Co-Generation Potential in Canada

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ABSTRACT

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 heat rejected from one process in the production of the other, substantial gains in energy efficiency are realized compared to the independent production of both products. Cogeneration represents just over 6% of national electricity production in Canada. This relatively low penetration (compared to Europe) is attributed to Canada's historically low energy prices and electric utilities policies on the provision of back-up power and the sale of surplus electricity. Despite these conditions, cogeneration has been adopted in some industrial applications, notably the pulp and paper and chemical products sectors where there is a large demand for both heat and electricity at each site.

This analysis assesses the potential for cogeneration in Canada. It looks at types and conditions of cogeneration, installed cogeneration capacity in Canada and the cogeneration potential under different conditions. It includes estimates of the total technical and total achievable potential for cogeneration, as well as the cogeneration potential generated by the CIMS under five scenarios, including a business as usual scenario.

If we assume that all heat loads in industrial, commercial / institutional and residential sectors can be met with cogeneration technologies that have low heat to power ratios (2:1 in industry and 0.9:1 in the other sectors), one could generate enough to supply about 80% of Canada's electricity demand. If we take a more realistic approach cogeneration could provide 30% of Canada's current electricity needs.

The results generated by CIMS shows the estimated cogeneration potential under five scenarios. The business-as-usual (BAU) scenario predicts the lowest penetration of cogeneration, 2.1 GW_e in 2015. Changes in discount rates have a dramatic impact on cogeneration potential, increasing it to 21 GW_e in 2015. When the price of electricity increases by 50%, the results indicate that the potential for cogeneration increases to 7.1 GW_e in 2015. Finally an increase of 50% in commercial fossil fuel prices would decrease the demand for cogeneration to 2.5 GW_e.

Introduction

This paper is an abridged version of a report prepared for Natural Resources Canada entitled "Cogeneration Potential in Canada *Phase 2*". A copy of the full report can be viewed at www.cieedac.sfu.ca.

Cogeneration, also referred to as combined heat and power (CHP), is the simultaneous production of electrical and thermal energy from a single fuel. By using heat rejected from one process in the production of the other, substantial gains in energy efficiency are realized, compared to the independent production of both products. Cogeneration has been widely adopted in many European countries for use in industrial, commercial / institutional and residential applications. It currently represents 10% of all European electricity production and over 30% of electricity production in Finland, Denmark and the Netherlands.[1] Within Canada however, cogeneration represents just over 6% of national electricity production. This lower penetration is attributed to Canada's historically low energy prices and electric utility policies on the provision of back-up power and the sale of surplus electricity. Despite these conditions, cogeneration has been adopted in some industrial applications, notably the pulp and paper and chemical products sectors where a large demand for both heat and electricity exists.

Cogeneration Systems

Cogeneration produces both electricity and useful thermal energy. The thermal energy can be used in heating or cooling applications. Heating applications include generation of steam or hot water. 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 an electricity generator 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.

Economic and Technical Viability of Cogeneration

Technology improvements and increasing access to the electricity grid for sale of excess electricity have created new opportunities for cogeneration. Now, cogeneration systems as small as 20 kW_e can be economically viable under the right conditions. The four main factors that determine the economic viability of cogeneration projects are: (1) the thermal and electrical loads, (2) the system type (its associated heat-to-power ratio and thermal quality), (3) fuel costs and relative fuel costs, and (4) the price paid for steam and electricity (buy and sell). Prevailing policy and economic conditions define the degree to which these conditions determine the degree of cogeneration activity. These are the primary criteria used by the model to assess technology choice.

Access to the electricity grid for the sale of excess electricity and for back up power is a key driver of cogeneration development in Canada. Most jurisdictions in Canada provide access to the grid for transmitting power to wholesale customers (i.e., electricity distribution companies) but not to retail customers (i.e., electricity consumers). Net metering, the use of a single meter to measure the difference between the amount of electricity provided to the grid and the amount consumed from the grid, increases the viability of small scale cogeneration.[2] Currently, only Alberta and Ontario provide retail access for electricity transmission and only Nova Scotia provides net metering.

