# Energy Consumption and Emissions in Small and Medium-Sized Industry

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## ABSTRACT

The industrial sector uses about forty percent of the electricity, natural gas and residual fuel oil consumed in Canada, and it is thus a major contributor to Canadian emissions of greenhouse gases. A major Canadian government initiative to reduce industrial sector greenhouse gas emissions is the Dollars to Sense program. This program provides small and medium-sized Canadian businesses with a set of three workshops that help participants find and implement energy cost savings measures and reduce emissions. This study found that the Dollars to Sense program led to annual industrial energy savings of 3,186 TJ and annual emissions reductions of 197 kilotonnes of carbon dioxide equivalent.

## Introduction

The industrial sector uses about forty percent of the electricity, natural gas and residual fuel oil consumed in Canada, and it is thus a major contributor to Canadian emissions of greenhouse gases. Major uses of electricity, natural gas and residual fuel oil in Canadian industry include water and process heat, space conditioning, process cooling and refrigeration, fans, pumps, compression, conveyance, electro-chemical processes, lighting and a wide variety of motor systems. A major Canadian government initiative to reduce industrial sector greenhouse gas emissions is the Dollars to Sense program. This program provides small and medium-sized Canadian businesses with a set of three workshops that help participants identify, plan, implement and monitor energy cost savings measures and reduce emissions. In summary, the purpose of the Dollars to Sense program is to help participants find and implement energy savings measures and address climate change issues.

Dollars to Sense includes three coordinated workshops for energy managers, energy services professionals and senior decision makers. The workshops are administered by Natural Resources Canada (NRCan) but delivered by private sector energy professionals. The structure and content of the workshops are periodically reviewed and modified in response to evolving client requirements and needs. In addition, customized workshops for participants in a single facility are offered.

A brief summary of the three workshops is as follows. In the Energy Master Plan Workshop, participants learn to develop and implement a comprehensive energy management plan including assembling an appropriate team, using financing options and developing cost-effective energy solutions. In the Energy Monitoring and Tracking Workshop, participants learn to save money on energy costs by collecting data, developing an energy use baseline, analyzing energy use and establishing and implementing an improvement plan. In the Spot the Energy Savings Opportunities Workshop, participants learn to identify and capitalize on immediate savings opportunities including reviewing energy basics, identifying opportunities in electrical and thermal processes and assessing and quantifying benefits. Some 2,000 industrial sector representatives have attended one or more Dollars to Sense workshops.

This paper reports on discrete choice modeling and engineering analysis that was used to estimate the impact of the Dollars to Sense program. The program impacts examined include retrofit actions undertaken, energy savings due to these actions, and consequent reductions in greenhouse gas emissions in the Canadian industrial sector.

## Background and Method

A number of recently published studies examine energy use in industrial facilities. BC Hydro 1991a, 1991b, and 1991c examine overall energy use as well as key technologies including fans, pumps and motors. Friedman 2001 provides similar information for California industrial energy use. Industry Canada 1996 and Jaccard et al 2003 examine opportunities for energy efficiency in Canadian industry. Taken as a group, these studies have found that the industrial sector has a number of cost-effective technologies which can reduce energy use and greenhouse gas emissions.

Since large industrial establishments often have on-site energy managers and specialized in-house engineering expertise, the Dollars to Sense program has focused on small and medium-sized establishments (SME). Because the program's industrial participants were typically small and medium-sized establishments, it was agreed that the focus of the study would be on industrial establishments with 500 employees or fewer. Focus groups were held in Montreal and Toronto to better understand how energy use decisions are made, the factors affecting these decisions, and the key technologies installed as a result of program participation.

Following a detailed literature review and interviews with program managers and staff, five main substantive issues were identified for study. The issues were:

(1) estimate industrial sector energy consumption by facility, by end use and by fuel;
(2) develop gross measure savings rates for the most important energy saving technologies;
(3) estimate the attribution rate or share of the market impacts on installation of energy saving technologies due to the program;
(4) determine program impact on energy savings due to installation of energy savings technologies; and
(5) determine program impact on greenhouse gas emissions in terms of kilotonnes of carbon dioxide equivalent.

