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Chapter 23: Combined Heat and Power Evaluation Protocol

The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures

Created as part of subcontract with period of performance
September 2011 – September 2016

This document was republished in August 2017 after a thorough review; no substantive changes were made. This supersedes the version originally published in November 2016.

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Preface

This document was developed for the U.S. Department of Energy Uniform Methods Project (UMP). The UMP provides model protocols for determining energy and demand savings that result from specific energy-efficiency measures implemented through state and utility programs. In most cases, the measure protocols are based on a particular option identified by the International Performance Verification and Measurement Protocol; however, this work provides a more detailed approach to implementing that option. Each chapter is written by technical experts in collaboration with their peers, reviewed by industry experts, and subject to public review and comment. The protocols are updated on an as-needed basis.

The UMP protocols can be used by utilities, program administrators, public utility commissions, evaluators, and other stakeholders for both program planning and evaluation.

To learn more about the UMP, visit the website, https://energy.gov/eere/about-us/ump-home, or download the UMP introduction document at http://www.nrel.gov/docs/fy17osti/68557.pdf.

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Acronyms

Btu	British thermal unit
CHP	combined heat and power
COP	coefficient of performance
EPA	U.S. Environmental Protection Agency
DOE	U.S. Department of Energy
gpm	gallons per minute
HHV	higher heating value
kW	kilowatt
kWh	kilowatt-hour
LHV	lower heating value
MBtu	thousands of Btu
MMBtu	millions of Btu (thousands of MBtu)
MW	megawatt
NYSERDA	New York State Energy Research and Development Authority
ORC	Organic Rankine Cycle
RMS	root mean square
SGIP	Self-Generation Incentive Program
UHRR	useful heat-recovery rate
UMP	Uniform Methods Project

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1 Measure Description

The main focus of most evaluations is to determine the energy-savings impacts of the installed measure. This protocol defines a combined heat and power (CHP) measure as a system that sequentially generates both electrical energy and useful thermal energy[1] from one fuel source at a host customer's facility or residence. This protocol is aimed primarily at regulators and administrators of ratepayer-funded CHP programs; however, project developers may find the protocol useful to understand how CHP projects are evaluated.

1.1 Scope of the Protocol

The protocol provides a comprehensive method for estimating energy impacts from CHP systems at the customer side of the meter. The protocol's focus on "site energy" rather than "source energy" is consistent with the scope and other protocols developed for the Uniform Methods Project (UMP). Stakeholders may calculate additional metrics, such as source energy impacts or emissions impacts, based on the site energy impacts described in this protocol.

This protocol focuses on CHP systems that are used to meet on-site energy needs and generally sized at less than 5 MW in rated electrical generating capacity. This size range represents 90% of the CHP systems installed since 2000 based on data from the U.S. Department of Energy's (DOE's) CHP Installation Database (DOE 2015).

In addition to providing ways to estimate electricity impacts, the protocol includes algorithms and techniques for assessing CHP fuel impacts and calculating several performance metrics for installed CHP systems. The protocol also allows for the evaluation of different fuel types through the use of energy content for the different fuels. Not every evaluation will need to estimate these performance metrics. In addition, some evaluations may lack data needed to conduct more in-depth evaluations.[2] When such data are missing, the protocol provides default values that can be used to develop impact estimates.

To assist evaluators, the protocol also provides a table to help determine the level of rigor and which equations should be used in estimating impacts. Evaluators should adopt the level of rigor that matches particular evaluation needs and the available data.[3] For larger CHP systems (e.g., 500 kW and more), we strongly urge the use of metered data. In addition, care should be taken to ensure that metered data represents the net electricity generated by the CHP system (net of parasitic loads) and the useful thermal energy actually provided from the CHP system and used by the host site.

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[1] *Useful thermal energy* refers to thermal energy that is recovered from the CHP system and used to displace thermal energy loads at a host site. Not all heat output from the prime mover can be assumed to be useful heat. Because thermal energy loads can vary, thermal energy available from the CHP system may sometimes exceed the thermal load at the site.

[2] For example, we show methods for calculating hourly impacts that are necessary in evaluating hourly peak demand; however, not all evaluations need to examine hourly impacts and can instead examine only annual energy impacts.

[3] As discussed in the section "Considering Resource Constraints" in the Introduction to this UMP report, small utilities (as defined under the U.S. Small Business Administration regulations) may face additional constraints in undertaking this protocol; therefore, alternative methodologies should be considered for such utilities.

For the purposes of this protocol and to ensure consistency with other UMP protocols, we use the following definitions in discussing gross and net electricity:

- **Gross generation** means the electricity produced by the CHP system (not all of which is usable at the host customer site).
- **Net generation** is the gross generation minus parasitic losses. (This is what most evaluators will measure.)
- **Net electricity impacts** means net generation plus any offset chiller energy.
- **On-site net electricity impacts** means net generation plus offset chiller energy minus exported electricity.

To avoid confusion regarding the impacts that can be attributed to the CHP projects in the evaluation, we refer to "net attributable" impacts. Net attributable impacts refer to the net impacts that are separate from the impacts due to free ridership or spillover. Net attributable impacts are considered in Section 6.3, "Net-to-Gross Estimation."

1.2 Topics Not Covered By This Protocol

The primary focus of this protocol is in estimating energy impacts on the customer side of the meter from installed CHP systems. It is beyond the scope of this protocol to examine the energy impacts at the source of the energy supply (beyond the customer boundary) or the environmental impacts (e.g., greenhouse gas emissions or criteria air pollutant emissions) resulting from CHP systems. Similarly, although CHP systems are a valuable component of the electricity system, it is also beyond the scope of this protocol to provide a means for calculating net electricity system efficiencies or examining the system-wide benefits such as improved reliability or resiliency that CHP may provide to the grid. Because environmental and system-wide electricity impacts can result from a wide variety of energy measures and not only CHP systems, it is appropriate to treat these impacts through a crosscutting protocol.

This protocol is not intended for CHP systems larger than 5 MW.[4] In addition, this protocol does not include an evaluation of bottoming cycles other than those related to steam Rankine cycles.[5]

1.3 Overview of CHP System Applications

For decades, CHP systems sized at 20 MW and more have been widely used in the steel, chemical, paper, and petroleum-refining industries. More recently, smaller CHP systems sized to help meet customer energy needs are being deployed at university campuses, in the food and health industries, and at commercial buildings.

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[4] Due to the higher investment associated with these larger systems, we have assumed that the utility or program administrator has worked closely with the CHP project developer and has a good understanding of the project impacts.

[5] Other than the steam Rankine cycle, in this protocol we do not address bottoming cycle CHP technologies such as Organic Rankine Cycle (ORC) because few of these systems appear to be installed through utility programs. The U.S. Environmental Protection Agency's (EPA's) market assessment shows that less than 40 ORC-type waste-heat-to-power systems were installed in the United States as of 2012 (EPA and Combined Heat and Power Partnership 2012).

In general, CHP systems are installed to help reduce energy costs by offsetting electricity and other fuel purchases. They achieve these cost savings partly through increased efficiency. Due to the integration of power generation and thermal energy recovery, appropriately designed and implemented CHP systems can be significantly more efficient than separate heat and power generating systems.

Due to their higher overall efficiencies, CHP systems shift electric load away from centralized power plants to the more efficient CHP unit, typically located near the point of use. Figure 1 shows a generalized configuration of a CHP system compared to separate heat and power systems. This figure provides an example of possible differences between separate and CHP systems. Because the local resources powering the grid can vary significantly by location, we strongly recommend using local grid efficiencies and resources for evaluation purposes when possible (EPA 2015).[6,7]

