# MARKET STUDY ON WASTE HEAT AND REQUIREMENTS FOR COOLING AND REFRIGERATION IN CANADIAN INDUSTRY:

# OPPORTUNITIES FOR HEAT PUMPING TECHNOLOGIES

*Daniel Giguère, Eng, Technology expert, CETC-Varennes, Natural Resources Canada, 1615 Blvd. Lionel-Boulet, Varennes, Québec, Canada*

*Richard Trottier, Eng, M.A.Sc., Senior Engineer, CETC-Varennes, Natural Resources Canada, 1615 Blvd. Lionel-Boulet, Varennes, Québec, Canada*

**Abstract:** Natural Resources Canada recently assessed the industrial opportunities to recover thermal energy from waste streams. Such thermal sources, both in principle and in practice, can be upgraded and reused in industrial operations involving process heating, cooling and refrigeration. The Canadian economy features many industrial sectors that, from a technical viewpoint, offer opportunities for thermal waste stream recovery. A market study was performed to quantify the individual thermal waste streams of eighteen (18) Canadian industrial processes. These streams constitute a theoretical market for energy recovery and upgrading technologies. The objective of the study was to provide information on the following:

- Thermal waste streams, characterized by discharged energy content and temperature range; and
- Cooling and refrigeration needs, characterized by energy content and temperature range.

The study results constitute an approximate guide to the market potential for recovery technologies that target thermal waste streams.

**Key Words:** ***heat pump, industrial waste heat, market study***

## 1 INTRODUCTION

The CANMET Energy Technology Centre - Varennes (CETC–Varennes) is one of three research and innovation centres, managed by the CANMET Energy Technology Branch of Natural Resources Canada (NRCan). CETC-Varennes' mission is to encourage targeted sectors of the Canadian economy to reduce their greenhouse gas (GHG) emissions, use energy more sustainably, and improve their innovation capabilities. CETC-Varennes designs and implements technological solutions. It also gathers and disseminates knowledge aimed at producing and using energy in ways that are more efficient and sustainable, and at stimulating the Canadian economy.

In order to achieve its energy efficiency and greenhouse gas abatement objectives, CETC-Varennes is currently assessing opportunities for the recovery of thermal energy from industrial waste streams. Both in principle and in practice, such thermal sources can be upgraded and reused in industrial operations involving process heating, cooling and refrigeration. The Canadian economy features many processing industries that, from a technical viewpoint, offer opportunities for thermal waste stream recovery. CETC-Varennes recently undertook a study [Stricker Associates Inc, 2007] that quantitatively assesses the thermal waste streams, of eighteen (18) major Canadian industries. These industries represent a potential market for energy recovery technologies.

In 2003, Canadians consumed 8,447 petajoules of energy (one petajoule (1 PJ) = 1 x $10^{15}$ joules or 1 PJ = 278 GWh or 1 PJ = 948 x $10^{9}$ British Thermal Units (BTU)). As shown in Figure 1, the industrial sector consumes 3,263 PJ, or about 39% of all secondary energy used in Canada. These constitute a significant portion of energy use, comparable to the combined use of the Residential, Commercial and Institutional buildings sectors (33%) or to the Transport sector (28%) [Statistics Canada, 2004; OEE, 2008]. The industrial sector's main sources of energy consumption are shown in Figure 1. The three sources are: the electricity provided by producers (830 PJ), the energy provided by fossil fuel suppliers (1505 PJ) and the energy resulting from the use of the biomass, waste products and products (928 PJ). The secondary energy provided to the industrial sector (830 PJ + 1505 PJ = 2,335 PJ) is billable and represents more than 71% (2,335 / 3,263 PJ) of the overall energy consumption of the industrial sector