**Table 1. Issues, Data Source and Methodologies**

| Study Issue | Data Sources | Methodologies |
|---|---|---|
| Estimate end use consumption | Customer survey<br>NRCan and DOE data<br>Focus groups | Engineering algorithms |
| Develop gross measure savings estimates | File review<br>Literature review<br>Focus groups | Engineering algorithms |
| Estimate attribution rates | Customer survey<br>NRCan data | Logit regression |
| Determine energy savings | Customer survey<br>NRCan data | Engineering algorithms |
| Determine emission savings | Customer survey<br>NRCana data | Engineering algorithms |

## Analysis

The initial step was the development of detailed end use consumption estimates for small and medium-sized industrial establishments. Industry Canada provided information on energy consumption by facility type, facility size, information on energy shares by major end use, and total energy consumption per square meter. Since the end use information was more aggregated than desired for this analysis, the detailed spreadsheets from United States Department of Energy were used to develop energy consumption shares for thirteen end uses. The resulting estimated end use shares were then checked with experts from the Office of Energy Efficiency to ensure that they were reasonable.

Table 2 provides estimates of consumption in GJ per year and consumption shares as decimal fractions. Average consumption for the facilities was about 101,858 GJ per year with the main end uses including other machine drives (25,913 GJ per year), pumps (12,795 GJ per year), water and process heating (10,878 GJ per year), electro-chemical processes (10,614 GJ per year), space heating (7,975 GJ per year) and compressed air (7,007 GJ per year).

**Table 2. Estimated SME Industrial Energy Consumption by End Use 2002**

| End Use | Consumption (JG per year) | Share |
|---|---|---|
| Water and process heat | 10,878 | 0.107 |
| Cooking | 1,020 | 0.010 |
| Process cooling and refrigeration | 6,264 | 0.062 |
| Pumps | 12,795 | 0.126 |
| Fans and blowers | 5,276 | 0.052 |
| Compressed air | 7,007 | 0.069 |
| Conveyance | 5,378 | 0.053 |
| Other machine drives | 25,913 | 0.254 |
| Electro-chemical processes | 10,614 | 0.104 |
| Space heating | 7,975 | 0.078 |
| Space cooling | 693 | 0.007 |
| Facility lighting | 6,804 | 0.067 |
| Other uses | 1,221 | 0.012 |
| Total | 101,858 | 1.000 |

The second step was the estimation of gross energy savings ratios. These ratios are estimates of the share of energy for that end use that will be saved on average through the installation of the efficient as opposed to the standard version of the technology. A wide variety of sources including Natural Resources Canada publications, technical reports on utility commission and program evaluation web sites, journal and conference literature and utility reports were reviewed to determine estimates of energy savings for key technologies. The gross measure savings ratio was estimated by the equation savings $\text{ratio}_i = (1 - \text{efficiency}_{st}/\text{efficiency}_{ef})$, where the savings ratio is the ratio applied to the end use consumption for a given measure and $\text{efficiency}_{st}$ and $\text{efficiency}_{ef}$ are the percentage efficiency levels of the standard and the efficient technologies for the relevant end use.

Table 3 provides estimates of savings by measure and by end use, for the most commonly used measures, as identified during focus groups with energy managers of industrial facilities held in Montreal and Toronto. In order to keep the customer survey manageable, emphasis was placed on those measures which were responsible for the bulk of expected savings. Note that the savings ratios vary substantially from a low of 0.042 for replacement of a less than 5 horse power standard efficient motor with a high efficiency motor to a high of 0.750 for replacement of a type-A incandescent lamp with a CFL.

**Table 3. Measure Savings**

| Measure | End Use | Standard Efficiency | High Efficiency | Savings Ratio |
|---|---|---|---|---|
| Drive/controls | Fans and blowers | Control vane 75% | ASD 95% | 0.211 |
| Fan motor 1-5HP | Fans and bowers | Standard 83.3% | High 87.5% | 0.048 |
| Drive/controls | Pumps | Control valve 80% | ASD 75% | 0.158 |
| Pump motor 6-25HP | Pumps | Standard 86.3% | High 95.1% | 0.042 |
| Drive/controls | Compressed air | Control throttle 83% | ASD 95% | 0.126 |
| Com motor 1-5HP | Compressed air | Standard 83.3% | High 87.5% | 0.048 |
| Reduce air leaks | Compressed air | Average leaks 75% | Reduced leaks 85% | 0.118 |
| Coupling/drive | Conveyance | Worm gear/v belt/helical 85% | ASD 75% | 0.105 |
| Con motor 6-25HP | Conveyance | Standard 86.3% | High 90.1% | 0.042 |
| Coupling/drive | Other process | Worm gear/v belt/helical 85% | ASD 95% | 0.105 |
| Other motor 6-25HP | Other process | Standard 86.3% | High 90.1% | 0.042 |
| Ovens | Cooking | Standard | Microwave | 0.100 |
| Mid-efficiency boiler | Space, process, water heat | Std efficiency 75% | Mid efficiency 85% | 0.118 |
| Hi-efficiency boiler | Space, process, water heat | Std efficiency 75% | High efficiency 95% | 0.167 |
| Mid-efficiency furnace | Space heating | Std efficiency 65% | Mid-efficiency 78% | 0.167 |
| Hi-efficiency furnace | Space heating | Std efficiency 65% | Condensing 90% | 0.278 |
| Economizer | Space cooling | No economizer | Air side economizer | 0.100 |
| Drive/controls | Refrigeration | Standard 85% | ASD 95% | 0.105 |
| CFL | Lighting | Type A 6% | CFL 24% | 0.750 |
| T8 | Lighting | T12 24% | T8 25.5% | 0.059 |
| HID lamps | Lighting | Mercury vapor 15% | HID 30% | 0.500 |
| Roof insulation | Space heating | Std 0.95W/m$^2$/°C | Std 0.48W/m$^2$/°C | 0.500 |
| Wall insulation | Space heating | Std 0.70W/m$^2$/°C | Std 0.35W/m$^2$/°C | 0.500 |

