Keeping Cool:

A Starting Point for Reducing Halocarbon Use in Refrigeration and Air Conditioning

Environment Canada
Environnement Canada

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Summary

Halocarbon refrigerants are a class of compounds commonly used in refrigeration and air conditioning equipment. Since the early 1980s it has been recognized that these compounds contribute to stratospheric ozone depletion and/or global climate change. As a result, dramatic changes have occurred in the selection, use, and handling of halocarbon refrigerants. New refrigerants have been introduced and codes of practise have been improved to prevent releases of halocarbon refrigerants. The use of halocarbons is being increasingly controlled by federal, provincial, and territorial legislation and/or regulations.

This document was prepared for Environment Canada as an introduction to the options available for reducing halocarbon use and finding alternatives to halocarbon refrigerants. The intended audience is persons working with facilities which require refrigeration and air conditioning equipment and who may have some knowledge but are not specialists in the field (e.g. property managers, engineers, architects, environmental coordinators, building and facility operators, etc.).

This document is a semi-technical educational aid to assist readers in understanding those technologies that are available now or under development and to provide some direction to locate further information relevant to their needs. The report contains 4 components. These are:

(i) an introduction to vapour compression refrigeration technology, the regulation of halocarbon refrigerants in Canada, and the methods for accounting for the environmental impacts of halocarbons emissions - specifically the effect on ozone depletion and global climate change;

(ii) an overview of options to reduce halocarbon use. This includes alternative refrigerants and technologies either currently available, under development, or used in other countries, and includes innovative building designs that can reduce the need for refrigeration equipment;

(iii) an overview of some of the specific options available for the residential, commercial, industrial, automotive and transport sectors. These sections provide examples of current technologies, new developments, and some of the trends that may become commercially available in the future;

(iv) a listing of resources for the reader to locate more information. This includes government, industry, and advocacy organizations. These resources are provided as Internet website address listings.

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1 Introduction

1.1 Objectives and Scope

This document provides an introduction to options for reducing halocarbon use in refrigeration and air conditioning applications in Canada. It is intended for persons who use, or are otherwise involved with, air conditioning and refrigeration equipment. This may include property and facility managers, operations staff, engineers, architects, and others. These readers may be familiar with some of the issues of refrigeration and air conditioning technology, but may not have an intimate knowledge of refrigeration technology.

The objectives of this document are to provide:

- a base level understanding of conventional refrigeration and air conditioning technology;
- an overview of the regulation and control of refrigerant gases under current legislation;
- an overview of potential alternatives to halocarbons for the residential, commercial, industrial, automotive and transport sectors in North America and an indication of some of the trends in some other countries in Europe and Asia; and
- references to further information resources for interested readers.

1.2 Benefits of Reducing Halocarbon Use

The implementation of technologies that reduce halocarbon use should be considered for the purpose of:

- reducing regulatory and environmental risk associated with the use of halocarbons and compliance with governing regulations; and
- reducing stratospheric ozone depletion and climate change by reducing emissions of halocarbon gases with ozone depleting or global warming impact.

It is important to note that any alternative systems must be implemented in accordance with all safety requirements and be designed, installed, and maintained by qualified professionals.

1.3 Definitions

Refrigeration in this report refers generally to a range of refrigeration, air conditioning, and heat pump systems. Specific terms will be used as much as possible.

Halocarbons are a category of chemicals containing carbon atoms and one or more of the halogen elements fluorine, chlorine, or bromine. Halocarbons with one or two carbons are commonly used in refrigeration and air conditioning equipment. Halocarbons include, but are not limited to CFCs, HCFCs, HFCs, and PFCs, as well as blends of these compounds.

Alternatives to halocarbons or **halocarbon reduction** in this document refer to technologies or practises that reduce the use of and/or the potential emissions of halocarbons. This includes technologies that use smaller quantities of refrigerants, systems that use non-halocarbon refrigerants, and engineering approaches that reduce the need for this equipment.

Ozone Depleting Substances (ODS) are compounds that have been found to destroy ozone molecules in the stratosphere. These comprise the CFC, Halon, and to a lesser extent, the HCFC chemical groups as well as blends of these compounds.

Greenhouse Gases (GHG) are compounds that contribute to global climate change through an atmospheric process called the greenhouse effect. In this report, the primary greenhouse gases of interest are CO_2 and HFCs.

Global Warming Potential (GWP) is a measure of a particular compound's potency to contribute to global climate change as compared to that of CO_2

An expanded **glossary** and **list of acronyms** is provided at the end of this document.

2 Background

2.1 Modern Refrigeration and Air Conditioning

Vapour compression technologies were first developed at the end of the 1800s - originally using hydrocarbons, ammonia, or sulphur dioxide as the refrigerants. In the 1930s chlorofluorocarbon (CFC) refrigerants were introduced. The widespread use of these halocarbon refrigerants led to an explosion of refrigeration and air conditioning applications and the development of entire industry sectors (e.g. frozen food industries, home air conditioning, etc.)

Conventional Vapour Compression Cycles

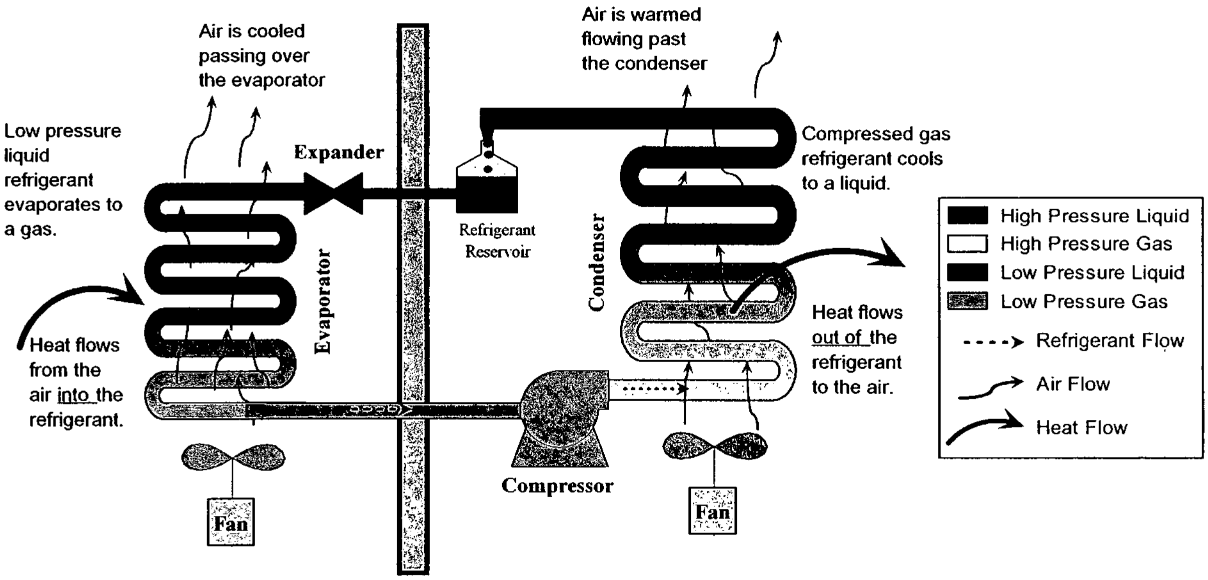
Vapour compression cycles operate by pumping a fluid around a closed loop. During the journey around the loop the fluid is expanded and heated into a gas, and then compressed and cooled into a liquid. During these stages, the fluid alternatively takes in, and then gives off heat.

In a vapour compression cycle, high pressure liquid flows through an **expander** - a valve or other control mechanism. Passing through the valve, the pressure is reduced and the refrigerant evaporates to a gas and absorbs heat in the process - similar to the way water absorbs heat when it boils and converts from a liquid to steam. The 'boiling' of the refrigerant occurs in the **evaporator**.

The source of heat to vaporize the refrigerant is air passing over the fins or tubes of the evaporator. The refrigerant does not contact the air directly but the heat is transferred through the evaporator material - usually metal. As a result, the air loses some of its heat content and becomes cooler.

After the liquid refrigerant has been converted to vapour (and has absorbed heat energy), it is compressed back to high pressure level by the **compressor**. The compressed gas contains all the heat that was absorbed from the cooled air. In the **condenser**, the high pressure gas is cooled. As it cools, it gives off its stored heat and becomes a liquid again and the cycle is complete.

The refrigerant goes around the cycle endlessly, absorbing heat when it is being converted to a gas (evaporation), and releasing (or rejecting) heat when it is being converted back to a fluid (condensation).



Schematic of a Conventional Vapour Compression Cycle

The **energy input** to run the system is the power required to drive the compressor. Some additional energy is used for the fans that blow air over the evaporator and condenser in order to speed the transfer of heat.

Vapour compression cycles actually *pump* heat in an analogous way that a water pump will pump water. A water pump takes water from a low elevation and 'pushes' it up to a higher elevation against the force of gravity, in spite of the desire for water to flow downhill. Similarly, a heat pump takes heat from a cold place and 'pushes' it to a warm place - against the direction of natural heat conduction (heat naturally flows from a warm place to a cold place).

Another useful mental picture is to think of a vapour compression cycle as a **heat sponge**. In the evaporator the sponge absorbs heat, and in the condenser the sponge is wrung out to remove the heat.

In a household refrigerator the evaporator is inside the cabinet, and the evaporation takes heat from the air inside, resulting in cold air circulating inside the refrigerator. The condenser is the tubing running up and down the back of the refrigerator. The condenser tubes on the back of a refrigerator usually feel warm because that is where the heat is expelled (or 'rejected') from the refrigerant.

While refrigeration and air conditioning systems make use of the cooling effect from the evaporator, the heat rejected at the condenser can be useful as well. A **heat pump** uses a vapour compression cycle to pump heat from a cool place (e.g. outside a building) to a warm place (inside). In the case of a heat pump, the desired comfort comes from warming of the *indoor* air that flows over the condenser. The evaporator is usually located outdoors, absorbing heat from the outside (even in winter).

Single Loop Systems

Single loop systems are sometimes referred to as **direct expansion (DX)** systems. There is only one fluid loop in a DX system. The evaporators are located at the point where the cooling is desired. Household refrigerators and air conditioners use single loop systems. Direct expansion systems can also be used in large installations. In a large supermarket, the compressor and condenser may be located in a mechanical room, and numerous evaporators may be positioned throughout the store at various display cases.

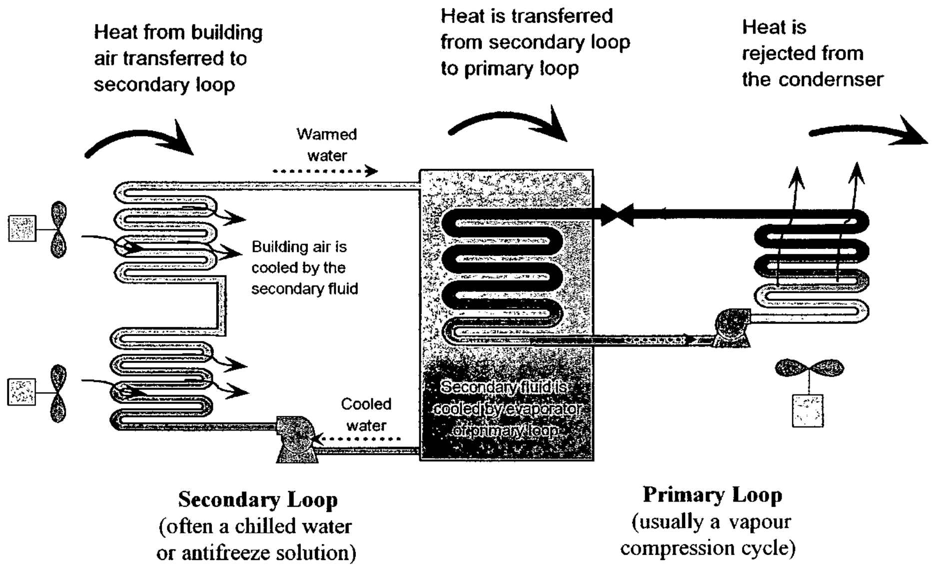
From the compressor - through the condenser - to the expander the refrigerant is on the *high pressure* side of the cycle. From the expander - through the evaporator - back to the compressor the fluid is on the *low pressure* side. Usually both sides of vapour compression loops are at pressures *greater* than atmospheric pressure. This is important since any cracks or holes in the piping will result in refrigerant leaking *out*, and not air leaking *in*. Some low pressure chillers operate under vacuum (pressures lower than atmospheric). For this equipment, a leak can result in air and moisture entering the equipment which could contaminate the refrigerant. These systems have purge valves to remove this air.

Secondary Loop Systems

Some refrigeration systems use a secondary loop. The first loop is a conventional vapour compression cycle but the evaporator cools another fluid instead of cooling air. This second fluid then circulates to provide cooling in the desired locations. Many building chiller systems use a primary loop (completely contained within the chiller equipment) to cool water. This cooled water (the secondary fluid) circulates through the building to provide cooling at numerous locations.

Many hockey rink systems use secondary loop systems. The primary loop uses a halocarbon or ammonia refrigerant contained in an equipment room which cools a secondary fluid such as a water-antifreeze mixture. The chilled antifreeze then circulates through pipes in the floor of the rink to keep the ice rink frozen.

Secondary systems have some advantages over single loop systems. They avoid long liquid and suction lines for primary refrigerant. This reduces the amount of refrigerant required as well as the length of tubing required which reduces the number of joints and potential leak locations. Secondary loop systems also contain the primary refrigerant in a contained location (e.g. in a hockey rink ammonia remains in the refrigeration room and chilled water circulates through the arena).



Schematic of a Secondary Loop System

A disadvantage is that secondary loop systems require an extra heat exchanger to transfer heat from the secondary to the primary fluid which can decrease some of the efficiency, as well as pumps, tubing, and control mechanisms for the secondary fluid. This may result in higher purchase and installation costs. Secondary loop systems are mostly used for large installations and are not used in small equipment or household appliances.

Ratings of Refrigeration Equipment

Refrigeration equipment capacity is defined by rate of cooling that is supplied. Several different unit systems are used. Historically, cooling has been described by a **Ton of Refrigeration** (TR). A ton of refrigeration is the amount of cooling required to convert 2000 pounds (one imperial ton) of water at zero degrees Celsius to ice at zero degrees in one day. Large commercial and industrial refrigeration units are often in the range of hundreds of tons.

In the English system of units, *heat* is measured in units of **British Thermal Units** (Btu). (A Btu is the amount of heat required to change the temperature of 1 pound of water by 1 degree Fahrenheit.) Refrigeration can be measured by the amount of heat removed per hour. Home air conditioning systems are often specified by this type of BTU rating. For example, a household unit might be advertised at 24,000 Btu, meaning 24,000 Btu *per hour*. One ton of refrigeration (TR) is 12,000 Btu per hour.

In the **metric** measurements system cooling is measured in Watts (a measure of energy used *per second*). Bigger systems use thousands of Watts (kilo-Watt or kW). One Ton of Refrigeration is about 3.5 kW.

