is based on Higher Heating Value (HHV).

$$Q_{steam} = F_{steam} \times \Delta H$$

Where:

Q_{steam} = steam supply in Btu/h

F_{steam} = steam flow rate in pounds per hour

 ΔH = increase in steam enthalpy in Btu/pound (enthalpy of steam output – enthalpy of feedwater input)⁴

$$\eta_{steam} = \frac{Q_{steam}}{Q_i}$$

Where:

 η_{steam} = net thermal steam efficiency based on HHV

 Q_i = total fuel into the system (Btu/h) based on HHV (including fuel used in duct burners or auxiliary boilers integrated into the system)

⁴ Enthalpy is a function of the pressure and temperature of steam or feedwater

ATTACHMENT C

MONITORING AND DATA COLLECTION STANDARD

FOR

DISTRIBUTED GENERATION/COMBINED HEAT AND POWER (DG/CHP) SYSTEMS

December 29, 2004

Revised

Submitted to:

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

Submitted by:

PO Box 641 132 Albany Street Cazenovia, NY 13035 (315) 655-1063

TABLE OF CONTENTS

Introduction]
Documenting System Details]
Describing DG\CHP Equipment	
System Schematic	
Feasibility Study and Estimated Annual Performance	3
Data Collection and Monitoring	
Monitoring Objectives	
Monitoring Hardware Issues	4
Monitored Data Points	
Selecting Monitoring Points for and EXAMPLE CHP SITE	7
Communications, Data Retrieval Procedures, and Web Presentation	

Attachment No. 1 to Appendix A-2 - Suggested Convention for Naming Data Points

GLOSSARY

DG/CHP System. The units, components, equipment and subsystems that make up the Distributed Generation/Combined Heat and Power system at a facility.

Data Acquisition System (DAS). The controllers, instrumentation and other equipment at the site to measure and record data related to the facility or DG/CHP system. Can be a dedicated data logger, a direct digital control (DDC) system for controlling facility operation, an industrial control system, or an on-board controller for the DG/CHP equipment. Generally, the DAS is located on-site near the DG/CHP System.

Data Collection, Logging, or Recording Interval. The time interval at which data are recorded or saved into memory in the on-site DAS.

Data Retrieval Interval. The time interval at which data are transferred from the on-site DAS to an off-site computer system for storage and analysis.

Data Point. The measured value or reading provided by a sensor or instrument installed as part of the on-site DAS or from other handheld instruments.

Demonstration Site. A facility or building where a DG/CHP system has been installed with financial support from NYSERDA.

Displaced Fuel Use. The natural gas or other fuels that would have been consumed if the DG/CHP system had not been installed/operating at the site.

Load. The equipment and systems in a facility or building that consume or use heat, power, or cooling that is produced by a DG/CHP system. In the absence of the DG/CHP equipment, the thermal load would be met with boilers, furnaces, chillers, or other fuel consuming equipment at the site. The electric load would have been met by the local electric utility.

Log or Logfile. The file or memory locations where control systems save or record time stamped data. This term is commonly used by building direct digital control systems.

Monitoring Plan. A document describing the sensors and equipment to be installed as part of the DAS. The plan explains the purpose and use of each sensor or data point.

Monitoring System. Same as Data Acquisition System (DAS).

Parasitic Power. Electric power consumed by the DG/CHP system. Can be power use internal to the DG/CHP unit (internal parasitics) or power use by pumps, fans, compressors and other components that are required to deliver heat, power or cooling to the load (external parasitics).

Scan or Sampling Interval. The time interval at which each sensor or instrument is read by the on-site DAS.

Introduction

This document describes the requirements and desirable attributes of an automated data collection system designed to monitor the performance of a distributed generation/combined heat and power (DG/CHP) system. This standard is intended to provide guidance to demonstration sites that are part of NYSERDA's DG/CHP program. Specifically, this document seeks to guide demonstration sites through the process of developing a monitoring system and preparing a Monitoring Plan for their DG/CHP site.

DG/CHP demonstration sites that receive funding from NYSERDA are generally required to collect key performance data at 15-minute intervals over the first year of operation. The monitored data are intended to quantify facility load profiles, generator power output, fuel consumption, useful thermal outputs, parasitic loads and equipment runtimes. These data provide the means to confirm electrical and CHP efficiencies over the year, determine equipment availability, and verify system economics.

