# Simplified Method for Determining the Net Carbon Dioxide Reduction from Installing a CHP System

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ABSTRACT

As awareness of the possible implications of greenhouse gas (GHG) emissions and the merits of energy efficiency increase, so do the number of facilities, institutions, and people that seek an active role in reducing their net GHG emissions and energy usage. With the increase in projects developed to achieve a targeted GHG reduction, it is becoming increasingly important to quantify CHP system performance in terms of GHG emissions. This work presents a preliminary method for evaluating the net GHG emissions of a combined heat and power (CHP) system as a means of evaluating the feasibility of installing a CHP system in a carbon dioxide reduction project.

## INTRODUCTION

As awareness of the possible implications of greenhouse gas (GHG) emissions and the merits of energy efficiency increase, so do the number of facilities, institutions, and people that seek an active role in reducing their net GHG emissions and energy usage. In some cases, the parties involved may be concerned only with reducing either GHG emissions or energy usage, although the two are intimately linked. GHG emissions result from specific energy conversion processes and, conversely, changing the energy usage characteristics of an end user through energy efficiency programs or other methods may result in reduced GHG emissions. With the increase in projects developed to achieve a targeted GHG reduction, it is becoming increasingly important to quantify performance in terms of GHG emissions.

One method of reducing the amount energy purchased from a utility company, although not necessarily a method for reducing on-site energy usage, is combined heat and power (CHP) or cogeneration. In most cases, the CHP process utilizes both the work and heat released from the conversion of a fossil fuel, such as natural gas or diesel fuel, both of which are hydrocarbons. The energy released when the bonds uniting the atoms of the hydrocarbon fuel molecules are broken is also accompanied by the release of free carbon atoms that are available to combine with other atoms in the atmosphere to form greenhouse gases.

Following somewhat naturally, it can be understood why end users, the primary concern of whom may strictly be the reduction of GHG and who may not have any technical understanding of energy conversion processes, may think that CHP applications will not reduce on-site GHG emissions. This thought may result from the observation that seemingly "clean" electricity formerly purchased from some unseen source would be replaced by electricity coming from a prime mover with directly observable emissions. The reduction of GHG emissions resulting from effective heat recovery in a CHP system can be met with skepticism because it may seem counterintuitive that the visible exhaust stack is reducing GHG emissions.

The actual reduction in GHG emissions resulting from the CHP application can be thought of as resulting from the sharing of GHG emissions amongst all the processes that receive energy from the CHP equipment. If the GHG emissions are considered as a cost of using energy, then the cost of the electric and thermal energy generated from a CHP application is some amount of emissions. This cost is shared by all of the equipment that receives energy from the CHP application. In the way that correctly designing and integrating a CHP system can generate cost savings, it can also generate GHG savings.

Consider a hypothetical facility that has an electric load and a heating hot water load. The electric load is currently purchased from the local utility and the heating hot water load is served by an on-site boiler plant. The electric kWh usage of the facility likely represents some power plant emissions if it can be assumed that the electricity does not come from "clean" energy sources such as hydro, wind, solar power, etc. The amount of GHG emissions per kWh of energy usage varies ultimately with the fuel used by the power plant that supplies the energy. The heating hot water may be generated by natural-gas-fired boilers. Each therm of natural gas represents some amount of GHG emissions that are released as a direct result of combustion. This description may be easier understood by Relation 1.

$$\text{On site GHG Emissions}_{UP} = \text{GHG}_{kWh,UP} + \text{GHG}_{boiler\ therms,UP} \tag{1}$$

In this relation, the subscript$_{U\{}$ denotes the emissions resulting from the corresponding energy source being "utility purchased."

If the same facility installs a CHP application with a natural-gas-fueled prime mover, the GHG emissions are represented by Relation 2.

$$\text{On site GHG Emissions}_{CHP} = \text{GHG}_{kWh,UP} + \text{GHG}_{boiler\ therms,UP} + \text{GHG}_{prime\ mover\ therms,CHP} \tag{2}$$

In this relation, the subscript$_{CHP}$ denotes the emissions resulting from the installation of a CHP system. Relation 2 is likely representative of the way people may think about CHP equipment as increasing GHG emissions. What is not readily apparent from Relation 2 is that a large reduction in utility purchased electricity and gas may result from the use of a CHP application. The net impact of a CHP system installation on site GHG emissions may be better described by Relation 3.

$$\text{Net CHP GHG Emissions} = \text{GHG}_{fuel} - \text{GHG}_{kWh,offset} - \text{GHG}_{boiler\ therms,offset} \tag{3}$$

From Relation 3, it becomes easier to understand that a CHP application can have net negative GHG emissions if it offsets enough GHG emissions from utility purchased electricity and gas. It must also be remembered that, in energy conversion processes, energy is conserved and not quantities of greenhouse gases.

This work details a preliminary method for quickly evaluating the net GHG emissions of a CHP system as a means of evaluating the feasibility of installing a CHP system in a carbon dioxide reduction project.