Refrigeration Capacity

Application	Tons of Refrigeration (TR)	Btus/hour	Metric Equivalent (kW)
Residential Central Air Conditioner	3	36,000	10.5
Transport Freezer Truck	2		7
50,000 square foot freezer warehouse	350	-	1225
Office building chiller	200 - 600		700 - 2,100
Large Industrial Water Chiller	200 and up	-	700 and up

Specified Capacities are examples only, a wide range of units are produced.
1 TR = 12,000 Btu/hr, and 1 TR = 3.5 kW

Energy Consumption

The **energy consumption** of a system is *not* the same as the amount of refrigeration the unit can deliver. Refrigeration systems are tools to 'move' heat energy and not to create new heat energy. They are very efficient and actually move more *heat* energy than they consume in *electrical* energy. An efficient vapour compression cycle can move 2 or 3 times more cooling energy than the compressor energy input. This efficiency is defined by the energy efficiency ratio (EER).

For consumer appliances, the energy consumption is indicated by the **EnerGuide** label attached to the appliance. The label indicates the amount of energy the appliance will use in a year under defined test conditions. This rating is not the same as the cooling capacity of the unit's refrigeration system.

Refrigerant Properties

Refrigerants are selected for their specific physical properties and equipment components are designed to match those properties. For example, the temperature of the fluid in the evaporator depends on the type of refrigerant as well as the pressure in the evaporator. Different refrigerants or different pressure levels are used depending on whether the unit needs to accomplish air conditioning, refrigeration, or freezing effects. Each refrigerant absorbs a certain amount of heat as it is evaporated and this affects the amount of fluid that has to be circulated, which in turn determines the size of the compressors.

The refrigerant fluid can be in service for years (or decades). To be useful for this length of service, an **ideal refrigerant** would be a stable compound that won't break down during normal use that is completely non-toxic, non-flammable, and environmentally benign. Halocarbons are used as refrigerants because they are stable (do not breakdown), and have low toxicity and low flammability. Unfortunately, their stability makes *some* of them environmental unfriendly. These stable compounds do not breakdown when released and can circulate for years (or decades) in the atmosphere. Some of these compounds contribute to ozone depletion in the stratosphere and global climate change.

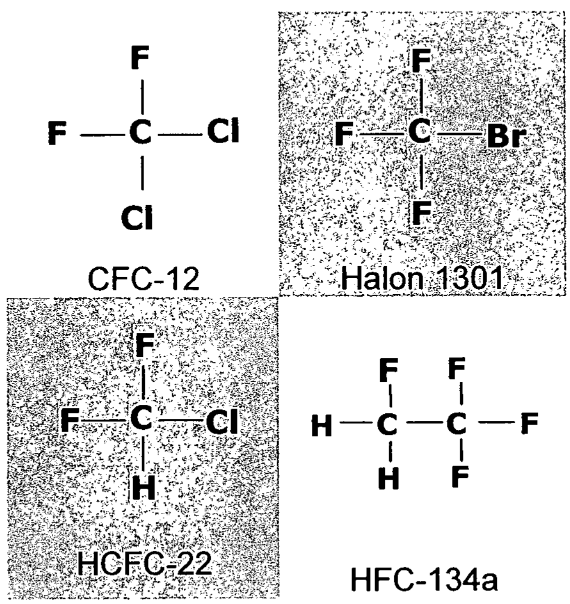
Some refrigerants have **toxic** or **flammable** properties. Examples are ammonia or hydrocarbons. Using these refrigerants requires special design features in construction and operation of the equipment. In spite of these concerns, in many situations there are advantages that make the cost and effort worthwhile. For example, ammonia is a very efficient refrigerant for cold storage and is commonly used in large freezer and warehouse situations in North America.

Types of Halocarbons

Halocarbons comprise an extensive number of chemical compounds. They all contain a carbon atom (C), or a chain of 2 or 3 carbon atoms at the core of the molecule. Attached to the carbon atom(s) are atoms of hydrogen (H), fluorine (F), chlorine (Cl), or bromine (Br). Four major types of halocarbons are:

Chlorofluorocarbons (CFCs): These contain chlorine and fluorine attached to the carbon atoms(s). These compounds deplete the ozone layer and have been or will be phased out for most applications. Examples of CFCs include R-11 (CFC-11) and R-12 (CFC-12). These are often referred to as 'Freons'.

Chemical Structure of Selected Halocarbon Refrigerants



Letter symbols represent component atoms and connecting lines represent chemical bonds

Halons: A halon is a CFC molecule with a bromine atom replacing one or more of the chlorine or fluorine atoms. These are more common in fire fighting equipment than refrigeration equipment. Examples of these compounds include Halon-1211 and Halon 1301.

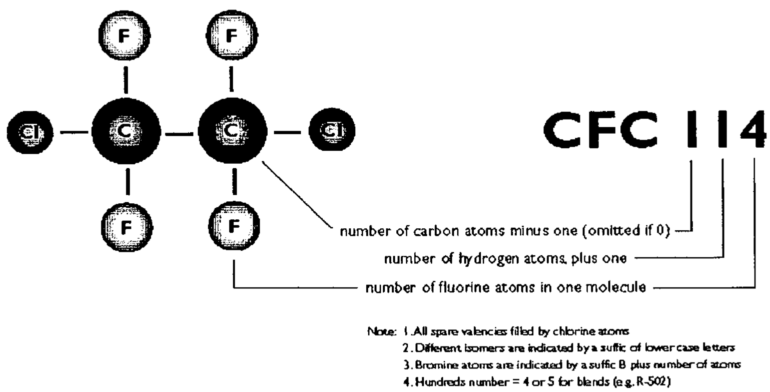
Hydrochlorofluorocarbons (HCFCs): In HCFCs, there is at least one hydrogen atom attached to the carbon chain along with the chlorine and fluorine atoms. These compounds deplete the ozone layer (but less than CFCs). A production freeze came into effect in 1996, and these will be phased out over the next 20 years. Examples of HCFC refrigerants include R-22 (HCFC-22) and R-123 (HCFC-123).

Hydrofluorocarbons (HFCs): These molecules contain only hydrogen and fluorine attached to the carbon. Since they have no chlorine or bromine, they do *not* create the chemical reactions that destroy the ozone layer. However, these compounds can contribute to global climate change if released to the atmosphere. The most commonly used HFC is HFC-134a.

Naming the Halocarbons

The **refrigerant numbering system** was originally designed for naming the CFCs. It describes the number of carbon, hydrogen, and fluorine atoms in the molecule. For single compound refrigerants (i.e. not mixtures), the numbering system can be used to identify the molecular structure of the refrigerant. (NB: The halon numbering system is different and is not presented here).

Halocarbon Naming Convention



How CFC Nomenclature Works

CFC numbers provide the information needed to deduce the chemical structure of the compound. The digit far right provides information on the number of fluorine atoms, the digit second from the right provides information on hydrogen atoms, and the digit on the left provides information on carbon atoms. Vacant valencies are filled with chlorine atoms. Adding 90 to the number reveals the numbers of C, H and F atoms more directly.

Graphic Courtesy of UNEP (2001)

In recent years, **refrigerant blends** have been developed which are mixtures of existing refrigerants. These are assigned numbers in the 400 and 500 series level. For these blends, the chemical structure of the components *cannot* be determined from the refrigerant number.

Not all refrigerants are halocarbons. The non-halocarbon refrigerants are also assigned refrigerant numbers. These include propane (R-290), butane (R600), carbon dioxide CO_2 (R-744), ammonia (R-717), and others.

In the past, all the refrigerants were named with using the letter R (e.g. R-12). Today they are identified by the type of halocarbon, and the number code. For example, Freon-12 and R-12 are the same compound and now are more accurately called CFC-12.

Some new products have used **unconventional numbering conventions**. For example, some suppliers have marketed potential CFC replacements with brand names based on the refrigerant they are meant to replace. For example, HC-12a is a brand name of a *proposed* alternative refrigerant to replace some uses of CFC-12, but its chemical structure cannot be determined from the number 12. This may create some confusion in the marketplace. The complete chemical nature of a compound is crucial for selecting the right equipment, and for proper safety and handling. Users should *always* understand which refrigerants they are implementing.

Refrigerants Naming Series

Naming System for Refrigerants

Category	Type of Refrigerant	Examples
R-11 to R-50	HFC, HCFC, and HFCs with 1 carbon	CFC-12, HCFC-22, HFC-32
R-100 series	HFC, HCFC, HFC, hydrocarbons with 2 carbon atoms	CFC-113, HCFC-141b, HFC-134a
R-200 series	HFC, HCFC, HFC, hydrocarbons with 3 carbons atoms	Propane
R-400 series	Mixtures of halocarbons	R-407a, R-410a
R-500 series	Mixtures of halocarbons	R-502
R-600 series	pentanes, ethers, amines	pentanes, ethers, amines
R-700 series	Inorganic	Ammonia, CO_2, helium, water, air

Note: Not all refrigerants are halocarbons.

2.2 Ozone Depletion and Global Warming Effects of Refrigerants

The primary atmospheric effects of halocarbons are the destruction of the stratospheric ozone layer and contributing to global climate change.

Atmospheric Potency

Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) of selected refrigerants

Refrigerant	ODP	GWP
CFC-12	1.0	10,600
CFC-113	0.8	6000
HCFC-22	0.055	1700
HFC-134a	0	1300
R-407a (HFC mixture)	0	2000
R-410a (HFC mixture)	0	2000
R-290 (propane)	0	20
R-717 (ammonia)	0	0

ODP uses CFC-11 = 1; GWP uses CO_2 = 1.
Sources: ODPs: UNEP 2000b, GWPs: Calm & Hourahan, 2001

Substances that destroy stratospheric ozone molecules are called **ozone depleting substances (ODS)**. It is the chlorine atom (Cl) and sometimes the bromine atom (Br) on CFCs, HCFCs, and Halons which makes them harmful to the ozone layer. High in the stratosphere, the chlorine atom is separated from the halocarbon by intense solar radiation. From there, this free chlorine atom actively breaks down ozone molecules in a chain reaction. The hydrogen (H) in the structure of HCFCs and HFCs makes these chemicals more likely to be broken down and removed in the lower atmosphere. HCFCs are less harmful to the ozone layer than CFCs because they are more likely to be removed in the lower atmosphere, and less likely to reach the stratosphere. HFCs contain no chlorine or bromine and so do not affect the ozone layer.

The strength of an ODS is measured by its **ozone depleting potential (ODP)**. This is the ability of the compound to destroy stratospheric ozone as compared to CFC-11 (R-11 or Freon-11). For example, an ODP of 0.8 means that one kg of the compound will destroy 80 % of the amount of ozone as one kg of CFC-11.

Halocarbons also contribute to global climate change through a process called the 'greenhouse effect'. Substances that contribute to climate change are called **greenhouse gases (GHG)**. The strength of a GHG is measured by its **global warming potential (GWP)**. This compares the effect of the gas on global climate change compared to an equivalent amount of carbon dioxide (CO_2). For example, a GWP of 1300 means that 1 kg of the compound will contribute to global warming by an amount equivalent to 1300 kg of CO_2 emissions. Many halocarbons have a high GWP. A small release of these compounds is equivalent to large amounts of CO_2 emissions (see table).

2.3 Regulation of Halocarbon Refrigerants

Montreal Protocol

In the late 1970s it was recognized that CFCs would accumulate in the stratosphere and destroy ozone molecules, which shield the atmosphere from harmful solar radiation. By the mid-1980s there was significant scientific evidence that ozone depletion was occurring and was attributable to CFCs.

Going, going, gone!

Phase out schedule of Ozone Depleting Substances according to the Montreal Protocol.

Category	Jan 1 of	Restriction
Halons	1994	No production, restricted import. No new systems. Restricted and declining use in existing systems.
CFCs	1996	No production or import. No new systems. Restricted use on existing systems.
HCFCs	1996	Freeze production
	2004	35 % reduction
	2010	65 % reduction
	2015	90 % reduction
	2020	99.5 % reduction
	2030	100 % reduction
HFCs	1999	Use in accordance with federal, provincial & territorial regulations

In response to the scientific evidence, an international treaty, the Montreal Protocol, was signed in 1987 through the United Nations Environment Programme (UNEP). This international agreement controls ODS emissions by regulating their production and trade. The protocol has been amended several times, primarily to accelerate the phase-out schedules for CFCs and Halons and to include HCFCs on the list of ODS.

Each signatory nation is responsible for establishing its own programs to meet the phase-out schedules - for example setting milestones for ending installation and servicing of equipment with ODS and many countries have established schedules which exceed the Montreal Protocol requirements. In Canada, federal, provincial, and territorial legislation, regulations, guidelines, and action plans have been established to meet the international commitments.

Climate Change and the Kyoto Protocol

In 1997, the international community, through the United Nations, created the Kyoto Protocol to address global climate change. This international agreement is a plan to stabilize global emissions of **greenhouse gases (GHG)** at prescribed levels. The Kyoto Protocol does not prohibit the emissions of greenhouse gases the way that the Montreal Protocol prohibits consumption of ozone depleting substances. Instead it is a mechanism to manage GHG emissions and to stabilize total global emissions.

Carbon dioxide (CO_2) produced from fossil fuel combustion is the largest source of GHG, but other gases such as methane and HFCs are also covered by the Kyoto Protocol. **HFCs** are one of six gases to be regulated under this protocol.

Individual nations are required to develop their own implementation plans to meet the emissions control target defined in the Kyoto Protocol. Over the next several years in Canada, actions plans will be developed and a series of voluntary measures, incentive programs, and possibly even regulatory controls are expected at the federal and provincial levels to manage GHG emissions.

HFCs are one of six greenhouse gases regulated by the Kyoto Protocol on climate change.

Federal Halocarbon Legislation

The federal government regulates ODS and halocarbons under the ***Canadian Environmental Protection Act, 1999 (CEPA 1999)***. The applicable regulations are (i) the ***Ozone Depleting Substances Regulations, 1998 (ODSR 1998)*** which control the import, export, transit shipment, manufacture, use, sale and offer for sale of ODS and (ii) the ***Federal Halocarbon Regulations (FHR)*** established in 1999 which control the use of *all* halocarbons in applications owned by the federal government, on federal or aboriginal lands, and for federal works and undertakings. As of the end of 2002, *both* of these regulations are being reviewed for amendment. For more information on these regulations visit the Environment Canada ozone website www.ec.gc.ca/ozone.

A component of ***CEPA 1999*** is the principle of **pollution prevention** (or P2) which is "the use of processes, practices, materials, products or energy that avoid or minimize the creation of pollutants and waste, and reduce overall risk to human health or the environment." P2 aims to design systems that do not pollute, instead of designing systems that clean-up or treat wastes after they have been created.

