Exploring CHP systems as a Conservation Measure in the context of Greenhouse Gas Emissions Policy

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ABSTRACT

The benefits of combined heat and power (CHP) systems to simultaneously provide heat and electricity have long been known in many jurisdictions. Depending on the greenhouse gas (GHG) emission intensity (EI) of the local electricity grid, CHP systems can either increase or decrease GHG emissions. As the world refocuses on GHG reduction policies, it is important to understand the environmental impacts of CHP projects and how their benefits can still be considered in low grid GHG EI locations as part of conservation programs.

In Ontario, a cap and trade system commenced in January 2017, where CHP projects are incented as a conservation measure and have gained popularity with many industrial facilities to improve their energy efficiency and energy security. Therefore, there will be a need for either altering the engineering design of CHP projects to reduce their stack emissions, or for a change in the conservation program design to mitigate the impacts of the emissions while maintaining viable project economics.

This paper provides an overview of technical and non-technical options to be considered for an energy conservation program for CHP projects. The advantage and disadvantages of each option are discussed from the perspective of the facilities where a CHP system is installed, and also that of the program designers. Additionally, a case study is used to demonstrate the potential cost impacts of implementing each of the proposed options in order to maintain the cost effectiveness of the CHP projects.

Introduction

Combined Heat and Power (CHP) systems have become a popular electricity conservation measure given their considerable electricity generation potential and cost benefits (C2ES 2011, EPA 2016, DOE 2016). CHP systems also increase the reliability of the power systems within the facility by reducing the reliance on the electricity grid, with the grid serving as a back-up source of power. In addition, several jurisdictions have designed policy and frameworks to support the implementation of CHP systems, which highlights the known benefits of these systems in terms of energy efficiency, cost benefits, reliability, and the environment (EPA Combined Heat and Power Partnership; ACEEE 2016; Kelly 2015). In Ontario, CHP systems can gain financial incentives through provincial incentive programs, such as the Save on Energy^{OM} (SOE) program (Dicion, Branker and Hosseini 2017). The SOE program typically provides incentives of the lower of 40% of the capital costs, or $200/MWh[1] of the net electricity generated. Other benefits of CHP systems to the region, where an incentive program is offered, include deferred or avoided investments in generation, transmission and distribution infrastructure to support the facility; improved local and regional air quality by shifting towards natural gas (a cleaner fuel compared to coal); increased employment opportunities via CHP

[1] All costs in Canadian Dollars unless otherwise specified.

market potential; and enhanced economics due to energy security, price certainty and competitiveness.

Conventionally, electricity and heat requirements of a facility are met with separate heat and power (SHP) systems. For example, electricity is drawn from the grid and heating may be provided by natural gas (NG) fired boilers. CHP systems typically combust a fuel source to generate both electricity and thermal energy (heating and/or cooling) simultaneously. As such, CHP systems are more energy efficient than SHP systems, and they are the 'best use of fossil fuel energy to create both electricity and thermal energy' (Lazlo 2014). Figure 1 provides a typical comparison of SHP and CHP systems.

