CHP's Potential to Reduce GHG Emissions in California

Evaluation of a June 2013 CRRI Conference Paper

Introduction

The EPA CHP Partnership advocates the use of combined heat and power (CHP) systems, a clean energy supply-side resource that results in lower greenhouse gas emissions compared to separate heat and power (SHP) systems. The Partnership's focus is on CHP applications that are technically and economically feasible and is reflected in the Partnership's information resources on project development and policy analysis.

The CHP Partnership contracted with ICF International (ICF) to review a recent paper[1] presented by Sonika Choudhary, Sam Wade and Ray Williams (Choudhary et al) at the Center for Research in Regulated Industries (CRRI)'s Annual Western Conference in June 2013. In the paper, the authors evaluated the greenhouse gas (GHG) emission reduction potential based on CHP systems' performance in California. The results of the analysis intend to inform energy regulators about the sensitivities around GHG emissions reduction potential and cost effectiveness of CHP systems.

In the paper, the authors make an efficiency-based comparison of GHG emissions between conventional fossil-fueled CHP systems and SHP systems. The paper concludes that conventional gas-fired CHP systems may have limited GHG emission reductions potential in California due to lower GHG emissions associated with the California electric grid over time. The conclusion appears to be counter to the CHP Partnership's experience in the industry, and a review was initiated to better understand the differences in the authors' and the Partnership's findings.

The ICF assessment shows that paper has the potential to provide a better understanding of CHP installed and being considered in California. The paper, however, includes some CHP assumptions and operational characteristics that are not entirely transparent and are inconsistent with ICF and the Partnership's experience with CHP systems. These tend to devalue and underestimate the benefits of CHP, including assumptions regarding CHP system thermal utilization, efficiency levels of comparison boilers, and the marginal heat rate for electricity generators in California. The following sections provide a description of how the key assumptions in the paper differ from ICF's experience in tracking CHP system performance for the EPA and DOE and how that leads to different results.

California CHP Market

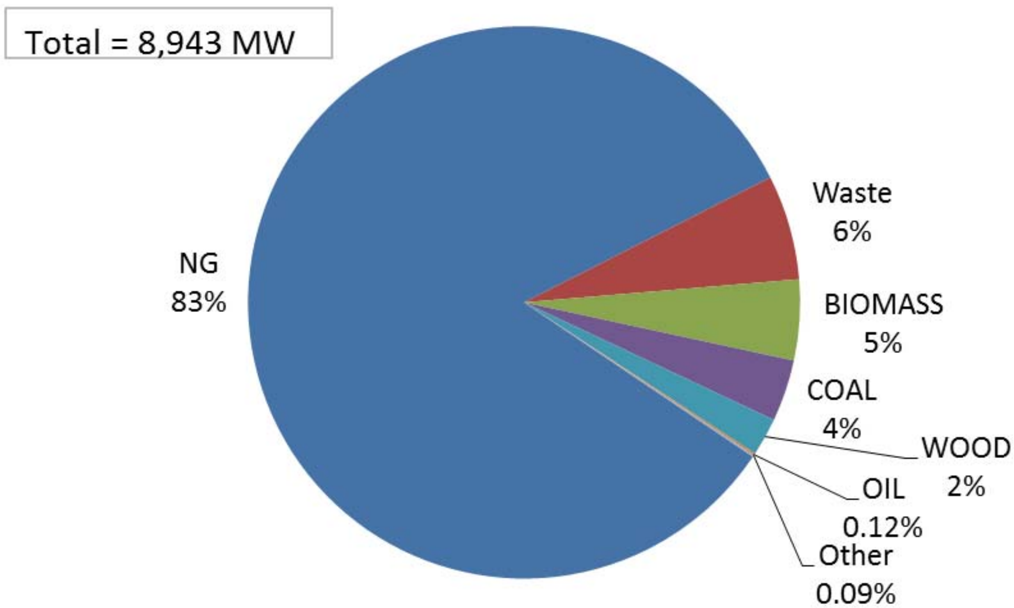
The June 2013 paper addresses four natural gas CHP technologies:

- Microturbine
- Fuel Cell
- Reciprocating Engine
- Combustion turbine

[1] Sonika Choudhary, Sam Wade and Ray Williams. "Evaluating the GHG Performance of CHP Systems: A Summary for Californian Policymakers". CRRI Annual Western Conference, June 2013.

Across these four technologies, the analysis also compares CHP systems that provide on-site electricity to those that sell power to the electric grid. In order to put the analysis in context, it's useful to start with a depiction of the currently installed CHP population in California. As of 2013, ICF's CHP database showed a total of 8,943 MW of CHP capacity installed in California. Figure 1 shows the breakdown of this capacity by fuel. Natural gas accounts for 83% of the capacity. Wood and biomass account for 7%; coal and waste fuel accounts for most of the rest.

Figure 1 - Fuel Breakdown for CHP in California (MW)



For natural gas fired systems, Figure 2 shows the breakdown by prime mover. Combustion turbine and combined cycle CHP systems account for over 90% of the gas capacity. Boiler/steam turbine systems account for 1% and reciprocating engines account for 5%. All other technologies, including microturbines and fuel cells, account for only 1%.