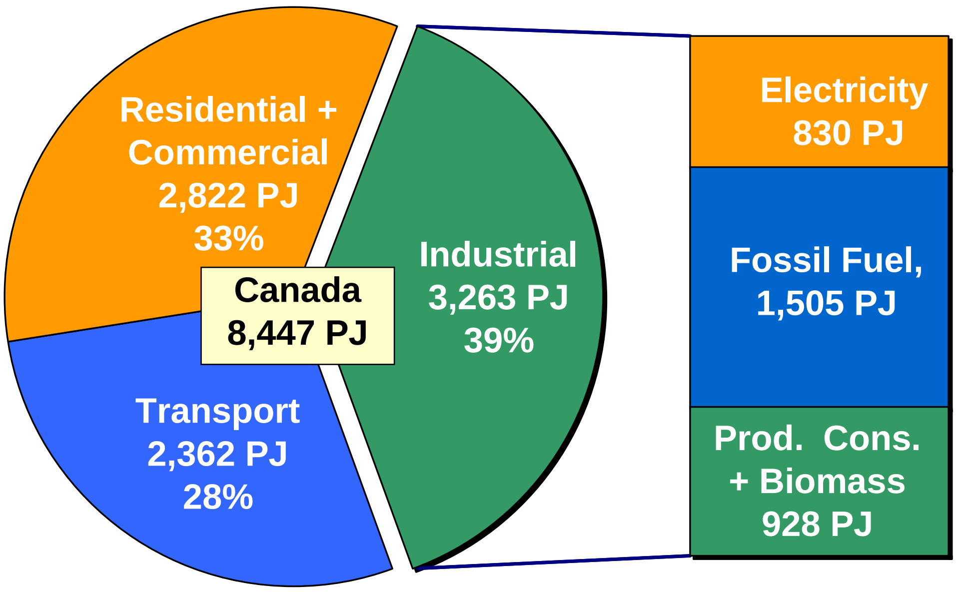


**Figure 1: Canada Energy Consumption**

The objective of the market study was to provide information on energy content and temperature range of industrial waste streams and for the cooling and refrigeration needs. The project aim was to provide an approximate guide to the technical potential for energy recovery and the development of waste stream recovery technologies.

## 2 METHODOLOGY

The methodology used to define the waste heat streams, and the cooling and refrigeration requirements of the Canadian industrial sector involves two sources of information: statistical data on energy usage, from the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC) database [CIEEDAC, 2005], and industrial flow-sheets developed by Drexel University for the U.S. Department of Energy [Drexel University, 1996], for processes used in 108 major industrial sub-sectors. The CIEEDAC database provides the energy consumption of all industrial sectors and sub-sectors, based on the North American Industry Classification System (NAICS). The industrial flow-sheets detail the typical process flows in

108 industrial processes. In the flow-sheets, each unit operation is represented with energy, mass, temperature and pressure inputs and outputs. Energy and mass are expressed per pound of process product. Initially, the flow-sheets were classified using the U.S. Standard Industrial Classification (SIC). The North American Industry Classification System (NAICS) has since replaced the U.S. Standard Industrial Classification (SIC) system.

For the study, the 18 industrial processes were selected using 3 criteria; the selected processes should 1] be included in the Drexel reference document [Drexel University, 1996], 2] represent a energetically significant sub-sector of Canadian industrial sector, and 3] be similar to the other energy intensive processes not included in the selected 18 processes.

The study methodology is illustrated in Figure 2; it comprises 5 steps:

1. Selection of 18 sub-sectors, in the 2003 Statistics data for the Canadian Industrial sector: The total secondary energy consumption (excluding biomass and producer consumption) for the 18 sub-sectors in 2003 was 1,900 PJ, representing 74% of the total secondary energy consumption of industrial sector (2,566 PJ). Table 1 lists the selected 18 sub-sectors and the corresponding North American Industry Classification System (NAICS) numbers.

2. Selection of the corresponding 18 flow-sheets, from the Drexel 108 process flow-sheets. The project team examined the data classifications, cross referenced them from NAICS numbers to the original U.S. Standard Industrial Classification (SIC), and finally linked them to the available analyses of the Drexel 108 industrial processes.

3. Allocation of the total energy to individual streams: For each process flow-sheet, the percentages of total input energy were worked out, for the 3 individual process cooling stream categories and for the 5 individual waste heat stream categories.

4. Extrapolation of energy figures from the typical flow-sheet to the total sub-sectors: For each process stream, the corresponding energy was calculated multiplying the percentage of input energy by the energy consumption of the corresponding sub-sector.