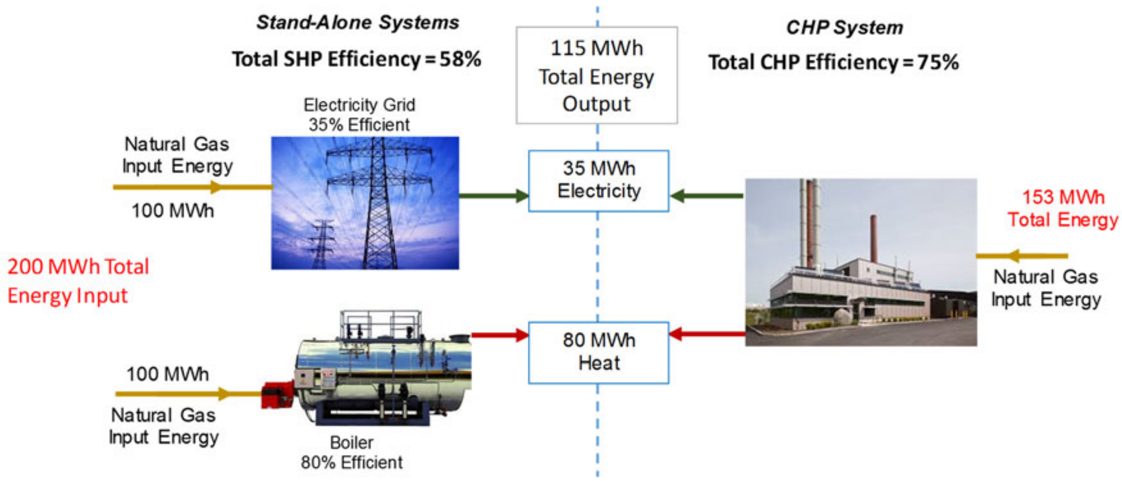

Figure 1. Comparison between CHP and stand-alone electricity and heat generation systems.

However, CHP systems can increase the facility's fuel consumption due to the on-site electricity generation. If the difference between the market price of natural gas and electricity (spark spread) is favorable, the overall utility costs are improved. The electrical load of facilities is generally supplied by central power plants, and installation of CHP systems transfers the burden of the required fuel for power generation onto the facility. On the other hand, the heat recovered by the CHP system reduces the facility's reliance on its existing thermal systems, which results in reduced fuel consumption for the heating/cooling systems. Hence, there is a tradeoff between the facility's increased CHP system fuel use, its reduced thermal system fuel use, and the reduced need for fuel for centralized power plants in the grid (Figure 2).

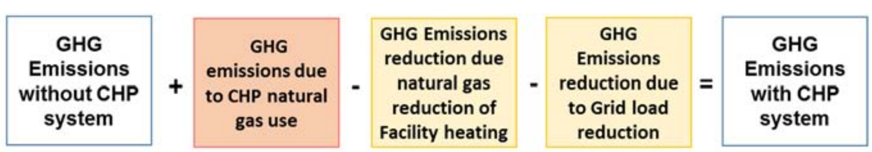

Figure 2: Balance of regional GHG emissions due to CHP systems

Greenhouse Gas Emissions and CHP systems

To mitigate anthropogenic impacts on climate change, there has been a refocus on GHG emissions policy following COP21 in Paris[2]. GHG emission policies seek to reduce GHG

[2] http://www.cop21paris.org/about/cop21

emissions through various policy tools such as a cap and trade system, carbon tax, and ambitious net-zero carbon targets (Forge and Williams 2008).

Installing CHP systems impacts regional GHG emissions. The extent of this impact depends on the GHG EI of the electricity supply mix[3]. For example, the electricity supply mix in Ontario is relatively clean due to the low proportion of fossil fuel-based generation. In 2015, Ontario generated only 10% of its electricity supply by burning NG. This is lower than neighboring states, such as New York where it is 56% of the supply mix (OME 2013; EIA 2013a, b; OME 2015). The low contribution of NG power plants in Ontario's supply mix creates a relatively low carbon footprint for the electricity grid, with an average GHG EI of 40 tCO_2e/GWh[4] (OME 2015). In addition, Ontario phased out coal-fired generation in 2014 (OME 2015). In regions where the grid GHG EI is low, installing CHP systems increases the regional GHG emissions, whereas, in coal-dominant electricity markets, CHP systems that run on NG reduce the regional emissions significantly.

Using the example systems in Figure 1 and the GHG balance in Figure 2, Table 1 illustrates the impact of various grid GHG EI. For the purpose of this paper, a low carbon emission grid has an average GHG EI below 400 tCO_2e/GWh, where NG fired power plants have a GHG EI of 400 to 500 tCO_2e/GWh.