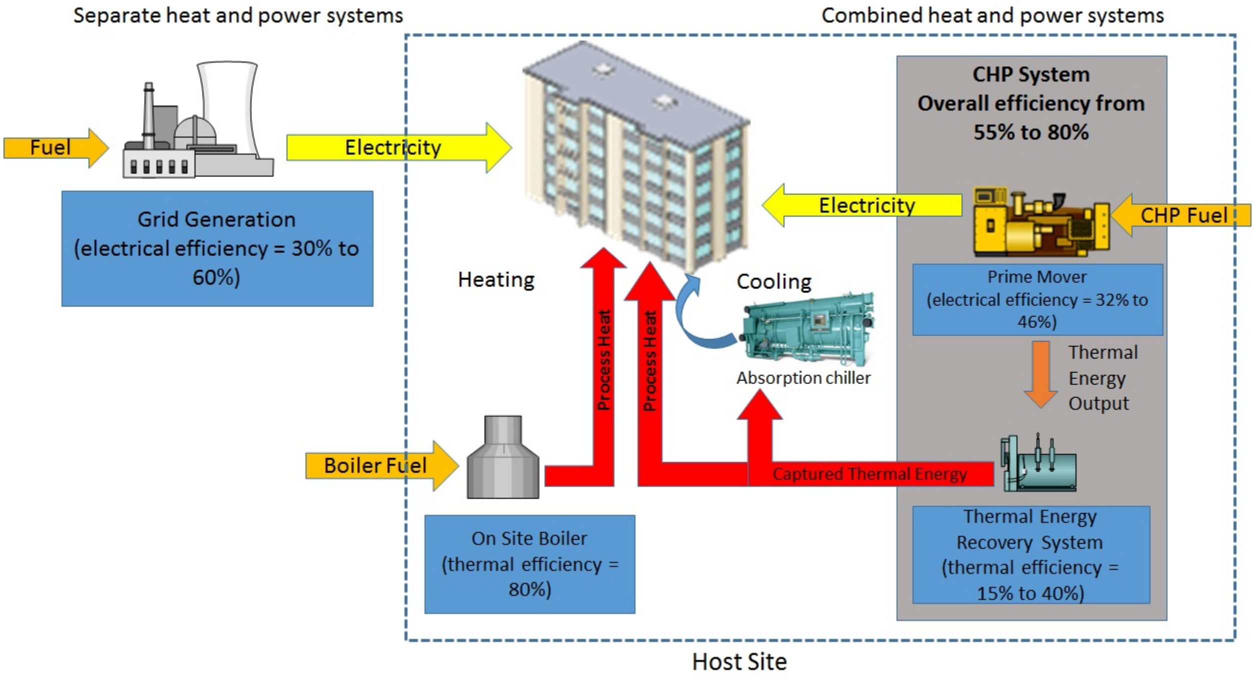

Figure 1. Diagram of separate heat and power compared to CHP

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[6] Grid generation can occur in a variety of configurations with associated electrical efficiencies. We use a range of central station power plant efficiencies, from 30% to 60% electrical efficiency, as examples. Although we also use a natural gas-fired combined-cycle system in this example, there are instances when a significant portion of the electricity supplied in the local grid comes from coal- or oil-based resources or, conversely, renewable energy resources. Note that when taking into account local renewable energy resources, such as wind or solar photovoltaics, adjustments need to be made to account for the lack of fuel consumption. In addition, line losses associated with the transfer of electricity from the central station system down through the transmission and distribution systems need to be taken into account. See EPA 2015 in "References" section of this document for guidance on calculating fuel and emission savings for CHP systems.

[7] The EPA provides a tool (eGRID) for estimating the electricity resource mix and net generation at various locations throughout the United States. See www.epa.gov/energy/egrid.

Under a separate heat and power system, electricity is provided to the host site from the grid while a boiler, fueled by purchased fuel, provides heat for on-site heat loads. In some instances, heat loads can include absorption chillers to provide on-site cooling needs. In comparison, a CHP system uses purchased fuel to power a prime mover that generates electricity. Thermal energy released from the prime mover is captured in a thermal energy (e.g., heat) recovery system and used to meet on-site heating and absorption cooling loads. The amount of thermal energy recovered *and used* to meet on-site thermal energy needs represents the useful thermal energy.

CHP systems used for self-generation purposes can displace electricity that would otherwise need to be generated and transferred to end uses from electric utilities. Because CHP electricity displacement can often coincide with electric utility system peaks, CHP systems can produce significant peak reduction on the grid.[8] This protocol describes common practice methods to account for hourly and annual energy impacts[9] resulting from installation of CHP systems.

As describe above, CHP systems can supply electricity and thermal energy to a business or industrial plant at a higher efficiency than conventional, separate electricity and thermal generation by capturing much of the heat energy normally wasted in power generation and avoiding line losses. In addition to reducing the total fuel required to provide electricity and thermal energy services to a user, a CHP system may also shift the types of fuel used. Installing a CHP system will generally increase the amount of fuel that is used at the site because additional fuel is required to operate the CHP system compared to the existing boiler that would have otherwise been used to serve the site's thermal demand; however, despite this increase in on-site fuel use, the total fuel use needed to deliver the required electrical and thermal energy services to the facility is reduced by the primary fuel savings generated by the reduced demand from the central station power plant.

Although CHP systems can also affect changes in air pollution emissions, including greenhouse gas emissions, this protocol does not address methods to take into account emission impacts from CHP.

A CHP system consists of a prime mover that consumes fuel to generate electricity and recovers the heat (thermal energy) discharged from the prime mover to produce useful thermal energy. CHP prime movers include a number of different technologies.

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[8] In addition, unlike other efficiency measures, CHP systems have the capability to ramp up electricity output, often rapidly. This feature enables CHP systems to be utilized as a dispatchable demand response resource to address local distribution system peak needs even when this does not coincide with the host customer's peak demand. The ability to ramp CHP is dependent on a number of factors, including the ability of the host site to use the captured heat. As more utilities investigate increased integration of distributed energy resources onto the grid, this aspect of CHP systems may become important in future evaluation efforts.

[9] We refer to *impacts* even though other energy-efficiency protocols refer to *savings*. Because CHP projects involve fuel consumption, which may exceed fuel savings, we believe it is more appropriate to refer to energy impacts.

A representative list of CHP prime movers is shown in Table 1.[10] This protocol primarily focuses on natural gas-fueled CHP, but it includes options to estimate energy impacts for CHP fueled by other sources, such as renewable biogas (methane).

Table 1. Representative CHP Prime Movers

Prime Mover	Description	Typical Size Range
Internal Combustion Engine	Reciprocating shaft power can either produce electricity through a generator or drive loads directly. It includes spark ignition and compression ignition engines.	Generally smaller than 5 MW
Gas Turbine	A gas turbine compresses and combusts fuel to create hot gases that are routed into the turbine, spinning the turbine blades. The rotating blades spin a generator to produce electricity.	500 kW to 40 MW
Microturbine	A microturbine is similar to gas turbine in that is uses burner exhaust gases to spin a generator.	30 kW to 250 kW
Fuel Cell	A fuel cell produces an electric current and heat from a chemical reaction between hydrogen and oxygen rather than through combustion.	Generally smaller than 5 MW
Steam Turbine	A steam turbine converts steam energy from a boiler or heat-recovery process into shaft power with a turbine.	50 kW to 250 MW

CHP systems often include auxiliary equipment such as pumps for circulating heat transfer fluids and fans for auxiliary heat rejection. In addition, CHP systems may be connected to other energy processes (e.g., absorption chillers) to help reduce electricity consumption at the host site.

The primary drivers of the electricity and fuel impacts of CHP systems are CHP system efficiencies and utilization:

- **Efficiency**—the effectiveness of fuel conversion and heat recovery in providing electrical and thermal energy services from a CHP system. The two components of overall CHP efficiency are:
    - **Electrical efficiency—**ratio of net electricity generation to fuel consumption[11]
    - **Useful heat-recovery rate (UHRR)—**ratio of heat recovered and used on-site to electricity generation (units: MBtu/kWh or MMBtu/MWh).
- **Utilization**—the extent to which a CHP system is actually used.[12] This performance driver depends on the percentage of time the system is operating as well as on the degree

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[10] Other than the steam Rankine cycle, in this protocol we do not address bottoming-cycle CHP technologies such as ORC because few of these systems appear to be installed through utility programs. The EPA's market assessment shows that less than 40 ORC-type waste-heat-to-power systems were installed in the United States as of 2012 (EPA and Combined Heat and Power Partnership 2012).

[11] Note that electrical efficiency is dimensionless by this definition because energy input and energy output are both the same units.

to which the system operates at rated capacity when running. (i.e., actual annual gross kWh generated/system rated kW times 8,760 hours).

Efficiency and utilization are also parameters that can be used in the evaluation in estimating electricity and fuel impacts.

Table 2 lists "target" operational characteristics, such as electrical and overall CHP efficiencies, and UHRR. The targets represent operational characteristics taken from the EPA and Combined Heat and Power Partnership's 2015 *Catalog of CHP Technologies*. The target values represent operations at ideal conditions and are based on a combination of equipment manufacturer specifications and a range of equipment sizes and assumed optimal conditions. For example, the optimal conditions assume that 100% of the thermal energy captured in the heat-recovery system can be used on-site. Evaluators may find observed values can be lower than the EPA targets for several reasons. For example, if evaluated systems are older, the observed values may reflect lower availability due to increased downtime. Similarly, low useful heat recovery rates may reflect there is not a good match between the thermal energy captured by the heat-recovery system and the thermal loads at the host site. We recommend the use of metered data in lieu of assumed values. Although thermal metering represents an additional cost, metering of the amount of thermal energy supplied to the host site (i.e., the useful heat) may be warranted if useful energy recovery is an important factor in the evaluation.

