Calculating Net Electricity Savings from Utility-Supported CHP Projects

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August 2012
(Updated and revised, April 2013)

The U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and other entities that support combined heat and power (CHP) seem to be in agreement on a method for calculating fuel savings from CHP systems compared to separate generation of heat and power. However, these entities have not agreed on an approach for calculating electricity savings from utility-supported CHP projects. When electric utilities provide incentives for CHP projects, such as through their custom incentive programs, they need a valid method for determining how much electricity savings they can claim, and for calculating whether the incentives provided for CHP pass the cost-effectiveness tests. Based on the work done to date in this area, the Southwest Energy Efficiency Project (SWEEP) proposes a new method for calculating electricity savings from CHP projects.

Fuel Savings from CHP Systems

The easiest way to calculate the fuel savings for any CHP system is to use the CHP calculator developed by the EPA's Combined Heat and Power Partnership.[1] The calculator uses the following methodology (Hedman 2011):

$$S_{FUEL} = F_{GRID, POWER} + F_{CHP, THERMAL} - F_{CHP, TOTAL}$$

Where S_{FUEL} is the fuel savings from the CHP system, and $F_{GRID, POWER}$ is the amount of fuel that would have been used by the grid to generate the electricity output of the CHP system. $F_{CHP, THERMAL}$ is the fuel that would have been used on-site by a thermal only system to provide the thermal output of the CHP system, and $F_{CHP, TOTAL}$ is the total fuel used by the CHP system.

$F_{GRID, POWER}$ can be calculated by multiplying the CHP system's total electrical output by the grid's average heat rate, and dividing by $(1 - T\&D\ losses)$.[2] Incorporating this definition of $F_{GRID, POWER}$ into the above equation yields:

$$S_{FUEL} = E_{CHP} * H_{GRID} / (1 - L_{TD}) + F_{CHP, THERMAL} - F_{CHP, TOTAL}$$

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[1] The CHP calculator is available at http://epa.gov/chp/basic/calculator.html
[2] Note that neither the ACEEE nor Massachusetts approaches, described below, include this T&D loss factor. This error/omission reduces the amount of savings attributable to CHP by at least 7%.

Where E_{CHP} is the electrical output of the CHP system in MWh; H_{GRID} is the average heat rate of the grid (MMBtu/MWh); and L_{TD} is the T&D losses for the sub-region, or the U.S. average of 7%.

EPA's Combined Heat and Power Partnership recommends using the "all fossil" average heat rates of the eGrid sub-regions, because this heat rate most closely approximates the combined heat rate of the plants that will be displaced by the CHP system (Hedman 2011). These heat rates are built into the EPA's CHP calculator, and are also shown in Table 1 below. The all fossil heat rates are calculated from heat (Btu) inputs for coal, oil, and natural gas, and net generation outputs (MWh) from these three types of generation. Although the total average CO_2 emission factors vary widely between sub-regions due to the different fuel mixes (including nuclear and hydro), the all fossil average heat rates do not vary nearly as much, staying within a range of 8.0-11.0 MMBtu/MWh.

Table 1: All Fossil Average Heat Rates for eGRID Subregions

eGRID Subregion Name	eGRID 2009 Subregion Baseload CO_2 Emission Factor (lb CO_2/MWh)	eGRID 2009 Subregion "All Fossil" Heat Rate (MMBtu/MWh)
ASCC Alaska Grid	1,281	10.32
ASCC Miscellaneous	521	9.38
WECC Southwest	1,182	8.77
WECC California	1,177	9.04
ERCOT All	1,352	10.24
FRCC All	1,593	9.38
HICC Miscellaneous	1,592	10.05
HICC Oahu	1,629	10.87
MRO East	1,348	10.14
MRO West	728	8.69
NPCC New England	611	8.47
WECC Northwest	498	8.68
NPCC NYC/Westchester	947	9.57
NPCC Long Island	1,659	10.02
NPCC Upstate NY	1,521	10.05
RFC East	1,750	10.36
RFC Michigan	1,002	9.20
RFC West	1,326	9.40
WECC Rockies	1,358	10.00
SPP North	1,036	9.70
SPP South	1,816	11.00
SERC Mississippi Valley	1,599	9.97
SERC Midwest	659	8.09
SERC South	819	9.68
SERC Tennessee Valley	1,825	10.57
SERC Virginia/Carolina	1,191	9.33
U.S. average	**1216**	**9.59**

Source: (EPA 2012).

Electricity Savings

The electrical savings attributable to the CHP system should be the CHP system's fuel savings divided by some heat rate for producing electricity from fuel. In other words,

$$S_{CHP, ELEC} = S_{FUEL} / H$$

What heat rate should we use here? The state of Massachusetts uses 3.412 MMBtu/MWh (see below), which basically assumes a generation efficiency of 100%, which is not possible. ACEEE suggests using the same H_{GRID} factor used in the fuel savings calculation above (Elliott 2009), which is a conservative approach, and does not take into account how efficiently the CHP system itself generates electricity. In other words, the Massachusetts approach gives too much electrical savings credit to CHP, while the ACEEE method does not give enough credit.