Table 1: Example comparison of GHG emissions from CHP systems versus SHP systems

Electricity and Heat Generation System for 35 MWh electricity and 85 MWh of heat	System GHGs for Heat Production, tCO_2e/y	System GHGs for Electricity Production, tCO_2e/y	System GHGs for 115 MWh of Energy, tCO_2e/y
CHP System	-	-	27.5
Ontario SHP: Grid and boilers	18	1.4	19.4
Alberta SHP: Grid and boilers	18	21.0	39.0
Michigan SHP: Grid and boilers	18	20.6	38.6
New York SHP: Grid and boilers	18	7.7	25.7

Boiler efficiency assumed as 80%. GHG EI derived using 2013 data from the EIA for the USA and energy ministries for Canada. System GHG emissions calculated based on average grid EI. Average Grid GHG EI of Ontario, Alberta, Michigan and New York are 40, 600, 589 and 220 tCO_2e/GWh respectively. The estimated CHP system GHG EI can range from 200 to 350 tCO_2e/GWh depending on the design and does not account for thermal output utilized. *Source:* OME 2013, EIA 2013a, b, AE, 2015.

This analysis simply uses the average grid GHG EI, which does not necessarily capture the actual generators that are displaced by the CHP system. This has been recognized by the EPA, where their calculation guideline includes emission factors for displacing fossil fuel and non-baseload generators using the eGrid database in different regions and states of the USA (EPA 2014, EPA CHPP 2015, Kelly 2015). Similarly, methodologies are being developed in Canada for the GHG intensity factors for the marginal electricity generation for each province (Farhat and Ugursal 2010; OME 2016). It should be noted that an electricity generation based GHG EI factor for CHP systems does not directly take into account the emissions per total energy unit produced. The proper accounting of CHP systems has been mentioned before by Kleinhenz, Seryak and Sever 2015. It is critical to ensure the appropriate method is used when

[3] Ontario electricity generation map: http://www.ieso.ca/localContent/ontarioenergymap/index.html
[4] tonnes per CO_2 equivalent per gigawatt hour

calculating the GHG emission reductions or increases as a result of CHP systems when informing policy and regulations.

Mitigation Options in a Low Carbon Electricity Grid

Once the method for defining the impact of CHP systems has been outlined, and there are GHG emission impacts to be mitigated, several policy and program options can be considered. This paper initiates the thinking on several potential technical and non-technical options, with a focus on the areas that have a more practical potential for implementation by a program designer. The context is for an incentive-based program that supports CHP systems as an energy conservation measure. The options are grouped into 4 policy and 5 program options.

Policy Options

These options are less program based and requires the program designer engaging with government bodies for acceptance of a given policy approach.

Policy Option 1: Business as usual. This option suggests allowing the prevailing carbon regulation policy (e.g. cap and trade) to regulate the GHG emissions from CHP systems. Where CHP systems cause an increase in GHG emissions, these emissions would be paid for, ideally, in the market. The revenue generated via this approach would then be invested in technologies to that reduce GHG emissions in higher impact sectors such as transportation.

Advantages include no change to the existing program that supports CHP systems, and less economical CHP systems with lower efficiency would likely not be implemented.

Challenges include conflicts between energy conservation programs and prevailing environmental policies, misunderstanding on who bears the burden of the carbon costs (the facility or the energy conservation program designer), and potential lack of impact on lowering GHG emissions, if the carbon regulation is not well designed.

Policy Option 2: Exemptions for CHP program participants. Depending on the carbon regulation policy, some facility types or technologies may receive free allowances or exemptions. If the benefits can be quantified for CHP systems that are appropriately designed for the specific jurisdiction, they could be made exempt. Advantages and disadvantages are the same as Policy Option 1. However, the challenge will be in specifying if all or some CHP systems can be exempt depending on the jurisdiction.

Policy Option 3: Conservation and/or Feed-in-Tariff (FIT) portfolio approach. Energy conservation is one of the most cost effective measures for GHG emission abatement (McKinsey 2009). The principle for this option is that GHG emissions are defined in a provincial/state (and ultimately global) context. The reduced GHG emissions from energy efficiency and renewable projects (non-CHP projects) can offset any increased GHG emissions from CHP systems. The portfolio option will need to recognize GHG reductions beyond electricity consumption to include other fossil fuel (e.g. NG) savings. While individual projects may not be affected, it is necessary to actively manage the balance of the portfolio of projects.

