COOL TECHNOLOGIES: WORKING WITHOUT HFCs
Examples of HFC-Free Cooling Technologies in Various Industrial Sectors

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A report under the same title was published by Greenpeace in 2000 and 2008 and it continues to be updated. Greenpeace welcomes receiving information regarding new examples of HFC-free technologies. Please forward them to jmate@telus.net.

Introduction
Just as there was no single "magic bullet" to replace CFCs, there is no single solution to replace HCFCs. But there is a wide variety of environmentally superior and technologically proven HCFC and HFC-free technologies to meet our cooling needs. Alternatives include natural refrigerants (CO_2, hydrocarbons, ammonia, water); secondary cooling systems; desiccant cooling; evaporative cooling, absorption cooling; and innovative building designs that eliminate the need for mechanical cooling.

The following sampling of companies and enterprises using HFC-free technologies is provided to demonstrate that there is already a wide array of safe and commercially proven HFC-free technologies available to meet those human needs that were formerly met by fluorocarbons.[1] (please see disclaimer below)

HFC-free cooling related technologies exist in the full spectrum of applications, such as:

- Domestic Refrigeration and Air-Conditioning
- Commercial Refrigeration and Air-Conditioning
- Industrial production
- Mobile Air-Conditioning
- Insulation Foam Blowing

And new HFC-free products are entering the market almost on a weekly basis. These technologies for the present are primarily used in industrialized countries, but there is no reason why they can not be used worldwide.

Developing countries would benefit greatly by leap-frogging HFCs altogether and going straight from HCFCs to long term solutions that rely on natural refrigerants and foam blowing agents. They could thus avoid reliance on more expensive, less efficient, HFCs that will need to be phased-out due to their significant contributions to global warming. Furthermore, they could finally escape the clutches of the chemical industry's monopoly over their choice of technology.

[1] Greenpeace disclaimer: The inventory presented is not meant to be all-inclusive nor is the inclusion of any enterprise an endorsement by Greenpeace of any company or its products.

A. DOMESTIC REFRIGERATION AND AIR CONDITIONING

A.1 *Greenfreeze Hydrocarbon Domestic Refrigeration:* There are over 400 million hydrocarbon, or Greenfreeze, refrigerators in the world today. The Greenfreeze technology was developed by Greenpeace in 1992. Greenfreeze refers to refrigerators that contain no fluorocarbons. Typically they use cyclopentane for the foam and isobutane for the refrigerant. The refrigerant charge of 30 to 60 gramms varies according to the size of the refrigerator. Greenfreeze refrigerators are available in all sizes with all the regular and luxury features, including automatic defrost systems.

100 million domestic refrigerators and freezers are produced annually globally. Between 35% - 40% of the global fleet production is Greenfreeze. All major European, Japanese and Chinese manufacturers now produce Greenfreeze refrigerators. The technology now dominates the market in Europe, Japan and China. It is also produced in Latin America, in Argentina and Brasil. Greenfreeze has not yet entered the market in the USA or in Canada.

Partial list of companies and countries producing Greenfreeze Refrigerators

COMPANY	COUNTRY
AEG	Germany
Bosch	Germany
Bosch Siemens Hausgerate BSH Mexico	Mexico
Bosch Siemens Hausgerate BSH Russia	Russia
Electrolux	Sweden
FisherPaykel	New Zealand
General Electric	USA (plans to produce Greenfreeze by 2010)
Godrej	India
Gorenje Deutchland	Germany
Gram	Denmark
Haier	China
Hitachi	Japan
Husky Deutchland	Germany
Indesit Deutchland	Germany
Inpud	Cuba
Kelon	China
Koh-I-Noor	Argentina
LG Electronics Inc.	South Korea
Liebherr	Germany
Matsushita	Japan
Miele	Germany
Panasonic	Japan
Sanyo	Japan
Sharp	Japan
Siemens Home	Germany
Toshiba	Japan
Vestfrost	Demark
Voltas	India
Zanussi Electrolux	Italy

Bosch begins marketing Greenfreeze refrigerators in Mexico in March, 2009: The German company Bosch, in cooperation with the retailer Sears Mexico, began marketing Greenfreeze refrigerators in Mexico. This is the first penetration of the hydrocarbon technology into the North American market.

General Electric plans to manufacture Greenfreeze for North American market: As a sign of changing times, in October 2008, General Electric announced that the company has formally requested the approval of the US Environmental Protection Agency, under the Significant New Alterntives Policy (SNAP) program, to produce hydrocarbon domestic refrigerators (Greenfreeze) for the US market. GE plans to introduce the hydrocarbon refrigerators in the North American market by 2010.

A.2 *Hydrocarbon domestic air-conditioning:* Since 1995, the large Italian manufacturer **De'Longhi** has sold its popular propane cooled portable air conditioners called Pinguino ECO on the European market. Additionally, **Elstar Company** of the UK is producing a variety of hydrocarbon based split-air conditioners for both home and office use.