Table 2. Targeted CHP Operational Characteristics[13]

Prime Mover	Electrical Efficiency (HHV)[14]	Overall CHP Efficiency (HHV)	Targeted UHRR (MBtu/MWh)
Internal Combustion Engine	27%–41%	77%–80%	2,996–6,698
Gas Turbine	24%–36%	66%–71%	2,843–6,682
Microturbine	22%–28%	63%–70%	4,265–7,444
Fuel Cell	30%–63%	55%–80%	2,843–5,687
Steam Turbine	5%–40%	near 80%	Not Available

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[12] We use capacity factor as "the unrestricted power output of the system divided by the installed capacity" and utilization as "the actual averaged system power output divided by the installed capacity."

[13] The targeted electrical efficiencies and overall CHP efficiencies are from the EPA and Combined Heat and Power Partnership's *Catalog of CHP Technologies* (2015), tables 1–3. The targeted UHRR are calculated based on the electrical and overall system efficiencies.

[14] Higher heating value (HHV) takes into account the latent heat of vaporization of water in the combustion products. Because CHP systems inherently recover some of this heat in the heat-recovery process, we use HHV in reference to efficiencies. In addition, another advantage of using HHV is that it allows for direct comparisons to boilers.

As UHRR increases and offsets on-site boiler fuel, it drives up fuel savings. In turn, the more that useful heat-recovery offsets boiler fuel use during the year, the annual fuel savings tend to decrease.[15] Similarly, the use of prime movers with higher electrical efficiency can result in increased electrical savings through greater displacement of lower efficiency grid-supplied electricity. In this situation, increased utilization of higher electrical efficiency prime movers drives up annual electricity savings.

However, CHP prime movers consume fuel, which affects the overall fuel impacts. Because the prime mover consumes more energy (as fuel) than can be recovered by the heat-recovery system, increased utilization of the CHP system tends to increase annual fuel consumption. Last, thermal energy recovered by the CHP system may be used to drive an absorption chiller to satisfy the cooling load. In this situation, the CHP system offsets the operation of an electric chiller and therefore helps reduce electricity consumption.

The actual performance of individual CHP systems is based on information from input and output energy flows. Typical CHP system components and energy flows are depicted graphically in Figure 2.[16]

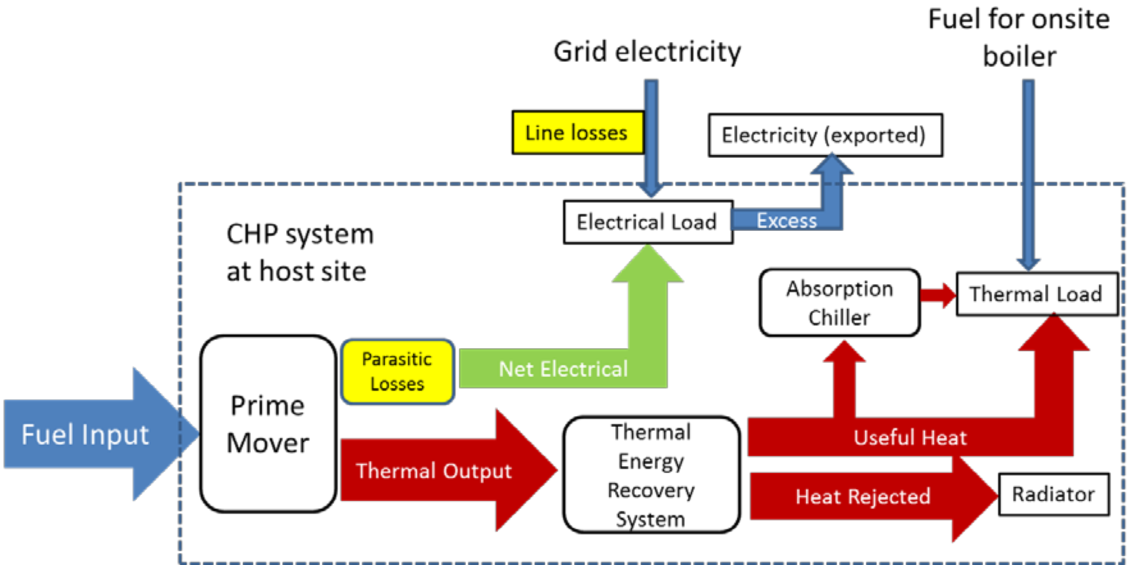

Figure 2. Schematic of CHP component and energy flows

The prime mover consumes fuel to produce gross electricity. Parasitic losses reduce the amount of electricity available for actual use (i.e., net electricity). The net electricity serves on-site electrical loads that would otherwise be served by the grid, thereby reducing grid-generated electricity required by the customer. In certain instances, electricity generated by the CHP

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[15] Note that fuel savings is decreasing from the top of the pyramid down; consequently, as the useful heat recovery increases, it pushes the fuel savings upward, thereby increasing fuel savings.

[16] Parasitic losses can occur with a variety of the equipment associated with the CHP system (e.g., pumps and fans for moving fluids or gases). For simplicity's sake, we have only referred to parasitic losses as though they are directly associated with the prime mover.

system may exceed the electrical load of the host site, and, if allowed, the electricity can be exported to the grid.[17] In the course of consuming fuel, thermal energy is generated by the prime mover. A thermal energy (heat) recovery system captures some fraction of the thermal energy generated by the prime mover to serve on-site thermal loads. In some instances, the on-site thermal load may decrease suddenly, and the amount of recovered heat exceeds the on-site load. In those situations, the excess heat is rejected through a “dump radiator.” In some instances, useful heat is supplied to an absorption chiller, which can offset electricity normally consumed by an on-site electrical chiller or reduce other electrically served cooling loads. By measuring the amount of fuel consumed by the prime mover and the electricity and useful heat supplied to the host site by the CHP system, we can estimate energy impacts from the system.

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[17] Not all utilities allow CHP systems to export electricity to the grid; however, a good example of where this is allowed is under California’s Self-Generation Incentive Program (SGIP). Under the SGIP, CHP systems are allowed to export up to 25% of their annual energy demand.

2 Application Conditions of Protocol

Energy-efficiency program administrators may treat CHP systems as a separate and distinct program, or they may include CHP systems as part of a broader population of commercial, multiunit residential, or industrial custom measures.

Energy-efficiency programs that support CHP systems typically provide technical and/or financial assistance to help lower market barriers or help increase customer benefits. Some of these activities may affect the amount of information available for measurement and verification and therefore affect estimated savings. CHP support mechanisms may include the following activities:

- **Prescriptive technology catalogs.** To help reduce costs, accelerate deployment, and increase customer acceptance of CHP systems, program administrators may develop a catalog of standardized sizes, configurations, and installation methods for CHP systems. For example, New York State Energy Research and Development Authority (NYSERDA) uses a prescriptive CHP catalog approach in its CHP Acceleration Program (NYSERDA 2016). Under this approach, programs may the support the installation of only prequalified and conditionally qualified CHP systems by approved CHP system vendors. Typically, these approaches will also include standardized metering installation methods, which can help provide measured performance data on the CHP systems.
- **Training and outreach.** CHP system performance is inherently tied to customer operations and business practices. For example, a business that operates only eight hours per day, 5 days per week and has low thermal energy demand will have lower potential for energy savings from use of CHP than a business that operates 24 hours per day, 7 days per week and has consistently high thermal energy demands. Program administrators may provide training and outreach to educate prospective end users about the “fit” of their business to a CHP project. In addition, program administrators may offer feasibility studies or software tools to help customers better understand CHP project costs and impacts.[18]
- **Rebates or financial incentives.** Program administrators—such as those in California, Massachusetts, and New York—often provide rebates or incentives for customers to install CHP systems that meet specific criteria (e.g., technology type, minimum electrical or system efficiency). Among the types of rebates that can be provided are up-front payments paid per unit of installed capacity (i.e., $/kW) or performance payments paid out per unit of delivered capacity power or energy. In addition, additional “bonus” rebates may be provided to promote the use of special fuels, a higher level of performance, or other preferences (e.g., use of equipment manufactured in the state or use of local installation companies).[19]

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[18] For example, utilities participating in the Massachusetts CHP Program require applicants to use a Benefit Cost Model, which takes into account power produced by the CHP system, parasitic losses, quantity and type of fuel consumed, as well as fuel displaced, and timing of power production and thermal loads (Mass Save 2014).