The main advantage of this approach is managing GHG emissions at the correct geographical scale as opposed to penalizing individual facilities. If the program designer manages both the non-CHP and CHP projects, they would be able to effectively manage a balance to the portfolio, including reductions over time. Program rules may not to need to be redesigned, but targets would be set for the technologies within the overall energy portfolio. This could represent a more effective management of program funding.

Some challenges in implementing this option include quantification and verification of GHG emissions/reductions of all non-CHP and CHP projects to the required level of assurance. It could be costly to quantify smaller project types, such as lighting retrofits. Beyond quantification, transparency and timeliness would be needed between quantification of GHG emissions in the portfolio and approvals for CHP projects. A disadvantage can be the perception that the program designer still provides an incentive with rate payer revenue to GHG emitting technologies.

Policy Option 4: No incentives for CHP Projects that increase overall GHG emissions. The principle for this option is that incentive programs should not support projects that lead to an overall increase in GHG emissions in a jurisdiction with a carbon regulation policy. This should be mandated within the GHG policy and would be adopted by the energy conservation program designer. This policy should be balanced with any other fossil fuel-based generation, such as for centralized power plants, that receives incentives (subsidies) to avoid any perceived bias. This option is the most extreme and must be carefully weighed against the benefits of the CHP systems.

A main disadvantage is that some jurisdictions are highly reliant on CHP systems to offset investments in transmission/ distribution and generation systems upgrades, and to assist meeting future electricity demand growth. In addition, industries rely on these systems for increased reliability and market competitiveness. Therefore, a transition plan should be introduced if this policy option is implemented and the transition strategy should include:

- Refocus on non-CHP energy efficiency measures
- Support of waste energy recovery generation measures
- Use a biofuel blend until a full conversion to all biofuel-fired CHP projects is possible
- Allow CHP projects/ portfolios that can reduce the overall GHG emissions.

An advantage is that this approach may be simple to implement; however, it can only be practical if an alternative technology or solution is available. Some potential costs are investments in program restructuring and infrastructure investments that were previously avoided, and providing greater incentives for preferred technologies.

Energy Conservation Program Options

These program options include technical and non-technical aspects that can be implemented by the energy conservation program designer.

Program Option 1: Prescription of mandatory CHP operating criteria. This option requires the operation of CHP projects to align with the use of high-carbon fuel sources in the electricity system. Therefore, a CHP system will only operate to displace generation by power plants that use high carbon fuel sources (e.g. NG and coal). Based on the fuel diversity of the generation supply mix, the GHG EI of the electrical grid can change at any given time depending on the dispatch of generation stations by type. For example, in Ontario, the GHG EI is higher in summer compared to the winter, due to the increased share of NG-fired power plants of the supply mix (OME 2016). Therefore, even for clean electricity grids, there are times that NG (or coal) –fired power plants are on the margin, simply to meet the demand for electricity. A comprehensive model is required to predict the hourly GHG emissions of the grid based on the historical trends for electricity demand and the generation supply mix. Ontario has been considering the concept of an hourly GHG EI profile, which will help with making this option practical (OME 2016).

A benefit of this approach is that the CHP systems' configurations may not need to be changed. However, their operating criteria would allow operation during hours where the predicted grid GHG EI will be higher. However, this approach will likely limit the electricity generation potential of CHP systems. Also, it may be complex to administer and track the grid's GHG EI by time and location, which will make it difficult to provide an adequate incentive to promote CHP installation. The reduced operating hours of the CHP projects also jeopardizes the overall project economics. Therefore, additional incentives may be required.

Program Option 2: Increasing CHP System Efficiency. GHG EI decreases with increased efficiency, as less fuel is required per unit of generated electricity. Figure 3 provides an illustration of this trend. There is a limit to the maximum, achievable total system efficiency (TSE). Most CHP systems have an efficiency of 60% to 87% (HHV[5]) depending on the technology and capacity. Increasing this number could reduce the GHG EI of CHP systems.