We are really asking how much electricity is or could be generated with the fuel savings of the CHP system. Why not use a calculated heat rate for the CHP system itself? Using similar logic as in the fuel savings calculation above, the amount of fuel used by the CHP system to generate electricity would be the total fuel consumption of the CHP system minus the amount of fuel that would have been used to provide its thermal output, or **($F_{CHP, TOTAL} - F_{CHP, THERMAL}$)**. Therefore, the calculated or effective heat rate for the CHP system would be:

$$H_{CHP} = (F_{CHP, TOTAL} - F_{CHP, THERMAL}) / E_{CHP}$$

Based on a few examples (see below) this calculated heat rate ranges between about 4.0 MMBtu/MWh and 7.5 MMBtu/MWh, which seems reasonable. The approximate heat rate for a combined cycle natural gas plant is 7.5 MMBtu/MWh.

However, it also makes sense that the electricity savings attributed to the CHP system should not exceed the CHP system's actual electrical output, E_{CHP}. How could the CHP system save more electricity than the amount it actually generates?

Therefore, SWEEP recommends that the electricity savings attributed to a CHP system should be calculated as follows:

> *Use the lesser of these two values:*
>
> a) *the actual electrical output of the CHP system, E_{CHP}; or*
> b) *the electricity savings calculated by finding the CHP system's calculated fuel savings (e.g., from the EPA's CHP calculator), divided by the CHP system's calculated heat rate:*
>
>   **($H_{CHP} = (F_{CHP, TOTAL} - F_{CHP, THERMAL}) / E_{CHP}$)**
>
> *For waste heat to power (WHTP) projects, the electrical savings should be equal to the electrical output of the WHTP system.*

If there is a need to allocate the CHP system's energy savings between electric and natural gas utilities, we would assume the total fuel savings are equivalent to the total electrical savings as calculated above,

and the two utilities would allocate percentages of the total savings to either fuel or electricity in a way that avoids double-counting. For example, if we allocate 50% of the fuel savings to the natural gas utility, then the electrical utility could take no more than 50% of the calculated electrical savings.

Examples

Following are a few examples to demonstrate SWEEP's suggested approach. For each of these examples, I used the EPA's CHP calculator to estimate the fuel savings. I used the "all fossil" heat rate for the "WECC Rockies" eGrid sub-region, and the heat inputs are based on replacing an existing gas boiler with an efficiency of 80%. I used the defaults for all other inputs except those listed below.

Note that based on these and additional sample calculations, when the overall efficiency of the CHP system is greater than about 71%, the electrical savings allowed using the SWEEP approach will always be equivalent to the total electrical output of the CHP system, E_{CHP}.

Overall efficiency of the CHP system = (thermal output + E_{CHP}) / $F_{CHP, TOTAL}$

(with E_{CHP} converted to MMBtu using the standard conversion factor (1 MWh = 3.412 MMBtu))

Example 1: Gas Combustion Turbine

Inputs: 1 MW gas-fired combustion turbine, 5840 hr/yr, all other default choices

Results:
- E_{CHP} = 5840 MWh/yr
- CHP Thermal output = 39,070 MMBtu/yr
- Fuel savings = **25,510 MMBtu/yr**

Overall CHP efficiency = (39,070 + 5840*3.412)/91,014 = 64.8%

The calculated heat rate for the CHP system:

$$H_{CHP} = (F_{CHP, TOTAL} - F_{CHP, THERMAL}) / E_{CHP}$$

= (91,014 MMBTU/YR – 48,840 MMBTU/YR)/5840 MWH/YR = **7.22 MMBTU/MWH**

Note that the value for $F_{CHP, THERMAL}$ (which is also provided by the CHP calculator) is the thermal output divided by the assumed efficiency of the existing thermal system, or 80%.

$$E_{SAVINGS, CHP} = 25,510 MMBTU/YR/7.22 = 3530 MWH/YR$$

Since this value is less than E_{CHP}, we would use this value as the electrical savings.

Example 2: Gas Internal Combustion Engine

Inputs: 1 MW gas-fired IC engine, 5840 hr/yr, all other default choices

Results:
- E_{CHP} = 5840 MWh/yr
- CHP Thermal output = 31,135 MMBtu/yr
- Fuel savings = **37,160 MMBtu/yr**

Overall CHP efficiency = (31,135 + 5840*3.412)/69,446 = 73.5%

The calculated heat rate for the CHP system:

$$H_{CHP} = (F_{CHP, TOTAL} - F_{CHP, THERMAL}) / E_{CHP}$$

= (69,446 MMBTU/YR – 38,918 MMBTU/YR)/5840 MWH/YR = **5.23 MMBTU/MWH**

$E_{SAVINGS, CHP}$ = 37,160 MMBTU/YR/5.23 = 7110 MWH/YR

Since this value is greater than E_{CHP}, we would use that value, **5840 MWh/yr** as the electrical savings.