## GHG EMISSIONS DATA

The first step when calculating the emissions associated with the installation of a CHP application is to determine which greenhouse gases are targeted for reduction. The second step is to establish the conversion coefficients that represent the amount of GHG emissions per unit of energy.

For simplicity, this work will focus on a theoretical carbon dioxide reduction project. The U.S. Energy Information Administration publishes emissions data for various fuel types and locations and from this, the coefficients for electric and natural gas related carbon dioxide emissions in California were obtained.

$$C_{kWh} = 0.61 \quad \frac{lb_{CO_2}}{kWh}$$

$$C_{therm} = 11.708 \quad \frac{lb_{CO_2}}{therm}$$

Once the coefficients for $CO_2$ emissions have been selected appropriately, the net $CO_2$ calculations proceed similarly to a calculation of the net cost savings of a CHP application.

## SAMPLE CALCULATION

The following calculation determines the net $CO_2$ emissions resulting from a CHP application. The prime mover is assumed to be a natural gas fueled internal combustion engine with the following performance specifications:

| | |
|---|---|
| Fuel Consumption Rate | = 82 therm/hr |
| Net Power Output | = 750 kW |
| Exhaust Heat Rate | = 7,200 Btu/kWh |

It is assumed that the engine is designed to meet the base electrical load of the facility and that the energy in the exhaust heat of the CHP system is used to generate hot water. The thermal load of the facility is assumed to have a continuous demand for hot water at a rate that exceeds the amount that can be generated by recovering heat from the engine. These conditions could be realized at a site such as a large correctional facility. It is also assumed that the engine is available for operation during 90% of the annual operating hours and from these assumptions, based on 8,760hr/yr, the engine is assumed to operate at full electrical output and heat recovery for 7,884hr/yr.

The calculation proceeds according to Relation 3.

$$\text{Net CHP GHG Emissions} = GHG_{fuel} - GHG_{kWh,offset} - GHG_{boiler\ therms,offset} \quad (3)$$

The method of evaluating the $CO_2$ emissions associated with the fuel usage of the CHP equipment is calculated in Relation 4.

$$GHG_{fuel} = (\text{Fuel Consumption Rate})(\text{Annual Operating Hours})(C_{therm}) \quad (4)$$

$$GHG_{fuel} = \left(82\frac{\text{therm}}{\text{hr}}\right)\left(7{,}884\frac{\text{hr}}{\text{yr}}\right)\left(11.708\frac{\text{lb } CO_2}{\text{therm}}\right) \approx 7.57 \times 10^6 \frac{\text{lb } CO_2}{\text{yr}}$$

The method of evaluating the $CO_2$ emissions associated with the power generation of the CHP equipment is calculated in Relation 5.

$$GHG_{kWh,offset} = (\text{New Power Output})(\text{Annual Operating Hours})(C_{kWh}) \quad (5)$$

$$GHG_{kWh,offset} = (750\text{ kW})\left(7{,}884\ \frac{\text{hr}}{\text{yr}}\right)\left(0.61\frac{\text{lb } CO_2}{\text{kWh}}\right) \approx 3.61 \times 10^6\ \frac{\text{lb } CO_2}{\text{yr}}$$

Assuming a heat recovery efficiency of 80% and an existing boiler efficiency of 75%, the method of evaluating the $CO_2$ emissions associated with offsetting part of the existing hot water boiler capacity is calculated according to Relation 6.

$$GHG_{boiler,offset} = (\text{Exhaust Heat Rate})(\text{Power Output})\left(\frac{\eta_{HX}}{\eta_{Boiler}}\right)(\text{Annual Operating Hours})(C_{therm}) \quad (6)$$

$$GHG_{boiler,offset} = \left(7{,}200\frac{\text{Btu}}{\text{kWh}}\right)(750\text{ kW})\left(\frac{0.8}{0.75}\right)\left(7{,}884\frac{\text{hr}}{\text{yr}}\right)\left(\frac{1\text{ therm}}{100{,}000\text{ Btu}}\right)\left(11.708\frac{\text{lb } CO_2}{\text{therm}}\right)$$

$$\approx 5.32 \times 10^6\ \frac{\text{lb } CO_2}{\text{yr}}$$

These values are substituted into Relation 3 to determine the net $CO_2$ output of the CHP system.

$$\text{Net CHP GHG Emissions} = GHG_{fuel} - GHG_{kWh,offset} - GHG_{boiler,offset} \quad (3)$$

$$\text{Net CHP GHG Emissions} = 7.57 \times 10^6 \frac{lb_{CO_2}}{yr} - 3.61 \times 10^6 \frac{lb_{CO_2}}{yr} - 5.32 \times 10^6 \frac{lb_{CO_2}}{yr}$$

$$\text{Net CHP GHG Emissions} = -\ 1.36 \times 10^6 \frac{lb_{CO_2}}{yr}$$

$$\text{Net CHP GHG Emissions} = -\ 680 \ \frac{ton_{CO_2}}{yr}$$

The final result is that a CHP system operating in such a scenario can be shown to not only reduce net $CO_2$ emissions, but to reduce net $CO_2$ emissions dramatically, on the order of hundreds of tons annually.