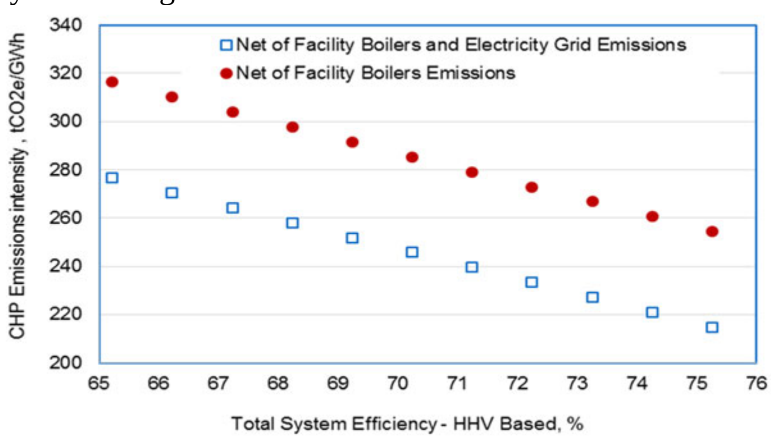

Figure 3. Effects of TSE on CHP systems incremental GHG EI, Electricity Grid of Ontario assumed

Increasing the TSE by increasing heat recovery has significant impacts on reducing the GHG EI. Assuming an electrical efficiency of 36% (HHV), and a boiler efficiency of 80%, the GHG emissions from a CHP system will be reduced by 22%, when heat recovery is increased to achieve a TSE of 75%, as shown in Figure 3. At 65% TSE, the facility's GHG EI is 316 tCO_2e/GWh. If the TSE increases to 75% (due to better design of the system, increased heat utilization, etc.), the average incremental GHG EI will be as low as 254 tCO_2/GWh.

The GHG EI of 316 tCO_2e/GWh only accounts for the GHG emissions of the CHP system less the avoided GHG emissions from the facility's existing boilers due to the heat recovered from the CHP system. It is important to highlight that the electricity generated by the CHP system reduces the electrical load on the grid. Therefore, CHP systems displace GHG emissions from the electricity grid as well. Accounting for the displaced GHG emissions from

[5] HHV is Higher heating value basis, otherwise called gross calorific value

the electricity grid (looking at the CHP system from a regional perspective and not just from the facility's point of view), the GHG EI of these systems would be lower depending on the location.

Where the facility's thermal load is significantly higher than the CHP system's available heat, and the existing boilers are inefficient, installation of heat recovery steam generators (HRSGs) with duct burners will lead to overall NG savings, rather than increased NG consumption. Therefore, the CHP system (equipped with duct burners) will be carbon neutral as is illustrated in Figure 4 for a boiler efficiency of 70% and a facility thermal load to CHP thermal output ratio of approximately 5:1. Additionally, Figure 4 shows that for facilities with large thermal demands (compared to the CHP system's available heat), the use of a duct burner will significantly reduce the overall GHG emissions.

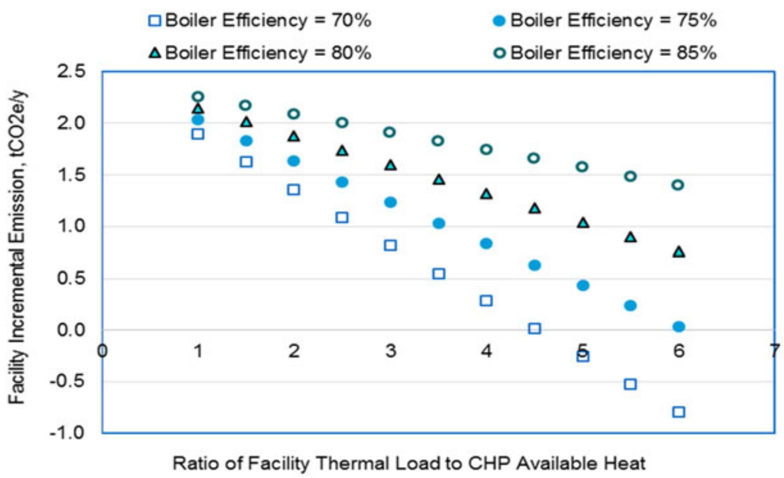

Figure 4. Facility incremental GHG emissions vs. thermal load, with various boiler efficiencies

This option would be difficult for existing systems to adopt. In addition, for a program that increases the TSE requirements, there would likely be a reduction in the uptake of CHP systems due to fewer applicable sites. From the perspective of a conservation program, other methods of reducing electricity would need to be encouraged.