Environment Canada maintains the **National Office of Pollution Prevention (NOPP)** to facilitate the management of toxic substances, to implement federal pollution prevention policy and legislation, and to develop new concepts and policy instruments that facilitate the transition to pollution prevention in Canada (www.ec.gc.ca/NOPP). Environment Canada also provides the **Canadian Pollution Prevention Information Clearinghouse (CPPIC)** (www.ec.gc.ca/cppic) which permits access to hundreds of documents to assist in pollution prevention.

Provincial and Territorial Legislation

Each province or territory has developed a set of halocarbon regulations and/or guidelines which regulate CFCs, Halons, HCFCs, PFCs, and HFCs. The intent of these regulations is to control the release of halocarbons into the atmosphere by specifying requirements for handling, storage, implementation, and disposal of halocarbons. All regulations now require recapture of refrigerants when equipment and appliances are maintained or retired. These regulations also specify factors such as the frequency of leak testing required for different sized systems.

During the past decade in Canada, halocarbon regulations have expanded from addressing ozone depleting substances (ODS) and now regulate all halocarbons.

The **Canadian Council of Minister's of the Environment (CCME)** have created a National Action Plan on the phase-out of ODS and the disposal of surplus stocks. This strategy is available from the Environment Canada Stratospheric Ozone website (www.ec.gc.ca/ozone). (The CCME is an inter-governmental forum in Canada for joint action on environmental issues of national and international concern. It includes representation from all provincial, territorial, and federal environmental agencies.)

HFC halocarbons are not ODS and so are not included in the Montreal protocol, but they *are* regulated through federal, provincial, and territorial halocarbon regulations. During the past decade in Canada, halocarbon regulations have expanded from addressing only ozone depleting substances (ODS) and now regulate all halocarbons (ODS and non-ODS). HFCs are also potent greenhouse gases, and so will be included in an implementation plan for the Kyoto Protocol.

Other Regulations and Requirements

Many aspects of refrigerant use are regulated in ways not related to the environmental impacts of the compounds. For example, **Transport Canada** (www.tc.gc.ca) regulates the transport requirements for dangerous goods and **Health Canada** (www.hc-sc.gc.ca) regulates safety in the workplace through the Workplace Health and Public Safety Programme (WHPSP) which was formerly the Occupational Health & Safety Agency (OHSA). Other federal, provincial, and territorial regulations apply. If in doubt about any aspect of refrigerant storage, use, or transport, check with your refrigeration professional.

The **Canadian Standards Association (CSA)** establishes safety and performance standards for a range of equipment and appliances. They have established a standard for mechanical refrigeration equipment (Standard CSA B52-99) which defines minimum requirements for the design, construction, installation, and maintenance of specified mechanical refrigeration systems. A copy of the standard is available for purchase from the CSA (www.csa.ca).

US EPA Significant New Alternatives Program (SNAP)

In the US, the United States Environmental Protection Agency (EPA) established a program to evaluate the alternatives to ODS to accompany the US ODS phase-out program. The **Significant New Alternatives Program (SNAP)** (www.epa.gov/ozone/snap) evaluates the environmental effects and safety of *replacements* for ODS. An objective of the SNAP program is to ensure that during the ODS phase out, that the alternatives that are developed do not have environmentally harmful properties. SNAP also has some jurisdiction over safety issues for ODS replacements. SNAP publishes a list of **acceptable** and **unacceptable** replacement compounds including both generic and brand names.

In the US, *any* replacement for an ODS must be approved by the SNAP program. There is some grey area since the SNAP program applies only to replacements for ODS and not necessarily to replacements for HFC operated equipment. Since most of the new equipment is now designed for HFC refrigerants with no ODP it is not always clear if the SNAP legislation applies to these systems. As a result there may be consumer confusion in some areas. An example is the automotive air conditioning market where hydrocarbon mixtures are prohibited from being used to refill existing CFC systems, but not expressly covered by SNAP as replacements for HFC-134a systems (though hydrocarbon mixtures may be regulated by state or local regulations). The issue of appropriate replacement refrigerants - particularly hydrocarbons - has been somewhat controversial in the U.S.

The SNAP program approves alternatives based on their *specific use*. For example, hydrocarbon refrigerants are approved replacements for ODS in industrial applications - presumably because appropriate design precautions can be employed - but are not yet approved for automotive air conditioning.

The SNAP program does *not* have any regulatory authority in Canada. However, SNAP requirements would be expected to apply to products exported to, and sold in the US market.

Industry Initiatives

In Canada, **Refrigerant Management Canada (RMC)** (www.hrai.ca/rmc) has been established under the **Heating, Refrigeration, and Air Conditioning Institute of Canada (HRAI)** (www.hrai.ca) to manage the disposal of Canada's surplus stocks of ODS in an environmentally responsible manner and to minimize and avoid the release of these substances to the atmosphere.

In the US, the Alliance for Responsible Atmospheric Policy - an industry-based coalition (www.arap.org) in cooperation with the US EPA have developed a set of **responsible use principles** for halocarbon refrigerants. These principles are designed to guide the industry to minimise emissions, promote a high levels of service and maintenance, and ensure proper recovery and disposal of refrigerants.

The responsible use principles are only *voluntary* measures promoted by industry and supported by the US EPA. In Canada, most regulations controlling ODS and halocarbons are *more* stringent than the voluntary use guidelines. For example, most regulations prohibit the release of all halocarbons, whereas the responsible use principles state that emissions should be minimized. Users should be aware that compliance with appropriate provincial, territorial, and federal regulations is required in Canada.

2.4 Accounting for Climate Change Impacts of Refrigerants

To reduce the climate change impact of a product, all the sources of GHG emissions from its life cycle should be addressed. When all the GHG emissions are known, then appropriate comparisons can be made between alternatives.

CO_2 Equivalent Emissions

The global warming impact of operating a refrigerant system is measured by all the CO_2 emissions released when using the system. This includes direct and indirect emissions.

Direct emissions are the emissions created at source by (i) the refrigerant that leaks out during the use and maintenance of the system, and (ii) any CO_2 emissions created at the source (e.g. running of a gas or diesel generator to drive the system). The estimated mass of halocarbon emissions is multiplied by its GWP to determine the emissions in **CO_2 equivalent** units.

> Some CFC replacements have a global warming potential (GWP) several thousand times that of CO_2.
>
> 1 kg of HFC-134a, if released, would have the global warming effect of 1300 kg of CO_2.

Most refrigeration systems and service practices have been improved in recent years as part of the compliance with new ODS and other halocarbon regulations. Thus the direct contribution due to refrigerant leakages are lower today than a decade or two ago.

Indirect emissions are the CO_2 emissions created by the generation of the electricity to operate the equipment. These usually occur at a power plant where electricity is generated. When a fossil fuel (coal, oil, natural gas) is used to generate electricity, CO_2 is emitted. When hydro, nuclear, or wind energy are used, then no CO_2 emissions are produced.

Location, location, location!

CO_2 emissions created in the generation of electricity

City	Portion of Electricity from Fossil Fuels (%)	CO_2 equivalent released per MW-hr electricity consumed (kg)
Vancouver	5.5	54
Edmonton	100.0	951
Toronto	13.7	158
Montreal	2.4	14
Halifax	89.2	968

Source: Environment Canada (1999a)
Includes NO_x emissions and transmission losses

For each geographic area in Canada, assessments have been made of the portion of the electricity that comes from fossil fuel sources, and the amount of CO_2 emissions created for each unit of electricity consumed. In areas where a high percentage of electricity comes from fossil fuels, there are more CO_2 emissions for the *same amount* of electricity consumed. As a result, the *same* electricity consumption can create *different* amounts of CO_2 emissions depending on the location of the electricity consumers.

Climate Change Measures for Refrigeration (TEWI, LCCP, LCA)

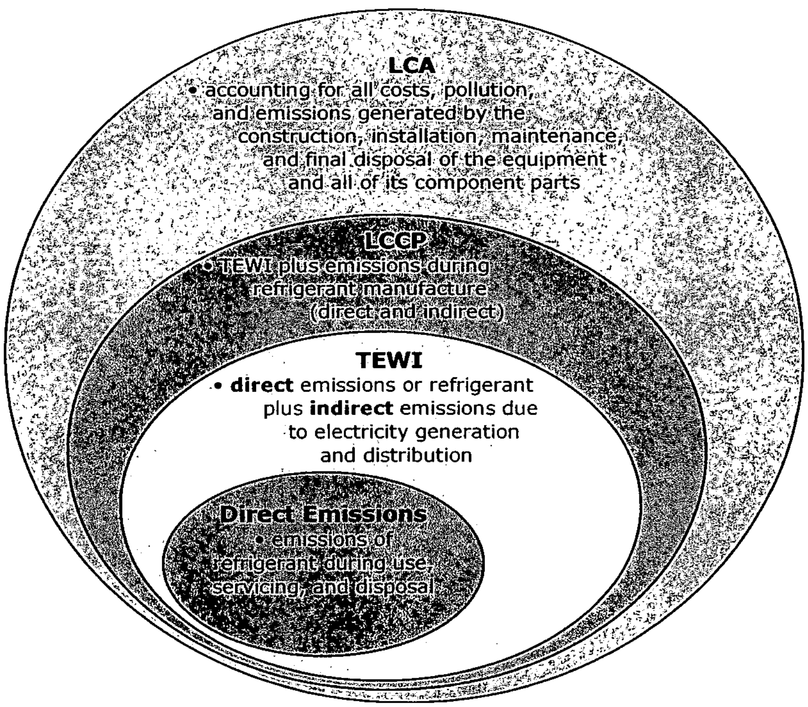
Several measures of the environmental effect of refrigerant use have been developed.

Direct emissions are the emissions of the refrigerant only, multiplied by the GWP value to provide a measure of the emissions of equivalent CO_2 emissions.

Total Equivalent Warming Impact (TEWI) incorporates the indirect emissions created when power is generated with the direct emissions of the refrigerant, all on a similar CO_2 equivalent basis.

Life Cycle Climate Performance (LCCP) was developed as an improvement to the TEWI method to include the emissions generated during the manufacture of the refrigerant, and the losses during its disposal. For example, when one kg of HFC-134a manufactured, between 13 to 38 kg of CO_2 equivalent emissions are created. In recent years, the TEWI analysis has evolved to include many of the features of the LCCP and these terms are often used interchangeable.

Life Cycle Analysis (LCA) documents all the energy and material inputs to a system to account for their environmental and financial impact. This includes the component raw materials of the equipment as well as the refrigerant. It also tracks the manufacturing and distribution chain to evaluate all the resource inputs needed to bring the system into place. It tracks the final decommissioning and disposal costs of all components. LCA analysis is an involved area of study and requires specific expertise and extensive information about the origin and composition of each component part. This type of analysis is an emerging and growing field and has been used to guide investment and policy decisions.



Schematic of the Scope of GHG Analysis Methods

Moving from the inner circles to the outer circles provides a more complete assessment of environmental impact but requires greater effort and greater information.

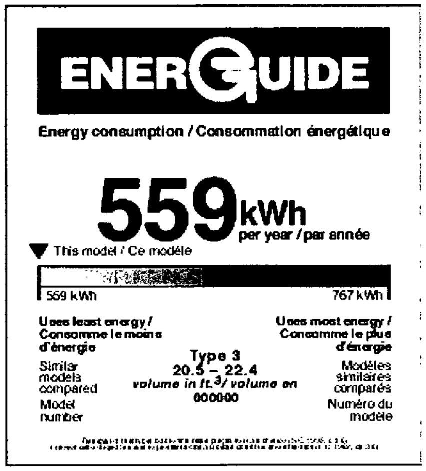
Note: TEWI and LCCP measures are becoming similar in scope and are sometimes used interchangeably.

The TEWI and LCCP analysis methods were developed to better understand the entire **CO_2 equivalent emissions** effect of different refrigeration systems and allow comparisons of the atmospheric environmental impacts of different systems. For example, removing a halocarbon refrigerant would eliminate the global warming contribution of any leaked refrigerant gas. But a replacement might use more or less electricity. And the electricity might be generated using coal, nuclear, or hydro power. The TEWI and LCCP measures include accounting for the global warming effect of these factors.

2.5 Energy Efficiency Standards

The TEWI and LCCP measures highlight that global warming impacts of refrigeration equipment is affected by energy consumption and not just the type of refrigerant.

Selecting energy efficient equipment is a first step towards reducing GHG emissions. For consumer appliances energy efficiency testing and ratings are made be several agencies to assist consumers in making appropriate energy efficient purchases.



The EnerGuide label describes the energy consumption of appliances.

In Canada, the **EnerGuide** program from the Office of Energy Efficiency (OEE) of Natural Resources Canada (NRCan) (www.oee.nrcan.gc.ca/energuide) provides an evaluation of the energy consumption of appliances. The EnerGuide label identifies that an appliance has been tested and evaluated. The rating indicates the expected energy consumption or energy efficiency of the equipment. An EnerGuide label is a rating of how much energy an appliance uses, and is *not* a certification that an appliance is the *most* energy efficient.

The **ENERGY STAR**® program (www.energystar.gov), was originally developed by the US EPA and the US Department of Energy. It is endorsed by Natural Resources Canada (www.oee.nrcan.gc.ca/energystar) and other agencies. The ENERGY STAR designation is a *certification* that a product meets high energy efficiency standards.

The ENERGY STAR certification certifies that an appliance meets high energy efficiency standards.

3 Halocarbon Reduction Options

This chapter describes halocarbon reduction options that are common to one or more industry sectors. The subsequent chapters provide some examples and resources that are specific to each sector. These chapters do not document all activities but provide some insight into some of the options that are available or under development.

3.1 Existing and Replacement Equipment

Maintenance of Existing Equipment

Identifying and preventing refrigerant leaks in existing equipment is an important step in reducing halocarbon emissions. Today regular leak testing is a regulated requirement for certain sized systems in most provinces and territories. Appropriate maintenance also ensures that equipment operates at the most energy efficient levels which saves electricity, reduces operating costs, and reduces CO_2 emissions created for electrical generation (indirect emissions).

Replacement of Existing Equipment

New refrigeration and air conditioning equipment is much more energy efficient than equipment used in the past. For example, compared to units installed 20 years ago, new building chillers can provide the same cooling power using as little as **one third of the electricity** as the older units. Substantial savings in operating costs have been documented for replacing old equipment. Some systems will pay back the capital costs incurred through electricity savings in as little as five years.

Replacement of older equipment with new equipment may also result in a reduction of the amount of halocarbons in use since newer systems are less likely to leak and may use a smaller refrigerant charge. At a minimum, new equipment uses either lower-ODP HCFCs or ozone friendly HFCs.

'Drop in' Replacements

An *ideal* scenario would be to simply replace a currently used gas in existing equipment with a different gas. These are called **'drop-in' replacements** for existing gases. In reality there are no perfect drop-in replacements. Most systems are designed for the specific thermodynamic and physical properties of the original fluid. For example, each refrigerant must be used with a compatible lubricating oil. As well, tubing, seals, or o-rings may need to be changed to allow a replacement to function or the compressor or expander valve may have to be re-sized. Always consult with a qualified refrigeration professional when considering changing refrigerants in existing equipment.