[1] The European Association for the Promotion of Cogeneration, A Guide to Cogeneration, March 2001

[2] Net metering allows a small-scale generator to sell and purchase electricity at the same price. In the absence of net metering, separate meters record electricity supplied to the grid and electricity purchased from the grid. The generator pays retail rates for the electricity it buys but receives only the avoided cost of energy for the electricity it supplies to the grid. In some cases, this price difference is very high.

Cogeneration in Canada

Table 1 displays the amount of new cogeneration installed in several time periods to illustrate the evolution of cogeneration in the various sub-sectors. There are two periods of significant growth in cogeneration. The first is in the 1970s and the second began in 1990 and is ongoing.

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. Three cogeneration systems installed in the 1970s (in the Petroleum Refining and Chemicals sectors) account for 64% of installed capacity.

Three dynamics may have stimulated the current period of growth in cogeneration. First, electric utilities across Canada responded to public protest over large-scale energy projects by encouraging the development of independent power projects (IPPs) to fulfill some of their resource requirements. Second, smaller cogeneration systems are becoming increasingly cost effective. And third, full retail access to the electricity grid in Alberta and pending access in Ontario has stimulated the development of large, grid-connected cogeneration systems (2.0 GW_e since 2000).

There are significant differences between cogeneration systems installed before 1990 and those installed after. Natural gas is the primary fuel used by 58 percent of cogeneration systems installed before 1990 and by over 90 percent of systems installed after 1990. And as shown in table 5, the size of cogeneration systems has changed considerably. Most cogeneration systems installed before 1990 were mid-sized (between 10 and 50 MW_e). Since 1990, most systems that have been installed are less than 10 MW_e while the number of facilities above 50 MW_e has more than tripled.

Cogeneration Scenarios

We describe here a method to estimate the technical and achievable potentials for cogeneration in Canada based on existing functions in CIMS, a model developed by the Energy and Materials Research Group at Simon Fraser University. This section defines the seven scenarios used to calculate cogeneration potential. We calculated the cogeneration potential under the first two scenarios, the total technical and the total achievable potentials, using the thermal load forecasts generated by CIMS for the years 1995 to 2015.[3] The results for the final five scenarios were generated directly by CIMS.

Total Technical and Total Achievable Potentials

The total technical potential for cogeneration is defined as the amount of cogeneration that would be installed if all thermal loads calculated by CIMS were met using cogeneration. The total achievable potential is the amount of cogeneration that could be installed when reasonable limitations are applied to the penetration of cogeneration.

[3] Results are tabulated at 5-year intervals.

Table 1. New Cogeneration Capacity (kW) by Year Installed*

Sector	< 1950	1950-59	1960-69	1970-79	1980-89	1990-94	1995-99	2000+	Total
Agriculture					450	12,885	5,250		**18,585**
Mining/ Quarry		1,600	35,000			1,400	102,000		**140,000**
Food	5,000	9,750			13,420	171,650	15,400		**215,220**
Beverage		7,500				5,000	450		**12,950**
Wood Prod.	7,500							20,000	**27,500**
Paper and Allied	71,512	180,600	150,000	257,200	164,500	403,200	358,000	362,000	**1,947,012**
Primary Metal	10,000								**10,000**
Transport Equip.						110,000	98,500	1,840	**210,340**
Petroleum Ref		7,500	68,000	314,000	19,500	157,700	299,000	676,000	**1,540,700**
Chemical Prod				361,000	71,031	50,000	236,150	1,150,000	**1,868,181**
Other Utilities					5,075	223,540	406,480	114,000	**749,095**
Federal Facilities						9,000	86,490	7,935	**104,425**
Education				600	2,400	40,660	8,200	3,000	**54,860**
Hospitals		800	18,000	14,200	19,930	71,705	1,700	6,700	**133,035**
Other Commerce						500		3,300	**3,800**
District Energy							150		**150**
Total	**94,012**	**207,750**	**271,000**	**947,000**	**296,306**	**1,257,240**	**1,617,770**	**2,344,775**	**7,035,853**
No. of plants	**7**	**10**	**10**	**17**	**20**	**50**	**40**	**21**	**175**
Average size	**13,430**	**20,775**	**27,100**	**55,706**	**14,815**	**25,145**	**40,444**	**111,656**	**40,205**

*The data do not include 53 cogeneration systems accounting for 700 MW of installed capacity contained in the CIEEDAC database because installation dates are not available.