Figure 2 - Natural Gas CHP Technology Breakdown for California (MW)

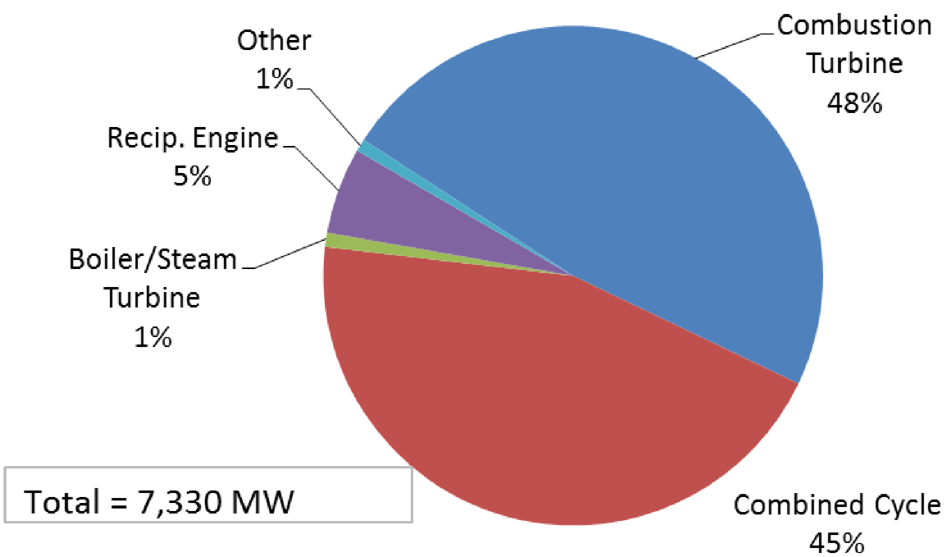


Table 1 shows the breakdown of these natural gas systems by size. The large (>20 MW) combustion turbine and combined cycle CHP systems account for 85% of the capacity. For systems less than 5 MW, reciprocating engines account for 60% of the capacity. For the systems for which data is available, 93% of the combustion turbine systems, 76% of the combined cycle systems, 44% of the reciprocating engine systems and only 13% of the microturbines are selling power to the grid (by generating capacity). None of the fuel cell systems reported selling power to the grid.

Table 1 - Natural Gas CHP System Breakdown in California (MW)

Prime Mover	<1 MW	1-5 MW	5-20 MW	20-100 MW	>100 MW	Grand Total
Combustion Turbine	2	112	445	1,819	1,136	3,514
Combined Cycle		8	63	947	2,261	3,280
Boiler/Steam Turbine	1	3	5	59		68
Recip. Engine	124	158	88	40		410
Microturbine	27	1				28
Fuel Cell	15	10				25
Waste Heat Recovery		4				4
Other	2					2
Grand Total	171	296	601	2,865	3,397	7,330

In summary, large combustion turbine and combined cycle systems comprise the vast majority of CHP capacity in California with most selling power to the grid, followed by reciprocating engines, which are about evenly divided between those behind the meter and those selling at least some power to the grid. Though the Choudhary et al analysis is built on commercially available CHP technologies, with a focus on microturbines, fuel cells, reciprocating engines, and combustion turbines, it is not representative of current CHP technologies in California.

Comparison of Assumptions

ICF then looked at the June 2013 CRRI paper to review whether the key assumptions reflected ICF's experience in the CHP industry. Table 2 summarizes the comparisons between the paper and ICF's key assumptions followed by an analysis demonstrating the implications of the different assumptions.

Table 2 - Differences in Assumptions: Key Comparison

	Choudhary et al Paper	ICF
Heat Rate Degradation	No degradation for CHP systems in optimistic scenario, 1%/yr degradation in pessimistic scenario. No degradation for SHP	No degradation in either CHP or SHP for consistency
Avoided Boiler Efficiency	SHP steam boiler efficiency of 80% or 85%	SHP steam boiler efficiency of 80% (based on the EPA Catalog of Technologies)
Thermal Utilization	CHP thermal utilization of 80% to 100% in optimistic scenario, 64% to 80% in pessimistic scenario	90% thermal utilization, based on a likely minimum thermal efficiency of 80% and a maximum of 100%
Marginal Emission Rate	2009 U.S. fossil average, 2020 marginal CA, and 2020 marginal CA with RPS and T&D adjustments	2020 marginal CA rate, 2020 marginal CA rate with RPS and T&D adjustments

Heat Rate Degradation. While some performance degradation over time may occur in any system, it would apply both to CHP and SHP systems. In addition, the degradation of a CHP system's (electric) heat rate would result in less electric energy output and more thermal energy output with the same fuel input. In some cases, this can increase overall system efficiency. It is unclear whether the paper's analysis accounts for increasing thermal CHP efficiency with decreasing electric CHP efficiency. ICF's analysis has excluded degradation from the CHP heat rate, the avoided boiler efficiency, and the avoided grid heat rate for consistency.

Avoided Boiler Efficiency. The range of thermal systems reflected in the analysis covers a variety of thermal technologies (from residential to medium industrial size) which could have widely variable efficiencies. While some residential boilers could be 85% efficient or even slightly higher in a few cases, most would likely be significantly less efficient. 85% is on the high side of typical assumptions for industrial boiler efficiency. Choudhary et al assume a high boiler efficiency, which is originally based on targets for boiler efficiency improvement programs[2], rather than actual boiler performance data. This original source estimates nominal industrial boiler efficiency to be in the 75 to 83% efficiency range. Using a higher boiler efficiency

[2] *Climate Leaders Greenhouse Gas Inventory Protocol Offset Project Methodology for Project Type: Industrial Boiler Efficiency*. U.S. EPA. August 2008. http://www.epa.gov/climateleaders/documents/resources/industrial_boiler_protocol.pdf

underestimates the emissions of the separate heat system and reduces the relative benefit of the CHP system. ICF has assumed an avoided boiler efficiency of 80% which is more typical for systems across these size ranges.[3]

Thermal Utilization. Reducing the thermal utilization implies that the CHP system generates thermal energy that is not used. Discounting thermal utilization results in reduced thermal output and reduced emissions from the separate heat boiler, resulting in lower SHP emissions relative to CHP emissions. A highly discounted thermal utilization (such as the paper's scenario of 64% for CHP systems less than 5 MW) has a significant impact on economics and emissions. However, ICF's experience is that a thermal utilization as low as 64% would not yield favorable CHP system economics in the first place and would be unlikely to be the basis for a CHP installation. While some underperformance has been reported for smaller systems in California, as pointed out in the Choudhary et al paper, the Self-Generation Incentive Program (SGIP) now requires reporting and successful attainment of performance goals.