[19] For example, under California’s SGIP, CHP systems powered by biogas fuels receive a “biogas adder,” whereas CHP systems developed by a California supplier receive additional incentives (Pacific Gas and Electric Company 2015).

- **Demonstrated savings.** The protocol gives guidance for estimating demonstrated savings through actual operation and monitoring. Estimating expected savings from design documents is not supported or recommended with this protocol.

This protocol provides direction on how to evaluate impacts from CHP systems using a consistent approach. The protocol is applicable to new CHP systems and systems that are acting as a retrofit to existing boilers. It does not apply to situations where there was an existing CHP system. This protocol evaluates only installed CHP system impacts. It does not address impacts achieved through training or through market transformation activities.

3 Impact Calculations

This section presents equations for high-level gross impacts that apply to all CHP systems.[20] When evaluating the impacts of CHP systems, electrical, thermal energy, and fuel impacts must be evaluated.[21]

Impacts are all presented on an hourly or finer interval basis.[22] Hourly impacts are summed during the course of the year to calculate annual impacts.[23]

3.1 Determining Electricity Impacts

Note that in some instances CHP projects generate more electricity than can be consumed on-site, and they may be allowed to export electricity to the grid. Because most other energy-efficiency measures do not export electricity, this may be a source of confusion in assessing electricity impacts. For CHP projects, exported electricity should be included in the impacts and noted explicitly. In the following sections, we provide methods for estimating electricity impacts. Although a key priority is the estimation of annual impacts, we provide methods that enable hourly impacts to be estimated. Hourly estimates are important in determining the impacts of CHP systems on utility peak demand. Because peak demand is an hourly occurrence, it requires a method for estimating hourly electricity impacts.

Equation 1a: Hourly net electricity impacts:

$$\begin{aligned}(Net\ Electricity\ Impacts)_t \\ &= [(Gross\ Electricity\ Generated)_t - (Parasitic\ Losses)_t) \\ &+ (Offset\ Chiller\ Electricity\ Use)_t]\end{aligned}$$

where:

$(Gross\ Electricity\ Generated)_t$ = electrical energy generated at hour t by the CHP equipment; units: kWh

$(Parasitic\ Losses)_t$ = electrical energy losses at hour t due to pumps, etc., that are required for CHP operation. Ideally, metering would be set up such that any measured generation is the net of parasitic losses, not gross; units: kWh

$(Offset\ Chiller\ Electricity\ Use)_t$ = electrical energy offset from electrical chillers at hour t if heat from the CHP measure is driving an absorption chiller; units: kWh.

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[20] In this instance, we refer to gross electricity impacts to distinguish them from net electricity impacts that account for parasitic losses, offset from electric chiller use.

[21] Because thermal energy impacts both electricity and fuel, these impacts are embedded in these two impact areas.

[22] In many instances, metered electrical data is collected in 15-minute intervals. Interval data can be aggregated to hourly values.

[23] In instances where hourly impacts are not of importance, annual data can be used.

Equation 1b: On-site net hourly electricity impacts:

$$(Onsite\ Net\ Electricty\ Impacts)_t = (Net\ Electricity\ Impacts)_t - (Exported\ Electricity)_t$$

where:

$(Exported\ Electricity)_t$ = net electrical energy generated by the CHP system at hour t that exceeds host site demand.

Note that host site electrical loads may not be known on an hourly basis. In that event, assume that all net electricity generated by the CHP system is consumed at the host site.

Annual net electricity impacts are calculated by summing the hourly impacts for the year.

Equation 2: Annual net electrical impacts:

$$Annual\ Net\ Electricity\ Impacts = \sum_{t=1}^{8760} (Net\ Electricity\ Impacts)_t$$

3.2 Determining Fuel Impacts

Fuel impacts are generally calculated as shown in Equation 3. All energy systems must adhere to thermodynamic laws wherein the amount of energy produced from the system would be less than the energy consumed by the system. As such, CHP fuel impacts are typically negative, meaning that CHP projects consume more fuel to power the prime mover than is saved through recovering the thermal energy from the heat-recovery system, and they offset fuel that would have otherwise been consumed in on-site boilers. Some projects may use one fuel for the CHP system and offset another fuel for heating. For example, a natural gas-fired CHP system may offset an oil-fired boiler. Care should be taken to account for such cross-fuel impacts.

In instances where hourly impacts are deemed unimportant or beyond the scope of the evaluation, the evaluation can use annual fuel data for calculating annual impacts; however, where hourly impacts are important (e.g., in assessing hourly peak impacts, determining efficiency of the CHP system during peak demand, or estimating coincidence between CHP useful thermal energy recovery and CHP generation), hourly fuel impacts need to be assessed. Equation 3 allows for the calculation of hourly fuel impacts.

Equation 3: Hourly fuel impacts:

$$(Fuel\ Impacts)_t = (Fuel\ Offset)_t - (Fuel\ Consumed\ by\ Prime\ Mover)_t$$

where:

$(Fuel\ Offset)_t$ = reduction in on-site fuel consumption at hour t that would have been used for on-site thermal energy needs and is derived exclusively from heat recovered by the CHP system; units: MBtu (HHV basis)

$(Fuel\ Consumed\ by\ Prime\ Mover\ )_t$ = fuel consumed at hour t by the prime mover; units: MBtu (HHV basis).

If there are multiple fuels, fuel impacts are calculated for each fuel type and then summed to estimate total fuel impacts. Note that because fuel consumption is based on an energy (HHV) basis, this equation can be used for multiple fuel types.

If fuel consumption data are not available, the fuel consumption can be estimated based on electrical generation and efficiency, as shown below:

$$(Fuel\ Consumed\ by\ Prime\ Mover\ )_t = \left(\frac{Gross\ Electricity\ Generated_t}{\eta_{EE}}\right)(3{,}412)$$

where:

$\eta_{EE=}$ = electrical efficiency of prime mover (HHV basis)

3,412 = conversion factor 3,412 Btu/kWh.

Section 4.7, "Detailed Procedures," provides more information on determining fuel impacts that take into account electrical efficiency and useful thermal energy recovery.

When multiple fuels are consumed and fuel consumption data are not available, fuel purchase and delivery records should be examined to determine percentage blends of the fuels for each period, *t*. The percentages can then be used to determine fuel impacts.

Annual fuel impacts are calculated by summing the hourly impacts for the year. Again, in instances where hourly fuel impacts are not important, annual fuel data can be substituted. If hourly impacts are important but only annual fuel data are available, hourly fuel rates can be estimated by proportioning them to hourly electricity generation values.

Equation 4: Annual fuel impacts:

$$Annual\ Fuel\ Impacts = \sum_{t=1}^{8760}(Hourly\ Fuel\ Impacts)$$

3.2.1 Special Fuel Situations: Use of On-site and Directed Biogas

Increasingly, CHP systems are being installed in locations such as wastewater treatment plants, landfills, and dairies. In these instances, CHP systems provide benefits by capturing and using the on-site biogas that would have otherwise been vented to the atmosphere or flared. In some of these locations, the host site may use on-site biogas in a boiler to meet on-site thermal needs but not to generate power; consequently, the installation of a CHP system does not increase fuel consumption for on-site biogas applications. For systems fueled by a mix of fuel and on-site biogas, a calculated or measured ratio should be used to calculate the fuel impacts.

Directed biogas refers to biogas that is collected from a landfill, wastewater treatment plant, or dairy facility that may be located far from the facilities that will use the biogas. The procured biogas is processed, cleaned up, and injected into a natural gas pipeline for distribution. There is no requirement that the directed biogas sold to a host site contain a significant amount of the original biogas, and in fact it may contain very little (i.e., molecules) of the original biogas. In this way, directed biogas acts much like a renewable energy credit. The difference is that a natural gas product (i.e., the directed biogas) is sold to customers even though it may contain a very inconsequential amount of actual biogas. For these reasons, directed biogas should be evaluated as having the same energy content as natural gas.

3.3 Determining Energy Offset (Baseline Consumption)

Energy consumed and generated by the CHP system on both an annual and hourly peak basis is relatively simple to calculate from metered data; however, a common challenge in evaluating CHP systems is to identify and determine the baseline energy being offset by the CHP system. In many CHP applications, the CHP system represents the retrofit to an existing boiler; consequently, the on-site boiler fuel consumption represents the thermal energy baseline, which will be offset by CHP thermal energy recovery. In most current situations, CHP systems are designed to match and follow thermal loads of the host site. As a result, it is common to assume that all electricity generated by the CHP system will offset a portion of the on-site electricity loads.