Program Option 3: Change CHP fuel requirement to consider biofuels. Many engine and gas turbine manufacturers provide technology compatible to run on both NG and a variety of biofuels. However, use of biofuels in CHP systems is limited by availability, quantity, and quality of the fuel source. The unit cost of fluid biofuels may vary between $3 and $12 per gigajoule (GJ) for a range of 35% to 95% methane content.

Capital costs are not an issue when designing a new CHP system, since dual fuel and NG engines have comparable costs. However, if biofuel is produced on-site (e.g. as a by-product of the facility), gas cleaning and pre-treatment will impose additional capital costs (20-25% increase in the capital costs for internal combustion engines). Purchased biogas usually does not require installation of such equipment as the biogas is treated at the source. For example, landfill gas is pretreated for the removal of SOx and moisture before being sold to customers.

Since the heating value of biogas is lower compared to NG, and higher volumes of biogas is required by the engine/turbine, there may be physical restrictions when retrofitting existing CHP projects. The percentage of incremental GHG emissions; and therefore the amount of biofuel required in the blend with NG to make the system carbon neutral, depends on the project specifics, such as displaced NG GHG emissions and the TSE. This is illustrated in Figure 5, assuming the grid GHG IE for Ontario. The facility heating system (e.g. boilers) efficiency and TSE of the CHP system affect the displaced NG emissions of the existing system and therefore, GHGs to be offset (See Figure 2 equation for the balance of emissions from a CHP system).

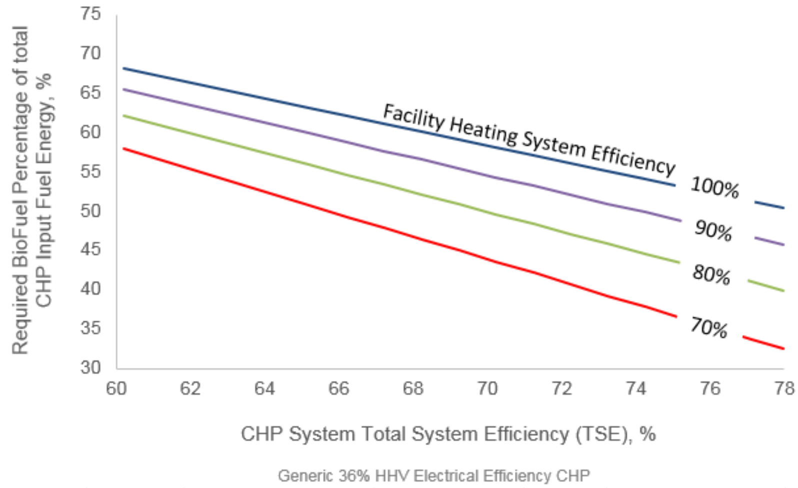

Figure 5: Impact of CHP system and Facility heating system efficiency on the share of biofuel needed for a carbon neutral system with average grid emissions of Ontario.

The concept has been seen in other jurisdictions. For example, in California, beginning in 2017, NG technologies must be fueled by a mixture of at least 10% biogas to retain program eligibility. This requirement becomes more stringent each year, up to 100% biogas in 2020 (self-generation incentive program). In Manitoba, only CHP projects fuelled with a biofuel as a primary fuel are allowed in their conservation program.

The advantage of this option is that it allows a transition in the technology by simply changing the fuel. However, the challenges include higher fuel costs, limited fuel supply, controversy around carbon neutrality of biofuels, and high capital and operating costs. A program designer could offer an incentive for alternative fuels to offset the difference between the price of biogas and the price of NG. However, this would be administratively burdensome as the incentive adjustment could fluctuate.