3.2 Alternative Refrigerants for Vapour Compression Cycles

Alternative refrigerants are gases that can be used in vapour compression cycles, but are not halocarbons. This group includes ammonia and hydrocarbon gases such as propane, butane, and pentane. The most effective applications of alternative refrigerants occur when they are implemented in conjunction with equipment specifically designed for their unique properties. Several alternative refrigerants are described below.

Ammonia (R-717)

Ammonia (R-717 or NH_3) is one of the oldest refrigerants. Ammonia has a large heat transfer capacity making it a very efficient refrigerant. The thermodynamic efficiency of ammonia makes it an excellent refrigerant for industrial applications which require a large amount of cooling. For these systems, the energy savings of an efficient refrigerant can be substantial. Ammonia is widely used today in cold storage, food processing, industrial applications, and settings such as ice skating rinks.

The International Institute of Ammonia Refrigeration (IIAR) (www.iiar.org) is an industry group for the ammonia industry. In Europe, primarily Germany - the group 'eurammon' promotes and disseminates information on natural refrigerants including ammonia (www.faktor3.de/eurammon/englisch/html/index.html).

Ammonia has some **toxicity** and over a narrow range of concentrations it is **flammable** so special precautions must be taken in with handling, storage, and use. Ammonia can be used with a secondary refrigerant loop so that the ammonia refrigerant is contained in a secure place - a refrigeration room for example. The extra precautions can add to the capital cost of an ammonia system. As a result, ammonia is generally used only for large systems - like hockey arenas or cold storage warehouses - where the extra costs and efforts are justified by large savings in energy use.

Ammonia has been used for over 100 years in many refrigeration and industrial applications. As a result, there are well documented handling, storage, and transport regulations and codes of practise in most jurisdictions.

Hydrocarbons

Hydrocarbons were common refrigerants prior to the development of CFCs in the 1930s. Potential hydrocarbon refrigerants include **propane** (R-290), **butane** (R-600), **isobutane** (R-600a), or **pentane** (R-601) and mixtures of these compounds. These hydrocarbons have suitable properties for evaporation and condensation at operating pressures and temperatures used in many refrigeration systems.

Lighter hydrocarbons such as methane and ethane are not attractive alternatives because they do not condense and evaporate at normal refrigeration temperatures and pressures. **Heavier hydrocarbons** like octane or diesel are typically too heavy. They remain in liquid form and would require very low pressures in order to vaporize which would require specialized designs and still have limited efficiency.

Hydrocarbon refrigerants are **flammable** and this issue must be accounted for in the design of any hydrocarbon refrigerant system. The benefit of hydrocarbon systems is that in many applications they can achieve equivalent or better performance than halocarbons and the cost of refrigerant is less. These factors have made the extra considerations required for hydrocarbon systems attractive in some situations.

Hydrocarbon systems are common in industrial applications. In the oil and gas sector, propane refrigeration is commonly used in gas plants and refineries. In these situations the entire facilities are designed to address flammability hazards so there is limited additional burden from using a hydrocarbon refrigerant. As well, propane may be available at little or no cost as part of a plant process.

Hydrocarbon refrigerants have found new popularity in consumer appliances in several overseas markets during the past 10 years. Hydrocarbon refrigerants are commonplace in appliances in Western Europe, and hydrocarbon-refrigerant domestic refrigerators are sold throughout Europe and in China, India, and as of 2003 in Japan.

Carbon Dioxide (R-744)

Carbon dioxide was widely used as a refrigerant in the early part of the century. It has the advantages of low toxicity, non-flammability, low cost, and universal availability. It has unique properties requiring specialized design. CO_2 has a critical temperature of 31 deg C. Below that temperature a vapour compression cycle can be designed but it is not very efficient. At condenser temperatures above 31 deg C, the CO_2 does not form a liquid in the condenser and a specially designed system is required. This cycle is called a 'trans-critical' cycle because the gas exceeds the critical temperature during part of the cycle.

An advantage of the CO_2 cycle is that high temperatures for heat rejection in the condenser (e.g. 90 deg C) are common with reasonable compressor efficiency. This makes CO_2 an ideal candidate for heat pump systems designed to heat domestic water. **Denso Corporation** (www.densocorp-na.com) has developed a CO_2 heat pump system for domestic water heating (for the Japanese market) that reduces CO_2 emissions by 50% compared with combustion water heaters.

The disadvantage of CO_2 systems is that they operate at higher pressures than conventional vapour compression cycles. This requires special components - i.e. CO_2 refrigerant is *not* compatible with existing equipment. New components must be built and tested. Some developments are occurring in this area. For example in 2002 the first CO_2 air conditioning system / heating system for a passenger vehicle was introduced to the market in a prototype hybrid vehicle (see Chapter 7).

3.3 Non-vapour compression technologies

Other technologies than conventional vapour compression exist for refrigeration. These **not-in-kind** technologies are at various levels of development - some are currently available on a commercial scale, some are niche technologies fitting specialty applications, and some are still in development.

Absorption Systems

Absorption systems use **heat** as the driving force instead of a compressor. To do this, two fluids are used. One is the absorber (carrier) solution the second is the refrigerant solution. The refrigeration effect occurs when the refrigerant is absorbed into the carrier fluid which creates a low pressure, low temperature environment. Later in the cycle heat energy input is used to regenerate the refrigeration fluid - i.e. to boil it off from the absorber fluid. Some pumps are required to keep the liquid solutions circulating, but no large horsepower gas compressors are required.

Several absorption cycles are common technology. In an ammonia-water absorption system, the ammonia dissolves in water. Later in the cycle, the mixture is heated and the ammonia is liberated as a gas for part of the cycle again. In a water-lithium bromide (Li-Br) absorber, a Li-Br salt solution is the absorber and water is the refrigerant. Most absorption systems are large industrial or commercial installations.

Absorption systems are most economical when a supply of unused (waste) heat (or waste fuel) is available from some other process. When no such sources exist, a gas or oil fired burner must be included but energy costs usually make this type of installation too expensive. In some places where electricity costs are high and natural gas prices are relatively low, an absorber system has been economical even when buying natural gas but these situations are not common.

Absorption systems use far less compressor and pumping energy (usually electrical) than electric drive vapour compression systems. In some critical use situations absorber units are used as back up cooling systems. Then, for example, in the event of a power outage, the absorber unit still may operate to provide cooling to critical systems without consuming a large amount of electrical power from the back-up power system as an electrical compressor would.

Specialty consumer applications of absorption technology are the small propane powered refrigerators used in recreational vehicles. These use the heat of a small pilot-light flame to regenerate the refrigerant (ammonia) from the absorber (water). The fluids circulate by gravity and convective forces (no pumps are used).

Adsorption

Adsorption systems, like absorption systems also use heat to regenerate a refrigerant. In an adsorption system the refrigerant attaches to (adsorbs to), and is released from, a solid media like zeolite instead being absorbed in a liquid solution. As with absorption, a supply of 'free' waste heat makes these systems more feasible. This technology is not common but has been investigated for applications like mobile coolers and some air conditioner units.

Stirling Cycle

The Stirling cycle uses an inert gas such as helium as the refrigerant. The cooling is provided by the expansion of a small volume of gas, which later undergoes compression to reject the heat absorbed. Energy input to the system is in the form of electricity to drive a motor which performs the compression. Currently these systems are used for niche applications only but several developmental projects are underway in Europe for more general applications.

Air Cycle

An air cycle uses air in a cycle similar to a vapour compression cycle. The air is expanded and compressed to take-in and reject heat. In an air cycle, however there refrigerant is always a gas and does not condense to a liquid. Air cycle systems have been used in some specialty applications like aircraft air conditioning systems.

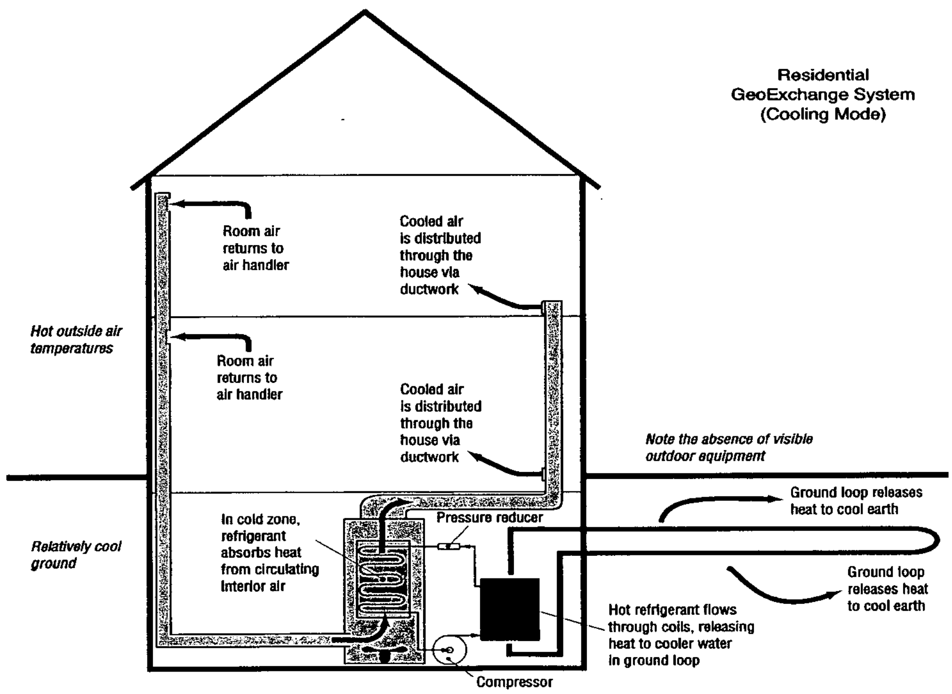
Ground Source Heat Pumps

Ground source heat pumps (GSHP) are a growing technology to reduce energy demands for heating and air conditioning. Sometimes called **geo-exchange** or **geothermal** this technology uses the ground as a source and 'sink' for heat. Since the temperature of the earth several feet below the surface does not vary substantially during the year, the equipment can be designed to use the ground as a heat source in the winter to provide heat for a building, as well as a heat sink in the summer as a place to take rejected heat to provide cooling.

Typically a water, brine, or antifreeze solution circulates to the outside of the building through the ground and back. A small heat pump is used to exchange heat between the building air and the circulated fluid in the ground loop. Typically this heat pump uses a vapour compression cycle using halocarbon refrigerants. (In this way GSHPs are not really true alternatives to vapour compression technology, but a very efficient application of existing technology.) The advantage of these systems is that they save substantial amounts of electricity - typically achieving energy savings of 40% compared to air source heat pumps, and over 70% compared to electric heating.

There are an estimated **650,000 GSHPs installed in the United States** to date. These range from single dwelling residential applications to institutional sized units for schools, museums and government offices.

The **Geothermal Heat Pump Consortium (GHPC)** (www.geoexchange.org) is an education and advocacy group that promotes GSHP technology. It provides extensive information and case studies of where this technique has been used. In 2000, Natural Resources Canada entered a three year agreement with the GHPC to increase its educational and awareness efforts for geothermal heat pump technology.



Geoexchange System Schematic

Illustration courtesy the Geothermal Heat Pump Consortium Inc.

District Cooling

District cooling is the cooling of numerous buildings from a single source. District cooling (and district heating) often results in efficiencies due to the large scale of systems that can be used and the possibility of making multiple use of systems - for example cogeneration or waste heat recovery. The International District Energy Association (IDEA) (www.districtenergy.org) is a non-profit trade organization formed to assist the district cooling sector.

Emerging and Niche technologies

Not-in-kind technologies such as **thermoelectric** refrigeration have been developed for specialized applications. Other technologies are still in the laboratory stage such as **thermoacoustic** refrigeration.

3.4 Demand Management Options

Reducing the demand for air conditioning systems reduces the amount of air conditioning and chiller power required and can result in substantial savings in energy and operating costs for commercial and office buildings. As well, it means that smaller chiller units can be used, which use a smaller amount of refrigerant.

Demand management is achieved through innovations in building design and materials. Numerous buildings have incorporated advanced design features to reduce cooling loads. These have become part of a rapidly growing field called **Green Building** design.

Advanced building design or 'green building' engineering can reduce the need for air conditioning refrigeration by as much as ½ of traditional building design systems.

A large component of Green Building design is the objective of *reducing* the demand for air conditioning at the outset rather than try to engineer more efficient air conditioning systems within existing design standards. Many design features that were once novel in this area are becoming common place in new buildings. Some examples of innovative building designs employed include:

- window glazing and solar shielding to prevent heat from entering a building.
- 'day-lighting' measures to increase the amount of natural light and reduce the lighting required and corresponding heat generated.
- under-floor air delivery systems which can provide a comfortable working environment with less chiller effort. For example, an under-

floor system could provide a comfortable space by delivering air at 17 deg C, while a conventional overhead system would need to deliver air at 12 deg C for the same comfort.

- utilizing site specific resources. For example, a Town Hall in Hinton Alberta uses municipal water as a cool water supply. The water is taken in on one side of the building - pumped through pipes to provide cooling to the building and released back into the municipal supply.

All factored in, these and *many* other design features could reduce the amount of air conditioning capacity required by as much as half over a traditional building design.

The **US Green Building Council** (www.usgbc.org) promotes the use of green building technologies as well as developing the **Leadership in Energy and Environmental Design (LEED™)** system of certification for buildings.

In British Columbia, the BC Buildings Corporation (BCBC) sponsors a program called **Green Buildings BC** (www.greenbuildingsbc.com) which promotes green building technology in both new building design and retrofits of existing buildings.

Research is ongoing on other building efficiency measures. Natural Resources Canada (www.nrcan.gc.ca), through its **CANMET Energy Technology Centre (CETC)** (www.nrcan.gc.ca/es/etb) promotes building efficiency research at its Technology Centre located in Varennes, Quebec (one of three CETC centres nation wide).

3.5 Alternative Refrigerant Trends in Europe and Asia

Alternative refrigerant systems - especially hydrocarbon use in domestic appliances - have achieved a high level of acceptance in Europe. Over the past decade, hydrocarbon refrigerant systems have become common in household and commercial appliances. These are also gaining acceptance in Japan.

Some examples of the acceptance and use of hydrocarbon refrigerants in Europe and Japan include:

- **Hydrocarbon refrigerators** were introduced to the German market in 1993 and by 2000, over 95 % of the new refrigerators sold in Germany used hydrocarbon refrigerants. For Western Europe as a whole, hydrocarbon units comprised 40% of new units in 1998. While there are still 140 million units using CFC-12 in Europe there are now 56 million units using HFC-134a, and already 25 million using hydrocarbons.
- Italian manufacturer **Delonghi's Piguino** line of portable room air conditioners includes several models using hydrocarbon refrigerant. The first models appeared in 1995. These units provide 6500 - 12,500 BTU/hr of air conditioning and dehumidification (www.delonghi.com).

