CHP
EPA COMBINED HEAT AND POWER PARTNERSHIP

How CHP Reduces Greenhouse Gas Emissions on a Cleaner Grid

As state and local decarbonization and clean energy goals are enacted, the electric grid continues to use a greater number of clean energy sources with lower emissions. Businesses, governments, insitutions, and even indivuals face choices about how to meet their electrical thermal needs, and can now choose from (and combine) several on-site and off-site energy options. On-site options include renewable generation and electrification of end-uses. Off-site options include power purchase agreements and energy atttribute certificates (such as renewable energy certificates). Combined heat and power (CHP) provides another range of options for on-site energy based on the technology used and the fuel choices available.

Key Takeaways from the Analysis

- ✓ At 50% electric load, CHP systems currently reduce carbon emissions compared to electric grids across the country, including the region with the lowest marginal emissions (California).
- ✓ When thermal utilization is reduced to 50% and CHP is operating at >75% electric load, CHP reduces emissions compared to separate heat and grid power in California.
  - At 50% load and 50% thermal utilization, CHP reduces carbon emissions compared to the electric grids in Texas, the Mid-Atlantic, the Midwest, and most of the U.S.
- ✓ Compared to California grid emissions, CHP only becomes a net carbon emitter when:
  - Thermal utilization drops below 50% or
  - Low electric load is combined with low thermal use (a poorly designed system).

Emission reductions associated with CHP depend on how organizations procure or generate electricity before installing CHP, the fuel used in the CHP system, and the amount of clean energy used to serve marginal loads in the regional grid. The reductions are also based on CHP's effect on the organization's emissions inventory. Because CHP needs less fuel to simultaneously produce two useful energy outputs (electricity and heat) and avoids transmission and distribution losses that occur when electricity travels over power lines, it produces fewer emissions than separately producing heat and grid power with the same fuels. Today, CHP systems fueled by natural gas emit less carbon dioxide (CO_2) than separately producing heat and grid power in most U.S. locations. As renewable resources are added to grid regions, CHP can continue to reduce CO_2 emissions when using low-carbon fuels like renewable natural gas (RNG) and green hydrogen.

To provide a better understanding of CHP's emission reduction in a decarbonizing grid, EPA conducted an analysis to compare natural gas CHP CO_2 emissions to the CO_2 emissions produced by power plants on the operating margin. The analysis focused on natural gas CHP systems, which represent about 70 percent of total installed CHP through 2020.[1]

Analysis Methodology

CHP systems designed to meet a facility's base electric and thermal requirements operate at close to full capacity and full thermal utilization to maximize efficiency and emissions savings. However, in practice not all CHP systems operate at full capacity or utilize all the available thermal energy. With these different operating paradigms in mind, EPA took the following steps:

1. EPA obtained performance data for four CHP systems: a 100 kW engine, a 200 kW microturbine, a 1 MW engine, and a 7.5 MW gas turbine. These systems are representative of the types of prime movers and system sizes found in CHP installations over the past decade. They also reflect the observed national trend of an increase of smaller CHP installations through standard packaged systems. Large (>10 MW) CHP systems are still being installed, but mostly at industrial sites or at sites where resiliency is a key driver and CHP is part of a larger sustainability strategy.

[1] U.S. Department of Energy CHP Installation Database, https://doe.icfwebservices.com/chpdb/

Performance characteristics of each of the systems (e.g., electric, thermal efficiencies) are based on the specifications of CHP packages found in the U.S. Department of Energy's CHP eCatalog. Operating characteristics for each of these systems at 100 percent, 75 percent, and 50 percent of nameplate capacity were used for the analysis. CHP units operating below 50 percent are not representative of typical CHP installations.

2. For each level of electric output, EPA calculated net on-site CO_2 emissions for varying levels of thermal utilization (50–100 percent) based on performance specifications (heat rate and thermal output) from the eCatalog. Many CHP systems cannot utilize all the available thermal output, and this analysis was used to determine the potential for emissions savings at lower thermal utilization levels.