Price and Policy Scenarios

In addition to the two total potential scenarios described above, we simulated five other scenarios using CIMS. The five price and policy scenarios are:

1. The **business-as-usual case (BAU)** simulates what would happen without any policy or price interventions. The results of this run are calibrated to Canada's Emissions Outlook Update generated by NRCan in 1999. Under this scenario, the penetration of cogeneration is fixed within the model.
2. The unconstrained case removes external limits on the penetration of cogeneration.

3. The promotion case discounts cogeneration technologies at 20% in the industrial sector and 15% in the commercial / institutional sector to simulate the impact of programs or policies that promote cogeneration.
4. The high electricity price (HEP) case increases the price of electricity by 50%.
5. The high fossil fuel price (HFP) case increases the price of all commercial cogeneration fuels by 50%. This has the effect of altering the relative price ratios in the various regions (and thus would give some different results by region).

The BAU case identifies the expected rate of cogeneration when CIMS is calibrated to the CEOU. The unconstrained case simulates the amount of cogeneration that would be expected without any external limits. The final three scenarios use the unconstrained case as their base to highlight changes and make comparisons.4

Assumptions and Results

There are many variables that govern how much cogenerated electricity and heat could be produced in Canada. These variables include the type of cogeneration system used, whether the system maximizes electricity production or heat production, and whether there are fuel constraints. This study used seven scenarios to examine a range of cogeneration potentials in Canada.

This section summarizes the results of the seven scenarios. The first two scenarios are the technical and achievable potentials. These two scenarios use the thermal demands generated by CIMS but calculate the amount of cogeneration potential outside of the model. In this case, we do not distinguish where the electricity is made by an industry, a commercial enterprise, an institution or by merchant cogenerators who sell both heat and electricity as products. The technical potential represents the maximum limit of cogeneration in Canada. The achievable potential uses reasonable limitations on the first scenario to what might be achievable in Canada. By estimating the degree to which an industry itself might cogenerate (e.g., under the unconstrained scenario defined below), one could estimate a rough estimate of the degree to which merchant cogeneration might take place as the difference between the two.

We used CIMS behavioural algorithms applied during simulations to generate the results for the remaining five scenarios. The first scenario, called Business-As-Usual (BAU), is calibrated to reflect CEOU and estimates the total cogeneration potential under existing conditions such that they align with results from the CEOU. The second scenario, the Unconstrained run relaxes fixed conditions in the model that were used to force CIMS to reflect the CEOU forecast. This run provides a base for the remaining three policy runs. The last three scenarios simulate various policy or pricing scenarios by changing one variable in the Unconstrained run.

All of the latter five scenarios exclude merchant cogeneration plants such as those currently being installed in Alberta and Ontario.[5] Typically, these plants are built, owned and operated by an energy company and sell heat and electricity to local industries or commercial facilities with surplus electricity fed to the grid. They tend to maximize electricity production by using combined cycle cogeneration systems. They are excluded

[4] Only one variable is changed in each scenario compared to the unconstrained case.
[5] The technical potential scenario would include, by default (not explicitly), merchant cogenerators.

from this analysis because CIMS is not currently set up to model these plants as they require both an electric and a heat distribution system. While electricity distribution is well understood, the transmission of heat intones distributed generation facilities where the heat need not travel long distances from source to end-use. The cogeneration potential under all scenarios would be higher than shown in this study if these plants were included in the analysis. But it is difficult to assess the degree to which this occurs because industries could separate cogeneration facilities from the actual plant (i.e., the firm may have a different firm cogenerate their electricity and heat; cogeneration then may take place on site and still be considered out side of plant boundaries). We are not able to estimate the degree to which this may take place.

Total Technical and Achievable Cogeneration Potentials

We calculated two scenarios that set the technical and achievable limits for cogeneration potential in Canada. The technical potential assumes that all thermal demands are met from cogeneration systems with a low heat-to-power (h/p) ratio of 2:1 in the industrial[6] sector and 0.9:1 in the commercial / institutional[7] and residential sectors. The second scenario, a more realistic achievable potential, incorporates reasonable limits on cogeneration to account for limiting factors such as facility size, fuel capacity, low thermal load intensities and facility isolation. CIMS generated the thermal demands (steam, direct heat and hot water) used in the calculations. The thermal demands for the industrial, commercial / institutional and residential sectors were simulated under the BAU scenario, calibrated to CEOU. Results are tabulated for the years 1995, 2000, 2005, 2010 and 2015.