## DISCUSSION

The $CO_2$ emissions reduction resulting from the installation of a CHP system is strongly dependent on factors such as the 1st Law efficiency of the prime mover, as well as the ratio of the efficiencies of the existing boilers and proposed heat exchanger.

The majority of the $CO_2$ emission reduction results from offsetting an existing gas-fired heat load with heat recovered from the exhaust of the CHP system. Prime movers with lower 1st Law efficiencies tend to have higher exhaust heat rates, which allows them to offset more of the existing gas-fired heat load than similar prime movers with higher 1st Law efficiencies. Thus, the amount of $CO_2$ emissions that can be reduced in this scenario is inversely proportional to the 1st Law efficiency of the prime mover.

The heat exchanger of the new CHP system should have the highest possible efficiency to ensure that the heat available for recovery is not wasted. No matter how efficient the new heat exchanger is, certain levels of $CO_2$ reduction may be unattainable because they also depend on the efficiency of the existing boiler. Offsetting the gas usage of a new and highly efficient boiler with a new heat exchanger will yield far less emissions reductions than offsetting the usage of an older boiler. In fact, the amount of $CO_2$ emissions that can be reduced by this CHP design

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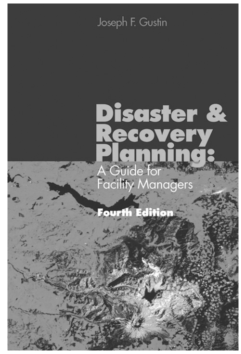


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is directly proportional to the ratio of the new heat exchanger efficiency divided by the existing boiler efficiency, as shown in Figure 1.

This fact is important because many emissions reduction programs are based on achieving specific levels of reduction often quantified in equivalent tons or as a percentage of site emissions. By measuring the efficiency of the existing boiler(s) and having an estimate of the new heat exchanger efficiency, engineers can use the methodology outlined previously to quickly determine whether a CHP system with a particular prime mover will be able to achieve a desired emissions reduction target.

## CONCLUSIONS

Although it may be counterintuitive, it can be shown that careful implementation of a CHP system with waste heat recovery to generate hot water can result in a net reduction of on-site GHG emissions. The

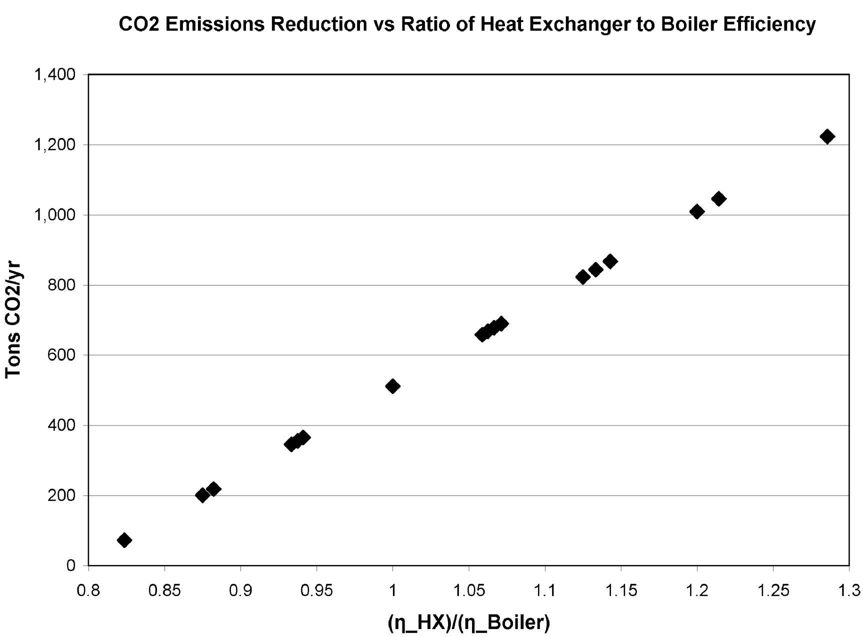


**Figure 1. Annual carbon dioxide emissions reduction vs. the ratio of heat exchanger to boiler efficiency for a specific prime mover and loading scenario.**

methodology presented can be used as a preliminary estimating tool for engineers developing GHG reduction projects. This will enable engineers to quickly determine the feasibility of achieving a targeted GHG reduction with a CHP application.

The GHG emissions associated with a CHP system can be thought of as costs with their net output calculated similarly. The factors that weigh heavily in the economics of CHP systems also weigh heavily on GHG reductions. Two of those factors are the manufacturers design specifications of the prime mover and the extent to which waste heat can be recovered and utilized.

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