Cogeneration Facilities in Canada
2014

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Summary

CIEEDAC has been gathering data for and reporting on cogeneration facilities in Canada since 1999. While initially relying on secondary data sources such as Statistics Canada, corporate websites and electric utilities, CIEEDAC now uses an electronic survey to gather primary data directly from system operators. As a result, the number of facilities and detail of data has steadily improved each year.

Last year, with support from Natural Resources Canada, CIEEDAC harmonized the cogeneration database with the other relevant databases maintained by CIEEDAC – the district energy and renewable energy databases – so that each facility is cross-referenced across all three databases. For example, a cogeneration unit fuelled with wood waste that services a district energy system now exists in all three databases.

This report presents the results of the most recent update to the cogeneration database, providing an overview of the state of cogeneration in Canada. Data presented here are stored in CIEEDAC’s cogeneration database, publicly available online at www.cieedac.sfu.ca.

Our analysis of the current database shows that:

**Canadian cogeneration capacity is growing.** The installed cogeneration capacity is now roughly 9.3 GWₑ at 216 facilities. Installed electrical capacity has increased by 12% in the last five years and has almost tripled since the late 1990s. Thermal capacity has also been growing, but the data for this metric is much less available or reliable than for electrical capacity. While this capacity is lower than previously reported by CIEEDAC, the change is due largely to the removal of several facilities that were either decommissioned, are no longer operational or were duplicates of already captured facilities.

**The utilities and oil and gas sectors make the greatest use of cogeneration, with gas turbines as the leading cogeneration technology.** The utilities sector boasts the largest cogeneration capacity at 4.4 GWₑ and the oil and gas extraction sector the second largest at 1.9 GWₑ. Note that the utilities sector serves a variety of thermal hosts in many industries as well as several district energy systems. Gas turbines account for 59% of all electricity generation capacity from cogeneration in Canada with steam turbines of various sorts the second largest category at 37%.

**Cogeneration systems see relatively high utilization, but data indicates a broad range for total system energy efficiency.** Based on a production weighted average of the available data, each kWₑ of installed electrical capacity generated 6,900 kWh/yr. This indicates roughly 78% capacity utilization. The average efficiency of the systems documented in the database was 67%, with typical system efficiencies ranging between 62%-82%. Unfortunately, only 30% of the facilities listed in the database have sufficient data to calculate energy efficiency. Therefore, the average efficiency of the sample may not be representative of all cogeneration in Canada.
We can use the database to estimate the total CO$_2$ emission and energy production from all cogeneration facilities in Canada, but the estimate is very uncertain. We used the data provided in the database to inform assumptions for fuel type, heat to power ratios, energy efficiency and capacity utilization for all cogeneration facilities in Canada. With this methodology, we estimate that CO$_2$ emissions from cogeneration facilities at 43.5 Mt, or 6%-7% of total Canadian GHG emissions. We estimate that cogeneration facilities produce roughly 68 TWh of electricity each year (11% of national electricity generation). Similarly, thermal energy production is 171 TWh/yr. These estimates should be used with caution: roughly half of each value is estimated from facilities with one or more unknown parameter (e.g., for many facilities, we estimate emissions and energy production when only the sector and electrical capacity is known, with the energy efficiency, capacity utilization and heat to power ratio based on sector and cogeneration technology averages).

It is very likely that cogeneration has reduced energy consumption and greenhouse gas emissions in Canada. We cannot make a reliable estimate of this reduction since we do not know how heat and electricity would have been produced without cogeneration. However, this conclusion remains true under a range of assumptions for the counterfactual energy efficiency of standalone heat and power generation.
Acknowledgments

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Cogeneration Facilities in Canada, 2015

1 Introduction

Cogeneration, also referred to as combined heat and power (CHP), is the simultaneous production of electrical and thermal energy from a single fuel. By making use of the waste from one process in the production of the other, substantial gains in energy efficiency can be realized compared to the independent production of both products. The efficiency of cogeneration in converting primary energy into electrical and thermal energy places the technology at the forefront of many CO$_2$ emission reduction strategies. National and international commitments to reducing CO$_2$ emissions have increased interest in cogeneration.

Cogeneration has been widely adopted in many European countries for use in industrial, commercial and residential applications. Today, nearly 12% of Europe’s electricity needs are met by cogeneration. In Denmark and Latvia, for example, cogeneration accounts for over 48% of national electricity generation (Cogen Europe, 2015) while in Canada cogeneration represents an estimated 11% of national electricity generation. This lower penetration rate may be attributable to lower energy prices and electric utility policies on the provision of back-up power and the sale of surplus electricity. Despite these barriers, cogeneration is common in some sectors (pulp and paper and oil and gas extraction sectors) and electricity market restructuring in Alberta and Ontario is fueling a dramatic rise in utility-scale cogeneration facilities.

CIEEDAC’s cogeneration database aims to provide a comprehensive list of cogeneration projects in Canada and present data on the performance of cogeneration systems. To date, no other comprehensive list of Canadian cogeneration projects has been identified. This task is becoming increasingly challenging as cogeneration capacity expands rapidly with changes in regulation in different parts of Canada.

Each year, CIEEDAC takes steps to refine and expand existing data in our database and report. Last year, the cogeneration database was harmonized with the district energy and renewable energy databases so that each facility is cross-referenced across all three databases. This step streamlined database maintenance, provides a clearer overview of Canada’s energy network, and ensures that new facilities are being properly categorized. This year, CIEEDAC focused on filtering through existing facilities and pinpointing areas where data are insufficient or potentially incorrect. Specific facilities were targeted for survey updates and clarification. This step refined the existing dataset by removing several facilities that are no longer operational or have been decommissioned, identifying and removing duplicate facility entries, and shoring up areas where data were weak.

This report contains the following sections:
Section 2: Descriptions of the types of cogeneration systems in use in Canada;
Section 3: Quality of cogeneration in Canada;
Section 4: Methodology used to identify cogeneration projects in Canada;
Section 5: A summary of cogeneration facilities in Canada by region and sector, system average performance characteristics and a timeline of cogeneration installations; and
Section 6: Brief conclusions.

1.1 CIEEDAC
The Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC) focuses on energy information relevant to Canada’s industrial sector. One of CIEEDAC’s primary goals is to expand and improve existing knowledge on energy use by establishing processes for the regular and timely collection of reliable data including data on cogeneration.
CIEEDAC provides a range of services to industry and government, one of which is the preparation of annual reports that present the latest data on energy use and related issues for the Canadian industrial sector. These annual reports include:
- Canada-wide historical trends in energy use and CO₂ emissions from 1990 onward;
- Industry- and region-specific reports, such as this one, to provide greater detail on energy use and greenhouse gas emissions in industry in Canada;
- annual updates of databases describing district energy, cogeneration and renewable energy facilities in Canada; and
- an annual review of data sources on energy use in industry.
CIEEDAC also provides specific analyses based on information from its databases at the request of interested parties.

1.2 Cogeneration and CHP Associations
COGENCanada is a federally incorporated, not-for-profit association promoting cogeneration and sustainable industrial development. Its objective is to promote research and development of technologies such as biomass fuel drying, gasification, and condensing heat recovery.
Currently, no associations exist in Canada that lobby or advocate for advancement or enhancement of CHP or cogeneration in the political or business sphere. Such associations do exist in Europe (Combined Heat and Power Association, UK; COGEN Europe) and the US (EPA Combined Heat and Power Partnership, US Combined Heat and Power Association, Midwest Cogeneration Association).
2 Cogeneration Systems

Cogeneration is defined as the simultaneous generation of both electricity (which includes direct drive power from steam turbines) and useful thermal energy for either heating or cooling applications. Heating applications include generation of steam or hot water while cooling applications require the use of absorption chillers that convert heat to cooling. A range of technologies can be used to achieve cogeneration, but the system must always include a power generator (either electric power or drive power) and a heat recovery system. The heat-to-power ratio, overall efficiency and the characteristics of the heat output are key attributes of cogeneration systems.

The heat-to-power ratio (H/P) is the ratio of the amount of useful thermal energy available to the amount of power generated usually expressed in terms of kW of heat (kW_h) per kW of power (kW_e). H/P ratios vary depending on the type of prime mover (drive system) and range from 0.2:1 to 20:1.

Overall system efficiency is the percent of fuel converted to electricity plus the percent of fuel converted to useful thermal energy. Typically, cogeneration systems where heat and power requirements are balanced have overall efficiencies of between 65% and 85%.