- **EarthCare Products** in the UK (www.earthcareproducts.co.uk) sells a range of air conditioning units using non-HFC technologies. This ranges from portable units to larger split systems.
- **Calor Gas** in the UK (www.calorgas.co.uk) a producer of liquefied petroleum gases (LPGs) such as propane and butane has supplied hydrocarbon refrigerants since 1994. Calor produces a product line of refrigerant gases under the CARE product line (www.care-refrigerants.co.uk).
- **Matsushita** (maker of the **Panasonic** and **National** brands) placed the first hydrocarbon refrigerant home refrigerator on the Japanese market in Feb 2002 (www.panasonic.co.jp/global/). It then announced in August 2002 that it would phase-out the use of HFC refrigerant in all home-use refrigerators over 300 Litres capacity by the end of 2003. These units use isobutane as the refrigerant and foaming agent and have included many design innovations. Matsushita's 2002 environmental report states that compared to the original HFC units, the new units are quieter, use **5% *less* electricity**, require *less* lead and PCBs in their manufacture, and have reduced the total refrigerant charge required from 130 g of HFC-134a to 50 g of isobutane.

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4 Residential Sector

Residential applications include household refrigerators and freezers, air conditioning units (both split and portable systems), and heat pumps used in place of a furnace. Smaller niche markets also exist - for example for small refrigerators for recreational vehicles.

4.1 Household Refrigerators and Freezers

In North America new household refrigerators and freezers no longer use CFC refrigerant. However there are still a substantial number of older CFC units in use. Since a typical refrigerator may last 15 to 25 years this stock will take many years to be replaced. As these units are retired the refrigerant is required to be recovered, either through municipal waste collection programs (where available) or through distributor collection programs.

Most new domestic refrigerators use HFC-134a which has an ODP of zero. A typical new 18 cubic foot household refrigerator will contain 175 g of HFC-134a refrigerant. As well, the insulating foam is blown into place with an inert chemical that may be a halocarbon. Use of ODS for foam blowing agents is also being phased out under the Montreal Protocol.

Potential Alternatives for Household Refrigeration

Hydrocarbon refrigerants - most commonly propane or isobutane - are the most promising alternatives to HFC refrigerants. Such systems are commonplace in Europe with tens of millions of units sold. Hydrocarbon refrigerators are now manufactured and sold in India, China (more than 1 million units annually), and Japan (launched Feb 2002). (see section 3.5 for other examples of hydrocarbon refrigerant use in Europe and Japan).

Alternative technologies exist for some specialty markets. Ammonia-water absorption refrigerators are used in recreational vehicles where gas or propane are more convenient energy sources than electricity, or in hotels where they have the advantage of being quiet (i.e. no moving compressor parts). Since this technology does not scale up very well it will be limited to small size units and is unlikely to be used for a full sized refrigerator.

Typical TEWI Analysis

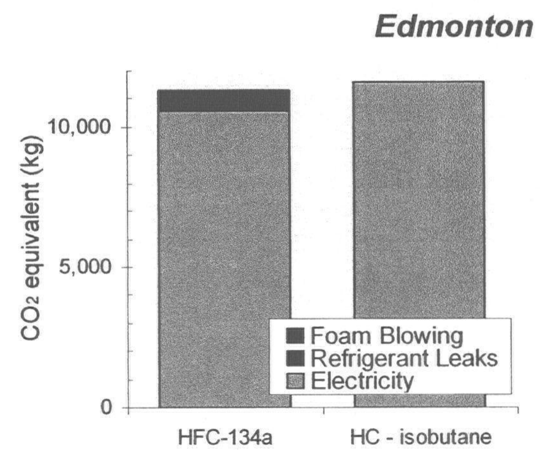
Environment Canada contracted studies of alternatives to ODS as part of its National Action Plan on ODS. A study of the residential sector (Environment Canada 1999a) evaluated the alternatives to CFC-based refrigerators and included an analysis of HFC and potential hydrocarbon systems (see sidebar). Sources of *direct* CO_2 equivalent emissions are the refrigerant and the foam blowing agent. Small amounts of refrigerant are expected to leak during a refrigerator's life - estimated at 2% per year and some during disposal - but at least 50% of the initial refrigerant charge is recovered at the end of the appliance life. The comparison in the example shows the total CO_2 equivalent emissions from operating a household refrigerator for a 17 life span. *Indirect* CO_2 emissions are produced during electricity generation.

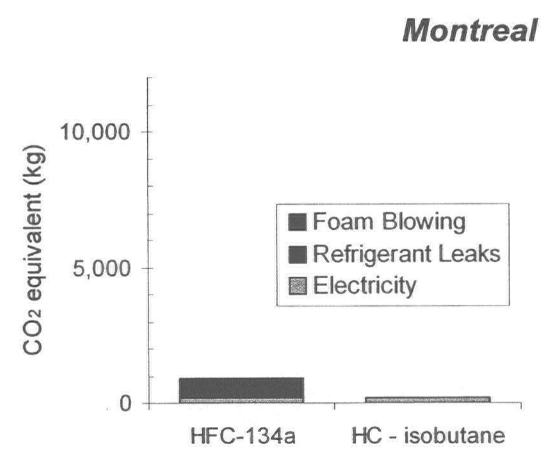
The Environment Canada study estimated that an isobutane system would use slightly more electricity than an HFC system. The CO_2 benefits of alternative technologies depend largely on the indirect emissions when the electricity is generated from fossil fuels. In areas where a high percentage of the electricity is generated from fossil fuels (e.g. Edmonton), most of the CO_2 equivalent emissions are due to electricity generation and distribution and only a small portion are due to the refrigerant losses or the foam blowing agent. In areas where a low percentage of the electricity comes from fossil fuels (e.g. Montreal which is mostly hydroelectric) the CO_2 emissions to make the electricity are far less than in Edmonton, reducing the impact of *both* options.

These are only estimates from a modeled refrigerator since consumer units for the *North American* market are not produced commercially and cannot be tested. However, this preliminary analysis shows that alternative refrigerant appliances should be expected to be close to current units in terms of energy efficiency.

In Europe, hydrocarbon refrigerants in domestic refrigerators are now a proven technology that are safely used in millions of household appliances. In Western Europe there are numerous product lines using hydrocarbons with over 24 million units sold to date. Over **95% of the domestic**

Modeled TEWI for a Potential Household Refrigerator





Indirect CO_2 emissions can be the major component of atmospheric effect in areas where electricity is generated from fossil fuels.

Source: Environment Canada (1999a)

refrigerators sold in Germany today use hydrocarbon refrigerants.

In Japan, Matsushita (maker of Panasonic and National) launched a model of its refrigerator with hydrocarbon refrigerant and found that it used **5% less electricity** than the HFC model. This is particularly important as Japanese refrigerators are more similar to North American refrigerators than European models (e.g. both have frost-free freezers while European models generally do not).

Barriers to Hydrocarbon Uses in Domestic Refrigeration

The examples of the European and Japanese markets over the past decade indicate that hydrocarbons can be used safely in household appliances. In spite of this, no household refrigerators are on the market in North America using hydrocarbon refrigerants. Reasons cited for not developing hydrocarbon systems in North America include:

- product liability fears, and potential lawsuits that could occur;
- North American refrigerators are typically larger than European models so they would require a larger charge of refrigerant - thus increasing flammability concerns;
- North American fridges usually have a frost free freezer (unlike European models) which includes a heater that may become a source of ignition;
- substantial efforts and expenses to gain regulatory approval (e.g. SNAP);
- costs to retool production facilities which meet fire codes for working with flammable gases, to educate and train repair and service employees.

Industry organizations promoting HFC use have argued that since a large component of the TEWI arises from indirect CO_2 emissions during the generation of electricity, then efforts should be devoted to improving the energy efficiency of appliances rather than changing the refrigerant.

4.2 Residential Air Conditioning and Heat Pumps

New **residential air conditioners** in North America typically use HCFC or HFC refrigerant since CFC units are no longer sold. Residential air conditioning system performance is regulated by performance regulations which have resulted in substantial improvements in energy efficiency in the past years. These define minimum values of the energy efficiency ratio (EER) or the seasonal energy efficiency ratio (SEER) that the appliances must meet. As well, in order to obtain an ENERGY STAR® rating, defined levels of efficiency must be exceeded.

For heat pump applications it is possible to use **engine driven heat pumps** instead of electric drive systems. Modern, efficient natural gas engines can drive a conventional heat pump system. Since heat pumps move more heat energy than they consume, they are more efficient than electrical resistance heating. There is still an energy cost, though it is in natural gas and not electricity. The environmental appeal of gas driven heat pumps is to reduce total CO_2 emissions since electricity losses in generation, transmission, distribution, and powering a motor may result in more CO_2 emissions than generating the energy at the location of use. In Japan, over 100,000 such units have been installed. In the UK, these units are undergoing testing by at least one energy company Advantica (www.advanticatech.com).

The *economic benefit* of engine driven heat pumps is dependant on many factors such as the relative prices for natural gas and electricity and the climate specific operating conditions. The *CO_2 emissions benefit* is dependent on the relative mix of fossil fuel generation in the electricity supply. This can vary with location across the country.

Ground source heat pumps use less energy than air source heat pumps and conventional air conditioners. At least one major air conditioning equipment manufacturer produces GSHP equipment in parallel with its line of conventional air conditioners and heat pumps. Several small manufacturers produce units for the North American market.

Some GSHPs include a desuperheater unit to heat domestic hot water. This unit captures heat that is normally 'rejected' out to the ground when the unit is in cooling mode, and captures it for domestic water heating. This feature only works when the unit is in cooling mode (i.e. summer time).

The **Geothermal Heat Pump Consortium (GHPC)** (www.geoexchange.org) provides extensive resources and examples for promoting heat pump technology. They estimate that ground source heat pumps have been used in 650,000 applications in the United States.

4.3 Reducing Residential Demand

Residential **home design and construction** can reduce energy needs - both for cooling and heating. The Office of Energy Management from Natural Resources Canada (NRCan) operates the R-2000 program (www.oee.nrcan.gc.ca/r-2000). R-2000 defines a set of energy efficiency performance standards. That is they define how a house must *perform*, not how it must be *built*. The **Canadian Home Builders Association** (www.chba.ca) is a partner in the R-2000 program and provides information on the program as well as access to listings of R-2000 approved builders (http://r2000.chba.ca/).

Typical R-2000 homes use 30% less energy than comparable new homes. Compared to an older house of 1970s vintage, an R-2000 home produces only *one third* of the CO_2 emissions. The R-2000 initiative has spawned many industry developments and innovative building products, such as heat recovery ventilators (now a $50-million per year industry) that exchange heat between incoming and outgoing air flows, high-performance windows, and integrated mechanical heating and cooling systems.

As well, Natural Resources Canada (NRCan) through its **Office of Energy Efficiency (OEE)** (www.oee.nrcan.gc.ca) actively promotes new and efficient technologies. It manages 17 energy efficiency initiatives that include information, education, and regulation of energy efficiency. Many of these are applicable to residential energy efficiency.

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5 Commercial Sector

The commercial sector includes commercial air conditioners and heat pumps, commercial supermarket and restaurant refrigerator and freezer systems, display cases and vending machines as well as large chillers for office buildings.

5.1 Commercial Air Conditioning and Heat Pumps

New systems today use either HCFC-22 or HFC refrigerants in North America. An office or commercial application might use one unit, or several units packaged together.

Alternative refrigerant systems (ammonia or hydrocarbons) are constrained by concerns regarding flammability or toxicity that have prevented manufacturers from developing and testing alternative refrigerant models.

In Central and Northern Europe ammonia and, to a lesser degree, hydrocarbon systems are being used. With the recent acceptance of hydrocarbon systems in domestic appliances over the past decade in Europe, hydrocarbon systems are becoming more common in commercial systems. For example:

- **EarthCare Products** (www.earthcareproducts.co.uk) in the UK produces a line of air conditioning systems from portable size to roof mounted commercial units which all use hydrocarbon refrigerants.
- **The Body Shop** has retro-fitted one of its stores in the UK with new hydrocarbon refrigerant air conditioning equipment.

5.2 Commercial Supermarket

Large commercial supermarkets often use a central refrigeration plant to supply cooling to numerous cold cases and freezers. These are single loop systems where the refrigerant is compressed in a refrigeration room, and circulated out to numerous evaporators at different display cases. These systems are called direct expansion (DX) systems. Typical air temperature requirements at the evaporator are -2 to -7 degrees C for meat, fish, dairy cases, and walk-in coolers, and -18 to -32 deg C for freezers and ice cream cases.

Direct expansion (DX) systems have the disadvantage that they have long tubing runs to carry the refrigerant to and from the evaporators. They require a large charge of refrigerant to fill the system (in the range of 300 kg to 1500 kg for a large grocery store). The long tubing runs increases the number of line segments and piping joints that could potentially leak. These systems traditionally have large leakage rates - historically as high as 30% of the total mass per year, though recent work suggests leakage of 15% per year is economically obtainable (A.D. Little 2002).

> Direct expansion (DX) systems in large supermarkets typically require between 300 and 1500 kg of refrigerant, and they may leak 15% of that each year.

Reducing Refrigerant Charge

Indirect systems use secondary loops of brine or antifreeze to distribute the cooling to the display cases. The primary refrigerant is then only used in a primary loop, dramatically reducing the refrigerant charge required - from hundreds of kg to tens of kg. In a California research project, use of a secondary brine loop system in a large supermarket reduced the amount of refrigerant from 2700 kg to less than 230 kg. Leakage rates are dramatically reduced with these systems from 15% to as low as 2% annually.

Distributed systems locate several refrigeration units through the store and close to the display cases instead of using a central compressor unit. For example, such a system might place the compressor unit above the display cabinets inside a sound proof box, or on the roof, directly above the coolers. Distributed systems reduce the length of tubing runs required and the total amount of refrigerant required. They have less leakage than DX systems (about 4% per year).

The **energy usage** of DX, indirect and distributed systems can be very close - results vary from study to study suggesting that each situation may require site-specific analysis. As a result, indirect and distributed systems may have comparable **operating costs** as DX systems. As these alternate applications become more commonplace, the cost competitiveness with DX systems is expected to improve.

Up front **capital costs** for indirect systems have traditionally been higher than for DX systems. This is due to the extra pumping and control mechanisms required. Distributed systems require the installation of several units within a single store instead of one centralized compressor and condenser facility.

Alternative Refrigerants

Large supermarket operations could use **ammonia** systems, though they would likely be designed as secondary loop (indirect) systems to prevent the risk of customer exposure in the event of a leak. These applications are likely be limited to new buildings due to the high costs of a complete retrofit to an existing building. Ammonia systems present some extra burden in handling and operation due to toxicity and flammability concerns.