Generally, thermal utilization is application, size, and site-specific. To attain optimal efficiency, CHP systems are primarily sized to thermal load, and failing to capture as much of the thermal output as possible would be reflected in the CHP site economics. While there are operational CHP facilities that have less than 100% thermal utilization, an optimally efficient CHP system case would maximize thermal utilization. ICF's experience indicates that a range of utilization from 80% to 100%, the higher range considered by Choudhary et al, would be more typical for economically viable CHP systems. The analysis here assumes 90% thermal utilization.

Marginal Grid Emission Rate. Choudhary et al compare CHP system performance to three different electric grid heat rates (and associated CO_2 emissions). The first heat rate for comparison is the 2009 U.S. average fossil heat rate. The second is a time-weighted average 2020 marginal grid emission factor estimate for California from the PLEXOS model (2020 CA). The third is the second heat rate (i.e., 2020 CA) adjusted for RPS and T&D losses (2020 CA RPS and T&D). The ICF analysis addresses the 2020 California heat rate as the central basis of its comparison of the CHP analysis in California as well as the 2020 RPS case.

Comparison of Results

Figure 3 shows the final "optimistic" and "pessimistic" summary charts in Choudhary et al's paper (referred to as Figure 6 in the paper). This double benchmark presentation is a very compact way of presenting the data but is not entirely transparent because it uses efficiency as a surrogate for an emissions comparison instead of directly expressing the absolute emissions or emission rates from each system. The efficiency factors are used with several additional details and supporting assumptions that can be found in the original Choudhary et al paper. There are three critical sets of assumptions that drive the results:

1. Three Groups of Avoided Grid Emissions Factors and Avoided Boiler Efficiencies[4]
    a. 2009 U.S. "all fossil average", represented by a dashed line in parts a and b of Figure 3
    b. 2020 California, represented by a solid line in parts a and b of Figure 3

[3] Table 1: Boiler/Steam Turbine CHP System Cost and Performance Characteristics. "Steam boiler efficiencies range from 70 to 85 percent HHV depending on boiler type and age, fuel, duty cycle, application, and steam conditions". http://www.epa.gov/chp/documents/catalog_chptech_full.pdf

[4] The avoided grid emission factors are converted to an equivalent marginal natural gas unit heat rate and corresponding system efficiency. This efficiency value is represented by the x-intercept. The avoided boiler efficiencies are represented by the y-intercept (i.e. 80% or 85%).

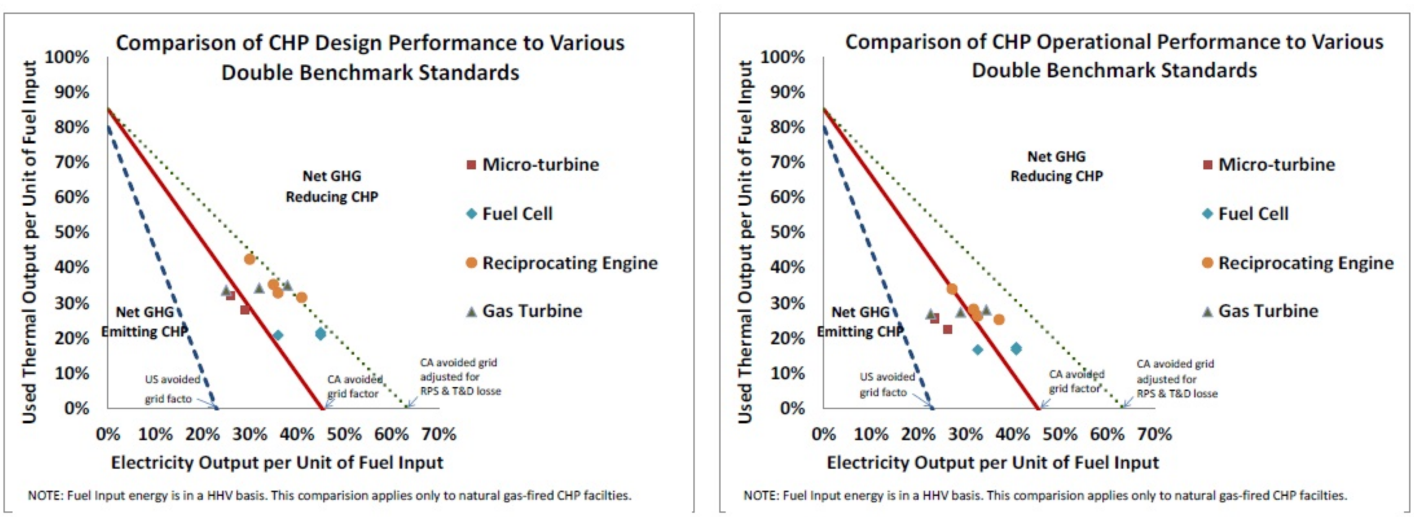
c. 2020 California with 33% RPS and 6.9% T&D adjustment, represented by a dotted line in parts a and b of Figure 3

2. Optimistic and Pessimistic CHP system Operational Characteristics[5]
   a. Thermal utilization, optimistic assumptions represented in part a of Figure 3 and pessimistic assumptions represented in part b of Figure 3
   b. Heat rate degradation, optimistic assumptions represented in part a of Figure 2 and pessimistic assumptions represented in part b of Figure 3
   c. Capacity factor
3. CHP Technology Data
   a. Data split by technology type (i.e., microturbine, fuel cell, reciprocating engine, and gas turbine), represented by individual data points in parts a and b of Figure 3

In Choudhary et al's analysis, if the CHP technology data points fall to the right of each of the three lines (i.e., the avoided grid emission factor and avoided boiler efficiency assumptions) then the CHP system is net GHG-reducing. Conversely, if the CHP technology data points fall to the left of the three lines, then the CHP system is net GHG- increasing.