Heat output from cogeneration systems varies greatly depending on the system type. The output can range from high pressure, high temperature (500°C to 600°C) steam to warm water (80°C or below). High pressure, high temperature steam is considered high quality thermal output because it can meet most industrial process needs. Hot water is considered a low quality thermal output because it can only be used for a limited number of thermal applications.

Cogeneration systems are classified by the type of prime mover used to drive the electrical generator. The six main types currently in use are steam turbines, gas turbines, reciprocating engines, microturbines, combined cycle gas turbines and organic rankine cycles. New systems currently under development include fuel cells and Stirling engines.

2.1 Steam Turbine

Steam turbines are the most common cogeneration system used in industrial applications. They range in size from a 500 kW_e to 80 MW_e. The smaller sized systems may not be economical unless the fuel used has no alternative commercial value (e.g., hog fuel). Steam turbine cogeneration systems usually produce significantly more heat than electricity per unit of fuel consumed and therefore have high H/P ratios. The ratios, typically determined by the thermal needs of the site, can range from 1:1 to 10:1. The lower the quality of heat required (i.e., lower temperatures or pressures), the greater the amount of electricity generated per unit of fuel.

Steam turbine cogeneration systems generate steam in a high-pressure steam boiler. The steam expands through a turbine to produce mechanical energy. This mechanical
energy drives an electric generator. The output heat serves process applications such as drying wood, pulp or papermaking, etc.

Steam turbines come in two types, back-pressure turbines and condensing turbines. Back-pressure turbines exhaust steam at a pressure higher than atmosphere while condensing turbines exhaust steam at pressures lower than atmosphere (i.e., a vacuum) and therefore require a condenser. With either type, steam can be extracted part way through at a pressure required by the thermal user. Condensing turbines produce more electricity per unit of fuel than back-pressure turbines because more of the energy contained in the steam is extracted by the turbine making less available for thermal applications.

Steam turbines can consume almost any fuel including the waste products of industrial processes, a key advantage in some applications.

2.2 Gas Turbine (GT)

GTs act as the most common prime mover in large cogeneration systems built more recently. They range in electricity output from 250 kW to 200 MW. GT systems produce more electricity per unit of fuel than steam turbines and have an average heat-to-power ratio of 2:1. Supplemental heating through secondary firing of the exhaust gases can increase this ratio to 5:1. Steam injection, which raises the volumetric flow through the turbine, can boost electrical output by 15%.

GT systems produce high temperature, high pressure gases in a combustion chamber. These gases expand through a turbine producing mechanical energy that drives the generator. The gases exit the turbine at temperatures of between 450°C and 550°C and are used to meet the thermal requirements of the site. They can be used directly for drying, or indirectly to produce high, medium or low pressure steam or hot water.

2.3 Reciprocating Engine

Reciprocating engines are internal combustion engines that operate by the same principles as a car engine. Systems range in size from 20 kW to 6 MW. The H/P ratio ranges from 0.5:1 to 2.5:1. As with gas turbines, supplemental firing can be used to increase the thermal output.

It is harder to use the thermal output from reciprocating engines because it comes from two sources: the exhaust gas and the engine cooling system. The exhaust gases are of high heat (up to 400°C) but the cooling system provides only low-grade heat (below 90°C). Often the two heat sources cascade to produce hot water. These systems produce more electrical energy per unit of fuel (35% to 53%) than either steam or gas turbines.

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1 The mechanical energy can also be used to drive equipment in the plant. However, this type of system is not covered in this report
2.4 Combined Cycle Gas Turbine (CCGT)

CCGT cogeneration systems have a gas turbine connected in series with a steam turbine. The hot exhaust gases from the gas turbine produce steam for the steam turbine. Thermal energy remaining in the steam exhausted from the steam turbine goes to process applications. The main advantage of the CCGT is its high electrical energy efficiency compared to the other systems described above.

2.5 Microturbines

Some small industry and institutional cogeneration applications use microturbines. Microturbine cogeneration systems are small versions of gas turbine systems and range in size from 20 kW to 250 kW. Microturbine systems consist of packaged high-speed generator plants with the turbine, compressor and generator all on one shaft. Microturbine cogeneration systems add a heat recovery unit to the packaged microturbine. They typically contain power electronics to deliver electricity to the grid and can run on natural gas or other liquid fuels including landfill gas and flare gas from oil, natural gas and coal extraction. Microturbine cogeneration systems are becoming increasingly cost-effective in regions such as Alberta where electricity prices are high relative to the cost of natural gas.

Microturbines have become commercially available only recently, so successful microturbine installations are still relatively few and total market share is limited. Some analysts predict widespread adoption of microturbine systems because of their modularity, low cost, low emissions and load flexibility.

2.6 Waste Heat Recovery, Organic Rankine Cycles

Recently some facilities have installed technologies that capture waste heat from processes to generate electricity using an Organic Rankine Cycle engine. A Rankine Cycle is a closed circuit steam cycle and an "Organic" Rankine Cycle uses a heated chemical instead of steam, usually a refrigerant. Typically, the refrigerant boils at a temperature below the temperature of frozen water. The resulting high-pressure refrigerant vapor is then piped to the Organic Rankine Cycle engine that can be used to produce electricity and eventually expend any remaining heat to other processes (e.g., space heating, fermentation processes).

2.7 New Technologies

Fuel cells and Stirling engines are emerging technologies to supply cogeneration.

2.7.1 Fuel Cells

A fuel cell captures the chemical energy released by the electrochemical reaction between hydrogen and oxygen and converts it to electrical energy. Fuel cells use an electrolyte to combine hydrogen (the fuel) with oxygen from the air to produce hot water or steam, depending on the type of fuel cell, and an electrical current. Hydrogen
can be obtained directly from fossil fuels (natural gas or coal) or from renewable sources such as biomass or via electrolysis of water powered by renewable electricity.

Typical fuel cells produce only a small voltage (~1 volt). Combined in series (a “stack”), they produce enough power for distributed generation applications. The hot water or steam can be applied to thermal applications. Fuel cell systems for use in residential cogeneration applications could range from about 1 kW_e to 5 kW_e.\(^2\) They have high efficiencies even at small sizes and low load conditions, have no moving parts which reduces interruptions in service, generate no or low emissions (they use pure hydrogen or natural gas), are quiet and can be sited almost anywhere.

Fuels cells are classified according to the material used for the electrolyte. The five types currently under development are phosphoric acid fuel cells (PAFCs), molten carbonate fuel cells (MCFCs), solid oxide fuel cells (SOFCs), alkaline fuel cells (AFCs), and proton exchange membrane (also called polymer electrolyte membrane) fuel cells (PEMFCs). PEMFCs operate below 200°C, while all other fuel cells operate at higher temperatures. This has several important implications. First, because they operate at low temperatures, the exhaust heat temperature in PEMFCs is low, and can only be used where there is demand for low quality heat (e.g., hot water). Other types of fuel cells can provide higher quality thermal output. Second, operating at high temperature enables fuel cells to internally reform natural gas into hydrogen and carbon dioxide, meaning that an external reformer is not required. In contrast, PEMFCs require an external reformer if they are to use a hydrocarbon fuel. Third, the lower temperatures of PEMFCs mean that materials do not have to be as temperature resistant in this type of fuel cell compared to the others.

2.7.2 Stirling Engines

Stirling engines are *external combustion* engines in which a fuel is burned outside of the cylinder containing the engine’s working fluid. This allows the fuel to be burned continuously, rather than in a series of discrete firings as in the internal combustion engine. It also allows for fuel flexibility – any type of fuel that can be used in a conventional boiler can also be used in a Stirling engine. Finally, it enables good heat recovery – the thermal efficiency of a Stirling engine is close to that of an equivalently sized conventional boiler. The gasses used inside a Stirling engine never leave the engine, so there is no need for exhaust valves and the engine runs very quietly. Stirling engines have relatively high H/P ratios, which makes them suitable for the load requirements of the residential sector. Stirling engines are currently being developed for combined heat and power application in the residential housing market, primarily in Europe and Japan.

\(^2\) Fuel cell systems can be even smaller than 1 kW but these systems would not be used for cogeneration
2.8 Efficiencies, Heat-to-Power Ratios and Thermal Energy Quality

Table 1 summarizes the efficiencies, heat-to-power ratios and the quality of the thermal output for cogeneration systems according to system type. Data were not available for all system types.