CHP projects may also use recovered heat to drive thermally driven chillers to offset electrical energy that would have been used for cooling. In those instances, baseline chiller electricity demand needs to be taken into account (and can be used to calculate the offset). Likewise, the CHP recovered heat may be used instead of the baseline boiler heat to drive previously operating thermally driven chillers.

Figure 3 shows how the production of electricity and thermal energy from a CHP system can be compared to a baseline.

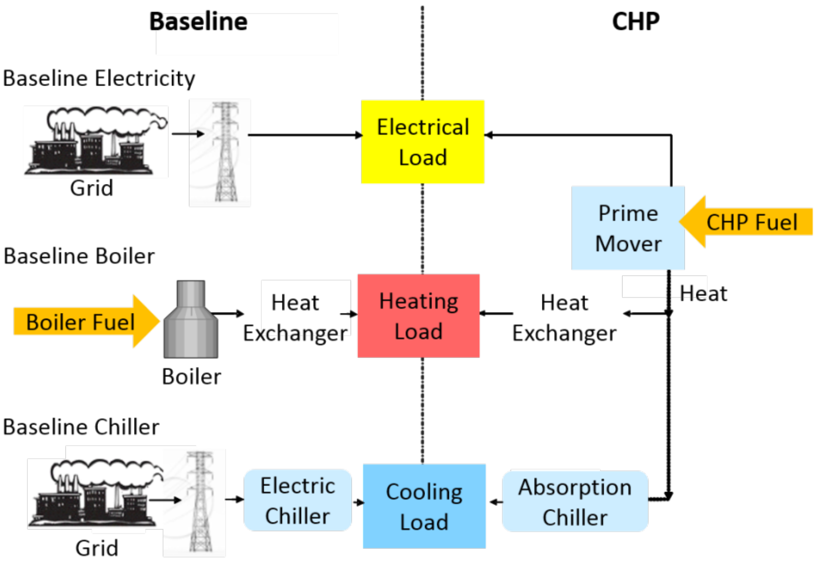

Figure 3. CHP and baseline energy flows

Ideally, site-level data (collected via tracking data or site inspections) are available to identify the boiler, electric chiller, and absorption chiller equipment located at the host site. Although this information may provide equipment specifications, it rarely provides data on operating efficiencies. As a result, some estimates of performance and engineering algorithms are usually required to calculate the amount of boiler fuel displaced by CHP heat recovery and electricity displaced by thermally driven chillers.

Electricity meters should be located such that the metered data explicitly includes the impacts of parasitic loads; however, if this is not the case, parasitic loads must be estimated.[24] The effect of parasitic loads tends to be small (approximately 3% of generation), so assumptions about parasitic loads likely have less of an impact on results than sampling error.[25] Another area that often requires approximation is determining the fraction of recovered heat used to offset heating equipment compared to cooling equipment (when an absorption chiller is present).

If actual on-site equipment details are not available, Table 3 provides recommended default values.

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[24] Spot metering can also be used to determine parasitic loads in some instances, but care should be taken to obtain spot measurements at several different operating conditions to determine a reasonable estimate of the parasitic losses. Equipment run time must also be estimated and/or monitored.

[25] Sampling errors occur when CHP systems are looked at in aggregate at the program level.

Table 3. Recommended Default Assumptions[26]

Parameter	Value	Source
Coefficient of performance (COP) for absorption chillers	0.7 for single effect (default) 1.0 for double effect	ASHRAE Standard 90.1-2013, Table 6.8.1C Water Chilling Packages—Efficiency Requirements (full-load)[27]
Electric chiller efficiency[28]	0.6–0.7 kW/t seasonal average or matched by size/type (equal to COP of approximately 5–6)	
Higher heating value of natural gas	1,032 Btu/ft^3	National Energy Technology Laboratory Specification for Selected Feedstock, January 2012, DOE/NETL-341/011812
Heating value of landfill gas	Ranges from 350 to 600 Btu/ft^3 (LHV)	EPA Landfill Methane Outreach Program
Heating value of digester gas	Ranges from 600 to 800 Btu/ft^3 (LHV)	EPA AgStar Program
Boiler efficiency	80%	Rough approximation based on minimum efficiencies specified in ASHRAE Standard 90.1-2010, Table 6.8.1F
Parasitic loads (fan and pump motors, dedicated heating, ventilating, and air-conditioning system and lighting)	3% of generation	Conservative assumption to avoid overstating net electricity, absent spot measurements, or metering
Electrical conversion efficiency	Varies by project and technology (see Table 2)	Project file review, prime mover specification sheet, or average prime mover type efficiencies drawn from industry literature
Fraction of recovered heat used for heat offsets	1.0 if end use of recovered heat is only heating	Approximations if no other data are available. If ex ante analysis includes

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[26] Note that lower heating value (LHV) is used for landfill gas and digester gas because this is the most common reference for heating values for these fuels. To convert LHV values to HHV, divide by 0.9.

[27] https://www.ashrae.org/resources--publications/bookstore/standard-90-1. Another source of efficiencies for electric chillers that is broken out by year installed and size is from the Texas Technical Resource Manual (see http://www.texasefficiency.com/images/documents/RegulatoryFilings/DeemedSavings/TRMv3.1v3.docx)

[28] We assume CHP systems are being installed at sites with existing and older chillers (e.g., installed after 2000). Where possible, use ratings specific to the installed chillers.

Parameter	Value	Source
	0.5 if end use of recovered heat is both heating and cooling 0.0 if all recovered heat is used for cooling	division of heat used for cooling vs. heating by season, that division can be reused here.

4 Measurement and Verification Plan

This section contains both recommended approaches to determine CHP energy impacts and the directions on how to use the approaches under the following headings:

- On-Site Inspections
- Vendor and Tracking Data
- Measurement and Verification Method
- CHP Performance Data Collection
- Multiple Fuels
- Interactive Effects
- Detailed Procedures.

4.1 On-Site Inspections

CHP systems installed as part of an energy-efficiency program typically undergo site inspections prior to receiving rebates. Site inspections may be conducted by the evaluation team or by other contractors. Generally, CHP project developers or host site representatives provide pre-inspection data within a program application. On-site inspections are conducted to verify installation of the CHP system nameplate ratings versus tracking data, check gross and net power and/or thermal energy output at the time of the inspection, and collect or coordinate delivery of relevant hourly trend data since the date of "regular" or "normal" operation.

One important aspect of a site inspection may be to establish when the CHP system "entered normal operations." Usually, the date the system enters normal operations is when system commissioning has been completed and the system is considered to be operating much like it will under commercial operations. In some instances, the date at which the system entered normal operations is when incentive checks have been first issued, or it defines the starting point for impact estimates for the program year. Ideally, the threshold for normal operations will have been defined as part of the specific program protocols to avoid confusion.

Site inspection reports should contain:

- Project information (i.e., project name, applicant and host customer name, account number, application number, and facility address)
- Date when the CHP system is considered to have entered normal operations
- Schematic of CHP system (including location of all installed meters) and layout of CHP within host site
- One-line diagrams for electrical distribution and thermal distribution between the prime mover and the useful loads, including rejected energy

- Description of how generated electricity and recovered thermal energy are used at the host site, including identification of the amount of useful thermal energy provided to any absorption chillers to displace electrical loads on electric chillers[29]
- Types of metering being conducted at the site and description of meter download procedures (i.e., how often data is downloaded and to what location)
- Presentation of key trend data, as available.

During the site inspection, the inspector should confirm that the system is a permanent installation connected to the grid and that the generator (prime mover) and heat-recovery system operate as designed.

Table 4 lists representative data collected from site inspections that are important for measurement and verification purposes.

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[29] Descriptions of the preexisting operational characteristics of on-site boilers and chillers should be compared to any tracking data obtained for the site.

Table 4. Representative Site Inspection Data

Dates	Fuel Sources	Prime Mover Data	Heat-Recovery System	Absorption Chiller[30]
Inspection date	Primary fuel source (% of energy input)	Technology type	Recovery system type	Chiller type (e.g., single vs. double effect)
Operational date	Flow rate of fuel	Manufacturer	Manufacturer	Manufacturer
	Secondary fuel source (% of energy input)	Model number	Model number	Model number
	Flow rate of secondary fuel	Equipment location	Equipment location	Equipment location
		Prime mover input rate (MBtu/h)$_{\text{HHV}}$	End uses served with heat recovery; note whether the BTU meter is net of dumped heat	End uses served with cooling
		Prime mover output (kW)	Hours per year of heat-recovery service	Hours per year of cooling service
		Number of prime mover units	Useful heat-recovery output (MBtu/h) $_{\text{HHV}}$	COP
		Total measured power output at inspection (kW); note whether output is net of parasitic loads	Inlet water temperature	Inlet water temperature[31]
			Outlet water temperature	Outlet water temperature
			Water flow rate (gallons per minute [gpm])	Water flowrate (gpm)[32]

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[30] Include absorption chiller information in this table only when a new absorption chiller is added as part of the CHP system. Existing absorption chillers are taken into account in the energy offset and through Table 3.