3. EPA compared the net emissions from natural gas CHP systems with marginal grid emissions (2019 AVERT uniform energy efficiency factors, which closely resemble the grid emissions impact of CHP operations) for California, Texas, and the U.S. average. California has the lowest marginal grid emissions in the country, and Texas falls between California and the U.S. average.

   EPA took this step to compare CHP emissions against marginal grid emissions that are avoided when a CHP unit is in operation. As the grids become cleaner over time, the AVERT emission factors will be reduced, and natural gas CHP systems will need to incorporate renewable or low-carbon fuel options to continue reducing emissions compared to the grid.

Analysis Assumptions

1. The CHP systems were assumed to displace on-site thermal energy from natural gas boilers with 80 percent efficiency and associated CO_2 emissions.
2. EPA derived net on-site emissions subtracting the avoided boiler emissions from the CHP emissions.
3. Emissions from marginal grid generation were approximated using EPA AVERT uniform energy efficiency emission factors, which represent a constant customer load reduction similar to the effect of CHP units running continuously.

The analysis compared CHP emissions to recent marginal grid emissions from the standard grid mix. Marginal grid emissions will be reduced in the future, but the magnitude and timing depend on the status of regional grids and local, state, or utility initiatives for clean grid power. CHP systems can also incorporate renewable or low-carbon fuels. For CHP systems using fuels with zero associated carbon emissions, all emissions from grid-produced electricity (currently over 1,000 lb CO_2 per MWh) would be avoided.

Analysis Results

The results of the analysis are shown in Figures 1 through 4 below. The figures show how the net emissions for each of the systems compare against the AVERT marginal grid emission factors under each of the three operating scenarios.

- Figure 1 shows the CO_2 emissions comparison for a 100 kW reciprocating engine. CHP produces fewer emissions than separately produced heat and grid power in all cases analyzed.
- Figure 2 shows the CO_2 emissions comparison for a 200 kW CHP microturbine. While the net CHP emissions exceed the California marginal grid rate at 50 percent power output and 50 percent thermal utilization, the CHP system reduces CO_2 emissions compared to the current grid in most operational scenarios.
- Figure 3 shows the CO_2 emissions comparison for a 1 MW CHP engine. CHP produces fewer CO_2 emissions than separate heat and current grid power in all cases analyzed.
- Figure 4 shows the CO_2 emissions comparison for a 7.5 MW gas turbine. The turbine experiences lower part-load performance than other CHP systems but still reduces CO_2 emissions compared to the current grid in most operational cases.