The sections that follow discuss the types of on-site measurements that are required or recommended to meet the goals and monitoring requirements. First, this document describes the need to fully document the salient details of the DG/CHP system and to develop a simple system schematic. Next, the process of setting monitoring objectives and goals for a CHP project are described. Then, the process of selecting monitoring hardware and instrumentation to meet the project goals is demonstrated by an example. Finally, the advantages and disadvantages of various communications and web presentation options are compared.

Documenting System Details

The first step in developing a monitoring plan is to define the key components and equipment as well as to provide the basic layout of the components in the DG/CHP system. This step is critical because it helps to determine the data points and measured parameters that must be monitored to quantify system operation.

Describing DG\CHP Equipment

At a minimum, the monitoring plan should include the basic equipment and system details listed in Table 1.

CDH Energy Corp. 1 December 29, 2004

Table 1. Documenting DG/CHP Equipment and Site Details

System overview	 Generator size and type Is power exported to the grid? standby power functionality heat recovery used to meet facility loads; describe loads and displaced fuels
Power generating equipment	 Nameplate data such as output, operating voltage, generator type, fuel input Basic nameplate data on standby power/auto transfer components protective relay functions and settings
Heat recovery system and displaced thermal equipment	 Rated performance and corresponding operating temperatures of heating/cooling systems Size and Nameplate data on boilers, chillers and other equipment that are displaced by (or provide backup for) heat recovery operation
Facility load details	 Facility size, use, and other application details Electric utility details: number of meters, original and current electric and gas tariff info

System Schematic

An important step to describing and understanding a DG/CHP system is to develop a simple schematic representation of the system. Unlike detailed engineering drawings that show the physical layout of all components in a system, a simple schematic conveys the functional layout of the system in order to understand the energy flows and thermodynamic boundaries. The key concepts conveyed by the schematic are the flow of fuel, electricity, and thermal energy between the DG/CHP system and the facility. The number of heat exchange steps, the direction of fluid flow, the operating temperature of each loop, the net power supplied to the building, and exported power are all shown.

Figure 1 shows a simple schematic of a CHP system that supplies heat recovery to a building via a hot water loop. Hot water from the CHP unit is supplied at 180°F. A heat exchanger (HX) is required to separate the building hot water loop from the CHP system loop. The extra heat exchange step lowers the fluid temperature that can be delivered to the load. A dump radiator rejects heat from the loop when it cannot be used to meet building thermal loads. The system supplies generated power into the main electric bus for the facility. This power is consumed internally (no power export to the utility). Some external parasitic power is required to run the

CDH Energy Corp. 2 December 29, 2004

pumps and dump radiator. The net purchases from the utility are also monitored at the main meter.

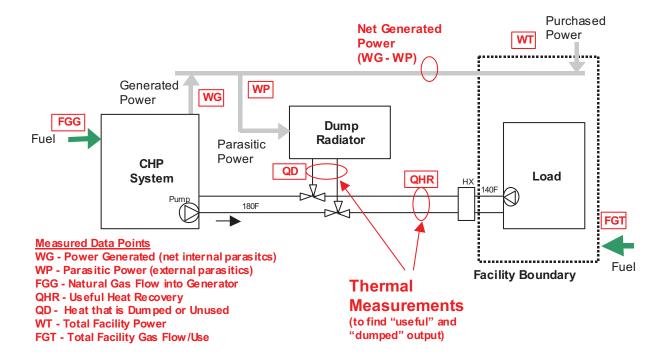


Figure 1. Simple Schematic CHP System

Figure 1 also shows the location of monitored data points that would be included to measure DG/CHP system performance. The data point name or tag corresponding to each sensor is shown as the red, box-enclosed text on the schematic¹. A key purpose of the schematic is to show the location of each measured point in order to demonstrate that meaningful data are being collected. The next section talks about process and rationale for selecting these points.

Feasibility Study and Estimated Annual Performance

In most cases a DG/CHP System is installed and built after a detailed engineering feasibility study has been completed to evaluate the cost effectiveness of the system. Generally this study would have assumed or calculated sizes and performance characteristics for key equipment and predicted annual power production, daily or monthly load profiles, annual heat recovery savings, parasitic power use, etc. The key results of the feasibility study should be briefly summarized in the monitoring plan. The original feasibility study could also be attached as an appendix or provided as a reference.