ICF finds some of Choudhary et al's assumptions regarding CHP system performance (i.e., thermal utilization, heat rate degradation, RPS adjustment to CA's 2020 grid heat rate, 85% boiler efficiency) are not consistent with our experience with CHP systems installed in the U.S. and all have the effect of reducing the benefits of CHP relative to SHP. In order to show this more clearly, ICF uses an emissions-based comparison, which we believe is more transparent and applicable to a GHG analysis than an efficiency-based comparison. We present the comparison using emission rates in metric tonnes of CO_2 per megawatt-hour (tonnes/MWh) across various technology types and system sizes.

Figure 3 - Summary Charts from Choudhary et al's Paper



a). Comparison of CHP Technologies Design Efficiencies (Optimistic Scenario) to Double Benchmark Standards

b). Comparison of CHP Technologies Operational Efficiencies (Pessimistic Scenario) to Double Benchmark Standards

[5] Thermal utilization and heat rate degradation assumptions for the optimistic and pessimistic scenarios are summarized in Table 2. Capacity factor is excluded because our analysis is focused on emission *rates*, which do not use capacity factors.

This emissions-based approach compares the CHP emission rates against SHP emissions rates in the same way as the Choudhary et al analysis but the results are depicted differently. CHP emission rates are calculated using the same technologies and technology assumptions considered in the Choudhary et al analysis. The emissions are determined using the heat rate (Btu/KWh) and the fuel CO_2 content (which in this case, is natural gas). The CHP system performance characteristics are fixed, so their emissions do not change from one case to the next. In all of the figures below, the "X" represents the CHP emission rate.

The following three figures (Figure 4-6) sequentially add various CHP and SHP emission components to the comparison. Figure 4 shows only the CHP emission rates by technology; Figure 5 shows the same CHP emission rates with the separate power component; Figure 6 shows the same CHP emission rates with the separate power component as well as the separate heat component.

The blue-stacked bar (Figure 5) and the violet-stacked bar (Figure 6) represent the separate power and heat emission rates, respectively. These rates vary according to the marginal grid heat rate (power), thermal utilization, and avoided boiler efficiency assumptions and the amount of heat and power displaced by each CHP system (heat). Figure 5, for example, shows how separate power emission rates are calculated from the marginal grid emission factor and are the same across technologies for each case.

Figure 4 – Summary of the CHP Emission Rates

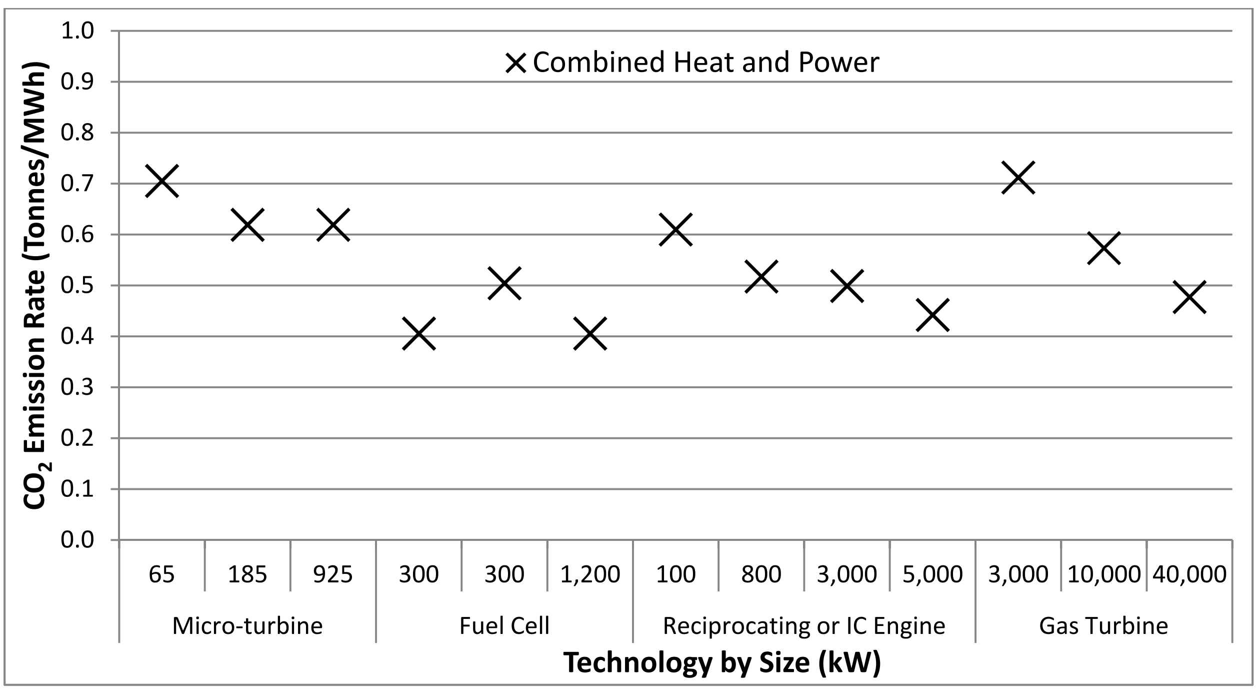
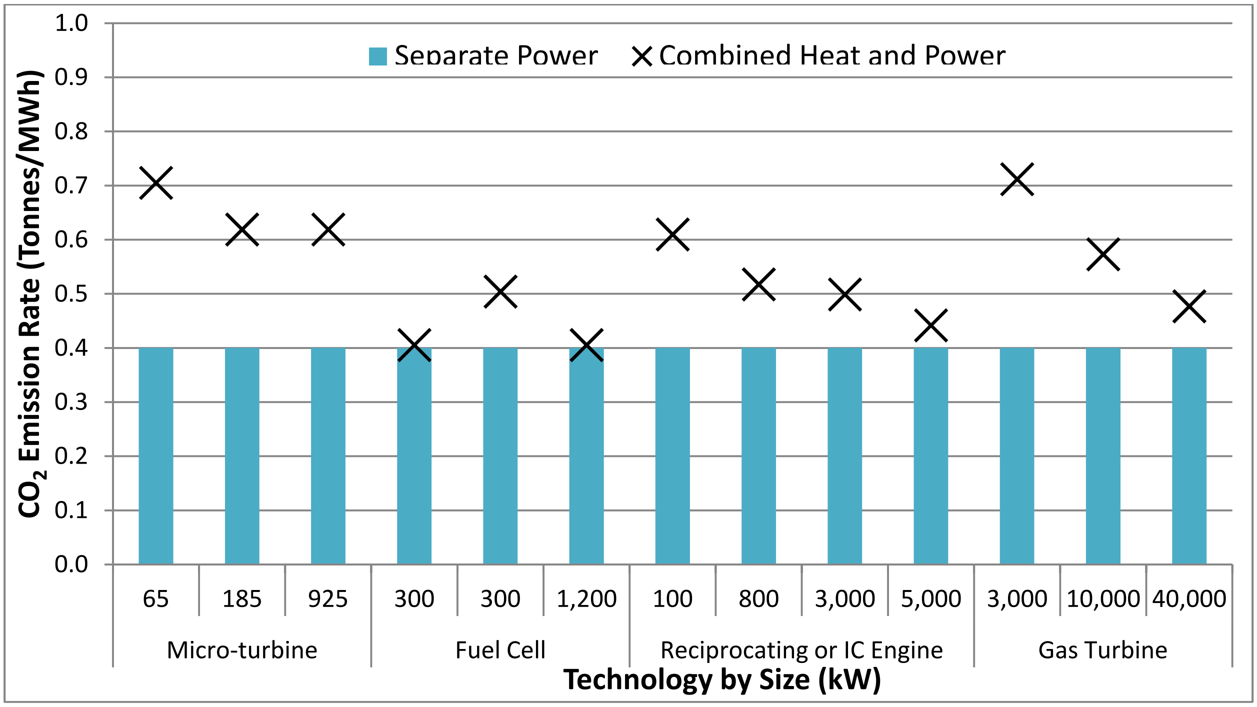