Figure 1. CHP Emissions Comparison for 100 kW Reciprocating Engine

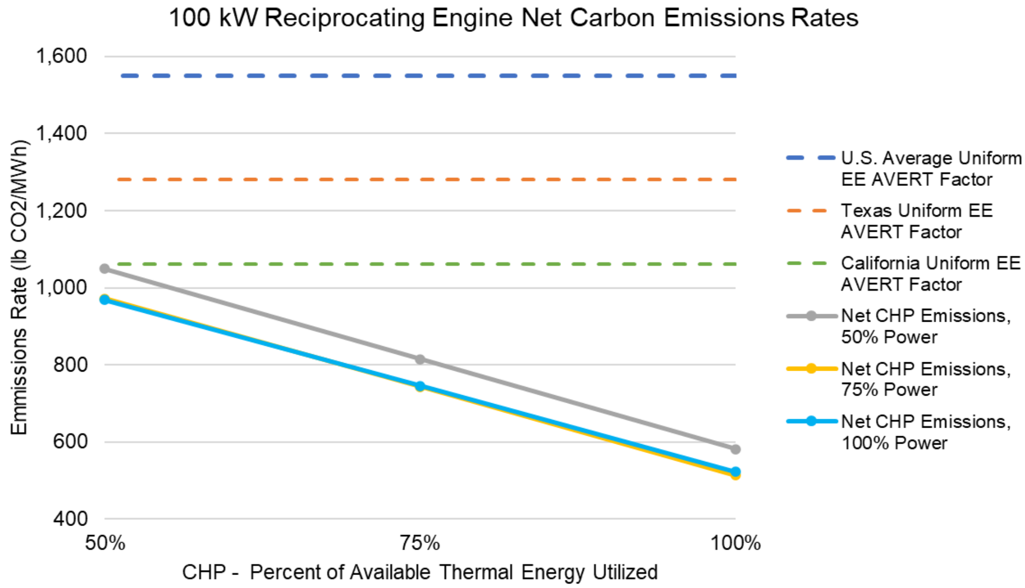


Figure 2. CHP Emissions Comparison for 200 kW Microturbine

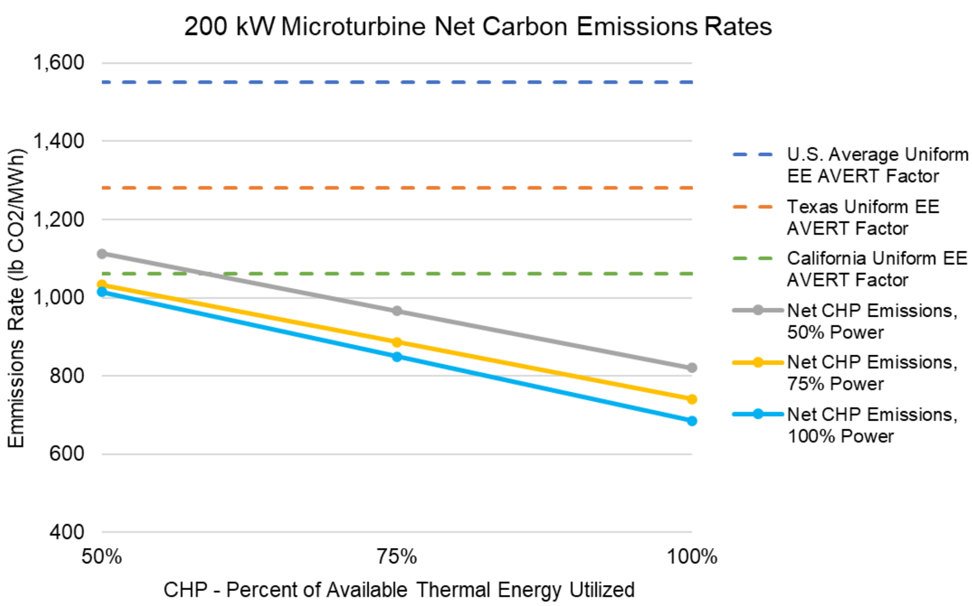


Figure 3. CHP Emissions Comparison for 1 MW Reciprocating Engine

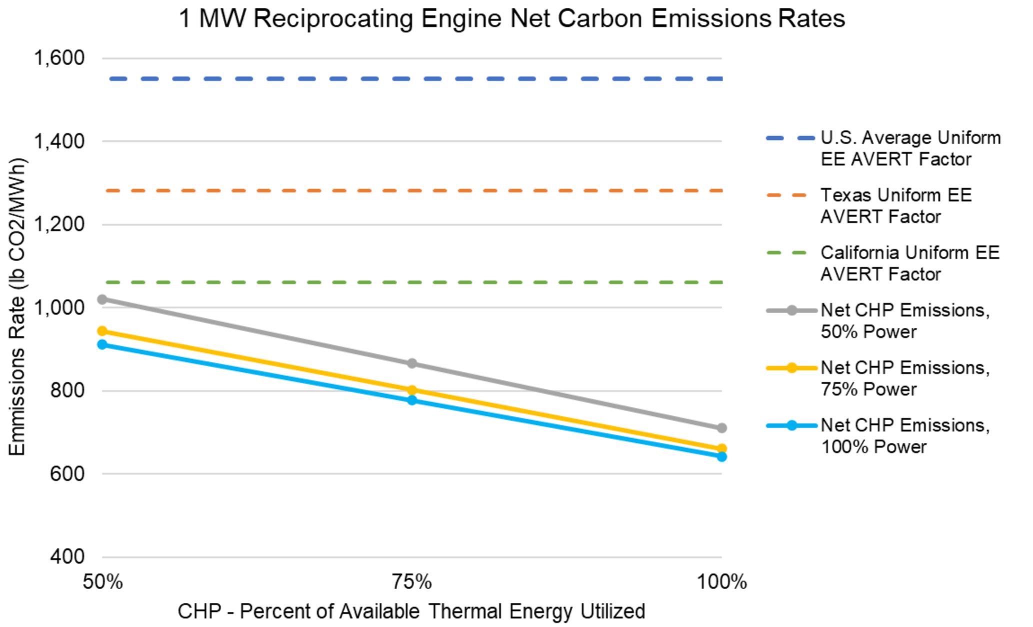
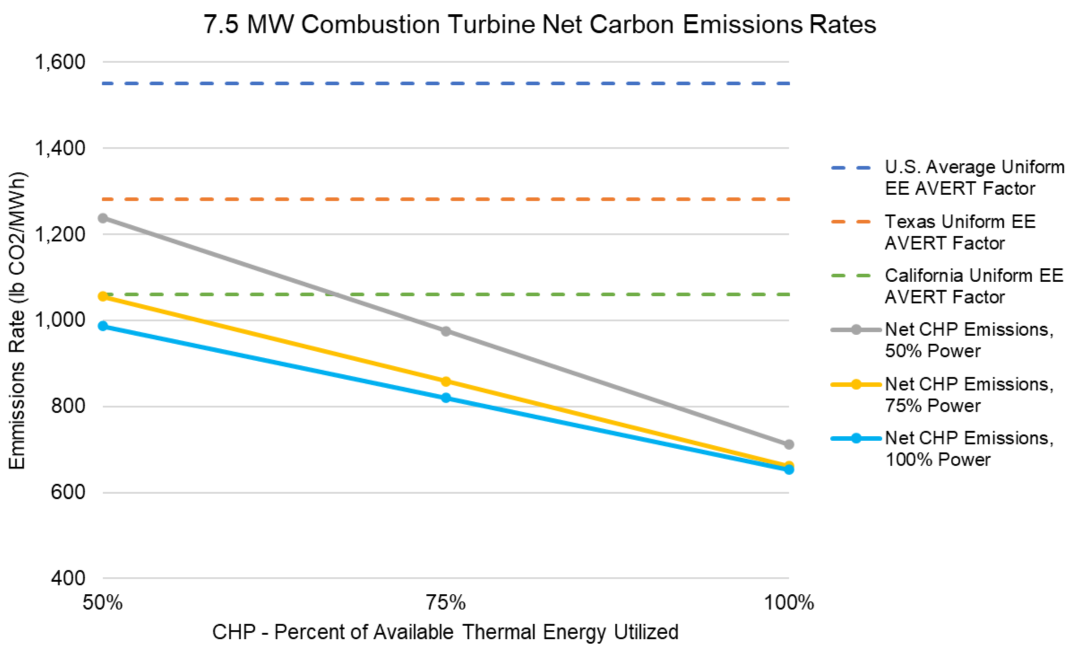


Figure 4. CHP Emissions Comparison for 7.5 MW Combustion Turbine



Overall, the analysis showed that CHP systems fueled by natural gas that occasionally operate at half load and/or half thermal utilization are still reducing CO_2 emissions compared to separate heat and grid power in most circumstances. Even in California where marginal grid emissions are lowest, natural gas CHP reduces CO_2 emissions compared to separate heat and current grid power under most operating paradigms.