The third step was to estimate the impact of the program on installation of energy efficient technologies, using the following models, $install_i$ = F(participant, industrial dummy, rate). $Install_i$ takes the value 1 if measure i is installed, but it is 0 otherwise. Participant takes the value 1 for workshop participants but is 0 otherwise. Rate is the average rate paid by commercial customers by service territory in dollars per MWh equivalent. Industrial takes the value 1 if the customer is in the forestry, mining or manufacturing sectors but takes the value 0 otherwise. The equations were estimated using logit regression, with standard errors shown in parentheses, because ordinary least squares regression would provide biased estimates of customer installation decisions. It is worth noting that if p is the probability of installing an efficient technology, then the logit is given by the log (p/1 – p), and it is rather naturally referred to as the log of the odds ratio, since the odds ratio is the ratio of the probability of installing an efficient technology divided by the probability of not installing an efficient technology. Mathematically, the logit function is the inverse of the sigmoid or logistic function, which is commonly used to model diffusion of a new technology.

**Table 4. Attribution Analysis**

| | Constant | Participation | Industrial | Electricity Rate | Chi-squared |
|---|---|---|---|---|---|
| Fans | -.358<br>(0.873) | 0.742<br>(0.268) | -1.155<br>(0.427) | -0.034<br>(0.014) | 16.31<br>(0.001) |
| Pumps | -0.838<br>(0.706) | 0.773<br>(0.257) | 0.450<br>(0.388) | -0.015<br>(0.012) | 10.91<br>(0.012) |
| Compressed air | -2.383<br>(0.997)) | 1.053<br>(0.335) | 0.364<br>(0.456) | -0.001<br>(0.015) | 13.13<br>(0.004) |
| Conveyance | -4.719<br>(1.631) | 1.105<br>(0.544) | 1.912<br>(0.730) | 0.003<br>(0.025) | 19.24<br>(0.000) |
| Other process | -2.335<br>(1.058) | 0.789<br>(0.346) | 0.393<br>(0.486) | -0.007<br>(0.106) | 8.05<br>(0.045) |
| Efficient oven | -3.467<br>(1.515) | 0.012<br>(0.510) | -0.026<br>(0.782) | 0.001<br>(0.022) | 0.11<br>(0.99) |
| Mid-efficiency boiler | -0.847<br>(0.880) | 1.067<br>(0.294) | -1.949<br>(0.531) | -0.017<br>(0.014) | 32.89<br>(0.000) |
| Hi-efficiency boiler | 0.215<br>(1.063) | 0.542<br>(0.334) | -2.869<br>(0.816) | -0.030<br>(0.017) | 23.79<br>(0.000) |
| Mid-efficiency furnace | -0.544<br>(1.038) | 0.956<br>(0.330) | -1.232<br>(0.519) | -0.030<br>(0.016) | 15.08<br>(0.002) |
| Hi-efficiency furnace | -0.400<br>(1.437) | 0.822<br>(0.448) | 1.265<br>(1.138) | -0.039<br>(0.023) | 23.60<br>(0.000) |
| Economizer | -0.773<br>(0.851) | 0.308<br>(0.272) | -0.634<br>(0.428) | -0.015<br>(0.013) | 3.58<br>(0.311) |
| Efficient refrigeration | -2.206<br>(0.892) | 1.221<br>(0.312) | 0.585<br>(0.428) | -0.002<br>(0.014) | 19.66<br>(0.000) |
| CFL | -0.449<br>(0.659) | 1.614<br>(0.221) | -0.925<br>(0.334) | -0.001<br>(0.010) | 67.02<br>(0.00) |
| T8 | 0.464<br>(0.681) | 1.606<br>(0.228) | -1.643<br>(0.353) | -0.021<br>(0.011) | 76.86<br>(0.00) |
| HID lamps | -0.957<br>(0.692) | 0.914<br>(0.226) | 0.004<br>(0.336) | -0.001<br>(0.013) | 17.69<br>(0.001) |
| Roof insulation | -1.876<br>(0.860) | 0.490<br>(0.285) | -0.290<br>(0.435) | -0.001<br>(0.013) | 3.68<br>(0.298) |
| Wall insulation | -2.765<br>(0.957) | 0.759<br>(0.326) | -0.012<br>(0.473) | 0.005<br>(0.014) | 5.95<br>(0.114) |