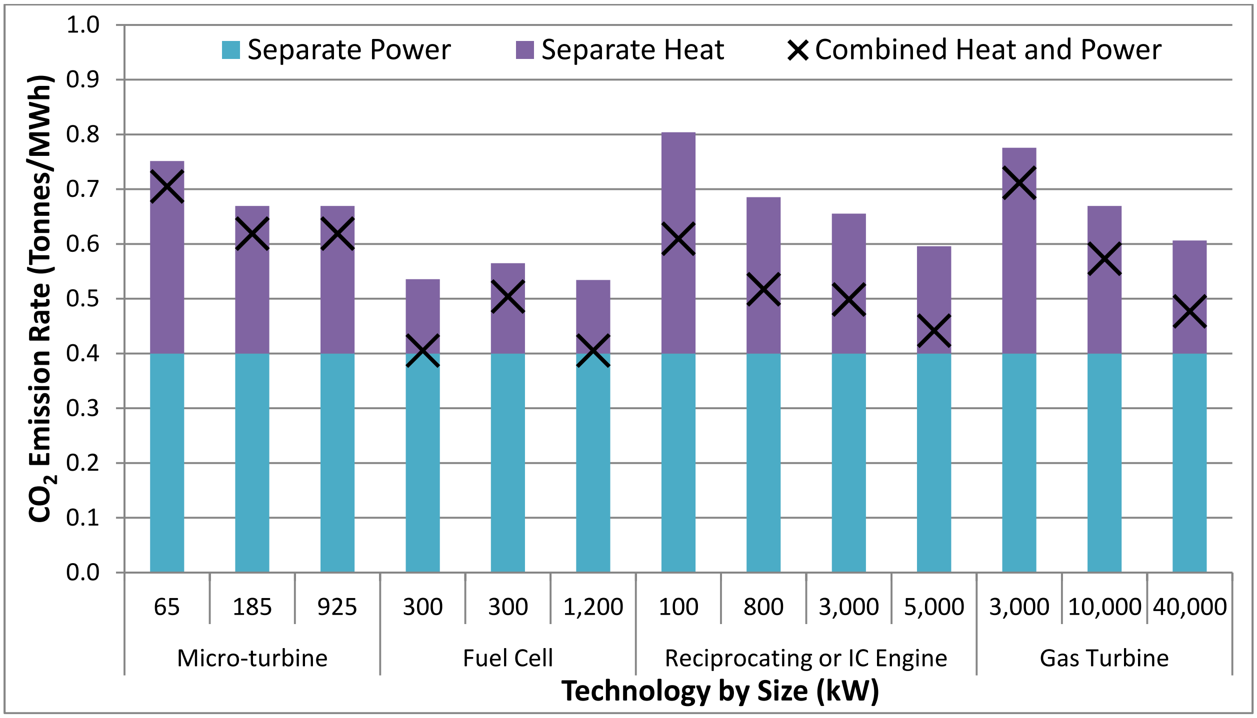
Figure 5 - CHP Emissions Compared to Marginal Grid Emission Rate



The separate heat emissions include the emissions from the separate heat production (boiler). Separate heat emission rates are calculated using the CHP system's calculated thermal output, the avoided boiler efficiency, the thermal utilization, and the natural gas CO_2 content. In Figure 6, the separate heat emission rates are the violet bars that vary across technologies based on the power-to-heat ratio.

The separate power and separate heat emission rates are additive, so if the "X" falls below the top of the stacked bars in the figures, then the CHP system is net GHG-reducing. Alternatively, if the "X" is above the top of the stacked bars, then the CHP system is net GHG-emitting. The varying assumptions affect the SHP system performance (marginal grid emissions and separate heat emissions), which changes relative to the fixed CHP system performance.