CDH Energy Corp. 3 December 29, 2004

¹ Appendix A explains the naming convention that was used for selecting the data point names shown in Figure 1.

Data Collection and Monitoring

Monitoring Objectives

In order to select the necessary monitored data points the project objectives should first be clearly stated, since they drive the monitoring and data collection requirements. The primary monitoring objectives (listed in Table 2) are usually required for NYSERDA DG/CHP sites. Other optional objectives are listed in Table 3. The data points necessary to meet these objectives are listed in each table.

Table 2. Primary (NYSERDA Required) Monitoring Objectives

No	Objective	Data Necessary to Meet Objective
1	Quantify the variation of DG/CHP system power output, gas consumption, and efficiency over wide range of annual operating conditions.	WG ¹ , FGG, TAO
2.	Quantify external parasitic loads (e.g., gas compressors, pumps, dump radiators, etc.).	WP
3.	Quantify the daily, weekly monthly, and annual variation of total facility power use (or power purchased from the utility) so that actual utility costs can be determined.	WT
4.	Determine the thermal loads imposed on the CHP system by the facility (or the useful thermal output supplied to the facility) to measure the total CHP efficiency of the system on a daily, monthly and annual basis; quantify the variation of these loads with ambient conditions and operating schedules so the findings from this site can be extended to other climates.	QHR (or integrated flows & temperatures), TAO
5.	Quantify the displaced fuel use on auxiliary equipment and systems to confirm the benefit of heat recovery.	Boiler fuel use, total facility fuel use (FGT), chiller electric consumption
6.	Quantify the amount of available thermal energy that is unused or "dumped" by the CHP system in order to demonstrate a system heat balance.	QD (or integrated flows & temperatures)

^{1 -} The data point names correspond to the points listed in Figure 1 and Attachment No. 1 to Appendix A-2.

Table 3. Optional Monitoring Objectives

No	Objective	Data Necessary to Meet Objective
7.	Determine the impact of generator operation on power quality in the facility (power factor, kVAR, frequency, total harmonic distortion); measure at generator output and/or main service entrance.	Volts, amps, kVA, hz, THD, etc (total and/or per phase)
8.	Collect diagnostic data to confirm the DG/CHP system operates as expected and/or support of maintenance and operation activities.	Component statuses, intermediate temperatures, pressures
9.	Develop performance maps of CHP equipment and components to verify manufacturer specifications.	QHR, flows, temperatures, statuses, etc.
10.	Determine environmental emissions from DG/CHP equipment to quantify net emissions impacts of the system.	CO, NO _x , THC, etc

The primary objectives listed in Table 2 require the relatively small set of monitored data points shown on Figure 1. The optional objectives would require a more extensive monitoring system. Generally all these data would be captured and recorded at 15-minute intervals. Though in some cases one-time readings with handheld meters will sufficient to quantify operation (e.g., one time readings of parasitic power for a constantly operating pump; one-time flow readings for loop flow rates that are constant). Some data, such as local weather data, can also be purchased instead of measured (www.ncdc.noaa.gov).

In some cases it may be more convenient to measure power at different locations in the system. For instance:

- measure total facility power use instead of net utility purchases,
- separately measure generator gross output and internal parasitics instead of net busbar power output.

These variations are acceptable but must be documented in the monitoring plan tables and schematic. The Monitoring Plan must include equations defining how the values shown in Figure 1 can be calculated from the measured data.

Monitoring Hardware Issues

The necessary sensors and equipment are driven by monitoring objectives as well as the type of monitoring system hardware and software that will be used. For instance, if the monitoring system is capable of counting pulses, then a utility-grade KYZ (or Form C) output can often be added to main electric meter at a relatively low cost. Otherwise an additional power meter with a more compatible output (e.g., a 4-20 ma output proportional to kW) might have to be installed on the building main. Similar issues are true for the gas meter installed on the CHP unit.