[31] The inlet water temperature to the absorption chiller is the outlet temperature from the heat-recovery system. In general, flows and temperatures for the absorption chiller are not metered unless there is a specific need for this level of rigor. When the evaluation includes numerous CHP projects, it is typical to use the COP to estimate the amount of thermal energy used by the absorption chiller.

4.2 Vendor and Tracking Data

In the course of sizing CHP systems, vendors typically develop estimates of CHP performance, including electricity generation and thermal energy production. In addition, many program administrators require vendors to submit estimated performance, or they may develop their own estimates of CHP performance. Expected CHP performance is contained in "tracking data," which acts as an expected baseline upon which program administrators can project estimated impacts throughout the life of the system. When possible, these vendor or tracking data should be obtained to act as an expected baseline of CHP operation.

4.3 Measurement and Verification Method

This protocol recommends an approach for verifying CHP savings that adheres to Option A—Retrofit Isolation: Key Parameter Measurement—of the International Performance Measurement and Verification Protocol.

Key parameters that require measurement are net electrical generation (and export), useful heat recovery, and fuel consumption. If metered prime mover fuel consumption is not available, it may often be estimated based on prime mover specification sheets and/or data from similar systems. Typically, CHP systems are installed as retrofits, displacing some or all of the thermal output from existing on-site boilers. There is usually no or limited metered data on hourly boiler fuel consumption. This protocol emphasizes metered data collected post-installation (of the CHP system), and it does not include pre-installation data collection requirements.

4.4 CHP Performance Data Collection

To assess energy impacts, data must be collected on CHP performance, including the amount of fuel consumed by the CHP system, electricity generated, and useful thermal energy supplied to the host site. Metered data to be collected include net electricity generated (kWh), net real power delivered (kW), and flow rates and associated inlet and outlet temperatures needed to determine useful thermal energy supplied to the host site. When possible, metered data for fuel consumption of the CHP system should be collected rather than data on site fuel consumption.[33]

When using Option A (the preferred approach) to assess CHP systems, the following measurement and verification elements require particular consideration:

- Measurement Period and Frequency
- Measurement Equipment.

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[32] The water flow rate is based on the split between the amount of duty allocated between the heating and cooling loads of the site.

[33] For smaller and older CHP systems, sometimes the only available fuel consumption data is that metered for the entire host site using a utility meter.

4.4.1 Measurement Period and Frequency

Metered data is to be collected post-installation. It is important to use measured data only after the CHP system has completed commissioning and shakedown. The amount of time this takes varies, but measurements can usually start once the CHP system operation approaches “normal” operation (e.g, power and thermal output reach levels that are consistent with expected commercial operation for more than two months). There are two important timing metrics: (1) the measurement periods and (2) the measurement frequency:

- Choose the measurement period (the length of the expected baseline and reporting periods) to capture a full year. This is important in capturing the seasonal impacts of both the CHP system performance and facility operation. If a full year is not available, we recommend capturing at least six months of operational (post-installation) data, with at least one month in summer and one month in winter.
- When hourly impacts are important, choose the measurement frequency (the regularity of the measurements during the measurement period) to provide at least hourly measurements.[34] If an integrating Btu meter is not used, then more frequent data collection intervals may be warranted.

4.4.2 Measurement Equipment

For the key parameters, data may be collected from existing CHP equipment vendor-supplied metering. In the event that the vendor-supplied metering cannot provide enough information,[35] then installing submeters is necessary to obtain data. Use the following guidelines to select the appropriate submetering equipment and procedures[36]:

- Net electricity generation meters:
    - Meters should be located to measure root mean square power output (RMS kW) from the CHP prime mover and ideally after power delivery to all parasitic loads. If not, separate meters or measurements for parasitic loads may be required. Meters should measure net electricity generated (RMS kWh) and net real power delivered (RMS kW).
    - Meters should be capable of collecting data at 15-minute intervals or better and generate accurate date/time stamps for all collected data points.
    - Meters should have the capability to retain collected data in the event of a power outage and should be capable of storing at least seven days of collected data.
    - Meters should have an accuracy of ± 0.5% or meet ANSI C-12.20 certification.

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[34] Some CHP incentive programs such as those in California, New York, and Massachusetts are requiring interval meters for measuring electricity generation, useful thermal energy recovered, and fuel consumption. CHP evaluation approaches should take advantage of incentive program metering requirements.

[35] For example, submetering may be required if the existing thermal metering system does not accurately measure useful heat but instead measures only heat output from the prime mover or does not take into account dump radiators. Similarly, some electrical meters may supply only cumulative energy instead of interval energy.

[36] For more on choosing meters, see “Metering Cross-Cutting Protocols” in *Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures* (Mort 2013).

    - Meters can be onboard or external interval data recording meters.
    - When it is feasible within the budget, meters should have the ability to communicate collected data to outside data collection entities (e.g., program administrators).
- Thermal energy recovery meters:
    - Flow meters with "Btu computers" should be insertion-type turbine meters, magnetic flow meters, or ultrasonic flow meters with real-time computation and totalizer.
    - Flow meter/Btu computers should have a field verified accuracy of ±3%.
    - Fluid temperature measurements should be based on temperatures in thermowells or in the flow stream when possible.
    - Flow meters should be calibrated before being placed in the field, verified once installed in the field, and calibrated at least every two years.
    - Metering points should be located to obtain useful thermal energy provided to the host site, taking into account possible radiator dumps.
- CHP fuel consumption meters
    - These are natural gas flow meters with pulse output. Typically, these are rotary-type meters that are temperature and pressure compensated.

Table 5 lists recommended levels of accuracy for the types of metering equipment used for CHP measurement and verification.

Table 5. Recommended Meter Accuracies

Meter Type	Purpose	Accuracy of Meter
BTU meter with flow rates and temperatures	Useful heat recovery	± 3%
Power meter	True RMS power (kW)	± 0.5%
Fuel flow rate meter	Natural gas flow rate	± 1% reading

4.5 Multiple Fuels

Some projects may consume one fuel in the CHP measure to offset a different heating or cooling fuel. For example, the type of fuel consumed by the prime mover may be different than the type of fuel consumed by the existing boiler. Care should be taken to capture all the impacts of the CHP measure on different fuel sources.

4.6 Interactive Effects

For projects evaluated under Option A and that are installed at sites with other efficiency measures, consider how these may interact with the CHP measure. For example:

- A site that installed both a more efficient boiler measure and a CHP system would see no benefits from the new boiler when heating loads were met from the CHP system. In addition, the thermal savings from the CHP system would be reduced somewhat because the boiler efficiency would be higher.

- A site that installed both a CHP system with an absorption chiller and a more efficient electric chiller would get no benefits from the electric chiller when cooling loads are met with the absorption chiller.

4.7 Detailed Procedures

This section presents detailed steps to calculating Equation 1 (electrical impacts) and Equation 3 (fuel impacts).[37] It involves calculating net electrical efficiency as well as electric chiller offset. This section also provides detailed steps to calculating CHP performance metrics such as overall system efficiency and UHRR.

Note that a significant variation in values over time is expected; therefore, each of the equations described in this section should be calculated using the same time frame (annual or hourly). It is not advisable to mix and match time periods when, for example, a one-hour calculation of electrical efficiency is applied to an annual measurement of fuel input.

Some systems may not include all of these parameters, especially absorption chillers, and in rare cases useful heat recovery. The basic components should be directly derived from metered data:

- Electricity generation: directly metered electrical generation, ideally metered as net generation
- Useful heat recovery: directly metered.

4.7.1 Electrical Efficiency

Equation 1 requires knowledge of the electrical efficiency of the CHP system. Electrical efficiency, defined as a measure of how much of the energy in the fuel input is converted to net electricity, is also a key parameter for evaluating CHP performance. This efficiency is largely driven by the type and model of CHP prime mover. Internal combustion engines tend to be more efficient than microturbines, and larger engines tend to be more efficient than smaller engines. Operating conditions also play a role. In general, the closer to full load a prime mover operates, the more efficient the system is at converting fuel to electricity. For larger installations, installing multiple prime movers[38] permits operators to optimize the full loading of each engine.[39] Mathematically, the electrical efficiency is defined as follows:

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[37] It is typical to calculate electricity impacts first and then fuel impacts because it is usually easier to identify anomalies in electricity output. The electricity impacts can then be used to confirm thermal energy and fuel impacts; however, it is possible to calculate fuel impacts first and then electricity impacts.