Figure 6 - Example CHP and SHP Comparison



In the following figures, we first display the results of Choudhary et al's assumptions using an emissions-based presentation approach (Figures 7 and 8) and then present additional scenarios to demonstrate how various assumptions affect the results (Figures 9 and 10).

Figures 7 and 8 present Choudhary et al 's analysis comparing the emissions to the CA 2020 avoided grid emission factor. The comparison is not identical, however, because Choudhary et al do not identify the exact thermal utilization for larger systems (i.e. 90-100% in the optimistic scenario or 72-80% in the pessimistic scenario). We use an 80% utilization for all systems in the Optimistic case (Figure 7) and a 64% utilization in the pessimistic case (Figure 8). The figures do not include the thermal degradation.

Figure 7 presents the emissions version of Choudhary et al 's paper, Figure 6, the Optimistic Case for CA 2020 avoided grid. Overall, most systems are still net GHG-reducing despite the relatively low thermal utilization of 80% applied to all systems, the relatively high avoided boiler efficiency of 85%, and the comparison to a projected 2020 California grid emission factor. Four of 13 CHP systems (three microturbine and one gas turbine) are net GHG-emitting ("X"'s above the stacked bars).

Figure 7 - CO_2 Emission Rate Comparison for Combined versus Separate Heat and Power 2020 CA Grid with 80% Thermal Utilization and 85% Avoided Boiler Efficiency

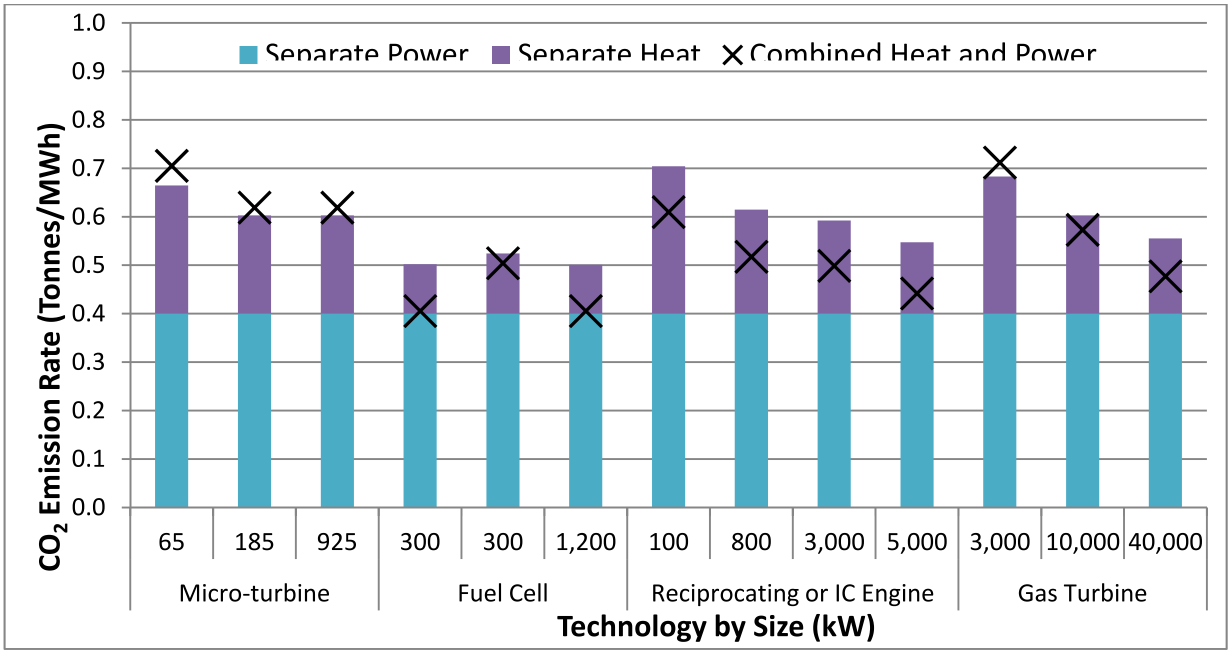
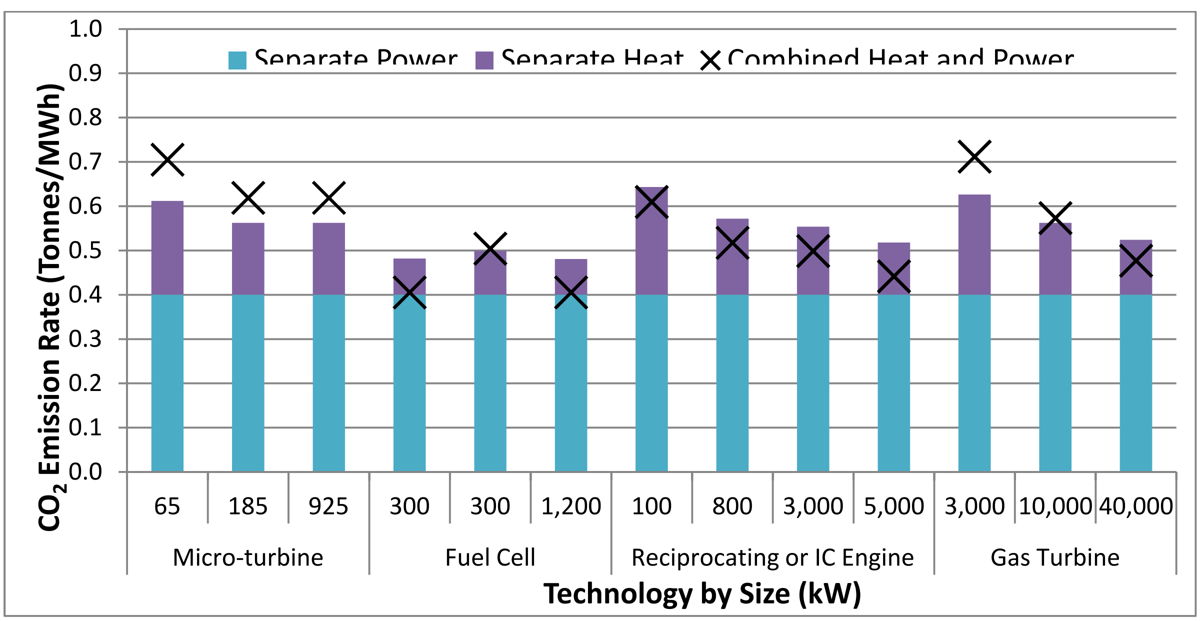