Program Option 4: Require carbon capture and storage (CCS) or carbon re-use technologies. Carbon capture is achievable through a variety of technologies including pre-combustion, post-combustion, and oxy-fuel combustion systems. These "capture" systems are expensive and cost \$50 to \$70 per tonne CO_2 captured for post-combustion systems, \$20 to \$50 for pre-combustion systems, and \$13 to \$80/tCO_2 for oxy-fuel combustion systems (CETC 2016). The captured carbon needs to be stored, which in most cases will be offsite. In addition, they are not economically applicable to smaller CHP systems that are typically encouraged by conservation programs.

Another option is to capture CO_2 using a chemical process on-site or transfer to a nearby facility for use. Greenhouses are a good candidate, where the captured CO_2 can be fed into the growing areas. Greenhouse facilities can treat the CHP system's exhaust gases and use the CO_2 to promote plant growth. The ambient air concentration of CO_2 is approximately 350 ppm, while the optimum CO_2 requirement for optimal growth of plants is over 700 ppm and up to 1,000 ppm to 1,300 ppm (Mikunda et al. 2015). There are several successfully implemented projects across

Ontario, Canada, and globally, that proves the technical and economic feasibility of using the CHP system's exhaust gas as a source of CO_2 for crop production[6].

If CCS technology were economically and technologically feasible for smaller CHP systems, they would be a desired solution. However, other solutions like using the exhaust gas heat and CO_2 as in a greenhouse would be more applicable. The advantage is that the CHP system additional costs would not be much greater than the current systems in place.

Unfortunately, a disadvantage to the approach is limited applicability to only compatible host sites. In addition, all incremental CO_2 emissions may not be removed by the process. A change in encouraging the occurrence of greenhouses paired with other facilities may be required.

Program Option 5: Facilitating carbon offset activity. This option includes undertaking offset actions directly or the purchasing of carbon offsets. The participant or the program designer undertakes specific carbon offset projects[7] meant to balance the incremental GHG emissions of the CHP projects. Beyond the non-CHP projects in the conservation program, this option also includes projects such as tree planting, replacing inefficient boilers, and waste energy and water recovery projects. The cost of this option varies for different projects. In addition, the GHG emissions offsets from the project should be quantified and verified to be accepted, which bears additional costs. The program rules may need to consider the costs of these GHG emissions-offsetting projects against the benefits of the electricity savings of the CHP projects, which may lower their cost effectiveness.

In the latter, offsets are purchased from the market, either locally or internationally. There are resources and markets for these offsets, including an indication of their quality and permanence (Pembina Institute 2009). Depending on the specific GHG policy, there may be a limit to the offsets that are allowed to be purchased. In Ontario, GHG market participants may only be able to use offsets to cover up to 8% of their GHG emissions (MOECC 2016).

Of the two, the direct purchasing of offsets would likely be easier to implement and administer, and the specific CHP system would be unchanged.

One challenge with the option is ensuring GHG reductions are local. Another is understanding who will need to pay for the offsets. Finally, the cost effectiveness of a program providing funding for offsets would come into question.

Cost Effectiveness Case Study

A case study was done to gain a relative indication of cost impact between the options, from the perspective of the conservation program. For each option, the incentive amount ($/MWh) was changed in order to maintain the project's simple payback of 5 years (inclusive of the incentive amount). The results are shown in Figure 6.

The analysis provides an indication of the most cost effective options. While increasing the TSE may be cost effective in some cases, it will not eliminate the incremental GHG emissions. For low prices of carbon (e.g. $18/tCO_2e$), the impacts of the costs of GHG emissions on the simple payback of the CHP project is negligible; therefore, simply paying for the carbon costs will avoid the need to change the energy conservation program rules or any alteration to

[6] Quad-generation project in Village Farms' greenhouse in Delta, British Columbia; Kingsville 55-acre greenhouse tomato operation in Kingsville, Ontario.