<table>
<thead>
<tr>
<th>Cogeneration System</th>
<th>Electrical Energy Output (% of fuel input)</th>
<th>Overall Efficiency (%)</th>
<th>Heat-to-Power ratio</th>
<th>Thermal Qualities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back-pressure steam turbine (BPST)</td>
<td>14-28</td>
<td>84-92</td>
<td>4-22</td>
<td>High</td>
</tr>
<tr>
<td>Condensing steam turbine (CST)</td>
<td>22-40</td>
<td>60-80</td>
<td>2-10</td>
<td>High</td>
</tr>
<tr>
<td>Gas turbines (GT)</td>
<td>24-42</td>
<td>70-85</td>
<td>1.3-2.0</td>
<td>High</td>
</tr>
<tr>
<td>Reciprocating engine (RE)</td>
<td>33-53</td>
<td>75-85</td>
<td>0.5-2.5</td>
<td>Low</td>
</tr>
<tr>
<td>Combined cycle gas turbine (CCGT)</td>
<td>34-55</td>
<td>69-83</td>
<td>1.0-1.7</td>
<td>Medium</td>
</tr>
<tr>
<td>Fuel Cells (FC)</td>
<td>40-70</td>
<td>75-85</td>
<td>0.33-1</td>
<td>Low to High</td>
</tr>
<tr>
<td>Microturbines (MT)</td>
<td>15-33</td>
<td>60-75</td>
<td>1.3-2.0</td>
<td>Medium to Low</td>
</tr>
</tbody>
</table>

Source: UN ESCAP and the European Association for the Promotion of Cogeneration

3 Good Quality Cogeneration

It is sometimes assumed that all cogeneration is good, i.e., better than the alternative stand-alone electricity and thermal energy generation both from an economic and an environmental perspective. This is not always the case, particularly in systems with high H/P ratios and moderate system efficiencies or systems that operate at part load for significant portions of time (see Park and Kim, 2008). For example, a natural gas-fired steam turbine with a system efficiency of 65% and a heat-to-power ratio of 5 would be less efficient than using an 80% boiler and a combined-cycle gas turbine to generate electricity and thermal energy separately.

This section defines the characteristics that maximize the environmental and economic benefits of cogeneration systems and suggests more meaningful parameters to describe cogeneration systems that allow for more accurate comparisons to alternative systems.

3.1 Maximizing Cogeneration Benefits

Two key conditions maximize the benefits of cogeneration: 1) maximizing electricity production, while 2) closely matching the thermal load requirements in terms of both quantity and energy quality. The thermal capacity of a cogeneration system should be sized to meet the base thermal load required by the host facility. The quality of the thermal output should not be significantly higher than that required to meet the needs because it means the unused thermal energy could have been used to generate more electricity. The ratio of electricity production to thermal energy output and the thermal energy quality are determined by the choice of generator and auxiliary equipment.
Some cogeneration technologies, such as reciprocating engines, retain higher efficiencies at part load than other, like gas and steam turbines. Figure 1 compares the part load efficiencies of three major cogeneration system types. If a gas turbine, steam turbine or CCGT system is operated at part load for a significant portion of time, the economic and environmental advantage of using a cogeneration system may be lost.

**Figure 1: Part Load Efficiencies of Generators**

The benefits of cogeneration systems are correlated to the alternative electrical and thermal energy system that would have been in their place. For example, industrial thermal loads are usually met by industrial boilers with efficiencies above 80%. However, residential heating and hot water loads are served using less efficient devices. Therefore, the minimum efficiency threshold for good quality cogeneration in an industrial application would be higher than in a residential or district energy application.

Finally, the benefits of cogeneration systems that generate excess electricity are maximized if the system is located in an area of the grid that requires additional generation capacity. This location issue is of particular importance to the cogeneration systems being developed in the oil sands region of Alberta. Estimates indicate that, in 2013, oil sands operations had an installed capacity of over 2,200 MW of cogeneration capacity, forecast to increase to almost 2,400-2,500 MW in 2014 (OSCA, 2014). It is expected that on-site cogeneration capacity in the oil sands could be almost 6,000 MW by 2023, driven by rising electricity and thermal energy demand from oil sands production (OSCA, 2014).

### 3.2 Alternative Parameters to Define Cogeneration Systems

The current parameters that are used to define the characteristics of cogeneration systems are inadequate for assessing whether or not a cogeneration system is better than the alternatives. Cogeneration systems are usually defined by their total electrical capacity and the system efficiency, but these two parameters do not provide enough
information to accurately assess the value of a cogeneration system and do not allow for direct comparison with stand-alone generation and thermal energy systems.

### 3.2.1 Cogeneration System Efficiency

Using system efficiency to describe cogeneration systems relative to stand-alone systems may not be an adequate way to compare them, although this is often done. For example, we compare a reciprocating engine system with an efficiency of 84% and a heat-to-power ratio of 1.4 to a steam turbine system with an efficiency of 81% and a heat-to-power ratio of 14.2 to a standalone natural gas boiler with an efficiency of 80% and a combined cycle gas turbine with an efficiency of 50%. The reciprocating engine system reduces GHG emissions by 67 tonnes of CO$_2$e per GWh (total energy) while the steam turbine system only reduces emissions by 11 tonnes of CO$_2$e per GWh. Thus, efficiency improvement is really a factor of overall efficiency and the power factor.

An alternative efficiency measure used by the US Environmental Protection Agency is Effective Electric Efficiency (E3). E3 is defined as the electrical output from a cogeneration system divided by the total energy input from the system minus the thermal output divided by the assumed efficiency of the alternative boiler. For an alternative boiler that is 80% efficient, the effective electric efficiency would be calculated as follows:

$$E3 = \frac{\text{Cogeneration electrical power output}}{\text{Total energy input to cogeneration system} - \text{Total heat recovered}}$$

E3 is a more informative way of comparing the efficiency of cogeneration systems because it makes it easier to compare cogeneration systems to stand-alone generators and determine their value. It also treats the cogeneration system as primarily a thermal energy device with electricity as the by-product of the process.

### 3.2.2 Capacity Factor

Another issue not addressed by the current method of characterizing cogeneration systems is that cogeneration systems do not always have the same capacity factor as stand-alone generation systems. Base-load electricity generation facilities tend to have capacity factors above 93%. This means that the generator produces electricity equal to the total electrical capacity multiplied by the total number of hours in a year (8,760) multiplied by 93%. However, the average capacity factor of electricity generation in Canada is approximately 56%. Capacity factor is affected by how many hours a system

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3 Data from the Canadian Cogeneration Database at CIEEDAC
5 Calculated from CANSIM Table 127-009 (Capacity) and CANSIM Table 127-0007 (Generation)
is running and at what load level. For example, a cogeneration system running 50% of the time at full capacity would have the same capacity factor as a cogeneration system running at 50% capacity full time. Because of the large variation, the capacity factor of a cogeneration system should be included as one of its defining parameters.

4 Methodology

Data are obtained from a number of sources or via CIEEDAC’s cogeneration survey. CIEEDAC analysts search the web and other media and contact various organizations, consulting agencies, engineering firms and the like to obtain information on installed capacity, technology and fuel consumption.

Data collected are reviewed and evaluated before they enter the online database.

4.1 Data Sources

CIEEDAC relies on a variety of data sources to inform the cogeneration database, but the primary source of data is the digital survey completed by cogeneration facility operators across Canada. This year, CIEEDAC conducted a review and update of facilities already existing in the database. As part of this review CIEEDAC analysts accessed industry and facility websites and consulted utilities and distribution agencies to confirm facility operation status and authenticate or collect data.

Additional and historical data sources include:

- **Canadian Gas Association (CGA):** In 1996, the CGA released a listing of Canadian gas-fired cogeneration systems that were in operation on December 31, 1995. These data focus only on natural gas-fired systems, and as a result miss a large number of systems fired by other fuels (i.e., oil, hog fuel, spent pulping liquor, coke oven gas, etc.). This database has not been updated.

- **Environment Canada:** Environment Canada provided information on gas-fired cogeneration facilities and combined cycle power plants that they had collected.

- **Consultants and Engineering firms:** Several consultants in the cogeneration business were contacted for information about existing facilities. ThermoShare Inc. generously shared their cogeneration databases with CIEEDAC. MEG Energy also provided data on cogeneration facilities working at the oils sands of Alberta.

- **Independent Associations:** A number of industrial associations such as the Independent Power Producers Society of Ontario (IPPSO) and the Independent Power Producers Society of Alberta (IPPSA) provided data on facilities in their region.

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6 CIEEDAC would like to thank Jonathan Carlson of MEG Energy.
- **Electric and Gas Utilities**: Most electrical and gas utilities were asked to provide data on cogeneration facilities in their service area.