Figure 8 shows the Choudhary et al 's "pessimistic" case (Figure 6), in emissions format. This case has a lower thermal utilization. This means that the CHP system is generating more thermal energy that is not being used, translating to lower levels of thermal energy requirements from the separate thermal system and therefore lower "separate heat" emissions. With these pessimistic assumptions, approximately half of these CHP systems are net GHG-emitting and half are net GHG-reducing. The higher assumed boiler efficiency also reduces the calculated SHP emissions.

Figure 8 - CO_2 Emission Rate Comparison for Combined versus Separate Heat and Power 2020 CA Grid with 64% Thermal Utilization and 85% Avoided Boiler Efficiency



We now explore two additional charts showing CHP versus SHP GHG emission rates using a series of assumptions more consistent with ICF's CHP experience. We have also added one additional bar to show the performance of a combined cycle CHP facility, which makes up a large share of the capacity in California. Figure 9 is comparable to Choudhary et al 's cases with more typical assumptions: 80% boiler efficiency and 90% thermal utilization. With these assumptions, the CHP systems are net GHG-reducing in all cases with a 2020 CA grid factor, and in most cases, considerably below the SHP emissions rate. Comparing Figure 9 with Figures 7 and 8, more typical boiler efficiency and thermal utilization assumptions translate to net GHG-reducing CHP systems across all system sizes analyzed.

Figure 9 - CO_2 Emission Rate Comparison for Combined versus Separate Heat & Power
2020 CA Grid with 90% Thermal Utilization and 80% Avoided Boiler Efficiency

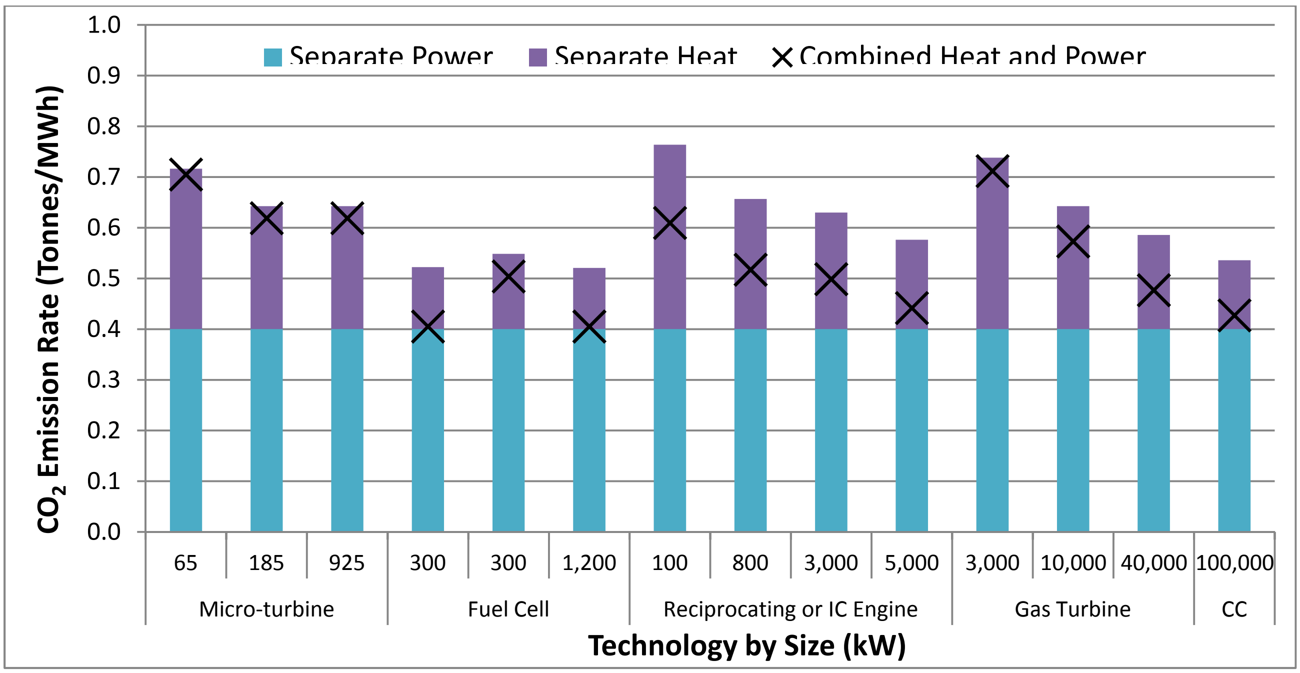
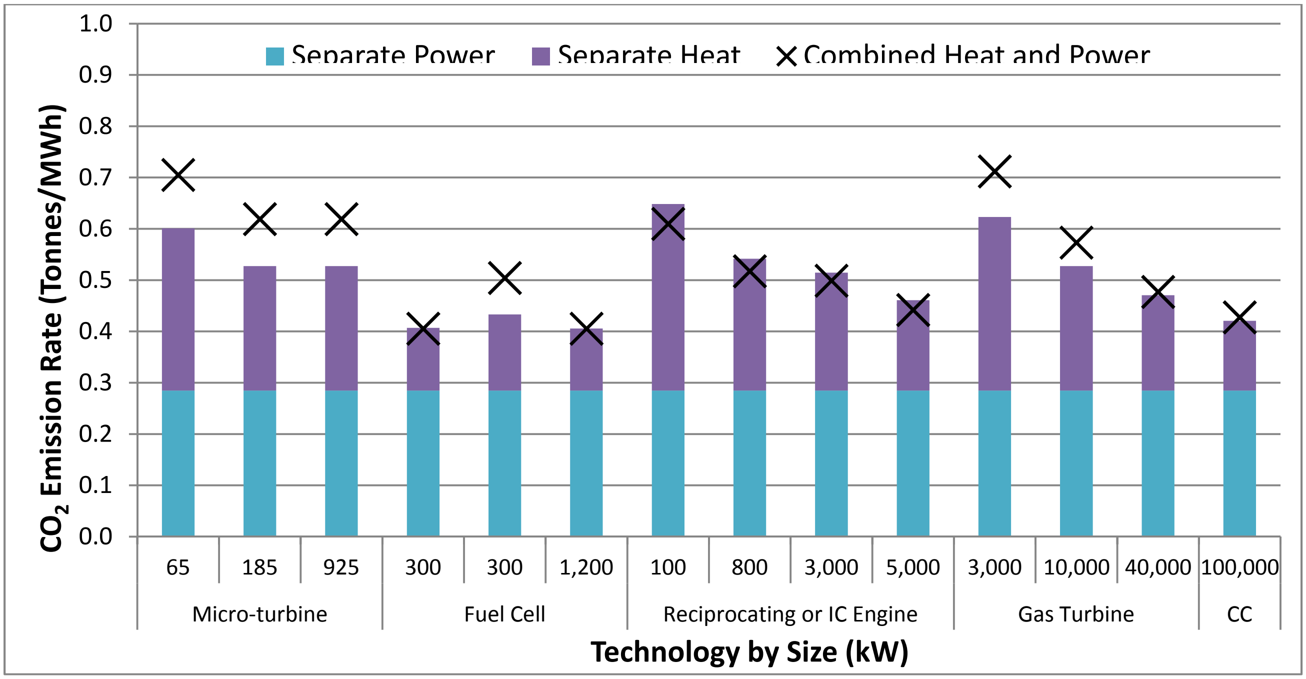