The fourth step was the estimation of energy savings. Energy savings were estimated for each measure where energy savings for measure i is the product of the use rate, the savings rate, the partial effect as calculated from the logit model and the number of participants. Note that the partial effect or the estimated impact of program participation on the install decision is the partial derivative of the likelihood with respect to the program participation variable in the equations in Table 3 above. Table 4 provides estimated energy savings in gigajoules (GJ) for each measure and end use examined. Note that for lighting products savings are adjusted for the assumed share of connected lighting load of 0.100 for screw type lamps, 0.800 for linear fluorescent tubes and 0.100 for high intensity discharge lighting. Note also that for insulation products savings are adjusted for the assumed share of heat loss of the opaque components of 0.500 for walls and 0.500 for roofs. Total measure savings were 3,186.2 TJ. The most important measures and their savings included mid-efficiency boilers (421.9 TJ), efficient fan systems (219.6 TJ), efficient pump systems (473.3 TJ), efficient compressed air systems (319.5 TJ), CFLs (307.8 TJ), other process equipment (398.5 TJ) and T8 tubes (199.2 TJ).

**Table 5. Energy Savings Analysis**

| Measure | End use | End Use per Facility (GJ) | Savings Rate | Partial Effect | Number of Participants | Energy Savings (TJ) |
|---|---|---|---|---|---|---|
| Efficient fans and motors | Fans | 5,276 | 0.259 | 0.106 | 1,516 | 219.6 |
| Pumps and motors | Pumps | 12,795 | 0.200 | 0.122 | 1,516 | 473.3 |
| Compression, leaks, motors | Compression | 7,007 | 0.292 | 0.103 | 1,516 | 319.5 |
| Conveyance and motors | Conveyance | 5,378 | 0.147 | 0.032 | 1,516 | 38.4 |
| Other process and motors | Other process | 25,913 | 0.147 | 0.069 | 1,516 | 398.5 |
| Efficient oven | Oven | 1,020 | 0.100 | 0.004 | 1,516 | 0.7 |
| Mid-eff boiler | Space, water, [process heat | 18,853 | 0.118 | 0.125 | 1,516 | 421.9 |
| Hi-eff boiler | Space, water, process heat | 18,853 | 0.167 | 0.040 | 1,516 | 188.5 |
| Mid-furnace | Space heating | 7,975 | 0.167 | 0.092 | 1,516 | 185.1 |
| Hi-furnace | Space heating | 7,975 | 0.278 | 0.003 | 1,516 | 8.7 |
| Chiller | Space cooling | 693 | 0.100 | 0.042 | 1,516 | 4.4 |
| Hi-efficiency refrigerator | Process cool | 6,264 | 0.105 | 0.142 | 1,516 | 141.5 |
| CFL | Lighting | 6,804 | 0.075 | 0.398 | 1,516 | 307.8 |
| T8 | Lighting | 6,804 | 0.050 | 0.386 | 1,516 | 199.2 |
| HID | Lighting | 6,804 | 0.047 | 0.189 | 1,516 | 91.6 |
| Roof insulate | Space heating | 7,957 | 0.038 | 0.061 | 1,561 | 28.1 |
| Wall insulate | Space heating | 7,957 | 0.176 | 0.075 | 1,516 | 159.4 |
| Total | | | | | | 3,186.2 |

The fifth step was the estimation of emissions savings, which were measured in terms of kilotonnes of carbon dioxide equivalent. This is a useful summary measure that aggregates the impacts of the various emissions produced through the use of a particular energy source or fuel. Carbon dioxide savings, disaggregated by fuel for the ith measure, are the product of energy savings for the measure multiplied by the fuel specific emission factor.