- **Statistics Canada (STC)**: (catalogue no. 57-206-XPB, Electric Power Generating Stations, 2009). This publication lists the capacity of electric generating stations in Canada both utility and privately owned, by province and by type (i.e., steam turbine, internal combustion and combustion turbine plant capacities, etc.). Used as a cross-reference, it does not explicitly distinguish cogeneration systems from any other generating system. In addition, the catalogue does not explicitly identify combined cycle gas turbines facilities; rather, it lists the combustion turbine separately from the steam turbine component of the system. The publication includes, with a few exceptions, all the cogeneration systems identified by the other report references. Some inconsistencies with respect to plant names, locations and capacities were noted when compared to other sources. Currently these data are not publicly available but CIEEDAC is negotiating the conditions under which the data may be made available.

- **Other Sources**: Additional sources of information included corporate and government websites, cogeneration manufacturer’s brochures and industry reports.

- **New in 2015 - Other CIEEDAC databases**: All CIEEDAC databases (district energy, renewable energy and cogeneration) have been harmonized as of 2015. Through this process, we uncovered cogeneration facilities that existed in the district energy database, but not the cogeneration database. We added these facilities to the database and will now use information gathered for the other databases as an additional source of information for the cogeneration database, and vice versa.

### 4.2 Survey

Historically, Canadian cogeneration data were gathered using a web-based survey directly linked to the database. Each facility operator was sent an electronic link that provides access to their facility’s data allowing them to update or complete the survey on-line. Feedback loops in the survey inform the operator of possible errors and increase the reliability of the data.

In 2014, the survey was updated and simplified to improve user response rate and refine the data being collected. Simple excel worksheets targeting specific information (e.g., contact information, capacity and system data, and emissions data) are produced for each known and new facility, populated with data from the database or from publicly available information and distributed to cogeneration system operators. Other recent additions to the data came from various organizations focused on cogeneration installations in various sectors (e.g., cogeneration in Alberta’s oil sands developments).

While some cogeneration systems may be missing because they are small or operate in remote locations, we feel that the latest Canadian Cogeneration Database is a comprehensive inventory of large and small cogeneration systems operating in Canada.
CIEEDAC continues to identify new cogeneration systems through websites, industry contacts, cogeneration equipment suppliers and electric utility personnel.

4.3 Data Review and Analysis
CIEEDAC analysts review the data once they have been obtained. The review consists primarily of evaluating the data provided for consistency (e.g., input energy exceeds output energy, reasonable output per unit installed capacity, reasonable H/P ratios, etc.). Analysts contact data providers if there are obvious errors.

After this review is completed, CIEEDAC analysts compare these data to what can be obtained from other sources. For example, STC lists all electricity generators over 500 kW.

The data, once reviewed, are placed in the online public database and can be obtained through CIEEDAC’s online query process. Some data used in CIEEDAC’s analysis are not available publicly due to confidentiality. Special dispensations of the detailed public data are available on request.

4.4 Allocation of Emissions in Cogeneration Units
While we made no attempt to allocate emissions to any of the products of cogeneration, carbon accounting is becoming more important as commodities, including energy, are sold or traded. The simplest method assigns CO₂ release to the products based on the share of energy generated from the production process; a heat to power ratio of 3 suggests that, of CO₂ released, 75% would be associated with the heat and 25% with the electricity. However, there are alternative approaches to allocating emissions to the end products, depending on how one views the value of the energy, the exergy⁷ content of the products or other characteristics of the cogeneration system. Appendix A provides examples of alternative methods of such allocation.

5 Results

5.1 Capacity
Table 2 summarizes Canadian cogeneration capacity in operation in 2014 by technology type and compared to Canada’s total. Total electrical capacity is 9,319 MWₑ (based on known capacities for 209 of the 216 facilities listed in the database). Gas turbines play the dominant role with 59% of total capacity (MWₑ) followed by steam turbines (all types).

---

⁷ Exergy is defined as the maximum amount of work that can be obtained from an energy carrier.
For 2014, CIEEDAC reported an electric capacity of 10,156 MW_e. This change is due largely to the removal of several facilities that were either decommissioned, are no longer operational or were duplicates of already captured facilities.

Thermal capacity data were not provided at the same level of detail. The known thermal capacity in the database is 11,582 MW_t. However, that data is incomplete: it is the sum of the known thermal capacity for only 110 of the 216 facilities listed in the database.

**Table 2: Cogeneration Capacity by Technology type, as Listed in the CIEEDAC Cogeneration Database**

<table>
<thead>
<tr>
<th>Technology Type</th>
<th>Electric Capacity (MW_e) (%)</th>
<th>Thermal Capacity (MW_t) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Turbine</td>
<td>5,467 59%</td>
<td>3,922 34%</td>
</tr>
<tr>
<td>Steam Turbines</td>
<td>3,455 37%</td>
<td>3,907 34%</td>
</tr>
<tr>
<td>BPEST</td>
<td>689 7%</td>
<td>1,730 15%</td>
</tr>
<tr>
<td>BPST</td>
<td>544 6%</td>
<td>709 6%</td>
</tr>
<tr>
<td>CST</td>
<td>372 4%</td>
<td>550 5%</td>
</tr>
<tr>
<td>ECST</td>
<td>673 7%</td>
<td>778 7%</td>
</tr>
<tr>
<td>ST</td>
<td>1,178 13%</td>
<td>141 1%</td>
</tr>
<tr>
<td>Spark Ignition/Engines</td>
<td>117 1%</td>
<td>81 1%</td>
</tr>
<tr>
<td>Microturbines</td>
<td>1 0%</td>
<td>2 0%</td>
</tr>
<tr>
<td>Unknown</td>
<td>278 3%</td>
<td>3,670 32%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9,319 100%</strong></td>
<td><strong>11,582 100%</strong></td>
</tr>
</tbody>
</table>

Source: CIEEDAC Cogeneration Survey, publicly available data on cogeneration systems.
Note: BPEST – back pressure extraction steam turbine, BPST – back pressure extraction steam turbine, CST – condensing steam turbine, CST – Extraction Condensing Steam Turbine, ST – steam turbine

### 5.2 CO₂ Emissions

Using the available data, we have estimated the annual CO₂ emissions from Canadian cogeneration facilities. Results are based on facility data where possible, but they remain uncertain. For facilities where not enough data are available to estimate emissions, we have estimated the missing parameters (e.g., capacity factor, energy efficiency and fuel mix) based on their technology (e.g., gas turbine, steam turbine, spark ignition) and sector (according to three digit NAICS code). Emissions are primarily from the utilities, oil and gas extraction, and paper manufacturing sectors within Alberta and Ontario.

#### 5.2.1 Method

To estimate CO₂ emissions, we started with the known emissions that could be calculated by facility without any derived parameters. We added to this the emissions we could we derive for each facility where one of the following data points was missing:

- Fuel mix and resulting greenhouse gas coefficient (t/GJ)

---

8 See Appendix B for emissions factors.
• Total system energy efficiency
• Capacity utilization
• The heat to power ratio

The emissions for each facility in the database were estimated by then deriving values based on two, then three and finally four unknowns from the above list. In other words, we estimated the CO₂ emissions for all facilities that have, at minimum, their electrical capacity listed in the database.

It is important to remember that the emissions estimate is very uncertain:
• It only covers facilities that are listed in the database with known electrical capacity.
• It is based on inferences made from the data, but these inferences are not statistically valid. A rough rule of thumb is that 30 samples are needed to infer averages for a population. To make inferences for operating parameters across all technologies (7, assuming all steam turbine types count as one), regions (13) and sectors (36 reported), we would need 3276 data entries. This number is much larger than the number of facilities in the database and surely greater than the number of cogeneration facilities in Canada. As a compromise, we inferred operating parameters based only on technology or sector averages, but this does not result in an estimate which we can statistically analyse. It is just a heuristic to understand the approximate scope of cogeneration in Canada.
• Even if the inferred values were based on larger sample, deviation from the mean would mean that actual CO₂ emissions for each facility province or sector could differ from estimated emissions by a significant margin. Presenting the estimate at a more disaggregate level, by sector or province as we do below, increases the uncertainty in the estimate.

5.2.2 Results

Figure 2 shows estimated annual CO₂ emissions from Canadian cogeneration facilities. CO₂ emissions are 43.5 Mt/yr, or roughly 6%-7% of national emissions.⁹ Cogeneration would be a greater contributor to national emissions but most facilities are fuelled with natural gas or biomass and therefore have relatively low emissions intensity.

The total CO₂ value is subdivided into categories according to how many unknown data points had to be assumed to calculate emissions. The error bar in the figure shows the variation in the result due to estimation method: +/- 10% or 4 Mt/yr using technology averages (resulting in lower GHG emissions) or sector averages (resulting in higher GHG emissions). The error bar is not a statistical determination of uncertainty.