Another monitoring system issue is the type of software used to sample, record, and save the monitored data. Building control systems have historically had the ability to sample data at specified interval and then save that information in a "log". In contrast data loggers and other

CDH Energy Corp. 5 December 29, 2004

more flexible control systems can usually scan or read sensors at relatively fast interval (e.g., every few seconds) and then average or totalize the readings over the recording interval (e.g., every 15-minutes). This distinction can become very important when aggregating the data to daily, monthly, or annual values. The relative impact depends on how much the outputs, inputs, or loads fluctuate in time. Generally, monitoring systems than can average or totalize over the recording interval will provide more accurate and useful data.

Key examples are the electric power output from a generator or total power use of a facility. The goal is usually to determine the overall energy production (kWh) as well as the average demand (kW) for each recording interval (e.g., 15-minutes). With a pulse output meter, the total energy use (kWh) is explicitly determined. However, the average demand (kW) in time interval can also be determined if the pulse resolution is sufficiently small. In this case the average demand is:

 $KW_{avg} = (measured kWh per interval) / (time interval)$

The other metering option would be to use a power meter that measures power (kW) and provides an analog output (e.g., 4-20 mA). This meter explicitly measures power demand. However, the overall energy use can also be inferred:

 $KWh_{total} = (measured kW) x (time interval)$

For systems were the measured value changes faster than the time interval, the error in determining the inferred kWh value can be large. This is especially true for monitoring systems that only take one sample in the recording interval. Scanning and averaging the power transducer at a faster rate can generally alleviate these concerns.

Other more expensive types of power meters solve this problem by independently providing a kWh and kW reading via a serial connection (e.g., MODBUS) for each interval.

Generally we believe that priority should be on explicitly determining energy use (kWh) with a high-resolution, pulse-emitting meter since this reading is most important to overall economics. The average demand in any interval can be closely inferred by the method described above.

Determining the thermal outputs from a CHP system has similar issues. Determining the thermal output generally requires that the flow and delta temperature be measured. The product of flow and delta temperature must be integrated (or summed) to determine the energy content:

$$q = k \cdot \Sigma \{gpm_i \cdot (Tin_i - Tout_i)\} \cdot (time interval)$$

Where i corresponds the readings at each scan interval. The factor "k" depends on the specific heat and density of the actual fluid at the site. The summation is completed for all the scans to find the total value "q" for the recording or logging interval (i.e., 15 minutes). The integration can be done by a control system/data logger or by using a dedicated electronic device known as a BTU Meter. If the flow is known to be constant throughout the year, then a one-time flow reading can be combined with continuous temperature measurements. In all cases, care should

CDH Energy Corp. 6 December 29, 2004

be taken to properly integrate the flow-temperature product at small intervals if the flow varies (or cycles on and off) to meet the needs of the load.

If a constant flow is assumed, then the Monitoring Plan must explicitly make the case that no pumps or valves in the loop will vary. At a minimum, a one-time flow measurement is required to verify the flow rate. Design flow values from drawings or engineering design calculations are not acceptable.

Monitored Data Points

The monitored data points that are ultimately selected need to specified in tabular and graphic form. The tabular summary needs to specify or provide:

- the data point name or tag
- a description of the measured value
- the engineering units of the measured/recorded value
- the type of sensor or transducer and key manufacturer information

Separate tables should be provided for continuous or automatically-collected data points and for measurements that a taken periodically or one-time with handheld or temporary meters.

The DG/CHP system schematic should be used to show the location of each data point in the system. The schematic must include sufficient detail to explain why and how the measurement location was selected.

Finally, the rationale and intended purpose for each data point should be described in the text. The description should explain how the measured point would be used to analyze and understand DG/CHP system performance. The description can be bulleted text or in narrative format. The next subsection shows an example of how the monitored data points could be presented and defined.

Selecting Monitoring Points for and EXAMPLE CHP SITE....

The continuously-monitored data points in Table 4 were selected to quantify the performance of the CHP system. Figure 2 shows the location of each monitored point in the system. The CHP system includes two 60 kW microturbines with integrated heat recovery. Hot water produced by the microturbines is used to provide space heating to the building. Hot water is also provided to an absorption chiller that can meet the space cooling loads in the summer. Heat recovery provided for space heating will displace boiler operation. Hear recovery used by the chiller will displace operation of the original electric chiller.