Results – Technical Potential

Table 2 displays the results of the technical potential scenario by sector. The total technical cogeneration potential in 1995 is estimated to be 89.4 GW_e. This is approximately 82% of Canada's total electricity generating capacity in 1998.[8] By 2015, the technical potential is 111 GW_e, 100% of current electricity generating capacity. To achieve this level of cogeneration capacity, fuel consumption would rise by roughly 41% in the industrial sector and 92% in the commercial / institutional and residential sectors.

Table 2. Total Technical Potential (MW_e)

Sector	1995	2000	2005	2010	2015
Industrial	21,206	23,673	25,669	27,163	29,808
Commercial/institutional	15,203	17,853	19,287	20,888	22,641
Residential	52,984	54,794	54,576	55,962	58,521
Total	**89,393**	**96,319**	**99,532**	**104,013**	**110,971**

[6] The industrial sector consists of 6 sub-sectors; pulp and paper, chemicals, iron and steel, metals, other manufacturing and refining.
[7] The commercial / institutional sector consists of 9 sub-sectors: warehouse / wholesale, large retail, small retail, large office, small office, hospitals / nursing homes, schools / universities, hotels / motels and miscellaneous.
[8] Estimated to be 110 GWe by the Canadian Electricity Association.

Results – Achievable Potential

Table 3 shows the achievable potential for the industrial, commercial / institutional and residential energy sectors of Canada expressed in MW_e.

Table 3. Total Achievable Cogeneration Potential (MW_e)

Sector	1995	2000	2005	2010	2015
Industrial	13,769	15,341	16,596	17,554	19,249
Commercial / institutional	6,350	7,532	8,165	8,856	9,616
Residential	13,246	13,698	13,644	13,990	14,630
Total	**33,365**	**36,571**	**38,405**	**40,401**	**43,495**

Putting reasonable restraints on the penetration of cogeneration in Canada drops the achievable potential in 1995 from 89.4 GW_e to 33.4 GW_e, a reduction of 63%. Over 70% of the reduction happens in the residential sector, 16% in the commercial / institutional sector and 13% in the industrial sector. In 2015, the reduction in cogeneration potential is 61%, slightly less than in 1995 with 65% of the reduction happening in the residential sector, 19% in commercial / institutional and 16% in industrial. The achievable scenario results in fuel increases of only 12% in the industrial sector and 27% in the commercial / institutional and residential sectors. Here the role of merchant cogeneration facilities could be increased, provided a suitable heat sink able to utilize commercial / institutional and residential demands are available.

Policy and Price Scenarios

We use CIMS to generate results in the industrial and commercial / institutional sectors for the following five scenarios. CIMS estimates the level of cogeneration potential that would result and the degree to which it is altered by changing key parameters. For the residential sector, we use data from the Municipalities Table Options Paper and other information to estimate cogeneration potential.[9]

CIMS uses discount rates, a probabilistic variance parameter, external limits and non-cost parameters to define different scenarios. Discount rates are intended to reflect the rate of return that companies expect from energy investments, one of the model's reflections of behaviour. The probabilistic variance parameter turns single point costs (capital and operating) into a probability distribution. Consumer choice is indifferent in the region where the cost distributions of two competing technologies overlap. Thus, the "cheapest" technology does not win 100% of the market because, under some conditions, it is, in fact, not the cheapest technology. The data used to define the degree of variability in the probability distribution are derived from literature studies on variability in purchases made among consumers.[10] External limits are used to reflect portions of the market that would not be eligible for certain technologies due to size or technical limitations. Non-cost parameters

[9] Cogeneration in the residential sector is assumed to be in the form of district energy systems not individual systems.
[10] Among other studies, this includes logit and probit types of analyses, often based on discrete choice assessments and analyses.

are used to simulate market barriers that reduce the penetration of a technology below what would be considered economic.