---

⁹ The Environment Canada National Inventory Report shows that Canada’s emissions at 699 Mt/yr in 2012.
CO₂ emissions from cogeneration come primarily from the utilities, oil and gas extraction, and paper manufacturing sectors (Table 3). However, note that many facilities operated as utility provide heat and electricity to other sectors (e.g. chemicals and petroleum refining, or to private homes via a district energy system). We estimate that roughly 70% of cogeneration emissions occur in Ontario and Alberta (Table 4).

**Figure 2: Estimate of Canadian Total Cogeneration CO₂ Emissions, 2014**

![Graph showing CO₂ emissions from cogeneration](image)

Source: Calculated from the Canadian Cogeneration Database, CIEEDAC; estimations of data are related to capacities and capacity utilization rates. See text for description.

**Table 3: Estimate of Total Canadian Cogeneration CO₂ Emissions by Sector, 2014**

<table>
<thead>
<tr>
<th>Sector</th>
<th>CO₂ Emissions (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilities</td>
<td>22.9</td>
</tr>
<tr>
<td>Paper and Wood Products</td>
<td>4.9</td>
</tr>
<tr>
<td>Oil and Gas Extraction</td>
<td>11.1</td>
</tr>
<tr>
<td>Chemical Manufacturing</td>
<td>1.1</td>
</tr>
<tr>
<td>Food and Beverage Manufacturing</td>
<td>1.2</td>
</tr>
<tr>
<td>Buildings (e.g. education)</td>
<td>0.8</td>
</tr>
<tr>
<td>Mining (except oil and gas)</td>
<td>0.5</td>
</tr>
<tr>
<td>Other Manufacturing</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>43.5</strong></td>
</tr>
</tbody>
</table>

Source: Calculated from the Canadian Cogeneration Database, CIEEDAC; estimations of data are related to capacities and capacity utilization rates. See text for description.
Table 4: Estimate of Total Canadian Cogeneration CO$_2$ Emissions by Province, 2014

<table>
<thead>
<tr>
<th>Province</th>
<th>CO$_2$ Emissions (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Columbia</td>
<td>2.0</td>
</tr>
<tr>
<td>Alberta</td>
<td>22.4</td>
</tr>
<tr>
<td>Saskatchewan and Manitoba</td>
<td>5.2</td>
</tr>
<tr>
<td>Ontario</td>
<td>8.6</td>
</tr>
<tr>
<td>Quebec</td>
<td>4.1</td>
</tr>
<tr>
<td>Atlantic</td>
<td>1.2</td>
</tr>
<tr>
<td>Territories</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>43.5</td>
</tr>
</tbody>
</table>

Source: Calculated from the Canadian Cogeneration Database, CIEEDAC; estimations of data are related to capacities and capacity utilization rates. See text for description.

5.3 Electricity and Thermal Production

We have estimated annual electricity and thermal production from Canadian cogeneration facilities. However, as with our estimate of CO$_2$ emissions, we have made this estimate using many assumptions derived from the database; it is therefore very uncertain.

Without annual surveys requesting annual production data, knowing actual production in any particular year is problematic. The following tables and figures present our estimate of energy production from cogeneration in Canada, based on a subset of facilities that have reported this data in the past, extrapolated to the total based on any available data. It is a reasonable estimate of energy production, but cannot be interpreted as energy production for a given year.

5.3.1 Method

We estimated electrical and thermal energy production using the method described for the CO$_2$ emissions estimation. This calculation required fewer assumption for unknown parameters since the fuels used by facility did not affect the results. However, the same uncertainties and caveats that apply to the CO$_2$ estimate also apply to our estimate of energy production.

5.3.2 Results

Figure 3 shows our estimate of annual energy production by Canadian cogeneration facilities. Electricity generation is 68 TWh/yr, while thermal generation is 171TWh/yr, indicating an average heat to power production ratio of 2.5:1. For context, annual electricity generation in Canada in 2014 was approximately 628 TWh, so cogenerated electricity accounts for roughly 11% of total production.$^{10}$ Using the same methodology,

---

we estimate that this energy production required roughly 1,165 PJ of primary energy. The implicit total system energy efficiency in our estimate is 74%.

**Figure 3: Estimate of Total Canadian Cogeneration Production, 2014**

Source: Calculated from the Canadian Cogeneration Database, CIEEDAC, estimations of data are related to capacities and capacity utilization rates. See text for description.

Note: See text for explanation of issues related to production year.

As with the CO₂ emissions estimate, the energy production estimate is subdivided into categories according to how many assumptions were required to make the calculation, with more unknowns resulting in more uncertain results. Thermal energy production is generally more uncertain than electrical production since many facilities in the database have only their electrical capacity listed. To calculate thermal energy production for these facilities, thermal capacity and annual capacity utilization had to be inferred from sector and technology averages derived from the data. For energy production, using sector versus technology averages made little difference to the assumptions used in our calculation.

The sector and regional trends for energy production from cogeneration are similar to those seen with CO₂ emissions. Utilities, oil and gas extraction, and paper manufacturing still account for 90% of energy production (Table 5). Almost 60% of energy production occurs in Alberta and Ontario, with an additional 14% in British Columbia (Table 6).
Table 5: Estimate of Total Canadian Cogeneration Energy Production by Sector, 2014

<table>
<thead>
<tr>
<th>Sector</th>
<th>Electricity (TWh/yr)</th>
<th>Thermal (TWh/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilities</td>
<td>39</td>
<td>60</td>
</tr>
<tr>
<td>Paper and Wood Products</td>
<td>9</td>
<td>58</td>
</tr>
<tr>
<td>Oil and Gas Extraction</td>
<td>13</td>
<td>39</td>
</tr>
<tr>
<td>Chemical Manufacturing</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Food and Beverage Manufacturing</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Buildings and Services</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Mining (except oil and gas)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Other Manufacturing</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>68</strong></td>
<td><strong>171</strong></td>
</tr>
</tbody>
</table>

Source: Calculated from the Canadian Cogeneration Database, CIEEDAC; estimations of data are related to capacities and capacity utilization rates. See text for description.

Note: See text for explanation of issues related to production year.

Table 6: Estimate of Total Canadian Cogeneration Energy Production by Province, 2014

<table>
<thead>
<tr>
<th>Province</th>
<th>Electricity (TWh/yr)</th>
<th>Thermal (TWh/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Columbia</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Alberta</td>
<td>27</td>
<td>67</td>
</tr>
<tr>
<td>Saskatchewan and Manitoba</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Ontario</td>
<td>15</td>
<td>33</td>
</tr>
<tr>
<td>Quebec</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>Atlantic</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>Territories</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>68</strong></td>
<td><strong>171</strong></td>
</tr>
</tbody>
</table>

Source: Calculated from the Canadian Cogeneration Database, CIEEDAC; estimations of data are related to capacities and capacity utilization rates. See text for description.

Note: See text for explanation of issues related to production year.

5.4 Has Cogeneration Reduced Energy Consumption and Greenhouse Gas Emissions in Canada?

While cogeneration has likely reduced energy consumption and CO₂ emissions in Canada, it is not possible to calculate this change with our data. To do this, we would also need to know the hypothetical quantity and type of fuels used to generate electricity and heat without using cogeneration for each facility included in this analysis.

However, given the inherent efficiencies of cogeneration, it is likely that it has reduced energy consumption in Canada. We estimate that cogeneration systems consumed 1,165 PJ/yr to produce a 68 TWh/yr of electricity (245 PJ) and 171 TWh of thermal energy (614 PJ). Assuming standalone heat production would have been 80% efficient and standalone electricity production would have been 35% efficient, this same energy production would have required 21% more energy consumption.
The energy savings associated with cogeneration is robust to a range of assumptions for the energy efficiency of standalone heat and electricity generation. Even with 90% efficient heat generation and 50% efficient electricity generation, cogeneration still reduced energy consumption by 1% (Table 7). This estimate does not include electricity transmission loss, which should be lower for cogenerated electricity. Therefore, the energy savings of cogeneration should be even greater.