The monitoring system will use a Campbell Scientific CR-10x data logger that samples and integrates every 10 seconds and records data at 15-minute intervals.

Table 4. Continuous or Automatically Collected Monitoring Points for EXAMPLE CHP System

Channel	Data Pt	Description	Eng	Company Trans
Туре	Name	Description	Units	Sensor Type
Analog-1		Thermocouple reference		
Analog-2	TAO	Ambient Temperature	F	type-T TC
Analog-3	TCHL	Chilled Water Supply - system	F	type-T TC
Analog-4	TCHE	Chilled Water Return - system	F	type-T TC
Analog-5	THXL	Hot Water from microturbines	F	type-T TC
Analog-6	THXE	Hot Water to microturbines	F	type-T TC
Analog-7	TBXL	Hot Water Supply on Boiler-Side of HX	F	type-T TC
Analog-8	TCWE	Cooling Water Entering Abs. Chiller	F	type-T TC
Analog-9				
Analog-10	FHW	Heat Recovery Flow	gpm	Onicon F-1110
Analog-11	FCH	Chilled Water Flow	gpm	Onicon F-1110
Analog-12	RHO	Ambient RH	%	Vaisala RH
Pulse-1	FGB	Building Gas Use	cu ft	Gas meter ¹
Pulse-2	FGT	Microturbine Gas Use	cu ft	Gas meter ¹
Pulse-3	WCH	Electric Chiller Power	kWh	Veris H-6010
Status-1	SCH	ABS Chiller Status	min	Veris 800
Status-2	SHV	Boiler/Abs CH Valve Status	min	Veris 800
Status-3	SCT	Cooling Tower Status	min	Veris 800
Status-4	SHP	Heat Exchanger Pump Status	min	Veris 800
MODBUS	WT1	Power Microturbine #1	kW/V/A	Veris Modbus
MODBUS	WT2	Power Microturbine #2	kW/V/A	Veris Modbus

Notes: 1- Gas meters are utility-grade, temperature- and pressure-compensated meters.

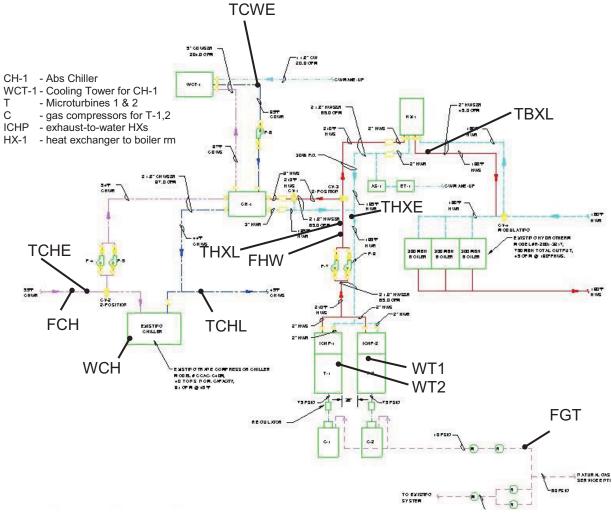


Figure 2. System Schematic Showing Sensor Locations in EXAMPLE CHP System

The electrical output of the microturbines (**WT1 & WT2**) will be measured with a MODBUS power transducer than can also measure volts, amps and true power for each phase (<u>Objectives 1 & 7</u>). The gas input to the turbines (**FGT**) will be measured by a single gas meter with pulse output (supplied by local utility) (<u>Objective 1</u>). The parasitic power use of the DC-powered gas compressors will be captured in the turbine power (so a separate power transducer is no longer needed) (<u>Objective 2</u>). A valve status sensor (**SHV**) will determine when the heat recovery output is going to the boiler load or to the chiller (<u>Objectives 4, 6 & 8</u>). The runtimes of the absorption chiller, constant-speed tower fans, and heat recovery pump will also be monitored (**SCH, SCT, SHP**) (<u>Objectives 2 & 8</u>).

The thermal output from the heat recovery unit will be determined from the flow and temperature difference (**FHW**, **THXL**, **THXE**) (Objectives 4 & 9). The data logger will integrate these readings every 10 seconds to determine the thermal output. We will also measure the temperature of the hot water supplied to the boiler loop after the boiler HX (**TBXL**) to determine how effectively the heat is being transferred into the boiler loop (Objective 8 & 9). Total gas use

CDH Energy Corp. 9 December 29, 2004

for the building (**FGB**) will be continuously monitored to provide an indication of how much boiler gas use is displaced by heat recovery (<u>Objective 5</u>).