Figure 10 shows the effect of explicitly accounting for the California RPS and reduced T&D losses for behind-the-meter CHP systems by discounting the grid emissions factor. Figure 10 is the same as Figure 9 except that the CA 2020 emissions are discounted to account for California's RPS (33% renewables by 2020) and increased to account for T&D losses (6.9%). This assumes that behind-the-meter CHP will avoid T&D losses but will be penalized for not being part of the RPS, which only applies to power sold by utilities. This adjustment has a large impact on the comparison of emission rates. All reciprocating engines are still net GHG-reducing, as are some fuel cells and large gas turbines, but many systems are now net GHG-emitting due to the lower implied grid emissions rate.

Figure 10 - CO_2 Emission Rate Comparison for Combined versus Separate Heat & Power 2020 CA Grid RPS and T&D with 90% Thermal Utilization and 80% Avoided Boiler Efficiency



There are several caveats to this analysis of the implications of the RPS on grid emissions.

- It only applies to behind-the-meter CHP systems that are not selling any power to the grid. As described above, the majority of CHP generation is from larger systems that do sell to the grid and do not meet this description.
- It is not clear that on-site generation will actually affect implementation of the RPS in a direct one-to-one proportion (i.e., for every MWh of electricity generated, there is one-third MWh of renewables discounted). Utilities will purchase (and are purchasing) renewable generation in advance and in large blocks that will not likely be fine-tuned to small changes in on-site generation. Thus the actual impact of on-site generation may be less than indicated by the RPS discount assumed in the Choudhary et al analysis. This may be a topic for additional analysis based on the actual implementation of the RPS.
- Finally, The CA 2020 analysis seems to assume that that gas combined cycle units are on the margin at all or most times (with a marginal heat rate of 7,537). However, it may be that less efficient peakers will be on the margin much of the time, especially when the RPS is implemented, in order to follow variable load from solar and wind resources. A recent study of different RPS scenarios[6] shows combustion turbines and gas steam plants being on-line during all hours of many typical days, which would suggest a higher marginal heat rate and emission rate.

Concluding Remarks

Several key assumptions used by the authors tend to devalue and underestimate the benefits of CHP. Under more typical assumptions for CHP system performance, most economically viable CHP systems will have lower emissions than SHP systems.

[6] "Investigating a Higher Renewables Portfolio Standard in California", Energy & Environmental Economics. January 2014

1. Most CHP systems will be sized to meet baseload thermal demand, thereby maximizing thermal utilization and CHP system economics while minimizing CO_2 emissions. For an optimally sized CHP system, a thermal utilization of above 80% is a reasonable assumption. A sub-optimally sized system with reduced thermal utilization will be less efficient and result in lower GHG reductions, but would also be less likely to be built because of less favorable economics.
2. An overly optimistic separate boiler efficiency assumption contributes to lower estimated GHG emissions for SHP when compared against a CHP system. Average separate boiler efficiency is typically between 75% - 80%. Assuming a boiler efficiency of 85% unrealistically devalues CHP system benefits.
3. If heat rate degradation is taken into account, it should be applied consistently for both separate heat and power units and not just for CHP, as each of these units will undergo some heat rate degradation.
4. The separate power emission rate, determined primarily by the marginal avoided grid efficiency, significantly affects the GHG emission rate comparison. The California marginal heat rate should be reviewed to ensure that it includes peaking units that will be needed on a daily basis to support fluctuating generation from renewable sources.
5. The treatment of the RPS heat rate adjustment should be reviewed to see if it is consistent with the way that renewable electricity will actually be purchased and supplied by utilities. In addition, the RPS adjustment only applies to behind-the-meter CHP systems that are not selling any power to the grid, whereas the majority of generation is from larger generators that do sell to the grid and do not meet this description.
6. The majority of existing California CHP is large combustion turbine and combined cycle systems that sell power to the grid. With typical boiler efficiency and thermal utilization values, these systems will be net GHG reducing compared to the 2020 California marginal grid emissions.