Centralized **hydrocarbon** systems with secondary loop cooling to the display cases have been installed in several European countries. Some examples of the supermarket and food industry sector using alternative refrigerants include:

- about 50 ammonia systems have been installed in supermarkets in Europe as of 2001.
- ten hydrocarbon systems operate in grocery stores in Germany as of 2001 and there are others reported in the UK.
- in Helsingborg, Sweden a new supermarket opened in the late 1990s using hydrocarbon refrigerants. The system uses a propane/ethane mix in a primary loop, and two secondary loops - one with CO_2 for the freezers, and one with antifreeze solution for the medium temperature refrigeration. A direct expansion system would have used 2100 kg of HCFC, but the installed system requires only 35 kg of hydrocarbon refrigerant for the primary refrigeration loop (UNEP 1999).
- a new **McDonald's** restaurant (www.mcdonalds.com) opened in Denmark on Jan 16, 2003 that uses only non-HFC refrigeration technologies.

5.3 Vending Machines and Display Cases

Soft drink coolers and ice cream freezers are almost always self-contained units, similar to a household refrigerator and not connected to any central compression facility. They may be located indoors or outdoors. In the case of vending machines, they are often unattended for extended periods. New units in North America typically use HFC-134a.

> Several large corporations have committed to using non-HFC refrigerators and freezers where ever possible. This includes Coca-Cola (by 2004) and Unilever's Ice Cream operations (by 2005).

In Europe, the vending and display refrigeration sector has begun to use hydrocarbon systems. Consumer desire has encouraged food and drink manufacturers to use alternative refrigerant systems for their products. Some examples of the applications of alternative refrigerants in commercial applications in Europe include:

- **Elstar Manufacturing** (www.elstar.co.uk), a UK producer of back bar and counter top beverage and cold drink glass-door merchandise coolers widely used throughout the retail and leisure industries, has converted its *entire* line to hydrocarbon refrigerants using the **CARE** line of refrigerants (www.care-refrigerants.co.uk).
- **Unilever** (www.unilever.com) the world's largest ice cream manufacturer with over two million freezers in place worldwide, tested hydrocarbon systems in its display cases at the Sydney Olympic Summer Games and has since pledged to use only hydrocarbon refrigerant units wherever legally and commercially viable by 2005.
- **Coca-Cola** (www.coca-cola.com) agreed to purchase non-HFC refrigerators, wherever available in time for the 2004 Athens summer Olympic Games. As well, they are requiring their suppliers to improve the energy efficiency of *all* new refrigeration devices by 40 - 50 % by 2010. The company promotes this policy as part of its corporate citizenship activities (www2.coca-cola.com/citizenship/climatechange.html).
- **Ben & Jerry's** (www.benjerry.com), a Vermont based ice cream maker, in cooperation with the US Office of Naval Research, is funding research at Penn State University to develop an economical **thermoacoustic refrigerator**. Thermoacoustic refrigerators use sound waves to compress and expand gas in order to achieve the desired cooling effect.

5.4 Large Commercial Chillers

Large commercial chillers are used to cool water for office and commercial buildings. Today, in North America, these units use HCFC or HFC single or blend refrigerants. This equipment has a long installed life and much of the marketplace still contains existing CFC equipment. In the US, it is estimated that half of the CFC chillers that were in place at the start of the CFC phase out are still in place. New compressor technology using screw and scroll compressors on the market is suitable for the new refrigerants and more energy efficient than earlier equipment.

Modern chillers are substantially more energy efficient that older units. In many cases the electricity savings from new equipment can pay for the capital costs of replacement in *as little as five years*. To assist the change over from older CFC equipment, the refrigeration industry, with the

> The "Responsible Use" principles for building air conditioning promote refrigerants that:
>
> - provide the highest health and safety, environmental, technical, economic, and other unique societal benefits;
> - minimize refrigerant emissions to the lowest practical level; and
> - maximize Life-Cycle Climate Performance (LCCP) by minimizing the combined emissions of refrigerant and greenhouse gases from the production of power for the equipment.

the support of the US EPA through its ODS programs (www.epa.gov/ozone) and the ENERGY STAR® product programs (www.energystar.gov), is encouraging the accelerated replacement of CFC chillers in commercial building applications. The **Building Air Conditioning Climate Protection Partnership (BACCPP)** is a program by industry and government to accelerate the removal of CFC equipment. This program promotes the "Responsible Use" principles for building air conditioning systems. (see sidebar). Note that the responsible use principles represent a *minimum* industry practise. Regulations in many jurisdictions are *more* stringent.

Alternative technologies have been installed in convention centres, universities and other large institutional settings. Some examples of alternative systems already in place to provide large building cooling include:

- in Hannover, Germany one of the largest ammonia air conditioning systems has been installed at the **Hannover International Trade Fair Building**. It uses 2.5 tonnes of ammonia in a system that supplies 3500 kW of cooling (1000 TR).
- the **Banque Generale du Luxembourg**, uses a gas fired co-generation system to generate electricity for the buildings operations, *and* uses the excess heat to drive three lithium-bromide absorption chillers. The system saves the bank an estimated 1 million dollars per year in energy costs (including both electricity costs and air conditioning power costs).
- in Toronto, **Enwave District Energy Ltd.** (www.enwave.com) is a provider of district heating and cooling to over 115 industrial and commercial buildings in downtown Toronto. Enwave is installing a deep-lake cooling project to use the cool water from the lake for cooling buildings in the downtown core. This project is incorporated with municipal water facility upgrades being implemented by the City of Toronto.
- at **Cornell University** in Ithica New York, a Lake Source Cooling project has used water from the bottom depths of Cayuga Lake to provide cooling to the University (www.utilities.cornell.edu/LSC) since 2000. This installation eliminated chiller use (and the associated halocarbons) to cool numerous buildings. This system saves the university **23 million kWh** annually in electricity costs and has eliminated 9.6 million kg of CO_2 emissions per year.

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6 Industrial Sector

The industrial sector includes process applications, low temperature cold storage systems, as well as ice making and ice rink systems.

Some alternative refrigerants are established technology in industrial applications because they provide long term energy and operating efficiency. Most industrial applications are isolated from the public and supervised by trained staff which allows for the use of flammable refrigerants. For example, **ammonia** is common in industrial freezer and refrigeration systems, and the US EPA SNAP program has approved **hydrocarbon** refrigerants for use in industrial applications.

6.1 Ice Arena Refrigeration

Ammonia systems are used for 60% of the ice rink refrigeration systems in Canada, the remainder using halocarbon systems. Ammonia rink systems typically operate with temperatures of -12 deg C in the evaporator and 35 deg C in the condenser. They usually feature a secondary loop which circulates a chilled brine or antifreeze under the ice surface. The entire ammonia loop is contained in a mechanical room - isolated from general access which is important for public safety reasons. Ammonia systems are well developed technology for ice rinks.

Ground source heat pumps are becoming a popular alternative for ice rink applications. While most ice rink systems already use ammonia and are halocarbon free these systems still use substantial amounts of electricity and require proper handling of the refrigerant. GSHP systems use a small halocarbon refrigerant charge in a heat pump unit. This unit transfers heat from a brine loop which circulates under the ice, to a fluid loop circulating to the outside ground.

These systems can result in substantial cost and electricity savings which may reduce total CO_2 emissions. Generally the halocarbon refrigerant is contained in a small unit and the total charge is small (e.g. one commercial unit on the market uses only 6 kg of halocarbon per cooling unit, and requires several units per ice sheet). For small communities, the advantages of these systems in reducing electricity and maintenance costs makes them attractive (see sidebar).

Ground Source Heat Pumps Provide Cooling for Ice Rinks

Ground source heat pumps (GSHP) are a proven technology for ice making systems for skating arenas and curling rinks. They usually result in substantial operating savings due to decreased energy and maintenance costs compared with traditional ammonia ice-maker systems.

GSHP systems can be designed to provide *both* heating and cooling for ice rink systems - while they provide cooling to the sheet ice, they provide heating for the clubhouse and spectator areas. Other benefits have included increased club house comfort levels due to the improved heating system which in one case lead to increased rental revenues.

As with any new technology, these systems require proper engineering evaluation and must be constructed by qualified contractors. However, the extra effort and capital costs up front can achieve cost savings for many years to come. This is particularly valuable for small public facilities with limited resources.

In the examples cited below, the rink operators received an incentive credit from their electricity suppler (already factored into the cost column). These may be available in some jurisdictions.

Example 1: Oliver BC Curling Rink Retrofit

	Option 1: GSHP System	Option 2: Repair Ammonia System	Difference
Capital Costs ($)	$ 74,000	$ 48,500	$ 25,500
Annual Operating Costs ($ / year)	$ 10,359	$ 28,993	($ 18,634)
Payback time of extra capital costs through operating cost savings (years)			**1.4**

Example 2: Miami Manitoba: Hockey Rink Conversion from Natural Ice to Ice Making

	Option 1: GSHP System	Option 2: Ammonia System	Difference
Capital Costs ($)	$ 212,500	$ 179,500	$ 33,000
Annual Operating Costs ($ / year)	$ 24,130	$ 54,025	($ 29,895)
Payback time of extra capital costs through operating cost savings (years)			**1.1**

Source: Natural Resources Canada (c) 2000 (www.canren.gc.ca)
Note: Results for other applications may differ due to site specific factors not detailed above.

6.2 Cold Storage and Industrial

Ammonia systems are the industry standard for industrial cold storage and food processing systems. Typically these are direct expansion units custom built on site. Direct expansion systems with ammonia are almost always more energy efficient than direct expansion halocarbon systems. Ammonia systems account for **80% - 90%** of warehouse applications in the US.

For industrial applications, safety procedures and workplace standards for ammonia are well established. Ammonia systems are attractive for these applications because they are efficient, and the hazards can be properly addressed in a controlled access installation with trained personnel.

Large chillers (hundreds of tons of refrigeration) are used in many industrial applications to cool process waters. Most vapour compression industrial chillers today use HCFC-22, HCFC-123, or HFC-134a. Absorption technologies, which require heat to separate the refrigerant from the carrier fluid have been used in applications where waste heat is available (see side bar).

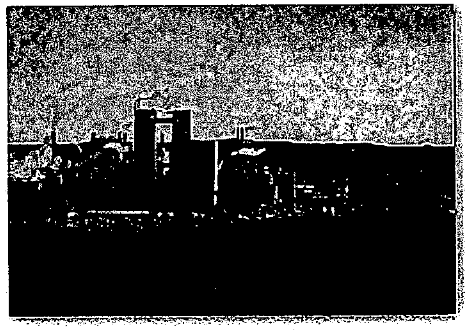
Absorption systems: Using Waste Heat to Chill

Pulp Mills need cool water to maintain the quality of their process systems. In summer, the source water temperature can become too high, and so many systems use cooling chillers. Electrical or diesel driven vapour compression systems are in place at many locations in Canada. Some of these older systems use ozone depleting CFCs.

Absorption systems use a fluid mixture to carry the refrigerant through part of the cycle. At one point the refrigerant must be liberated from the liquid stream in the generator stage of the absorption system. Heat is required to regenerate the refrigerant.

Absorption systems were more common in the 1960s but the oil price shocks of the 1970s made stand alone systems unworkable. Today absorption systems are less economical if the fuel must be bought and burned to create heat.

Many pulp mills have excess heat such as low pressure steam that is not needed elsewhere in the mill. This can be used to power absorption systems. In a fortunate twist, many mills have excess steam in the summer, just when the process water needs the most cooling. In the winter, the source water is cooler and the chillers may not need to operate. Then the steam can be deployed elsewhere.



Northwood Pulp uses Fraser River water in its bleaching process. As water temperatures rise, chillers must be used to maintain the right process temperatures

At Northwood Pulp in Prince George, an electric driven CFC refrigerant system required an overhaul in the mid-1990s. The chiller heat exchanger tubes were plugging and cooling efficiency was deteriorating. With the CFC phase-out underway, an absorption system was installed to take advantage of otherwise unused energy.

Many mills in BC have made such retrofits to make use of excess steam heat including mills in Prince George, Kamloops, Castlegar, Duncan and Nanaimo.

Information and photo courtesy Trane Inc. (Vancouver).

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7 Automotive and Transportation Sectors

7.1 Automotive

In early 1995, the industry standard refrigerant for automobile air conditioners changed from CFC-12 to HFC-134a. CFC systems are no longer sold in North America and it is now prohibited to recharge an existing automobile air conditioning system with CFCs. In Canada, current regulations require that all halocarbon refrigerants (CFC, HCFC, and HFC) removed from an automobile system must be recaptured.

Hydrocarbon Refrigerant Alternatives

In North America, no new passenger vehicles are currently sold with hydrocarbon air conditioning systems. The flammability of these mixtures creates a concern that a refrigerant leak into the passenger compartment could create a fire hazard and perhaps a product liability issue.

Some research has shown that single loop hydrocarbon systems similar to current units could be designed with a small additional risk. More likely, the development of secure air conditioning systems (perhaps incorporating a secondary loop) will be required before original equipment manufacturers (OEM) are willing to market such devices.

Various **hydrocarbon** refrigerant blends are available as **after-market** retro-fit products and have been installed in numerous vehicles in North America and Australia. These are mixtures of ethane, propane, and butane, and are marketed with a variety of trade names. There may be some consumer confusion with regard to whether these refrigerants are approved drop-in replacements. Retro-fitting existing systems with hydrocarbon refrigerants should always be verified with the original equipment manufacturer (OEM). The use of an unauthorized refrigerant may affect the validity of the vehicle or air conditioning warranty, or insurance, and may pose a serious hazard as current systems are not designed for flammable refrigerants.

In the US, the EPA is responsible for regulating the environmental impacts and safety of alternatives to ozone depleting substances through its SNAP program (www.epa.gov/ozone/snap). As of 2002, no hydrocarbon has been approved as a replacement for an ODS in automobile air conditioning systems. A grey area still exists however, because the EPA does not regulate replacements for **non**-ODS (i.e. HFC-134a) and after-market manufacturers sell hydrocarbon refrigerants to replace HFC refrigerants but not as a replacement for a CFC or HCFC system. However, many states in the US have prohibited the use of hydrocarbon refrigerants through state motor vehicle legislation.

Alternative Systems

Promising alternatives to vapour compression HFC systems are CO_2 systems and secondary loop systems.

Carbon dioxide (CO_2) systems have been developed for automotive applications. CO_2 refrigerant itself is environmentally benign because the gas is typically extracted from another plant process waste stream, and the volumes of CO_2 used are very small. These systems have not yet been commercialized on a large scale. First generation systems have come to market in prototype vehicles (see sidebar).

Secondary loop systems could be designed to use flammable refrigerants such as hydrocarbons because they contain the hydrocarbon in a primary loop, away from the vehicle interior. The secondary loop would then circulate through the passenger compartment. They also would use a smaller volume of the flammable refrigerant. Prototype testing of secondary loop systems has been performed. Commercial installation is not underway.

Research into other systems has been performed by laboratory and air conditioning organizations in the US and Europe. Prototype systems using an **air compression** cycle fluid have been tested, but it is unlikely they will be commercialized in the short term.

Not-in kind technologies such as **desiccant** systems have been prototyped but none are expected to be commercialized.