**Table 7: Estimated % Energy Savings Resulting from Cogeneration relative to Standalone Generation**

<table>
<thead>
<tr>
<th>Efficiency of Stand-alone electricity production</th>
<th>Energy efficiency of standalone heat production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70%</td>
</tr>
<tr>
<td>30%</td>
<td>-31%</td>
</tr>
<tr>
<td>35%</td>
<td>-26%</td>
</tr>
<tr>
<td>40%</td>
<td>-22%</td>
</tr>
<tr>
<td>45%</td>
<td>-18%</td>
</tr>
<tr>
<td>50%</td>
<td>-15%</td>
</tr>
</tbody>
</table>

Cogeneration in Canada reduces energy consumption under almost all reasonable scenarios. Therefore, it is similarly likely to reduce CO₂ emissions.

### 5.5 Regional Cogeneration Capacity

Table 8 summarizes Canadian cogeneration capacity in operation in 2014 by region and compares it to the total.

**Table 8: Canadian Cogeneration Capacity by Region, as Listed in the CIEEDAC Cogeneration Database**

<table>
<thead>
<tr>
<th>Province</th>
<th>Electric Capacity (MWₑ)</th>
<th>Electric (%)</th>
<th>Thermal Capacity (MWₜ)</th>
<th>Thermal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Columbia</td>
<td>812</td>
<td>8.7%</td>
<td>3,182</td>
<td>27.5%</td>
</tr>
<tr>
<td>Alberta</td>
<td>4,221</td>
<td>45.3%</td>
<td>5,214</td>
<td>45.0%</td>
</tr>
<tr>
<td>Saskatchewan/Manitoba</td>
<td>557</td>
<td>6.0%</td>
<td>730</td>
<td>6.3%</td>
</tr>
<tr>
<td>Ontario</td>
<td>2,563</td>
<td>27.5%</td>
<td>1,072</td>
<td>9.3%</td>
</tr>
<tr>
<td>Quebec</td>
<td>798</td>
<td>8.6%</td>
<td>192</td>
<td>1.7%</td>
</tr>
<tr>
<td>Atlantic</td>
<td>341</td>
<td>3.7%</td>
<td>1,174</td>
<td>10.1%</td>
</tr>
<tr>
<td>Territories</td>
<td>26</td>
<td>0.3%</td>
<td>18</td>
<td>0.2%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>9,319</strong></td>
<td><strong>100%</strong></td>
<td><strong>11,582</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Source: Canadian Cogeneration Database, CIEEDAC

Note: Electric capacity data is more readily available than thermal capacity data, so while the capacity values look similar, the total thermal capacity is an underestimation (based on data from only 110 out of 216 known facilities, rather than 209 for electric capacity).
Based on information obtained in our 2015 review and update of the cogeneration database, total operational cogeneration capacity for 2014 is at least 9,319 MW_e. For 2014, CIEEDAC reported an electric capacity of 10,156 MW_e. This change is due largely to the removal of several facilities that were either decommissioned, are no longer operational or were duplicates of already captured facilities. Again, total electrical capacity is based on known capacities for 209 of the 216 facilities in the database. Total thermal capacity listed in the database (11,582 MW_t) is an underestimation of the actual capacity; it is the total thermal capacity of only 110 of the 216 known facilities (i.e., only ~51% of facilities list or report thermal capacity).

Based on the data updated this year, Alberta has more operational cogeneration capacity (4,221 MW_e) than any other region of Canada, followed by Ontario (2,563 MW_e) and British Columbia (812 MW_e). The majority of Alberta’s capacity serves the conventional and non-conventional oil and gas industries. The industries served by cogeneration in Ontario range from manufacturing and forest products to hospitals and universities. The majority of the cogeneration capacity in BC, Manitoba, Quebec and the Maritimes serves the forest products sector.

5.6 Sector Cogeneration Capacity
CIEEDAC allocated cogeneration facility electrical capacity by system operator and primary thermal host to identify the key industries utilizing cogeneration. The North American Industrial Classification System (NAICS) is used to code the facilities.

Table 9 shows electric and thermal capacity by 8 main sector groups. The Utilities sector has the largest cogeneration electric capacity at 4,362 MW_e while the Oil and Gas Extraction (1,907 MW_e) and Paper and Wood Products (1,595 MW_e) sectors have the next largest capacities. However, the Paper and Wood Products sector has the largest thermal capacity by far, followed by Oil and Gas Extraction and Utilities. This trend is a result of the typical configuration of utility cogeneration plants to maximize electricity production while Paper and Wood Products primary goal is to provide heat for paper making processes.

5.7 Cogeneration System Performance Characteristics
The cogeneration system performance in this section is based on production weighted averages of the data in the CIEEDAC cogeneration database. If the necessary data are not available for a facility, that facility does not contribute to the calculation. Therefore, the system characteristics listed in this section may differ from those implicit in our estimation of the total CO_2 emissions and energy production from cogeneration in Canada.
Table 9: Canadian Cogeneration Capacity by Region, as Listed in the CIEEDAC Cogeneration Database

<table>
<thead>
<tr>
<th>Sector</th>
<th>Electric Capacity (MWₑ)</th>
<th>(%)</th>
<th>Thermal Capacity (MWₜ)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilities</td>
<td>4,362</td>
<td>47%</td>
<td>1,367</td>
<td>12%</td>
</tr>
<tr>
<td>Paper and Wood Products</td>
<td>1,595</td>
<td>17%</td>
<td>5,921</td>
<td>51%</td>
</tr>
<tr>
<td>Oil and Gas Extraction</td>
<td>1,907</td>
<td>20%</td>
<td>3,030</td>
<td>26%</td>
</tr>
<tr>
<td>Chemical Manufacturing</td>
<td>366</td>
<td>4%</td>
<td>99</td>
<td>1%</td>
</tr>
<tr>
<td>Food and Beverage Manufacturing</td>
<td>237</td>
<td>3%</td>
<td>259</td>
<td>2%</td>
</tr>
<tr>
<td>Buildings and Services</td>
<td>342</td>
<td>4%</td>
<td>294</td>
<td>3%</td>
</tr>
<tr>
<td>Mining (except oil and gas)</td>
<td>55</td>
<td>1%</td>
<td>456</td>
<td>4%</td>
</tr>
<tr>
<td>Other Industry</td>
<td>455</td>
<td>5%</td>
<td>157</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9,319</strong></td>
<td><strong>100%</strong></td>
<td><strong>11,582</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Source: Canadian Cogeneration Database, CIEEDAC
Note: Electric capacity data is more readily available than thermal capacity data, so while the capacity values look similar, the total thermal capacity is an underestimation (based on data from only 110 out of 216 known facilities, rather than 209 for electric capacity).

Table 10 displays the average performance characteristics of the systems, categorized by the major cogeneration sectors in Canada and the number of data points, or observations, that the statistics are based on. The average amount of electricity generated per kWₑ of installed electrical capacity for all cogeneration systems in Canada is 6,900 kWh/yr per kWₑ, corresponding to a capacity utilization of 78%. This average is based on 118 of the 216 facilities in the database.

Table 10: Canadian Cogeneration System Performance in 2014 by sector, as listed in the CIEEDAC Cogeneration Database

<table>
<thead>
<tr>
<th>Sector</th>
<th>Electricity Generation (MWh/kW)</th>
<th>Data points</th>
<th>H/P ratio</th>
<th>Data points</th>
<th>Average Efficiency by facility</th>
<th>Data points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilities</td>
<td>7.8</td>
<td>32</td>
<td>1.2</td>
<td>10</td>
<td>62%</td>
<td>10</td>
</tr>
<tr>
<td>Paper and Wood Products</td>
<td>5.7</td>
<td>32</td>
<td>6.4</td>
<td>19</td>
<td>63%</td>
<td>19</td>
</tr>
<tr>
<td>Oil and Gas Extraction</td>
<td>7.4</td>
<td>4</td>
<td>2.5</td>
<td>3</td>
<td>76%</td>
<td>3</td>
</tr>
<tr>
<td>Chemical Manufacturing</td>
<td>5.8</td>
<td>5</td>
<td>1.4</td>
<td>2</td>
<td>70%</td>
<td>2</td>
</tr>
<tr>
<td>Food and Beverage Manufacturing</td>
<td>7.2</td>
<td>11</td>
<td>0.9</td>
<td>8</td>
<td>63%</td>
<td>8</td>
</tr>
<tr>
<td>Buildings and Services</td>
<td>4.2</td>
<td>23</td>
<td>2.0</td>
<td>15</td>
<td>68%</td>
<td>15</td>
</tr>
<tr>
<td>Mining (except oil and gas)</td>
<td>4.6</td>
<td>1</td>
<td>8.3</td>
<td>1</td>
<td>82%</td>
<td>1</td>
</tr>
<tr>
<td>Other Industry</td>
<td>3.8</td>
<td>10</td>
<td>0.9</td>
<td>7</td>
<td>69%</td>
<td>7</td>
</tr>
<tr>
<td><strong>All Sectors</strong></td>
<td><strong>6.9</strong></td>
<td><strong>118</strong></td>
<td><strong>3.3</strong></td>
<td><strong>65</strong></td>
<td><strong>67%</strong></td>
<td><strong>65</strong></td>
</tr>
</tbody>
</table>

Source: Canadian Cogeneration Database, CIEEDAC.
Note: “Data Points” indicates the number of confirmed entries in the database.

