

Catalog of CHP Technologies

Appendix A: Expressing CHP Efficiency

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Combined Heat and Power Partnership



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The September 2017 revision incorporated a new section on packaged CHP systems (Section 7).

This Guide was prepared by Ken Darrow, Rick Tidball, James Wang and Anne Hampson at ICF International, with funding from the U.S. Environmental Protection Agency and the U.S. Department of Energy.

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A.1 Expressing CHP Efficiency

Many of the benefits of CHP stem from the relatively high efficiency of CHP systems compared to other systems. Because CHP systems simultaneously produce electricity and useful thermal energy, CHP efficiency is measured and expressed in a number of different ways¹¹⁶ **Table A-I** summarizes the key elements of efficiency as applied to CHP systems.

As illustrated in **Table A-I** the efficiency of electricity generation in power-only systems is determined by the relationship between net electrical output and the amount of fuel used for the power generation. **Heat rate**, the term often used to express efficiency in such power generation systems, is represented in terms of Btus of fuel consumed per kWh of electricity generated. However, CHP plants produce useable heat as well as electricity. In CHP systems, the **total CHP efficiency** seeks to capture the energy content of both electricity and usable steam and is the net electrical output plus the net useful thermal output of the CHP system divided by the fuel consumed in the production of electricity and steam. While total CHP efficiency provides a measure for capturing the energy content of electricity and steam produced it does not adequately reflect the fact that electricity and steam have different qualities. The quality and value of electrical output is higher relative to heat output and is evidenced by the fact that electricity can be transmitted over long distances and can be converted to other forms of energy. To account for these differences in quality, the Public Utilities Regulatory Policies Act of 1978 (PURPA) discounts half of the thermal energy in its calculation of the efficiency standard (EFF_{FERC}). The EFF_{FERC} is represented as the ratio of net electric output plus half of the net thermal output to the total fuel used in the CHP system. Opinions vary as to whether the standard was arbitrarily set, but the FERC methodology does recognize the value of different forms of energy. The following equation calculates the FERC efficiency value for CHP applications.

$$EFF_{FERC} = \frac{P + \frac{Q}{2}}{F}$$

Another definition of CHP efficiency is **effective electrical efficiency**, also known as **fuel utilization effectiveness (FUE)**. This measure expresses CHP efficiency as the ratio of net electrical output to net fuel consumption, where net fuel consumption excludes the portion of fuel that goes to producing useful heat output. The fuel used to produce useful heat is calculated assuming typical boiler efficiency, generally 80 percent. The effective electrical efficiency measure for CHP captures the value of both the electrical and thermal outputs of CHP plants. The following equation calculates FEU.

$$FUE = \frac{P}{F - \frac{Q}{EFF_Q}}$$

¹¹⁶ Measures of efficiency are denoted either as lower heating value (LHV) or higher heating value (HHV). HHV includes the heat of condensation of the water vapor in the products. Unless otherwise noted, all efficiency measures in this section are reported on an HHV basis.

FUE captures the value of both the electrical and thermal outputs of CHP plants and it specifically measures the efficiency of generating power through the incremental fuel consumption of the CHP system.

EPA considers fuel savings as the appropriate term to use when discussing CHP benefits relative to separate heat and power (SHP) operations. Fuel savings compares the fuel used by the CHP system to a separate heat and power system (i.e. boiler and electric-only generation). The following equation determines percent fuel savings (S).

$$S = 1 - \left[\frac{F}{\frac{P}{\text{Eff}_p} + \frac{Q}{\text{Eff}_q}} \right]$$

In the fuel saving equation given above, the numerator in the bracket term denotes the fuel used in the production of electricity and steam in a CHP system. The denominator describes the sum of the fuel used in the production of electricity (P/Eff_p) and thermal energy (Q/Eff_q) in separate heat-and-power operations. Positive values represent fuel savings while negative values indicate that the CHP system in question is using more fuel than separate heat and power generation.

Table A-1. Measuring the Efficiency of CHP Systems

| System | Component | Efficiency Measure | Description |
|-------------------------------|---|---|--|
| Separate heat and power (SHP) | Thermal Efficiency (Boiler) | $\text{EFF}_Q = \frac{\text{Net Useful Thermal Output}}{\text{Energy Input}}$ | Net useful thermal output for the fuel consumed. |
| | Electric-only generation | $\text{EFF}_P = \frac{\text{Power Output}}{\text{Energy Input}}$ | Electricity Purchased From Central Stations via Transmission Grid. |
| | Overall Efficiency of separate heat and power (SHP) | $\text{EFF}_{\text{SHP}} = \frac{P + Q}{P/\text{EFF}_{\text{Power}} + Q/\text{EFF}_{\text{Thermal}}}$ | Sum of net power (P) and useful thermal energy output (Q) divided by the sum of fuel consumed to produce each. |
| Combined heat and power (CHP) | Total CHP System Efficiency | $\text{EFF}_{\text{Total}} = (P + Q)/F$ | Sum of the net power and net useful thermal output divided by the total fuel (F) consumed. |
| | FERC Efficiency Standard | $\text{EFF}_{\text{FERC}} = \frac{(P + Q/2)}{F}$ | Developed for the Public Utilities Regulatory Act of 1978, the FERC methodology attempts to recognize the quality of electrical output relative to thermal output. |

Table A-1. Measuring the Efficiency of CHP Systems

| System | Component | Efficiency Measure | Description |
|--------|--|---------------------------------------|--|
| | Effective Electrical Efficiency (or Fuel Utilization Efficiency, FUE): | $FUE = \frac{P}{F - Q/EFF_{Thermal}}$ | Ratio of net power output to net fuel consumption, where net fuel consumption excludes the portion of fuel used for producing useful heat output. Fuel used to produce useful heat is calculated assuming typical boiler efficiency, usually 80 percent. |
| | Percent Fuel Savings | $S = 1 - \frac{F}{P/EFF_p + Q/EFF_Q}$ | Fuel savings compares the fuel used by the CHP system to a separate heat and power system. Positive values represent fuel savings while negative values indicate that the CHP system is using more fuel than SHP. |

Key:

P = Net power output from CHP system

Q = Net useful thermal energy from CHP system

F = Total fuel input to CHP system

EFF_p = Efficiency of displaced electric generation

EFF_Q = Efficiency of displaced thermal generation