[38] When multiple prime movers are used in tandem, the equations should take into account the aggregate capacity of the multiple prime movers; however, if the prime movers are arranged to provide redundancy, care should be taken to aggregate only the systems that will be operated in tandem.

[39] Multiple engines are one simple and effective way of optimizing engine operation to meet varying loads. This method, however, must be balanced with expected load profiles, higher efficiencies often associated with larger engines, and many other factors.

Equation 5: Net electrical efficiency

$$Electrical\ Efficiency_{HHV\ Basis} = \frac{(Net\ Electricity\ Generated_{kWh})}{\left(Fuel\ Input_{MBtu/hr}\right) \times \frac{1\ kWh}{3.412\ MBtu}}$$

where:

$Fuel\ Input$ = fuel consumed by the CHP system; make sure to use HHV basis; units: dimensionless.

As noted above, net electrical efficiency requires metered net electricity generation data.

4.7.2 Useful Heat-Recovery Rate

Equation 3 is based on the fuel consumed by the prime mover and the fuel offset. The fuel offset in turn depends on the amount of useful heat recovery achieved by the CHP system. UHRR is one measure of the effectiveness with which thermal energy is recovered from the prime mover and used to meet on-site thermal needs, either on-site heating loads or on-site cooling loads. System design (e.g., sizing) and the timing and magnitudes of facility electrical and thermal loads play key roles in determining a CHP system's heat-recovery rate. Mathematically, the UHRR is defined as follows:

Equation 6: Useful Heat Recovery Rate:

$$Useful\ Heat\ Recovery\ Rate\ (UHRR) = \frac{Useful\ Heat\ Recovered}{Net\ Electricity\ Generated}$$

where:

$Useful\ Heat\ Recovered$ = heat that is actually recovered from the CHP system, including any heat recovered for absorption chiller use and used on-site; units: MBtu (HHV basis).

Note that the UHRR has units of MBtu/kWh.

4.7.3 Overall CHP Efficiency

Electricity generation and recovered heat are combined to form an overall efficiency to quantify how much of the energy input is used. If a CHP system generates substantial quantities of electricity when facility thermal loads are low, large quantities of heat will be rejected to the atmosphere, which will reduce the overall efficiency of the CHP system. Overall efficiency is defined as follows (note the conversions to maintain consistent units):

Equation 6: Overall efficiency:

$$Overall\ Efficiency = \frac{Net\ Electricity\ Generation + Useful\ Heat\ Recovered \times \frac{1\ kWh}{3.412\ MBtu}}{Fuel\ Input\ \times \frac{1\ kWh}{3.412\ MBtu}}$$

Note that, as in Equation 6, useful heat recovery should include any heat recovered for absorption chiller use.

4.7.4 Electric Chiller Offset (Using Thermally Driven Chiller)

Some CHP systems use an absorption chiller to convert useful heat to cooling energy. This allows the CHP system to operate in summer. Equation 8 shows how this electrical cooling offset should be calculated.

Equation 7: Electrical energy offset$_{Chiller}$:

$$ElectricityOffset_{Chiller} =$$
$$\text{Net Electricity Generation} \times UHRR_C \times COP \times \left(EffElecChlr \frac{kWh}{ton-hr\ of\ cooling} \right) \left(\frac{ton-hr\ of\ cooling}{12\ MBtu} \right)$$

where:

$ElectricityOffset_{Chiller}$ = electricity a power plant would have needed to provide for a baseline electric chiller; units: kWh

$NetElectricityGeneration$ = net electrical energy generated by the CHP system; units: kWh

$UHRR_C$ = UHRR that is used to drive an absorption chiller; units: MBtu/kWh

COP = COP of the absorption chiller; unitless

$EffElecChlr$ = efficiency of the baseline electric chiller; units: $\frac{kWh}{Ton-hr\ of\ cooling}$

The hourly impact of CHP systems with a chiller component would be based on the overall concept outlined in Equation 3. It would take into account the boiler efficiency and UHRR and is shown below in Equation 9.

Equation 8: Fuel impacts:

$$Fuel\ Impacts\ =\ Fuel\ Offset -\ Fuel\ Consumed$$

$$= \frac{Net\ Electricity\ Generation\ \times UHRR_H}{Boiler\ Efficiency} - \frac{Net\ Electricity\ Generation}{Net\ Electrical\ Efficiency} \times \frac{3.412\ MBtu}{1\ kWh}$$

$$= Net\ Electricity\ Generation \times \left[\frac{UHRR_C}{Boiler\ Efficiency} - \frac{1}{Net\ Electrical\ Efficiency} \times \frac{3.412\ MBtu}{1\ kWh}\right]$$

where:

$Fuel\ Offset$ = reduction in fuel consumption that would have been used for heating that can be attributed to the CHP system; units: MBtu (HHV basis)

$Fuel\ Consumed$ = fuel consumed by the CHP system. For biogas-fueled CHP systems, this can be zero. This value can be estimated based on electrical generation and efficiency; units: MBtu (HHV basis).

$UHRR_H$ = URRH that is used to offset on-site heating; units: MBtu/kWh

$Boiler\ Efficiency$ = efficiency of the boiler of other heating equipment that would serve heating loads in absence of the CHP system; unitless (HHV basis).

4.7.5 Default Assumptions

When possible, the actual efficiencies of heating and cooling equipment should be used in Equation 3 and Equation 8. If this level of detail is not available, Table 3 provides some recommended default assumptions and the reasoning behind them.

4.8 Overall Approach in Estimating Impacts

As identified at the beginning of this protocol, differing levels of rigor can be applied in estimating impacts of CHP projects. Table 6 summarizes the different approaches that can be used in estimating CHP impacts depending on the necessary level of rigor. The rigor and approach can be tailored to the appropriate level of evaluation needs and available data. In addition, Table 6 provides the equations associated with the different CHP performance parameters.

A “full” approach assumes that the evaluation requires not only estimates of energy and fuel impacts but also that these need to be conducted on an hourly basis. For example, this type of approach may be required when the evaluation needs to account for the impact of the CHP systems on peak demand, or if there is a need to determine the degree to which CHP electricity is coincident with useful thermal energy recovery. This approach may typically be used for larger CHP systems or when the CHP systems are part of an incentive program that requires an assessment of peak demand and coincidence of CHP electricity generation to useful thermal energy recovery.

Under a “modified” approach, only electricity impacts are evaluated on an hourly basis, whereas fuel impacts are evaluated on an annual basis. This situation can occur when the evaluation requires an assessment of the impact of CHP on electricity peak demand but there is no requirement to assess the coincidence of CHP electricity with useful thermal energy recovery.

A "simplified" approach is to be used when the evaluation is focused only on annual impacts. This situation may typically be used for very small CHP systems or when CHP systems make up a small portion of an overall energy-efficiency program. Evaluators are warned, however, that if this simplified analysis relies on totalizing meters that report the cumulative usage (total electricity generated, fuel fired, or thermal energy used), additional uncertainty is added to the final results because any meter failures that may have occurred during the aggregation period cannot be detected. This has been a problem particularly with totalizing thermal metering systems.

Table 6. Summary of Approaches for Estimating Impacts

CHP Performance Parameter	Equation(s)	Approach Used for Specified Level of Rigor		
		Simplified	Modified	Full
Net Electrical Impact	1 & 2	Annual	Hourly	Hourly
Net Fuel Impact	3	Annual	Annual	Hourly
Net Electrical Efficiency	4	Annual	Hourly	Hourly
UHRR	5	Annual	Annual	Hourly
Overall Fuel Conversion Efficiency	6	Annual	Annual	Hourly
Electrical Energy Offset	7	Optional	Hourly	Hourly
Fuel Offset	8	Optional	Annual	Hourly

5 Sample Design

At times, evaluators need to assess overall impacts to an energy-efficiency program that has multiple CHP systems. If the number of CHP systems is large, it may be cost prohibitive to collect metered data for all the installed systems. In that event, metered data may be collected from a sample of the operating CHP system.