The emission factors, which were supplied by Natural Resources Canada, are: (1) electricity – 64.23 tonnes of $CO_2E$ per TJ; (2) natural gas – 50.45 tonnes of $CO_2E$ per TJ; (3) fuel oil – 75.43 tonnes of $CO_2E$ per TJ; and (4) fossil fuels – 56.79 tonnes of $CO_2E$ per TJ. The latter estimate is based on a fuel split of 74.6% natural gas and 25.4% fuel oil. Disaggregated information was not available which would allow a more detailed breakdown between natural gas and residual fuel oil by end use.

Total annual emissions reductions were 197.4 kilotonnes of $CO_2$. The most important measures and their savings included mid-efficiency boilers (24.0 kilotonnes of $CO_2$), efficient fan systems (14.1 kilotonnes of $CO_2$), efficient pump systems (30.4 kilotonnes of $CO_2$), efficient compressed air systems (20.5 kilotonnes of $CO_2$), CFLs (19.8 kilotonnes of $CO_2$), other process equipment (25.6 kilotonnes of $CO_2$) and T8 tubes (12.8 kilotonnes of $CO_2$).

**Table 6. Emissions Reduction Analysis**

| Measure | End Use | Energy Savings (TJ) | Main Fuel | Emissions Factor | Carbon Dioxide Reduction (kilotonnes) |
|---|---|---|---|---|---|
| Efficient fans and motors | Fans | 219.6 | Electricity | 64.23 | 14.1 |
| Pumps and motors | Pumps | 473.3 | Electricity | 64.23 | 30.4 |
| Compression, leaks, motors | Compression | 319.5 | Electricity | 64.23 | 20.5 |
| Conveyance and motors | Conveyance | 38.4 | Electricity | 64.23 | 2.5 |
| Other process and motors | Other process | 398.5 | Electricity | 64.23 | 25.6 |
| Efficient oven | Oven | 0.7 | Gas/oil | 56.79 | 0.0 |
| Mid-eff boiler | Space, water, process heat | 421.9 | Gas/oil | 56.79 | 24.0 |
| Hi-eff boiler | Space, process, water heat | 188.5 | Gas/oil | 56.79 | 10.7 |
| Mid-furnaceN | Space heating | 185.1 | Gas/oil | 56.79 | 10.5 |
| Hi-furnace | Space heating | 8.7 | Gas/oil | 56.79 | 0.5 |
| Chiller | Space cooling | 4.4 | Electricity | 64.23 | 0.3 |
| Hi-efficiency refrigerator | Process cooling | 141.5 | Electricity | 64.23 | 9.1 |
| CFL | Lighting | 307.8 | Electricity | 64.23 | 19.8 |
| T8 | Lighting | 199.2 | Electricity | 64.23 | 12.8 |
| HID | Lighting | 91.6 | Electricity | 64.23 | 5.9 |
| Roof insulation | Space heating | 28.1 | Gas/oil | 56.79 | 1.6 |
| Wall insulation | Space heating | 159.4 | Gas/oil | 56.79 | 9.1 |
| | | 3,186.2 | | | 197.4 |

## Summary and Conclusions

The study has three main conclusions as follows. First, average annual energy consumption for small and medium-sized industrial facilities was about 102,000 GJ per year with the main end uses including other machine drives (25,900 GJ per year), pumps (12,795 GJ per year), water and process heating (10,878 GJ per year), electro-chemical processes (10,600 GJ per year), space heating (8,000 GJ per year) and compressed air (7,000 GJ per year).

Second, total savings attributable to the Dollars to Sense program were 3,186.2 TJ. The most important measures and their savings included mid-efficiency boilers (421.9 TJ), efficient fan systems (219.6 TJ), efficient pump systems (473.3 TJ), efficient compresses air systems (319.5 TJ), CFLs (307.8 TJ), other process equipment (398.5 TJ) and T8 tubes (199.2 TJ).

Third, total annual emissions reductions attributable to the Dollars to Sense program were 197.4 kilotonnes of $CO_2E$. The most important measures and their savings included mid-efficiency boilers (24.0 kilotonnes of $CO_2$), efficient fan systems (14.1 kilotonnes of $CO_2$), efficient pump systems (30.4 kilotonnes of $CO_2$), efficient compressed air systems (20.5 kilotonnes of $CO_2$), CFLs (19.8 kilotonnes of $CO_2$), other process equipment (25.6 kilotonnes of $CO_2$) and T8 tubes (12.8 kilotonnes of $CO_2$).

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