The average H/P ratio of systems operating in Canada is 3.3 (i.e., for every kWh of electricity produced by cogeneration systems, 3.3 kWh of useful thermal energy is produced). Table 10 shows that the Paper and Wood Products manufacturing sector, as
well as Mining sector, have the highest average H/P ratio. The utilities sector shows low H/P ratios because the systems are generally designed to maximize electricity production.

The average efficiency of systems operating in Canada is 67%. The highest average efficiency occurs in the Mining sector at 82%. These calculations are based on data received and, while these data are reviewed, outcomes are uncertain. Furthermore, survey respondents are reluctant to provide energy production and fuel use data. Consequently, the number of facilities that report enough data to allow CIEEDAC to calculate the efficiency and heat-to-power ratio is limited. The averages of these two metrics are based on data from only 65 of the 216 facilities in the database.

Table 11 shows the average system efficiency for various cogeneration systems based on generator type as well as the number of units on which CIEEDAC has efficiency information. Again, the average efficiency differs from the average in Table 10 as it is based on different data points (i.e., we have fuel consumption and energy production data for some cogeneration facilities which do not have the technology listed or data for individual units).

### Table 11: Canadian cogeneration unit performance in 2014 by Technology, as listed in the CIEEDAC Cogeneration Database

<table>
<thead>
<tr>
<th>System Type</th>
<th>Average Efficiency % by unit</th>
<th>Range</th>
<th>No. of Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Turbine</td>
<td>67%</td>
<td>39%-95%</td>
<td>33</td>
</tr>
<tr>
<td>Steam Turbines</td>
<td>60%</td>
<td>39%-96%</td>
<td>37</td>
</tr>
<tr>
<td>Spark Ignition/Engine</td>
<td>52%</td>
<td>41%-94%</td>
<td>40</td>
</tr>
<tr>
<td>Microturbines</td>
<td>59%</td>
<td>44%-78%</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>113</strong></td>
</tr>
</tbody>
</table>

Source: Canadian Cogeneration Database, CIEEDAC

Gas turbines have the highest average efficiency while spark ignition/engine systems have the lowest average efficiency. Unfortunately, reporting for all system types is generally low resulting in a small sample size and a large range of efficiencies. Thus, these estimates of system performance should be used cautiously. Even for the cogeneration systems with the highest response rates there is a high degree of uncertainty indicated by the range in efficiency.

#### 5.8 Cogeneration Installations by Date

Table 12 shows the amount of cogeneration capacity by start year to illustrate the evolution of cogeneration in Canada. There are two periods of significant growth in cogeneration. The first is in the 1970s and the second began in the 1990s and stretches into the 2000s. The first period coincides with a dramatic increase in energy prices in Canada. Cogeneration systems may have been installed as a response to these prices and to a perceived scarcity of energy resources.
Table 12: Cogeneration plants by start year and sector (MWₑ)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilities</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>951</td>
<td>2,882</td>
<td>346</td>
<td>183</td>
<td>4,362</td>
</tr>
<tr>
<td>Paper and Wood Products</td>
<td>25</td>
<td>48</td>
<td>182</td>
<td>149</td>
<td>256</td>
<td>466</td>
<td>220</td>
<td>59</td>
<td>190</td>
<td>1,595</td>
</tr>
<tr>
<td>Oil and Gas Extraction</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>90</td>
<td>0</td>
<td>255</td>
<td>991</td>
<td>571</td>
<td>0</td>
<td>1,907</td>
</tr>
<tr>
<td>Chemical Manufacturing</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>208</td>
<td>20</td>
<td>47</td>
<td>91</td>
<td>0</td>
<td>1</td>
<td>366</td>
</tr>
<tr>
<td>Food and Beverage Manufacturing</td>
<td>2</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>0</td>
<td>199</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>237</td>
</tr>
<tr>
<td>Buildings and Services</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>145</td>
<td>1</td>
<td>78</td>
<td>52</td>
<td>22</td>
<td>42</td>
<td>342</td>
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<tr>
<td>Mining (except oil and gas)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>35</td>
<td>0</td>
<td>0</td>
<td>55</td>
</tr>
<tr>
<td>Other Industry</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>151</td>
<td>209</td>
<td>0</td>
<td>95</td>
<td>455</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>27</td>
<td>51</td>
<td>194</td>
<td>596</td>
<td>297</td>
<td>2,147</td>
<td>4,500</td>
<td>998</td>
<td>510</td>
<td>9,319</td>
</tr>
</tbody>
</table>

Source: Canadian Cogeneration Database, CIEEDAC
Note: This table does not take into account capacity that has been taken out of commission.

The more recent period of growth is likely a reaction to three stimuli. First, electric utilities across Canada responded to public protest over large-scale energy projects by offering to purchase power from independent power projects (IPPs). This created a market opportunity for industry to install cogeneration systems and sell excess power to the electricity grid. Second, smaller cogeneration systems are becoming increasingly cost effective expanding market opportunities beyond large-scale installations. Third, full retail access to the electricity grid in Alberta has stimulated the development of large, grid-connected cogeneration systems.

6 Conclusions

CIEEDAC has published data on cogeneration in Canada since 1999. The database contains information on approximately 9.3 GWₑ of cogeneration capacity in Canada from 216 installations. The database, on-line at www.cieedac.sfu.ca, can be queried to generate reports by region, sector, thermal host, performance, and start year and includes an advanced search option for further refinement of data. The data presented on CIEEDAC’s website do not include confidential information pertaining to individual system performance.

Last year, we harmonized the CIEEDAC cogeneration database with the other relevant databases maintained by CIEEDAC: the district energy database, and the renewable energy database. With this change, each facility is cross-referenced across all three
databases. For example, a cogeneration unit fuelled with wood waste that serves a district energy system now exists in all three databases. This step streamlined database maintenance, provides a clearer overview of Canada’s energy network, and ensures that new facilities are being properly categorized.

Based on the updated database, gas turbines account for 59% of all electricity generation capacity from cogeneration in Canada with steam turbines of various sorts the second largest category at 37%. When allocated according to sector group, the Utilities sector boasts the largest cogeneration capacity at 4.4 GW_e and the Oil and Gas Extraction sector the second largest at 1.9 GW_e. Because respondents do not routinely provide thermal capacities for their systems, we were not able to provide a full accounting of thermal capacity by technology type. Nonetheless, the data show that the Paper and Wood Products sector has the highest known thermal capacity at 5.9 GW_t, followed by the Oil and Gas Extraction sector at 3.0 GW_t.

Installation of cogeneration facilities has been dramatic in the last decades. In the 1990s, 2.1 GW_e were installed, twice as much as the sum of all years prior. Between 2000 and 2009, this was almost doubled again (another 4.5 GW_e), with almost another 1 GW installed since 2010. The installation date for a further 0.5 GW_e is unknown.

On average, each per kW_e of installed electrical capacity generated 6,900 kWh per kW_e and on average, for every kWh of electricity generated, 3.3 kWh of useful thermal energy was produced (H/P = 3.3). The average efficiency of the systems documented in the database was 67%, with typical system efficiencies ranging between 39%-96%.

CO_2 emissions from all cogeneration units in Canada are estimated using the available data. We used the data provided to inform assumptions for fuel type, heat to power ratios, energy efficiency and capacity utilization for all cogeneration facilities in Canada. With this methodology, we have estimated CO_2 emissions at 43.5 Mt, or 6%-7% of total Canadian GHG emissions. Emissions from utilities and the oil and gas extraction facilities (primarily bitumen operations) account for more than three-quarters of the total.

Production data were estimated using the same method as the CO_2 estimate. Total electricity cogeneration is 68 TWh/yr while thermal generation is 171 TWh/yr, indicating an average heat to power production ratio of about 2.5:1. The bulk of the electricity (just over 75%) is generated by utilities and oil and gas operations and 90% of thermal energy generation comes from these two sectors and paper and wood products.