Consult the UMP's *Chapter 11: Sample Design Cross-Cutting Protocol* for general sampling procedures if the CHP system population is sufficiently large[40] or if the evaluation budget is constrained. Ideally, use stratified sampling to CHP systems by technology and/or the magnitude of claimed (ex ante) project savings. Stratification ensures that evaluators can confidently extrapolate sample findings to the remaining project population. Regulatory or program administrator specifications typically govern the confidence and precision targets, which will influence sample size.

5.1 Detecting and Handling Suspect or Missing Data

Not all received raw metered data are accurate. They may contain errors due to calibration issues, problems with meter operation, or other unforeseen nonsystem issues. All collected data should undergo validation. For example, collected data should be checked to ensure that date/time stamps match actual operation. Similarly, data validation techniques should be used to check and flag suspect data. For example, received electricity generation data that show values significantly higher than those expected given the rated generation capacity of the system should be flagged as suspect. Similarly, data that show zero delivered energy but high values for useful heat recovery should be flagged as suspect.

In some instances, metered data for sites within the sample may not be available for a time period due to outage of the meter or some other nonsystem operational aspect. Ratio estimation is used to generate hourly estimates of performance for periods when observations would otherwise contain missing values.

The premise of ratio estimation is that the performance of unmetered projects can be estimated from similar projects with metered data using a "ratio estimator" and an "auxiliary variable." The ratio estimator is calculated from the metered sample, and the auxiliary variable is used to apply the estimator to the unmetered portion of the data stream. Table 7 provides an example of the different ratio estimators and auxiliary variables used to estimate electricity generation, fuel consumption, or useful heat recovery data.

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[40] In general, sampling depends on budgetary considerations; however, a census is recommended at the onset of an energy-efficiency program when CHP systems are beginning to be installed. As the program expands, sampling is recommended when installations of small and same-type systems exceed 20. For larger installations (e.g., 1 MW or larger), energy impacts are significant enough to warrant measurements. In general, sample designs should be set to achieve 90% confidence with 10% precision, depending on budgetary constraints.

Table 7. Example Ratio Estimators and Auxiliary Variables

Variable Estimated	Ratio Estimator	Auxiliary Variable	Stratification
Electricity generation (kWh)	Capacity factor (kWh/kW·hr)	Rebated capacity (kW)	Hourly, by technology type, fuel type, program administrator, operations status, incentive structure, capacity category, and warranty status
Fuel consumption (MBtu)	Electrical conversion efficiency (unitless)	Electricity generated (kWh)	Annual, by technology type
Useful heat recovered (MBtu)	UHRR (MBtu/kWh)	Electricity generated (kWh)	Annual, by technology type

Another issue that arises with collected data is treating “zero” values. In instances when the CHP system is down, a zero value accurately represents nonperformance and should be recorded as a zero value; however, when the CHP system is operational but a zero, null, or missing value is received in the data stream, the zero may simply represent a problem with the metering or the data handling system. Just as validation techniques are used to flag higher-than-expected values, validation techniques should be used to check consistent reporting of missing or bad readings versus true zero values. In the case of suspect useful heat-recovery values, care should be taken to check flow-rate data against temperature data. When data sets contain large amounts of suspect data, it may be necessary to conduct phone surveys to determine the operational status of CHP systems.

6 Other Evaluation Issues

When claiming lifetime and net program CHP measure impacts, consider the following evaluation issues in addition to first-year gross impact findings:

- Early retirement and degradation
- Normalizing CHP performance
- Net-to-gross estimation
- Inter-utility effects.

6.1 Early Retirement and Degradation

CHP projects are often expected to last 10 to 25 years (International Energy Agency 2010); however, during their lifetime, CHP systems can show degradation in availability (which affects capacity factor), electrical, or thermal performance from first-year operations unless a maintenance program is in place. In turn, changes in site operations, fuel, or electricity prices can result in systems being retired after only a handful of years. Evaluators should therefore take care when estimating lifetime performance from first-year savings. That could include persistence studies or leaving metering in place long term to capture savings throughout time. Programs are strongly encouraged to require ongoing metering of electricity output as a requirement for participation.

6.2 Normalizing CHP Performance

The savings from most energy-efficiency measures are correlated to either weather or operating hours; therefore, most energy-efficiency measures can be weather normalized to adjusted weather during the study period to a typical weather period. CHP, however, presents a number of challenges to weather normalization because CHP utilization can be highly variable based on host behavior and other factors. These factors include:

- The cost of fuel (often natural gas)
- The cost of electricity
- The relationship between the cost of fuel and electricity (i.e., if fuel costs rise in relation to electricity, the CHP system will tend to run less; conversely, if fuel costs fall in relation to electricity prices, the CHP system will tend to run more)
- CHP system maintenance (is the system properly maintained on a regular basis so it is available as wanted?)
- Process loads for systems that serve process loads
- Weather for systems that serve heating and cooling loads.

Weather does play a role in CHP operation, but the impact of weather varies from one site to another compared to the other factors listed. CHP host customers can choose to not operate the system and meet their energy needs with more traditional methods. This is quite different than, light-emitting diode lighting, for example, or new space-conditioning equipment that completely replaces the existing equipment so the host can only chose to not have light or heating/cooling or remove the equipment. Therefore, this protocol recommends against attempting to weather normalize CHP performance.

Like other energy measures, CHP performance tends to decrease throughout time, but the impact of this varies and can be influenced by periodic maintenance and servicing. Ultimately, CHP performance should be based on observations (e.g., metered data) that span multiple years. Evaluations that use CHP performance data to normalize operations throughout the life of the system or a program need to account for the factors described above.

6.3 Net-to-Gross Estimation

CHP systems are complex, requiring detailed engineering and sometimes significant effort in obtaining air-pollution control permits and commissioning to bring the system to expected levels of operation. For these reasons, free ridership and spillover do not occur as frequently as they do for other, more common energy-efficiency measures. For some more mature programs, in some instances host sites may install CHP systems without the use of incentives or they may install greater capacity than what can be rebated. As programs mature or as the cost-effectiveness of CHP systems increase, free ridership and spillover need to be taken into account.

The UMP cross-cutting chapter “Estimating Net Savings: Common Practices” discusses various approaches for determining net program impacts. To ensure adjustments to impacts are not double counted at a population level, follow the best practices that include close coordination between (1) staff estimating gross and net impact results and (2) the teams collecting site-specific impact data.

6.4 Inter-Utility and Overall Grid Effects

In some instances, CHP systems may involve multiple utilities. For example, the host site may purchase fuel from one utility and electricity from another. In these situations, evaluators should take care to assess and identify baseline conditions as outlined in Section 3.3, “Determining Energy Offset (Baseline Consumption).” This is particularly important if the impact evaluation baselines are to be used for later CHP cost-effectiveness evaluations.

One of the basic premises of CHP systems is that they offer the potential to provide energy more efficiently and at a lower cost than conventional grid resources. Although defining and providing a means to evaluate net grid impacts is beyond the scope of this protocol, evaluators should make a reasonable attempt to identify the mix of local resources that provide electricity to CHP host sites and the electrical efficiency with which the power is supplied to the site, taking into account transmission and distribution system line losses.

6.5 Other Resources and Examples of Impacts Studies

This protocol provides a methodology for estimating energy impacts from CHP projects that has undergone public review. In developing this protocol, we have relied on a number of past studies that provided insights into the measurement and evaluation of CHP systems. These include the September 2000 measurement and verification guidelines for federal energy projects (DOE 2000), the State of Illinois 2015 *Technical Reference Manual for Combined Heat and Power Systems*, the November 2008 Association of State Energy Research and Technology Transfer Institutions Distributed Generation Combined Heat and Power Long-Term Monitoring Protocol, and the 2005 EPA *Distributed Generation and Combined Heat and Power Field Testing Protocol* (Greenhouse Gas Technology Center Southern Research Institute 2005). These studies served as valuable resources to help augment this protocol.

Impact evaluations are not new to programs incorporating CHP systems. New York has been actively installing CHP systems and NYSERDA has been evaluating their performance for more than a decade. In 2015, NYSERDA released an evaluation report that covers CHP systems installed from 2001 through June 2011 (Energy & Resource Solutions, Inc., and Itron, Inc. 2015). Similarly, Massachusetts and California have been installing numerous CHP systems. Examples of impact evaluations of CHP systems installed in Massachusetts include studies conducted in 2009 and 2010–2011 (KEMA, Inc., Energy & Resource Solutions, Inc., and Itron 2012; KEMA, Inc., 2013). Within California, impact evaluations on CHP systems have been conducted annually since 2003.[41]

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[41] Copies of annual impact reports can be downloaded from the CPUC SGIP website at http://www.cpuc.ca.gov/General.aspx?id=7890.

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