5. Extrapolation of energy figures from the 18 sub-sectors flow-sheets to the whole industrial sector.

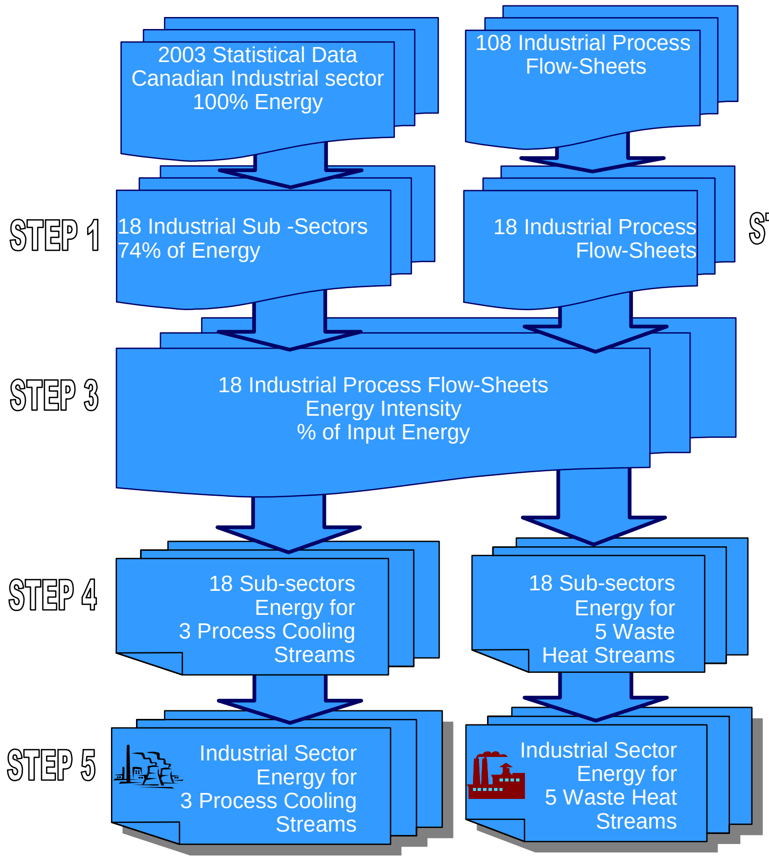


**Figure 2: Methodology to Estimate Thermal Reject Streams and Refrigeration & Cooling Requirements**

**Table 1: Selected Industrial Sectors and Sub-Sectors for the Market Study**

| 8 Major Manufacturing Sectors | 18 Manufacturing Sub-Sectors |
|---|---|
| **1 Paper Manufacturing (NAICS 322)** | Paper Mills except Newsprint (NAICS 322121) |
| | Paper Mills Newsprint (NAICS 322122) |
| | Chemical Pulp Mills (NAICS 322112) |
| **2 Wood Products (NAICS 321)** | Sawmills (NAICS 321111) |
| | Particle Board & Fiberboard Mills (NAICS 321216) |
| **3 Primary Metals (NAICS 331)** | Iron & Steel Mills and Ferro-Alloys (NAICS 3311) |
| | Non-ferrous metal except alum. (NAICS 33410) |
| | Aluminium Production (NAICS 331313) |
| **4 Petroleum & Coal (NAICS 324)** | Petroleum Refining (NAICS 32411) |
| **5 Non-Metallic Minerals (NAICS 327)** | Cement (NAICS 32731) |
| | Lime Manufacturing (NAICS 32741) |
| **6 Food Manufacturing (NAICS 311)** | Dairy Products (NAICS 3115) |
| | Meat Products (NAICS 3116) |
| **7 Beverage & Tobacco (NAICS 312)** | Breweries (NAICS 31212) |
| **8 Chemical Manufacturing (NAICS 325)** | Petrochemical (NAICS 325110) |
| | Other Basic Organic Chem (NAICS 325190) |
| | Fertilizer (NAICS 325310) |
| | Alkali and Chlorine (NAICS 325181) |

### 2.1 Thermal Waste Streams

In the processes examined, the thermal waste streams (or rejected thermal energy flows) were identified and classified according to the following categories:

1. Stack Losses: combustion gases and hot drier air (150°C to 800°C)
2. Steam Losses: low and medium pressure steam (100°C to 257°C)
3. Process gases and vapors: exhaust gases and moist air (80°C to 500°C)
4. Liquid Streams: liquids (50°C to 300°C)
5. Other Losses: includes miscellaneous or general process losses that were calculated in order to balance the energy input and output quantities.

The above first four categories are potentially recoverable because of the temperature levels, the amount of contained energy and the nature of the media involved in the energy transport. However, the waste heat of the fifth category is difficult to recover, because the losses involve a variety of mechanisms that are difficult to harness for quantification or capture; for example, equipment shell losses, leakage, endothermic reactions, elevated final product temperatures, etc.

### 2.2 Process Cooling

In the processes examined, Process Cooling requirements (to above-ambient or sub-ambient final temperatures) were identified and classified according to the following categories:

1 Open-cycle air or water cooling, in which air or water is passed directly over the product
2 Atmospheric indirect cooling (to between 15°C to 35°C) using a heat exchanger having a secondary stream cooled through evaporation (for example, cooling towers)
3 Refrigeration (-50°C to 0°C): in such operations, the process is most often linked to a vapor compression refrigeration system (single-stage or dual-stage) through a heat exchanger. In certain industrial processes much lower refrigeration temperatures are used; in the present study, only the production of ethylene (NAICS 32511) works at a temperature lower than -50°C. The amount of cooling energy used at such lower temperatures was therefore lumped with the (-50°C to 0°C) category, for simplicity.