It is very likely that cogeneration has reduced energy consumption and greenhouse gas emissions in Canada. We cannot make a reliable estimate of this reduction since we do not know how heat and electricity would have been produced without cogeneration. However, our analysis shows that this conclusion is true even if we assume standalone heat and electricity generation are very energy efficient (i.e. 90% efficient heat generation, 50% efficient electricity generation).
CIEEDAC will continue to track and update this database with the objective of improving and refining the accuracy of the data and publish a revised annual report. As with all reports published by CIEEDAC, we encourage and appreciate feedback from our readers.
7 Reference List


UNESCAP, Overview of Cogeneration and Its Status in Asia, Internet publication.
Appendix A: Allocation of CO₂ Emissions from Cogeneration

This appendix summarizes seven methods that can be used to allocate the CO₂ emissions generated by cogeneration systems to the electrical and thermal products. When the owner/operator, the thermal host and the electricity consumer are not the same, the allocation of emissions to each product is necessary to ensure that each stakeholder is credited with their share of the CO₂ emissions produced by the system.

The following adapts six calculations of fuel allocation to the thermal and electrical products of a cogeneration system\(^\text{11}\). The fuel allocation is multiplied by the appropriate CO₂ emission factor to calculate the share of emissions for each product.

**Allocation based on energy content of the products**

This is a simple method of allocation of CO₂ emissions. The main criticism is that it does not account for the quality of the energy produced and its ability to do useful work. Therefore, it underrates the electricity share of energy and emissions.

\[
C_E = \left(\frac{E}{E + H}\right) F \phi \\
C_H = \left(\frac{H}{E + H}\right) F \phi
\]

Where:

- \(C_E\) = amount of CO₂ emissions allocated to electrical production;
- \(C_H\) = amount of CO₂ emissions allocated to heat production;
- \(E\) = net electricity production of the cogeneration system
- \(H\) = net heat production of the cogeneration system
- \(F\) = primary fuel consumed by the cogeneration system; and,
- \(\phi\) = CO₂ emission coefficient (i.e., unit of CO₂ produced per unit of primary fuel consumed)

**Allocation based on exergy content of the products**

Allocation based on exergy\(^\text{12}\) content accounts for the quality the energy form. As a result, the allocation of fuel and emissions is lower for the thermal product than the allocation based on energy content.

\[
C_E = \left(\frac{E}{E + \beta H}\right) F \phi \\
C_H = \left(\frac{\beta H}{E + \beta H}\right) F \phi
\]

Where:

- \(\beta\) = ratio of exergy to energy content of heat produced. The ratio for electricity is 1.0, 0.6 for steam at 600 degrees C and 0.2 for water at 90 degrees C (Wall, G., Energy, Society and Morals, 1997).

\(^{11}\) Phylipsen, et.al, Handbook of International Comparisons of Energy Efficiency in the Manufacturing Sector, 1996

\(^{12}\) Exergy is defined as the maximum amount of work (work here being the physics definition of work) that can be obtained from an energy carrier.
**Allocation based on economic value of the products**

This method may have some advantages for owner/operators that sells the electrical and thermal products independently.

\[
C_E = \left( \frac{C_e E}{c_e E + c_H H} \right) F \phi \\
C_H = \left( \frac{C_H H}{c_e E + c_H H} \right) F \phi
\]

Where:
- \(c_e = \) the economic value of electricity produced
- \(c_H = \) the economic value of thermal energy produced

**Allocation of incremental fuel consumption to electrical production**

This method considers electricity to be a by-product of the thermal process and is consistent with the “Fuel Charged to Power” (FCP) calculation done by many consultants in the cogeneration field. The FCP calculation nets out the fuel consumed by the reference boiler (i.e., an independent boiler providing the same steam as the cogeneration system) from the total fuel consumed by the cogeneration system.

\[
C_E = \left[ F - \left( \frac{H}{\eta_p} \right) \right] \phi \\
C_H = \frac{H}{\eta_p} \phi
\]

Where:
- \(\eta_p = \) efficiency of the boiler that would have been used in the production of the same amount of heat energy as produced by the cogeneration system (i.e., reference boiler).

**Allocation of incremental fuel consumption to the heat production**

In contrast to the previous method, this calculation nets out the fuel used by an independent generator/power plant needed to provide the same amount of electricity.

\[
C_E = \frac{E}{\eta_{pe}} \phi \\
C_H = \left[ F - \left( \frac{E}{\eta_{pe}} \right) \right] \phi
\]

Where:
- \(\eta_{pe} = \) efficiency of the power plant that would have been used in the production of the same amount of electricity as produced by the cogeneration system (i.e., reference power plant).

**Allocation based on a shared emission savings between heat and electricity**

A shared-savings approach may be a compromise to allocating all savings to either the electrical or thermal products.

\[
C_E = \left( \frac{E}{\eta_{pe} E + H} \right) F \phi \\
C_H = \left( \frac{H}{\eta_{pe} E + H} \right) F \phi
\]
Allocation by agreement

In some cases, the allocation of CO\textsubscript{2} emissions to each product of cogeneration will be determined by a contractual agreement between the various parties to the project.

Allocation of CO\textsubscript{2} emissions associated with transmission and distribution

One of the advantages of cogeneration systems is that they are typically located close to the thermal load and the electricity user(s). Under these conditions, the losses associated with transmission and distribution of electricity are reduced or eliminated. However, accounting for these reductions would be on a case-by-case basis. If the electricity is sold to the grid, this spatial advantage of cogeneration is lost.
Appendix B: CO₂ Emissions Factors

This appendix shows the annual energy consumption and CO₂ emissions per MWₑ capacity based on the average characteristics of cogeneration by technology and sector.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Annual Energy Consumption per MWₑ, TJ</th>
<th>Annual CO₂ per MWₑ, kt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam Turbine</td>
<td>267</td>
<td>5</td>
</tr>
<tr>
<td>Combined Cycle Gas Turbine</td>
<td>103</td>
<td>5</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>114</td>
<td>6</td>
</tr>
<tr>
<td>Microturbine</td>
<td>91</td>
<td>5</td>
</tr>
<tr>
<td>Organic Rankine Cycle</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Diesel Engine</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>Spark Ignition Engine</td>
<td>96</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sector NAICS</th>
<th>Sector Description</th>
<th>Annual Energy Consumption per MWₑ, TJ</th>
<th>Annual CO₂ per MWₑ, kt</th>
</tr>
</thead>
<tbody>
<tr>
<td>311</td>
<td>Food Manufacturing</td>
<td>165.3</td>
<td>8.5</td>
</tr>
<tr>
<td>312</td>
<td>Beverage and Tobacco Product Manufacturing</td>
<td>354.5</td>
<td>19.0</td>
</tr>
<tr>
<td>322</td>
<td>Paper Manufacturing</td>
<td>255.0</td>
<td>3.5</td>
</tr>
<tr>
<td>221</td>
<td>Utilities</td>
<td>91.4</td>
<td>4.2</td>
</tr>
<tr>
<td>325</td>
<td>Chemical Manufacturing</td>
<td>70.8</td>
<td>3.7</td>
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<td>622</td>
<td>Hospitals</td>
<td>82.5</td>
<td>4.1</td>
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<tr>
<td>611</td>
<td>Educational Services</td>
<td>85.4</td>
<td>4.5</td>
</tr>
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<td>211</td>
<td>Oil and Gas Extraction</td>
<td>123.1</td>
<td>6.2</td>
</tr>
<tr>
<td>713</td>
<td>Amusement, Gambling, and Recreation Industries</td>
<td>70.3</td>
<td>3.5</td>
</tr>
<tr>
<td>321</td>
<td>Wood Product Manufacturing</td>
<td>204.8</td>
<td>0.0</td>
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<tr>
<td>562</td>
<td>Waste Management and Remediation Services</td>
<td>441.1</td>
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<td>111</td>
<td>Crop Production</td>
<td>48.1</td>
<td>2.4</td>
</tr>
<tr>
<td>336</td>
<td>Transportation Equipment Manufacturing</td>
<td>30.0</td>
<td>1.5</td>
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<tr>
<td>541</td>
<td>Professional, Scientific, and Technical Services</td>
<td>30.4</td>
<td>1.5</td>
</tr>
<tr>
<td>911</td>
<td>Federal Government Public Administration</td>
<td>101.8</td>
<td>6.3</td>
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<tr>
<td>332</td>
<td>Fabricated Metal Product Manufacturing</td>
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<td>331</td>
<td>Primary Metal Manufacturing</td>
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<td>315</td>
<td>Apparel Manufacturing</td>
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<td>Support Activities for Transportation</td>
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<td>721</td>
<td>Accommodation</td>
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<tr>
<td>212</td>
<td>Mining (except Oil and Gas)</td>
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</table>