First CO_2 Automotive Air Conditioner

Toyota Motor Company and Denso Corporation of Japan announced in December 2002 that they have developed a CO2 heat pump and air conditioning system for automobile use.

This unit will be installed in Toyota's new fuel cell hybrid vehicle (FCHV-4) launched in December 2002 (www.toyota.com). Six of the FCHV-4 vehicles are being delivered to two universities in California for field testing.

Other manufacturers have investigated the performance of CO_2 systems for mobile air conditioning (MAC) and so more units may be on the market in the future.

Automotive TEWI Considerations

Energy consumption just to power the air-conditioners on light duty vehicles consumes 27 *billion* litres of gasoline annually in the US alone!

Total Equivalent Warming Impact (TEWI) calculations combine the warming impact of the refrigerant emissions and the CO_2 emissions from burning fuel to power the air conditioner. The analysis looks beyond the refrigerant emissions alone and considers the burden of the weight and power requirements of the air conditioning equipment on fuel efficiency. For example, alternative designs could weigh more than a conventional system and lose some energy through heat transfer which might require additional fuel consumption. They might also require extra pumps and controls which could pose a drain on the engine systems resulting in a loss of fuel efficiency, and higher CO_2 emissions.

The individual effect of a small change in energy efficiency due to an air conditioning system change may seem minor. However, the cumulative effect is dramatic. In the US, the current consumption of gasoline by light duty vehicles *just to power* the air conditioning units is estimated at *27 billion litres of gasoline* annually (Farrington 2002). A change of a few percent in the energy draw of air conditioners would have a substantial effect on total CO_2 emissions and energy consumption.

The emerging technologies show some promise that they may soon be able to deliver a similar cooling power without a penalty of lowered fuel efficiency. An Environment Canada modelling study estimated that hydrocarbon and CO_2 systems would create only slightly more CO_2 emissions from the tailpipe but would not release any refrigerant directly. The modelled result was a net-decrease of total CO_2 equivalent emissions.

Automotive Trends

The **Society of Automotive Engineers** (www.sae.org), through its Alternative Refrigerant Cooperative Research Project, conducts engineering evaluations of alternate refrigeration systems. This project includes North American, Asian, and European vehicle manufacturers. Environment Canada is a partner in this project.

The **US Department of Energy's (DOER) National Renewable Energy Laboratory (NREL)** (www.nrel.gov) conducts research towards the goal of reducing the fuel used for automotive climate control by 50% within 5 years and to an ultimate goal of 75%. Measures being researched include new glazes for windows to reduce cooling requirements, targeted delivery of cooling, and more efficient cooling equipment.

7.2 Truck Transport Refrigeration

Transport refrigeration uses self contained cooling systems complete with a self contained power supply - usually a diesel generator. These attach to trailers for long haul systems or to the cargo hold on delivery style vehicles but generally do not link to the drive engine for power, heat, or compressor drive electricity. New equipment in North America use HFC refrigerants. Transport systems must be robust to maintain set point temperatures in all varieties of climate - sometimes requiring both heating and cooling functions.

Truck Transport alternatives include hydrocarbon systems. A prototype of a propane based system has been built for testing in Germany. It required no additional safety installations and no additional use restrictions were cited. The system was a 10 kW refrigerator (3 TR) and required 2.5 kg of refrigerant. Limited interest appears to exist from buyers, so the commercialization of such equipment is not likely in the short term.

Other technologies, such as absorption have not been developed for the transport market. An absorption system could be efficient if it could make use of waste heat from the engine. Otherwise it would not be expected to be as efficient as a vapour compression cycle. This would complicate the design since most trailer transport refrigeration units are attached to the trailer and not connected to the drive unit.

A new alternative technology has been developed using liquefied CO_2. The liquid gas is evaporated to produce cooling. This system is not a cycle but rather a flow through system venting the CO_2 to the atmosphere and capturing the cooling power of the evaporation process (see side bar)

7.3 Marine Transport Refrigeration

Most marine transport cargo refrigeration systems use exclusively HCFCs. Sea going vessels typically use CFC, HCFC, or HFC air conditioning systems. About 2/3 of the global fleet are based in countries that do not have to eliminate ODS for many years so these systems are likely to be around for some time.

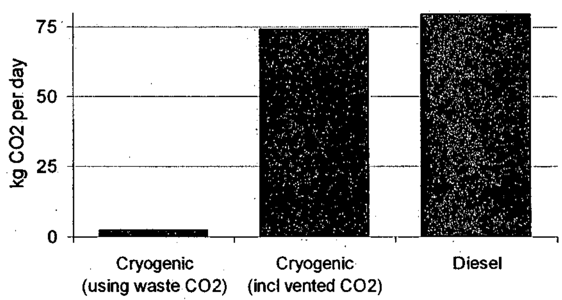
Since 1994 some European built vessels have used **ammonia** systems, and at least one Japanese manufacturer has built one as well. While ammonia had not been used for many years in western fleets, its use was accepted again after it became clear that CFCs would be banned. Currently about 50 systems are built annually. There exists a large stock of fishing vessels using ammonia refrigeration - almost exclusively in the Russian and Eastern European fleets.

There are an estimated 410,000 refrigerated **intermodal containers**. About half still use CFC-12, and the remaining use HCFCs or HFCs. Flammable refrigerants such as hydrocarbons or ammonia are not allowed on these units by International Marine Organization (IMO) legislation.

Cryogenic Refrigeration: CO_2 keeps deliveries cool and delivery trucks quiet.

Temperature controlled transport and delivery vehicles have to keep fresh and frozen products at prescribed temperatures - often in the same vehicle. To maintain a 2 deg C container with fresh food might mean cooling in the summer and heating in the winter. Typically these systems use vapour compression refrigerators mounted to the trailer unit or cargo bed.

A unique new cooling system has been developed called 'cryogenic refrigeration' that uses the expansion of liquid CO_2 to a gas to provide the cooling effect. Used since 1997 in Europe and launched in North America in 2002, this system is quiet (no compressor) and free of diesel exhaust which is important for complying with municipal noise and emission regulations. The system provides fast cooling - up to three times faster than traditional units - which is important for delivery trucks where the doors are opened regularly.



The Life cycle CO_2 emissions per delivery day for a CO_2 system and a diesel system

The model launched in North America holds a charge of 450 kg of CO_2 which will last for about a day. The need to refill the unit often makes them most applicable to local delivery trucks rather than long distance transport.

If the CO_2 source is processed from another waste stream (e.g. fertilizer or brewery process exhaust) then the direct CO_2 emissions of the gas are zero (i.e. no new emissions). There is energy 'embedded' in the CO_2 gas to compress it to a liquid which may have resulted in CO_2 emissions.

A Life Cycle Assessment (LCA) done in Sweden (where 7% of electricity generation is from carbon fuels) showed that less CO_2 was emitted from this system than from a conventional diesel system when all sources were factored in. Even when the CO_2 gas was included, this system had similar emissions as a diesel powered system.

The units currently cost 5%-10% more than a comparable diesel unit. The greatest difficulty is that they need to be refilled with CO_2 which requires a special CO_2 filling station which costs about US $150,000. Spread across a large fleet of trucks that might just be worth the expense. For example, Market Day, a food delivery cooperative based in Chicago has ordered 12 refrigeration units and a filling station.

In Sweden, a (CO_2) gas supply company has partnered with a commercial diesel depot to provide CO_2 to its customers. In that area, buying one or two refrigerator units does require having to buy an entire filling station. This approach could make cryogenic refrigeration economic to smaller sized delivery fleets.

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8 Acronyms

AC or A/C	Air Conditioning
AFEAS	Alternative Fluorocarbons Environmental Acceptability Study
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
Btu	British thermal unit
CFC	Chlorofluorocarbon.
COP	Coefficient of Performance
CCME	Canadian Council of Ministers of the Environment
CSA	Canadian Standards Association
DOE	Department of Energy (US)
DTIE	Division of Technology, Industry and Economics (of the UNEP)
DX	Direct Expansion
EER	Energy Efficiency Ratio
EPA	Environmental Protection Agency (US)
FPWG	Federal - Provincial Working Group (of the CCME)
GHG	Green house gas(es)
GSHP	Ground Source Heat Pump
GWP	Global Warming Potential
HC	Hydrocarbon
HBFC	Hydrobromofluorocarbons
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HVAC	Heating, ventilation and air conditioning
kg	kilogram
kW	kilo Watt
kW-hr	kilo Watt-hour
LCA	Life Cycle Assessment
LCCP	Life Cycle Climate Performance
LPG	Liquefied Petroleum Gas
MAC	Mobile Air Conditioning
MW	mega Watt
MW-hr	mega Watt-hour

NOx	Nitrous oxides
ODP	Ozone Depleting Potential
ODS	Ozone Depleting Substance(s)
OEM	Original Equipment Manufacturer
PFCs	Perflurocarbons
R-	Refrigerant
R-2000	R-2000 home building standard
SAE	Society of Automotive Engineers
SEER	Seasonal Energy Efficiency Ratio
SNAP	Significant New Alternatives Program
TCA	Total Cost Accounting
TEAP	Technology and Assessment Panel (of the Montreal Protocol)
TEWI	Total Equivalent Warming Impact
TR	Tons of refrigeration
UL	Underwriters Laboratories
UNEP	United Nations Environment Program
US EPA	United States Environmental Protection Agency

9 Glossary

Btu	A measure of heat energy. Specifically this is the heat required to raise (or lower) the temperature of one pound of water, one degree Fahrenheit.
Btu/hr	The rate at which heating or cooling can be supplied. Residential air conditioners are frequently rated in Btus (e.g. 24,000 Btu units) however these ratings actually mean Btu *per* hour.
Charge	(i) The amount of refrigerant in a piece of equipment. "..the refrigerant charge is 200 kg." (ii) The act of adding refrigerant to a system. "..to charge a system always follow manufacturers instructions."
Chillers	Large refrigeration units typically used to chill water for circulation through a building air conditioning system.
Chlorofluorocarbon (CFC)	A class of chemicals that contain chlorine and fluorine atoms bound to a carbon atom (or chain of carbon atoms). These chemicals are ozone depleting substances (ODS).
Climate Change	The altering of the global climate due to the heat-trapping action of natural and man-made greenhouse gases.
Coefficient of Performance (COP)	A measure of the cooling output obtained for the amount of energy put in (all in consistent units). For example, a COP of 3 means that the system provides 3 Watt of cooling power for each Watt of electrical power consumed. (NB COP * 3.413 = EER)
Direct Emissions	Emissions of GHG (refrigerant or CO_2 from combustion) that occur at the point of using a piece refrigeration equipment. (see also 'indirect emissions')
Direct Expansion	Single loop systems in which the evaporators of the refrigerant are located at the point of cooling. Typically, this terminology is applied to large systems where there may be options to use others systems such as distributed systems or secondary loop systems. (While a domestic refrigerator is a direct expansion

system, it is rarely referred to this way because all domestic refrigerators are direct expansion systems.)

Distributed Systems — Systems for large commercial applications (e.g. supermarket) where the refrigeration units are distributed throughout the store.

Drop-in Replacement — The procedure of changing a CFC refrigerant for a non-CFC refrigerant in existing equipment without doing major modifications. The terms is slightly misleading since a retrofit of some nature is usually required including changes to the lubricant, and the expansion device, and some fittings.

Energy Efficiency Ratio (EER) — A measure of efficiency used for residential and small commercial sized air conditioning equipment. This is defined as the cooling effect (in Btu/hr) divided by the power used by the equipment (in W not kW). Higher numbers indicate higher efficiency. (NB: EER = COP * 3.413)

Environment Canada — Canadian Federal agency administering acts and regulations to protect the environment.

Environmental Protection Agency (EPA) — US federal agency administering acts and regulations to protect the environment.

Global Warming Potential (GWP) — The ability of a gas to contribute to global climate change by an effect called the greenhouse effect. The measure is expressed relative to the strength of CO_2.

Greenfreeze — A name applied to non-HFC refrigeration technology - specifically in Europe to hydrocarbon refrigerant refrigerators and air conditioners.

Greenhouse Gas (GHG) — Gases which contribute to global climate change due to a process referred to as the 'greenhouse effect'. CO_2 is the primary greenhouse gas of concern. Five other GHG are monitored. These are methane (CH_4); nitrous oxide (N_2O); sulfur hexafluoride (SF_6); perfluorocarbons (PFCs); and hydrofluorocarbons (HFCs).

Halogens — A class of highly reactive elements which include fluorine, chlorine, bromine, and iodine.

Halocarbons — A class of chemicals defined by a chain of one or more carbon atoms with halogens (e.g. fluorine, bromine, chlorine) attached.

Halons — A class of chemicals containing one or more carbon atoms with fluorine, chlorine, and bromine atoms attached. Halons are most commonly used in fire fighting equipment.

Heat Exchanger — A device which transfers heat from one fluid to another, without mixing the fluids. Typically the two fluids flow through the unit and heat is conducted from the warmer one to the cooler one through the metal material of the heat exchanger.

Heating Seasonal Performance Factor (HSPF) — A rating used to measure the heating efficiency of a heat pump. Higher values of HSPF indicate better energy efficiency of the heat pump system.

Hydrocarbons	A class of compounds with one or more carbon atoms in a chain, with hydrogen atoms attached.
Hydrochlorofluorocarbon (HCFC)	A class of chemicals that contain hydrogen, chlorine and fluorine atoms bound to a carbon atom (or chain of carbon atoms). These chemicals are ozone depleting substances but are less potent than CFCs and Halons. They are considered interim replacements for CFCs.
Hydrofluorocarbon (HFC)	A class of chemicals that contain chlorine and fluorine atoms bound to a carbon atom (or chain of carbon atoms). These chemicals do not deplete the ozone layer.
Indirect Emissions	Emissions of GHG (usually CO_2 and NOx from combustion) that occur away from the point of use of a piece of refrigeration equipment. Usually these are emissions created during the generation of electricity from fossil fuel power sources.
Indirect System	A secondary loop system.
kilowatt (kW)	A rate of energy consumption (or power output). 1 kW = 1000 W
Kyoto Protocol	An international agreement under which emissions of green house gases are stabilized.
Latent heat	Heat required to change a substance from one form to another without changing temperature. For example, water at 100 deg C absorbs heat to boil and become vapour at 100 deg C. This heat requirement is the latent heat to vapourize water.
Life Cycle Climate Performance (LCCP)	A method for accounting for CO_2 emissions that includes direct and indirect emissions
Montreal Protocol	An international agreement under which ozone depleting substances are no longer used or produced.
Nitrous Oxides (NOx)	By-products of combustions processes. Nitrous oxides have some GWP potential.
Ozone	A molecule consisting of three oxygen atoms. In the stratosphere ozone molecules block dangerous solar radiation from reaching the earth's surface. At ground level, ozone is a pollutant and common component of smog.
Ozone Depleting Potential (ODP)	The relative ability of a compound to deplete the ozone layer. The ODP is the potency of a compound compared to that of CFC-11. The ODP of CFC-11 set to a strength of 1. Thus an ODP = 0.1 means that one kg of the compound will destroy 10% of the ozone molecules that 1 kg of CFC-11 would.
Ozone Depleting Substance (ODS)	A substance that, when transported to the stratosphere, will break down ozone molecules, which form a protective layer for the atmosphere.
Perfluorocarbon (PFC)	A class of chemicals containing only fluorine molecules attached to a carbon atom (or chain or carbon atoms).