In Canada, many process cooling applications make use of seasonal “free cooling”. This scheme uses atmospheric indirect cooling in the cooler months, and supplements it with mechanical cooling in warmer months; no statistical data is available on this topic.

## 3 PROCESS WASTE HEAT

The market study evaluated eighteen (18) industrial sub-sector processes that account for 74% of the total Canadian industrial secondary energy consumption. The remaining 26% can be estimated by extrapolation. In order to extend the results to the totality of the industrial sectors, the estimated waste heat and cooling requirements of each sub-sector were mathematically scaled to cover the full industrial sector.

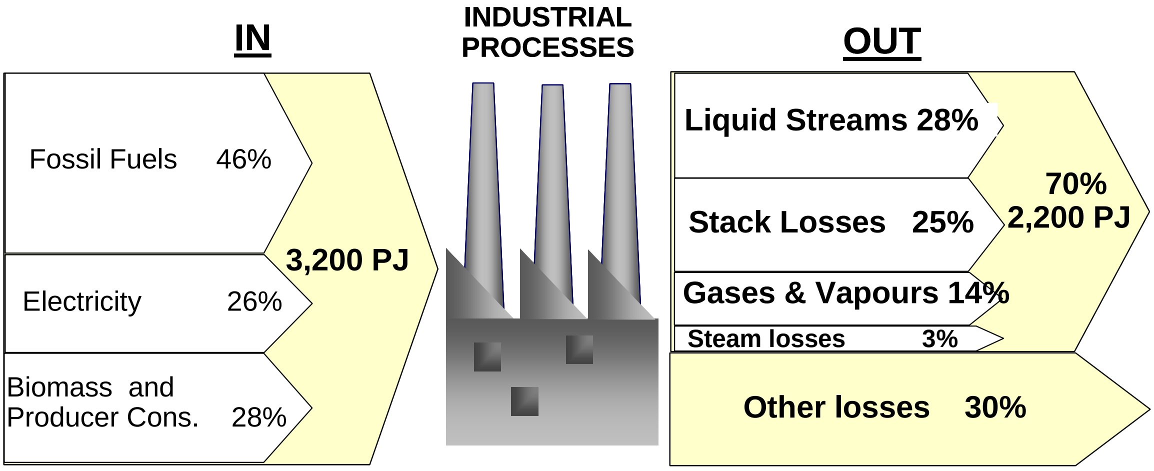


**Figure 3: Rejected Thermal Energy Flows, for the Canadian Industrial Sectors**

Figure 3 provides a graphical representation of the study results: Overall, the total of the different input energies, plus the process-generated minus the process-sunk energies yields the amount of energy released into the environment as waste heat. Most of this waste heat is released via four categories of identifiable waste heat streams: liquid streams, process gas streams, rejected steam streams and stack losses. This rejected heat corresponds to 70% of the total net input energy. These four streams are potential targets for heat recovery efforts.

The remaining 30% of the waste heat energy is accounted for by “other losses”, consisting mainly of highly distributed, low-grade losses from equipment and material streams. They do not generally constitute a target for heat recovery measures.

## 4 PROCESS COOLING

For the industrial sector, cooling operations require an estimated 30% of the net input energy. The majority of process cooling, about 85%, is provided by atmospheric cooling via cooling tower technology; open-cycle cooling accounts for 10%, and the balance, about 5%, is provided by refrigeration technology. Since most refrigeration machines ultimately reject their heat of compression to the atmosphere, there is a certain amount of double-counting in the total cooling estimate, for the industrial sector.

The extrapolation of the methodology to the 18 sub-sectors indicates that Refrigeration (i.e., all sub-ambient cooling operations, using mechanical vapor compression systems) accounts for 33 PJ, a part of the total cooling requirements.

If one uses the average industrial refrigeration COP: 1.9 (refrigeration load / refrigeration plant energy consumption) of the Drexel ‘108 Industrial Processes’, then each year 17 PJ of electricity would be consumed to provide a 33 PJ of refrigeration load, while sending 50 PJ of waste heat to atmospheric cooling towers. Improving the average refrigeration cycle efficiency by 10% would then decrease electrical consumption by 1.7 PJ (equivalent to 470 million kWh per year, or to an average electrical demand reduction of 54 megawatt (MW), year-round).