Note that the analysis is comparing CHP emissions to 2019 estimates for marginal grid emissions through the standard grid mix. Some customers purchase renewable power from the grid or through off-site contracts. For customers whose electricity can be attributed to renewable generation resources, CHP systems will not reduce emissions. Additionally, as renewable resources are incorporated into the standard grid mix, CHP systems that incorporate renewable or low-carbon fuels will continue to reduce emissions.

General Findings

- All of the CHP systems analyzed reduced CO_2 emissions compared to the grid in most operating scenarios.
- Even when operating at half electric load and half thermal utilization, the 100 kW and 1 MW engines produced fewer CO_2 emissions than the current California electric grid.
- Operating at part electric load (down to 50 percent) has a small impact on emission reductions, with gas turbines affected more than engines and microturbines.
    - As the electric load decreases compared to the nameplate capacity:
        - Electric efficiency is reduced (more fuel required per kWh produced).
        - Thermal efficiency increases (less fuel converted to electricity, more heat available in relative terms).
        - Total CHP efficiency (electric + thermal) remains approximately the same.
    - Avoided grid CO_2 emissions are reduced with low electric output, but this is somewhat offset by improved thermal efficiencies.
- Reducing thermal utilization has a direct impact on CO_2 emission reductions. CHP systems designed to provide base thermal requirements utilize the majority of available thermal energy, and this is important for maintaining emission reductions compared to separately producing heat and grid power.
    - Avoided boiler emissions are a large part of CHP emission savings; when thermal energy is not utilized, these avoided emissions are simply removed from the equation.
    - Fifty percent thermal utilization has a larger impact on net on-site emissions than 50 percent electric load.

Average (All Sources) or Marginal Emissions Rates?

Businesses and organizations considering on-site distributed energy resources (DERs) like CHP often wish to estimate the CO_2 emissions benefits of their investment. Electricity from CHP displaces utility-delivered electricity from a mix of power plants. While *average emissions rate* of all generation in a given period can be used to estimate avoided emissions from grid electricity, *marginal emissions rates* are more representative. When DERs are installed, they reduce grid demand, lowering the need for marginal grid resources that serve incremental customer loads (resources that are scaled back or avoided when grid demand is reduced, which tend to use fossil fuels).

Average emissions rates include “must-run” baseload resources like nuclear power and “must-take” variable resources like wind and solar power. If these resources are included in estimates of avoided grid emissions, the CO_2 reduction potential of DERs may be significantly underestimated.

To measure the emissions impact of DERs like CHP, *marginal emissions rates* should be used. EPA’s AVoided Emissions and geneRation Tool (AVERT) was created to estimate *marginal emissions rates* associated with U.S. electric grid regions for various of DERs and energy efficiency measures. *Non-baseload* emissions rates from EPA’s Emissions & Generation Resource Integrated Database (eGRID) can also be used to estimate marginal grid emissions.

Conclusions

The results of the analysis explain the ability of CHP to reduce CO_2 emissions compared to typical scenarios of separately produced heat and grid power during the transition to clean energy. By capturing and using heat energy that would otherwise be wasted, CHP systems operate far more efficiently than grid electricity and on-site heating, typically achieving total system efficiencies of 60 to 80 percent. This efficiency advantage can result in CO_2 emission reductions compared to separately produced heat and grid power.

Depending on regional grid resources and local decarbonization initiatives, CHP systems fueled by natural gas or low-carbon fuel blends can continue to reduce CO_2 emissions compared to the standard grid mix in the future. CHP’s CO_2 emissions vary by fuel, technology, power output, and thermal utilization. CHP systems operate most efficiently at full capacity when utilizing all thermal output. In practice, there may be periods of lower power output and lower thermal utilization. The analysis shows that CHP fueled by natural gas reduces CO_2 emissions compared to current marginal grid generators—and for that reason, CHP installations, combined with other on-site and off-site renewable power options, can contribute to decarbonization strategies during an energy transition to a cleaner grid.