Price and Policy Scenarios

This section describes the parameters used by CIMS to simulate the five scenarios for the industrial and commercial / institutional sectors. It also describes the assumptions made to calculate the cogeneration potential in the residential sector under each scenario.

Business-As-Usual (BAU)

For the BAU scenario, CIMS was calibrated to reflect NRCan's 1999 update of Canada's Emissions Outlook (CEOU). This involved using NRCan and secondary information to match the CEOU assumptions and outputs on: (1) economic output, (2) structural change, (3) major technology and process developments, (4) energy use, and (5) emissions.

For the BAU, the following parameters were used in CIMS for the industrial and commercial / institutional sectors:

1. Industrial sector discount rates for new technologies including cogeneration technologies were set at 50% (reflecting a standard two year payback).
2. Commercial / institutional sector discount rates were set at 40% for private sector facilities, 30% for public sector facilities and 35% for cogeneration technologies.
3. The penetration of cogeneration in each industrial sector was set exogenously
4. The penetration of cogeneration in the commercial / institutional sector was limited to a percentage of each building type.
5. Cogeneration is not an option to provide hot water in the commercial / institutional sector.
6. Non-cost parameters are applied to industrial sector technologies to calibrate CIMS results to the CEOU. These parameters remain the same for each of the five scenarios.
7. Non-cost parameters are applied to cogeneration technologies in the commercial / institutional sector. These parameters effectively increase the cost of cogeneration technologies by an additional 10% in Alberta and Ontario and 20% in all other regions.
8. For the residential sector, we assumed that the penetration of cogeneration under the BAU scenario would be close to zero. We found no data to suggest that cogeneration will penetrate this sector to a significant degree.

Unconstrained Scenario

The Unconstrained scenario is the same as the BAU except the industrial sector cogeneration limits are removed and the commercial / institutional sector non-cost parameters are removed.

Promotion Scenario

The Promotion scenario is the same as the Unconstrained scenario except the discount rate for cogeneration technologies is reduced to 20% in the industrial sector and 15% in the commercial / institutional sector and cogeneration was assumed to penetrate the residential sector by 20% in the year 2015 (1% per year starting in 1995) through district energy systems.[11]

High Electricity Price (HEP) Scenario

The HEP scenario is the same as the Potential scenario except in the commercial / institutional and industrial sectors the price of electricity is 50% higher in all regions and cogeneration was assumed to penetrate the residential sector by 5% in 2015 (0.25% per year) through district energy systems.[12]

High Fuel Price (HFP) Scenario

The HFP scenario is the same as the Unconstrained Scenario except in the commercial / institutional and industrial sectors, the prices of natural gas, coal and oil are 50% higher in all regions.

Results

The following four tables summarize the results of the five policy and price scenarios. The High Electricity Price Scenario suggests that 7.1 GWe of cogenerated electricity would be available by 2015 with the residential sector contributing most of the increase (3.0 GWe, see Table 11, more than double the Unconstrained Scenario. High electricity prices make cogeneration an attractive option resulting in an increase over the unconstrained case. Finally, cogeneration potential under the High Fuel Price (HFP) Scenario is lower than the Unconstrained Scenario; raising the price of fossil fuels makes cogeneration a less desirable option. The industrial sector dropped 300 MWe

Table 4 summarizes the results of the scenarios for all sectors. The total cogeneration potential under the BAU Scenario is 2.2 GW_e in 2015. The potential increases under the Unconstrained Scenario to 3.0 GW_e. Most of this increase (600 MW_e) occurs in the commercial / institutional sector (see table 10). If one could effectively promote cogeneration (the Promotion scenario), one could realize a 7-fold increase in cogenerated electricity in 2015, to about 21 GW_e. In this case, the majority of the increase (11.7 GW_e) comes from residential sector (district energy, see Table 11)

The High Electricity Price Scenario suggests that 7.1 GW_e of cogenerated electricity would be available by 2015 with the residential sector contributing most of the increase (3.0 GW_e, see Table 11, more than double the Unconstrained Scenario. High electricity prices make cogeneration an attractive option resulting in an increase over the unconstrained case. Finally, cogeneration potential under the High Fuel Price (HFP) Scenario is lower than the

[11] This estimate is based on the results of the MUN023 group of measures in the Municipalities Table Options Paper, Final Report, December 1999.