## 5 GREENHOUSE GAS (GHG) EMISSIONS

In 1990, the industrial sector emitted 140 Megatonnes of Carbon Dioxide Equivalent (Mt) (one Mt = 1 x $10^6$ tonnes) and 170 Mt in 2003 [OEE, 2008]. In spite of the reduction in the energy intensity of the Canadian industrial processes since 1990, the emissions of GHG increased by 30 MT (20% more than 1990).

Greenhouse Gas emissions from the industrial sector can be further reduced by recovering currently rejected thermal energy, and by improving refrigeration efficiencies to displace a portion of the currently purchased input energy. The potential heat recovery identified in the study represents approximately 70% of all GHG emissions, or 120 Mt of GHG (= 0.7 X 170). This assumption constitutes a good estimation because most industrial GHG emissions result from energy consumption. A targeted reduction of 30 Mt of GHG represents 25% (30 Mt/ 120 Mt) of the industrial processes recoverable waste heat.

## 6 CONCLUSION

The analysis of major industrial processes within these 18 sub-sectors indicates that about 70% of the rejected heat is released to the environment via four categories of identifiable waste heat streams. The GHG reduction potential associated with the recovery and re-use of heat from rejected thermal streams is very important since most of the energy flowing into plants (and generating GHG emissions) eventually is discharged as thermal waste streams.

The recovery and re-use of heat from waste streams can reduce the amount of purchased energy necessary for any industrial sub-sector, but requires commitment, knowledge and investment. In industrial processes, part of the waste heat can be reused directly while the rest must be upgraded, to be usable. The heat pump is the only technology capable of upgrading low and medium temperature thermal waste streams; such upgraded heat should be used to reduce energy consumption and GHG emissions, in industrial processes. Promotion of this opportunity will bring about the development of advanced heat pump technology, for high temperature applications such as thermal compression ejectors and sorption. Even the most energy efficient processes will reject energy whose quality could make it usable by other industries or buildings in the vicinity of the plant, as illustrated on figure 4.

Increasing energy costs, economical value of rejected energy, GHG emission reductions objectives, $CO_2$ credits, social pressure for “environmental” attitude are all factors that industrial sector should consider for the future. Based on financial and environmental potential gains, it is worthwhile to pay attention to the opportunities of thermal waste heat management.

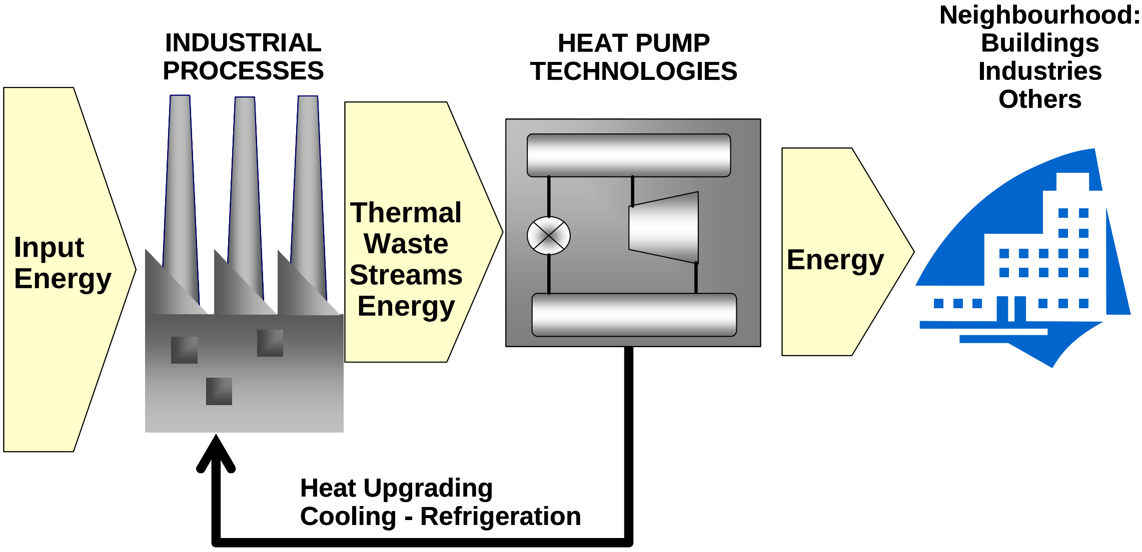


**Figure 4: Heat pump technologies**

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