Example 3: Steam Turbine

Inputs: 1 MW steam turbine, 5840 hr/yr, 5 MMBtu/hr of process steam output

Results:
- E_{CHP} = 5840 MWh/yr
- CHP Thermal output = 29,200 MMBtu/yr
- Fuel input = 60,452 MMBtu/yr
- Fuel savings = **43,730 MMBtu/yr**

Overall CHP efficiency = (29,200 + 5840*3.412)/60,452 = 81.3%

The calculated heat rate for the CHP system:

$$H_{CHP} = (F_{CHP, TOTAL} - F_{CHP,THERMAL}) / E_{CHP}$$

= (60,452 MMBTU/YR – 36,500 MMBTU/YR)/5840 MWH/YR = **4.10 MMBTU/MWH**

$E_{SAVINGS, CHP}$ = 43,730 MMBTU/YR/4.10 = 10,670 MWH/YR

Since this value is greater than E_{CHP}, we would use that value, **5840 MWh/yr** as the electrical savings.

The results of these three examples are summarized in Table 2 below:

Table 2: Summary of Three Sample CHP Electrical Savings Calculations

CHP System	Fuel Savings (MMBtu/yr)	Overall CHP System Efficiency (%)	CHP System Heat Rate (MMBtu/ MWh)	Calculated Electrical Output Using Heat Rate (MWh/yr)	CHP Electrical Output, E_{CHP} (MWh/yr)	Allowed Electrical Savings (MWh/yr)
Example 1: 1 MW gas turbine	25,510	64.8%	7.22	3,530	5,840	**3,530**
Example 2: 1 MW gas IC engine	37,160	73.5%	5.23	7,110	5,840	**5,840**
Example 3: 1 MW steam turbine	43,730	81.3%	4.10	10,670	5,840	**5,840**

Massachusetts Formula and Comparison to ACEEE Approach

According to Massachusetts' Alternative Energy Portfolio legislation (Massachusetts 2007, emphasis mine), the electrical savings attributable to CHP is "equal to the result, if positive, of the following calculation: take the sum of (1) the **electrical energy generated** divided by the overall efficiency of electrical energy delivered to the end-use from the electrical grid (which efficiency is equal for this purpose to 0.33); and (2) the **useful thermal energy** divided by the overall efficiency of thermal energy delivered to the end-use from a standalone heating unit (which efficiency is equal for this purpose to 0.80); and subtract from this sum the **total of all fuel and any other energy consumed by the CHP Unit** in that quarter expressed in MWh and calculated using the energy content of the fuel based on its higher heating value."

In mathematical terms, this would be:

$$S_{CHP, ELEC} = E_{CHP} / .33 + T_{CHP} / .80 - F_{CHP, TOTAL}$$

T_{CHP} and F_{CHP} are converted to MWh using 3.412 MMBtu/MWh (Massachusetts 2007).

Therefore:

$$S_{CHP, ELEC} = E_{CHP} / .33 + (T_{CHP} / .80 - F_{CHP, TOTAL}) / 3.412$$

This appears to be different from ACEEE's suggested formula for calculating electricity savings from CHP (Elliott, 2009):

$$S_{CHP, ELEC} = E_{CHP} - (F_{CHP, TOTAL} - F_{CHP, THERMAL}) / H_{GRID}$$

or

$$S_{CHP, ELEC} = E_{CHP} + (F_{CHP, THERMAL} - F_{CHP, TOTAL}) / H_{GRID}$$

However, $T_{CHP}/.80 = F_{CHP, THERMAL}$ (the amount of thermal energy that would be needed from the conventional on-site thermal system, assuming an efficiency of .80). Also, $H_{GRID} = 3.412/.33$ (they are assuming an efficiency of .33 for the grid)

Therefore, we have

$$S_{CHP, ELEC} = 3.412/3.412 * E_{CHP}/.33 + (T_{CHP}/.80 - F_{CHP, TOTAL})/3.412$$

$$= (H_{GRID} * E_{CHP} + F_{CHP, THERMAL} - F_{CHP, TOTAL})/3.412$$

Now, we are getting closer. The problem is that Massachusetts is using 3.412 instead of H_{GRID} to convert the thermal energy savings from the CHP unit into electrical energy. If instead of dividing by 3.412, if we divide by H_{GRID}, then the two equations would be the same:

$$S_{CHP, ELEC} = (H_{GRID} * E_{CHP} + F_{CHP, THERMAL} - F_{CHP, TOTAL})/H_{GRID}$$

$$= E_{CHP} + (F_{CHP, THERMAL} - F_{CHP, TOTAL})/H_{GRID}$$

Therefore, Massachusetts is giving more credit to CHP by converting the fuel savings from the CHP system to electricity savings by dividing by 3.412 MMBtu/MWh rather than the heat rate of the grid (about 10 MMBtu/MWh), or some other heat rate.

References

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