[7] Referred to as "directed actions" per ISO 14064 with regard to emissions reduction projects within the facility.

the installed (or to be installed) CHP projects. Purchasing pre-treated biogas (to an amount equivalent to the incremental GHG emissions of the CHP system) is also cost effective, while using renewable NG and implantation of CCS technologies are more expensive. A combined option is TSE improvement with purchasing biogas to offset the incremental GHG emissions. Improving the TSE (through duct-burners, and use of condensing heat recovery systems) reduces the incremental GHG emissions from the CHP system that needs to be reduced to make the CHP system carbon neutral (for example through implementing energy efficiency projects in the facility). Therefore, the following options provide better resolutions to mitigating the impacts of the incremental GHG emissions from CHP projects:

- Purchasing and mixing biogas with the CHP system's NG feed to offset the incremental GHG emissions without the need for pre-treatment
- A combined option of increasing efficiency and purchasing biogas
- Use of duct burner for facilities with large thermal loads or targeting facilities with larger thermal loads,
- Use on sites that can use the CO_2 from the CHP system, and,
- Paying for the carbon cost where the cap and trade system would result in investments in GHG emissions reductions elsewhere in the economy.

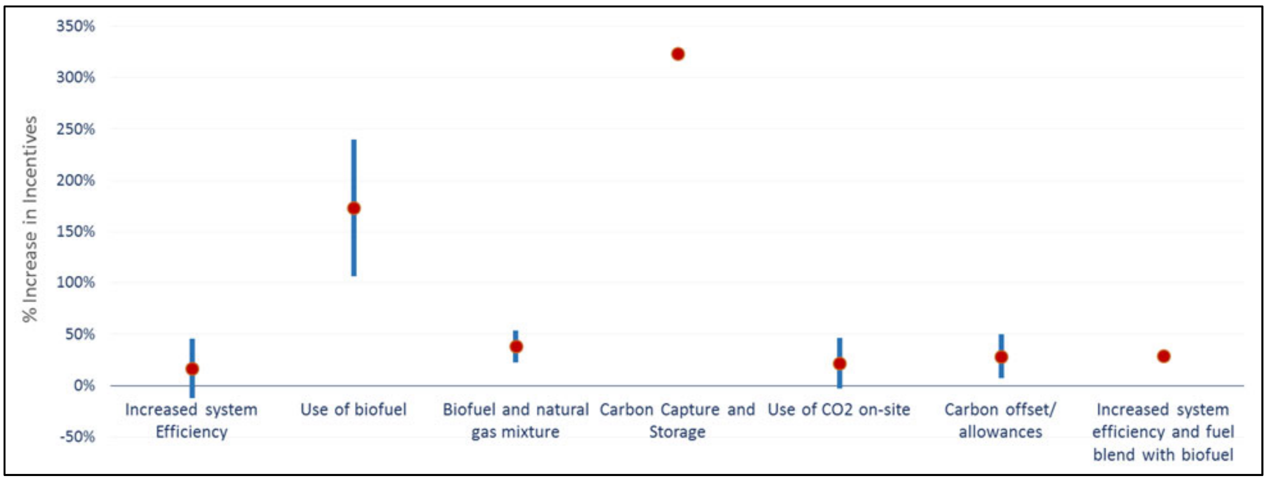

Figure 6: Required changes in the Project Incentive to avoid economic impacts for each quantifiable option

Conclusions and Next Steps

This paper provides an overview of options for would-be CHP program designers to consider, particularly in low-carbon intensity electric grids. The recommended course of action to establish a framework for GHG reporting in a CHP program is as follows:

1. Develop a clear evaluation framework for how GHG emissions are calculated, whether based on the average GHG EI of the supply mix, the GHG EI of the marginal supply resource, or evaluating the GHG EI for how the CHP system performs when compared to the hourly operation of the electricity grid.
2. Evaluate the GHG emissions of all projects calculated as part of the incentive application, using the agreed evaluation framework.
3. Include GHG emissions and other Non-Energy Benefits (e.g. electricity grid security) in cost effectiveness calculations used by program designers.

Once the above is completed, further investigation on specific options for the program can then proceed. As efforts continue to reduce the emissions impact of electricity and thermal energy production, CHP systems will continue to play a role as a transition technology. As other technologies evolve, there will be continued research into alternative CHP systems that are not fueled by natural gas. To this end, program designers will need to assess the provision of alternative financial incentives to encourage their adoption and support market transformation.

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