Split System	An air conditioning unit where the evaporator and condenser units are contained in two separate machines, with refrigerant piped between them. For example, many residential central air conditioning systems are split systems with the condenser unit located outside the house, and the evaporators inside the house.
Seasonal Energy Efficiency Ratio (SEER)	A measure of cooling efficiency for air conditioners and heat pumps used for residential equipment. Higher SEER values indicate that the unit is more energy efficient.
Secondary Loop	A refrigeration system with two fluid loops. The first loop usually contains a vapour compression cycle, and the second loop is often a brine or anti freeze solution. The primary loop cools the secondary fluid, and the secondary fluid is transported to other parts of a building to provide cooling.
Total Equivalent Warming Impact	A method to account for the direct and indirect CO_2 equivalent emissions from the use of refrigerating equipment. The TEWI is not a property of a refrigerant. The TEWI is a measure of the global warming impact of operating a specific system in a specific location and includes effects of leaks from the system, CO_2 emissions generated on site, and CO_2 and NO_x emissions created when electricity generated elsewhere, is consumed to drive the system.

10 Further Information

Ozone Depleting Substances (ODS) Resources

Organization	Web Site Comments
Environment Canada: Stratospheric Ozone	www.ec.gc.ca/ozone Environment Canada's Official Site for Ozone Depleting Substances
US EPA (EPA) Ozone	www.epa.gov/ozone United States Environmental Protection Agency Ozone Website
United Nations Environment Program: Ozone Secretariat	www.unep.org/ozone The Secretariat for the Vienna Convention for the Protection of the Ozone Layer and for the Montreal Protocol on Substances that Deplete the Ozone Layer. The site is a clearinghouse of information related to the Ozone and the challenges faced in its preservation.
UNEP OzoneAction: United Nations Environment Program Division of Technology, Industry and Economics (DTIE)	www.uneptie.org/ozonaction Supports the phase out of ozone-depleting substances (ODS) in developing countries under the Montreal Protocol through its information clearinghouse and capacity-building services.
Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol	www.teap.org Provides technical information related to the ODS alternatives that have been investigated. Part of the Montreal Protocol on Substances that Deplete the Ozone Layer. This site contains reports produced by the TEAP and its sector specific Technical Options Committees and Task Forces, including annual progress reports.

Climate Change Resources

Organization	Web Site Comments
Government of Canada Climate Change Web Site	www.climatechange.gc.ca Gateway to Federal Government plans and initiatives on climate change. Includes links to Federal Departments
Environment Canada	www.ec.gc.ca/climate Environment Canada's Climate Change home page
US EPA Global Warming Site	http://yosemite.epa.gov/oar/globalwarming.nsf/content/index.html United States Environmental Protection Agency Global Warming Website
United Nations Framework Convention on Climate Change	www.unfccc.int Main gateway to the United Nations resources on climate change.

Federal, Provincial, and Territorial ODS and Halocarbon Regulations

Organizations:	Web Site / Comments
Environment Canada: Stratospheric Ozone	www.ec.gc.ca/ozone Environment Canada's Ozone Depleting Substances site. Includes the Ozone Depleting Substances Regulation and the Federal Halocarbon Regulation 2002
Environment Canada: National Office of Pollution Prevention	www.ec.gc.ca/NOPP Environment Canada's National Office of Pollution Prevention
Environment Canada: Canadian Pollution Prevention Information Clearinghouse	www.ec.gc.ca/CPPIC Environment Canada's Canadian Pollution Prevention Information Clearinghouse (CPPIC), a searchable inventory of pollution prevention (P2) information
Canadian Council of Ministers of the Environment (CCME)	www.ccme.ca Forum of all federal, provincial, and territorial governments for joint action of environmental issues of national and international concern.

Organization	Web Site / Comments
BC Ministry of Water, Land, and Air Protection (WLAP)	http://wlapwww.gov.bc.ca/air/ozone Stratospheric Ozone site, including the Ozone Depleting Substances and other Halocarbons Regulation - 1999
Alberta Alberta Environment	Ministry of Environment site www3.gov.ab.ca/env Ozone Depleting Substances and Halocarbon Regulation www.qp.gov.ab.ca/Documents/REGS/2000_181.CFM
Saskatchewan Ministry of Environment and Resources	Saskatechewan Environment Home www.se.gov.sk.ca Queens Printer site for the ODS Control Act, and the ODS Control Regulation www.qp.gov.sk.ca
Manitoba	Ozone Depleting Substances Act (C.C.S.M. c. 080) http://web2.gov.mb.ca/laws/statutes/ccsm/o080e.php Ozone Depleting Substances Regulation (103/94) http://web2.gov.mb.ca/laws/regs/pdf/o080-103.94.pdf
Ontario Ministry of the Environment	Ozone Depleting Substances Home Page www.ene.gov.on.ca/envision/Ozone/home.htm Ozone Depleting Substances Regulation - General (Reg 356) http://192.75.156.68/DBLaws/Regs/English/900356_e.htm Refrigerants Regulation (189/94) http://192.75.156.68/DBLaws/Regs/English/940189_e.htm
Quebec	Quebec's ODS Home Page (English) http://www.menv.gouv.qc.ca/air/saco_strategie-en/part-1.htm
New Brunswick	Clean Air Public Information Access Site (includes ODS) http://www.gnb.ca/0009/0355/0005/0001%2De.html Clean Air Act www.gnb.ca/0062/acts/acts/c-05-2.htm ODS Regulation (OC 97-922) www.gnb.ca/0062//regs/97-132.htm
Nova Scotia	Environment Act www.gov.ns.ca/legi/legc/statutes/environ1.htm Ozone Layer Protection Regulations (54/95) http://www.gov.ns.ca/just/regulations/regs/env5495.htm
PEI	Environmental Protection Act www.gov.pe.ca/law/statutes/pdf/e-09.pdf ODS and Replacements Regulation (contact information - regulation not online) http://www.gov.pe.ca/infopei/onelisting.php3?number=20125
Newfoundland & Labrador	Environmental Protection Act (E-14.2) www.gov.nf.ca/hoa/statutes/e14-2.htm Ozone Depleting Substances Regulations www.gov.nf.ca/hoa/regulations/rc970120.htm

Federal, Provincial, and Territorial ODS and Halocarbon Regulations (con't)

Organization	Web Site Comments
Yukon: Department of Renewable Resources	Department of Renewable Resources Main Page www.renres.gov.yk.ca/environ Environment Act: http://renres.gov.yk.ca/downloads/envact.pdf ODS and other Halocarbon Reg - 2000 http://renres.gov.yk.ca/downloads/odsregs.pdf
Northwest Territories Dept Resources, Wildlife and Economic Development, Environmental Protection Service	Home Page for Environmental Protection Act and Guideline for Ozone Depleting Substances http://www.gov.nt.ca/RWED/eps/leg.htm
Nunavut	Environmental Protection Act (R.S.N.W.T. 1988, c. E-7) http://www.lex-nu.ca/en/cons_laws/pdf/Type061.pdf

Note: A version of this information is available from the Environment Canada Ozone Website at www.ec.gc.ca/ozone. Click on the link to 'Regulations' and look for 'Provincial and Territorial Regulations'.

Alternative Refrigerants / Refrigeration Industry Organizations

Organization	Web Site Comments
Multisectoral Initiative on Potent Greenhouse Gases (MIPIGGs)	www.mipiggs.org An awareness and advocacy group promoting alternatives to HFCs, PFCs, and SF6 in many industry sectors. The membership includes government agencies, manufacturers of alternative gases and systems, and non governmental organizations.
eurommon	www.faktor3.de/eurammon/englisch/html/index.html European industry group including many German companies promoting "competence for the use of natural working fluids in refrigeration. The initiative sees its mission in providing a platform for information and knowledge sharing." This resource focuses on ammonia, carbon dioxide, and hydrocarbon refrigerants.
International Institute of Ammonia Refrigeration	www.iiar.org Industry group promoting the use of ammonia refrigeration.
Ammonia Refrigeration Technician's Association	www.nh3tech.org A new technical association formed in 1996 "dedicated to assisting operators and technicians in making ammonia refrigeration a safer trade for all of us."
International Ground Source Heat Pump Association	www.igshpa.okstate.edu Industry group promoting ground source heat pumps
Geothermal Heat Pump Consortium (GHPC)	www.geoexchange.org Non-profit organization created in 1994 to increase the use of GeoExchange technology for both commercial and residential heating and cooling.
Earth Energy Society of Canada	www.earthenergy.ca Represents the earth energy (ground-source or GeoExchange) industry, to promote quality installations, and to promote earth energy technology as a viable economic and environmental option in Canada's energy scenario. This site provides background information for Canadians who are considering earth energy:

Refrigeration Industry Organizations

Organization	Web Site / Comments
Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI)	www.hrai.ca Partnership of industry sector organizations that represents Heating, Ventilation, Air Conditioning and Refrigeration (HVACR) manufacturers, wholesalers and contractors.
Refrigerant Management Canada (RMC)	www.hrai.ca/rmc Not-for-profit organization established by the HRAI and the Canadian refrigeration industry to provide a program that manages the responsible disposal of Canada's stocks of surplus ODS from the Canadian refrigeration and air conditioning industries.
Air Conditioning & Refrigeration Institute	www.ari.org The Air-Conditioning and Refrigeration Institute (ARI) is the national trade association representing manufacturers of more than 90 percent of North American produced central air-conditioning and commercial refrigeration equipment.
American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)	www.ashrae.org ASHRAE advances the arts and sciences of heating, ventilation, air conditioning, refrigeration and related human factors to serve the evolving needs of the public and ASHRAE members.
Refrigerating Engineers and Technicians Association (RETA)	www.reta.com Dedicated to the professional development of industrial refrigeration operators and technicians.
Refrigeration Service Engineers Society	www.rses.org A HVAC/R Training Authority, offering industry-leading educational and certification programs to service professionals engaged in heating, ventilation, air conditioning or refrigeration.
Association of Home Appliance Manufacturers	www.aham.org Industry association of home appliance manufacturers.
Air Conditioning Contractors of America ACCA)	www.acca.org Non-profit industry association representing the heating ventilation and air conditioning contractors industry.
Alternative Fluorocarbons Environmental Acceptability Study (AFEAS)	www.afeas.org Industry group. Contracted studies by A.D. Little which first introduced the terms TEWI and LCCP
Alliance for Responsible Atmospheric Policy (ARAP)	www.arap.org Industry coalition organized in 1980 to address the issue of stratospheric ozone depletion. It is presently composed of about 100 manufacturers and businesses which rely on CFCs, HCFCs, and HFCs.
European Partnership for Energy and Environment (EPEE)	www.epeeglobal.org A group of companies, national associations, and European associations active in the European air-conditioning, heat pump and refrigeration industry. It was formed in September 2000 to contribute to the development of effective European policies to reduce green-house gas emissions from the use of refrigerants.
International Institute of Refrigeration	http://www.iifiir.org The International Institute of Refrigeration (IIR) is a scientific and technical intergovernmental organization enabling pooling of scientific and industrial know-how in all refrigeration fields on a worldwide scale.
Japan Air Conditioning, Heating, and Refrigeration News (JARN)	www.jarn.co.jp Japanese industry association
Association of European Compressor and Controls Manufacturers	www.asercom.org Asercom aims to be the "guiding force in dealing with scientific and technical challenges, promoting standards for performance and safety, serving the refrigeration and air conditioning industry and its customers.

Building Management, Green-Construction, Energy Efficiency

Organization	Web Site / Comments
Canadian Home Builders Association	www.chba.ca Industry group representing Canada's housing industry- new home builders and renovators, land developers, trade contractors, product and material manufacturers, building product suppliers and others.
Building Owners and Managers Association (BOMA)	www.boma.org (International Organization) www.bomacanada.org (Canadian Branch) Organization represent building owners and managers.
US Green Building Council (USGBC)	www.usgbc.org Develops the Leadership in Energy and Environmental Design LEED™ products and resources, policy guidance, and educational and marketing tools that support the adoption of sustainable building. This site includes links to dozens of green building related web sites.
Green Buildings BC	www.greenbuildingsbc.com An initiative of the BC Buildings Corporation (a crown corporation), Green Buildings BC has been established to reduce the environmental impact of provincially-funded buildings and, in the process, foster the growth of BC's environmental industry. It targets both new and existing facilities through two related programs - a New Buildings program and a Retrofit Buildings program.
Natural Resources Canada (NRCan): Office of Energy Efficiency R-2000 Program	www.oee.nrcan.gc.ca/r-2000 Developed and administers the R-2000 Program, with Canada's residential construction industry. It showcases tried and tested new energy technologies and trains builders in energy-efficient techniques.
International District Energy Association (IDEA)	www.districtenergy.org/ A not-for-profit trade association representing over 900 members who are district heating and cooling executives, managers, engineers, consultants and equipment suppliers from 20 countries.

Transportation and Automotive

Organization	Web Site / Comments
Society of Automotive Engineers	(i) www.sae.org (ii) www.sae.org/technicalcommittees/altrefrig.htm Establishes standards for all aspects of automotive engineering. (i) General home page. (ii) Alternative refrigerants Research home page.
Automotive Parts Manufacturer's Association	www.apma.ca/client/apma/apma.nsf Industry organization for Original Equipment Manufacturer (OEM) industry.
Automotive Industries Association	www.aiacanada.com Industry organization for after-market automobile products
Vehicle Auxilliary Loads Reduction Program	www.ott.doe.gov/coolcar/ Under US Department of Energy, Office of Transportation Technologies. This program aims to increase vehicle efficiency and reduce tailpipe emissions while improving passenger thermal comfort through innovative technologies.

Other Organizations

Organization	Web Site Comments
Canadian Standards Association	www.csa.ca Establishes standards
Underwriters Laboratories	www.ul.com An independent, not-for-profit product safety testing and certification organization. Tests products for public safety.
International Energy Agency (IEA)	www.iea.org An autonomous agency within the Organization for Economic Co-operation and Development (OECD). primarily concerned with monitoring and ensuring global petroleum supplies.
Heat Pump Centre	www.heatpumpcentre.org Non-profit organized under the international Energy Agency (IEA) to cooperate on projects related to heat pumps and refrigeration. Facilitates research into new technologies and applications through research projects.
US EPA: National Risk Management Research Laboratory	www.epa.gov/ORD/NRMRL/lcaccess Home page for Life cycle Assessment (LCA). Includes LCA 101, an introduction to the concepts of LCA as well as links to all EPA activities and numerous US Associations involved with Life cycle assessment.

NB: All Internet links in this section confirmed as functional as of March 28. 2003.

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