The output of the total chiller system (electric and absorption) will be measured (**FCH**, **TCHL**, **TCHE**) along with the condenser water temperature (**TCWE**) entering the absorption chiller (Objectives 4, 5 & 9). This data will allow us to confirm that the COP and capacity of the chiller is consistent with the manufacturer's performance specifications. Absorption chiller and cooling tower parasitic power will also be determined by combining one-time power measurements (WABS, WCTF, WCTP) with the continuously recorded component runtimes (**SCH**, **SCT**, **SHP**) (Objective 2). The total power for the electric chiller (**WCH**) will be continuously monitored with a power transducer (Objective 5).

Table 5. One-Time Measured Data Collected for EXAMPLE CHP System

Name		Eng Units	Sensor Type
WCH	ABS Chiller Parasitic Power	kWh	Handheld Pwr Meter
SCT	Cooling Tower Fan Power	kWh	Handheld Pwr Meter
SHP	Heat Exchanger Pump Power	kWh	Handheld Pwr Meter

Communications, Data Retrieval Procedures, and Web Presentation

Communications with the monitoring system can range from manual data retrieval to fully automated broadband connections that allow for real-time (or near real-time) display of measured values on a web page. The type of communication link needed for a project depends on:

- the type of DG/CHP equipment,
- how the system is operated, maintained, or dispatched, and
- the reporting needs for monitoring.

Strictly speaking, it might be fully rational to provide a complex monitoring system with no communications capability if on-site staff are available to operate/maintain the system and to periodically transfer monitored data from a computer to a CD or memory stick. Conversely, a very simple monitoring system may require a direct broadband connection if system operation were critical and responsible personnel were remotely located. NYSERDA's DG/CHP sites are generally encouraged to have some form of communication connection so that system status and periodic reporting can be provided on the web.

Table 6. Communications Options for Data Retrieval and Monitoring

Type of Communications	Description / Example
for Data Collection	
None / Manual download	Data is manually downloaded or transferred to a CD or
	memory stick on a periodic basis (monthly, weekly, daily).
Phone	Data are automatically (or manually) retrieved via phone-
	modem link using dedicated software. Data retrieval rates can
	be hourly, daily, weekly or monthly.
Broadband	A DSL or Ethernet connection allows continuous automated
	data retrieval. The operating state and performance of the
	DG/CHP system can be displayed in real or near-real time. A
	web connection can be established directly with the unit
	controller or via an intermediate server capable of aggregating
	data from many sites.

The system that displays DG/CHP operating data and performance history on the web can be implemented with a variety of communications options. The key question is whether the web site is intended to present a real time snapshot of system operation (such as Figure 3 and Figure 4) or present a higher-level summary of recent and historic performance (Figure 5). Real time control and monitoring of the DG/CHP system clearly require a DSL or Ethernet connection (though an phone-modem connection polled hourly can approach real time functionality). Requirements for monitoring alone can be less stringent so that a phone-modem connection is sufficient. The choice of the communications option is often driven by the cost or difficulty of providing either a phone or broadband connection in the facility.

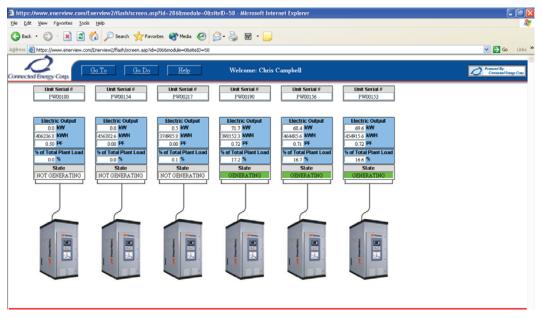


Figure 3. Example of a Real time Web Page Showing System Status (Served from Intermediate Site)