[12] This estimate is based on the results of the MUN022 group of measures in the Municipalities Table Options Paper, Final Report, December 1999.

Unconstrained Scenario; raising the price of fossil fuels makes cogeneration a less desirable option. The industrial sector dropped 300 MW_e

Table 4. Cogeneration Potential under CIMS Scenarios – All Sectors (MW_e)

Scenario	1995	2000	2005	2010	2015
BAU	723	1,252	1,470	1,824	2,163
Unconstrained	723	1,364	1,921	2,385	2,989
Promotion	723	5,967	10,724	15,532	20,950
HEP	723	2,049	3,712	5,277	7,138
HFP	723	1,242	1,662	2,038	2,530

Conclusions

To summarize, if we assume that all heat loads in industrial, commercial / institutional and residential sectors can be met with cogeneration technologies that have low heat to power ratios (2:1 in industry and 0.9:1 in the other sectors), one could generate enough to supply about 80% of Canada's electricity demand. If we take a more realistic approach, cogeneration could provide 30% of Canada's current electricity needs.

The results generated by CIMS under five scenarios reflecting certain policy parameters show the estimated cogeneration potential. The business-as-usual (BAU) scenario predicts the lowest penetration of cogeneration, 2.1 GW_e in 2015. Removing the constraints to cogeneration imposed when CIMS was calibrated to reflect Canada's Emissions Outlook Update increases the potential for cogeneration to 3.0 GW_e in 2015. Changes in discount rates have a dramatic impact on cogeneration potential, increasing it to 21 GW_e in 2015. When the price of electricity increases by 50%, the results indicate that the potential for cogeneration increases to 7.1 GW_e in 2015. Finally, an increase of 50% in commercial fossil fuel prices would decrease the demand for cogeneration (when compared to the unconstrained scenario) to 2.5 GW_e.

In any modelling assessment, there are conditions and primary assumptions that must be understood in terms of the results. The following general conclusions can be made about the results presented:.

1. The results presented above are not predictive but illustrative of the impacts of various policies and prices on the amount of cogeneration in Canada. They can provide a degree of belief in the potential that various programs may have but cannot give precise or absolute answers to future outcomes.
2. While the outcomes cannot indicate the reasons for low penetration of cogeneration under the BAU and Unconstrained Scenarios (i.e., the specific barriers), they do show the range of outcomes if we are able to counteract some of these barriers. This sort of information is valuable to the decision maker as it provides both a point of focus and a sector of focus.
3. The results are "sector driven" meaning that they reflect the behaviour and decision criteria of the thermal hosts in each sector. Therefore, the amount of cogeneration that is considered desirable under each scenario is limited by each facility trying to match their heat load without increasing fossil fuel energy consumption. This guideline is also helpful in understanding the focus of future policies and programs.

4. CIEEDAC's Cogeneration Database shows installed cogeneration capacity in the industrial sector to be 4.2 GWe in 2000. Both Total Potential runs show that much more exist even if we just consider the Achievable potential. On the other hand, all five Price and Policy Scenarios show dramatically less cogeneration potential in the industrial sector. Much of this difference can be attributed to the exclusion of merchant cogeneration plants in CIMS (which account for almost 3 GWe of cogeneration capacity in 2002 according to the CIEEDAC database) and the willingness of some industrial facilities to increase their fuel consumption in order to maximize electricity production in regions with open electricity markets (see point 3 above).
5. CIEEDAC's Cogeneration Database shows installed cogeneration capacity in the commercial / institutional sector to be 320 MWe in 2000. In the commercial / institutional sector only the BAU shows less cogeneration, while the Unconstrained, HEP and HFP scenarios have slightly higher installed capacities. This difference will likely diminish as CIEEDAC further investigates existing commercial / institutional sector cogeneration. It speaks in favour of the present strength of the model and points to continued review of the modelling system as a basic requirement.
6. The Total (Technical and Achievable) Potential scenarios cannot be reasonably compared to the Policy and Price scenarios because the former assumes that all thermal loads are available for cogeneration, that cogeneration fuels are unlimited and that most existing heat generating equipment would be replaced. It also ignores technical and economic barriers to cogeneration. However, it does provide a useful upper boundary to possible penetration of cogeneration technologies.

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