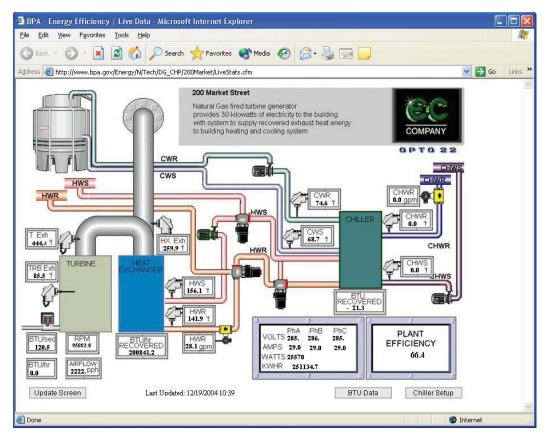
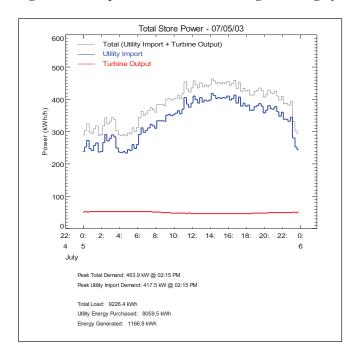


Figure 4. Example of a Real time Web Page Showing System Status (Served by Site-level PLC/computer)



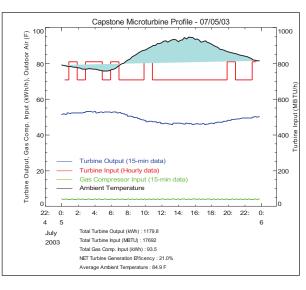


Figure 5. Example of a Web Page Showing Recent System Performance (Served from an Intermediate Site)

The frequency of data retrieval from a monitoring system can vary based on the project needs. For monitoring systems with a broadband connection, data retrieval rates can take place every few seconds. For phone-modem systems, data retrieval can take place as quickly as once every hour.

Even more important than the rate of data retrieval is the need for a robust system for archiving and capturing all the data regardless of the communications status. Data loggers generally are most robust at this task since data logging and recording is the highest priority function (i.e., data logging continues even when communications with the remote host are taking place). Even if the communication connection is lost, the on-board memory can continue to record data for several days or weeks until communications are reestablished. PLCs (programmable logic controllers) are at the other end of the spectrum since they can only save the most recent readings and a loss of communications typically results in a loss of data.

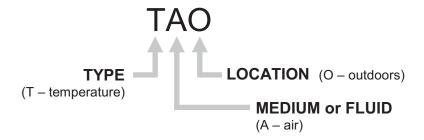
A robust monitoring system must place as much emphasis on reliably storing the collected data in the local controller as it does on the real time display of those values.

CDH Energy Corp. 13 December 29, 2004

Attachment No. 1 to Appendix A-2 Suggested Convention for Naming Data Points or Tags in a Monitoring System

An important but often overlooked aspect of developing a monitoring system is to select rational and easily-understood naming conventions for each data point. Consistent naming helps communications within the project team as well as with outside entities. The following is one possible convention.

Each data point should be named according a hierarchy, for instance:



Suggested designations for the type, medium, or location are given in the table below. One or more letters can be used for each designation. The actual letter designations can change based on project needs and preferences. The important aspect is the hierarchy of the naming convention. Each site or monitoring entity is encouraged to develop and use their own consistent naming conventions.

Data Point "TYPE"	Data Point "MEDIUM"	Data Point "LOCATION"
T – temperature	A – air	O – outdoor
P – pressure	G – gas (natural)	I – indoor
RH – relative humidity	CH – chilled water	E – entering
W – Power (watts/watt-hr)	CW – cooling water	L – leaving
F-flow	HW – hot water	
S – status/runtime	CT – cooling tower	
V-volts	B – boiler	
I – current/amps		
HZ - frequency		

Examples

TCHL: $\underline{\text{temperature}} - \underline{\text{ch}}$ illed water $-\underline{\text{l}}$ eaving

TBXL: \underline{t} emperature $-\underline{b}$ oiler heat \underline{e} changer $-\underline{l}$ eaving

WT1: \underline{w} atts/power – \underline{t} urbine # $\underline{1}$ FGT: \underline{f} low – \underline{g} as – \underline{t} urbines FCH: \underline{f} low – $\underline{c}\underline{h}$ illed water

VAT1: volts – phase A – turbine 1