Benson Air Conditioning of Australia is marketing split-unit domestic hydrocarbon air-conditioners, manufactured in China and Thailand. According to the company, the hydrocarbon units perform with 15-20% better energy efficiency than the company's comparable previous R22 range. Benson sells 5 models with the following heating/cooling capacity and associated Energy Star Ratings under Australia's MEPS scheme:

Type	Cooling Size	Energy Rating	HC Charge
Wall Mounted Split Systems	2.31 kW / 2.6 kW	4.5/5.5 star	300g
	3.4 kW / 3.4kW	4.5/4.5 star	
	5.1 kW / 5.6 kW	4/3.5 star	
	6.3 kW / 6.6 kW	4/4 star	
	8.2 kW / 8.4 kW	4/3 star	
Ducted Systems			
Single phase	10.3 kW / 10.4 kW	3/3.5 star	
	12.3 kW / 12.1 kW	5/4.5 star	
	16.3 kW / 16.2kW	3.5/4 star	
Three phase	12.8 kW / 12.8kW	4.5/4.5 star	
	17.5 kW / 17.1kW	4/5 star	1.2 kg

Gree Electric Appliances of China developed and successfully tested in 2009 a highly efficient hydrocarbon air-conditioner, with COP of 3.6, energy efficiency 15% better than corresponding HCFC-22 unit, and total hydrocarbon charge less than 300 grams.

B. COMMERCIAL REFRIGERATION & AIR CONDITIONING

B.1 *Refrigerants, Naturally!*: Refrigerants, Naturally! is a global initiative of multinational corporations that aim to replace the use of HCFCs and HFCs in their point-of-sale cooling applications. The initiative is supported by Greenpeace and the United Nations Environment Program (UNEP). Current partners include: Coca Cola, Unilever, McDonald's, Carlsberg and PepsiCo.

- **Unilever**: By 2008 Unilever had placed up to 275,000 hydrocarbon ice-cream coolers in the field. These coolers contain approximately 100 grams of hydrocarbons, and have a 9% energy savings over their HFC counterparts.[2] In an industry precedent setting move Unilever pioneered the testing of hydrocarbon ice-cream freezers in the United States in 2008. The company has requested to test up to 2,000 units. With this move Unilever penetrated the wall of regulatory obstacles that had until then kept hydrocarbon cooling technologies out of North America.

- **Coca Cola**: Coca Cola has developed a new, high efficiency, CO_2 technology for vending machines, and plans to have up to 30,000 CO_2 vending machines in the field in 2008, and 100,000 by 2011. All the machines at the 2008 Beijing Olympics were HFC-free.[3] The company plans to deploy up to 1,800 HFC-free and energy efficient coolers and vending machines throughout the US and Canada in 2009. These include 1,400 machines that will be used at the 2010 Winter Olympics in Vancouver. Energy savings with these units average 26%.

- **McDonald's**: In 2003 McDonald's opened the "first fluorocarbon free restaurant" in Vejle, Denmark. The company has reported 15% energy savings on the refrigeration equipment

[2] http://www.unilever.com/ourvalues/environment-society/case-studies/climate-change/hydrocarbon-ice-cream-cabinets.asp
[3] ACR News (2007) 'Coca-cola's Olympic coolers 100% HFC-free'

compared with an HFC reference restaurant. The company is currently building another HFC-free restaurant in Denmark and plans to only purchase HFC-free equipment in Europe after 2010.

- **PepsiCo**: PepsiCo is currently testing new vending machines using natural refrigerants, hydrocarbons as well as CO2. By 2009 PepsiCo had deployed 5,831 testing units, the majority of which use hydrocarbons. The units are deployed primarily in Europe, China and Japan. The company also began testing CO2 vending machines in the US market in 2009.

- **Carlsberg**: Carlsberg is investigating ways to achieve its aim to replace HFCs in point-of-sale applications.

B.2 *Nestlé*: The world's largest food processing company, Nestlé, announced on October 1, 2001 that "wherever possible, Nestlé will use natural refrigerants in new industrial refrigeration systems"… with a preference for "using the combined characteristics of ammonia and carbon dioxide…" Nestlé stated: "The future of many replacement refrigerants, such as HFCs, is in doubt due to global warming concerns." The statement from the company emphasizes the technical reliability, efficiency and safety of natural refrigerants. Nestlé is also testing HFC-free technologies in commercial equipment, such as ice-cream freezers.

B.3 *Commercial Point-of-Sale Hydrocarbon Equipment on the market:* The UK based **Earthcare Products Ltd**. is marketing a wide range of commercial cooling equipment that uses hydrocarbons:

Wall mounted and ceiling mounted split air conditioners	**Dehumidifiers**	**Sliding door display coolers**
Range of ground source heat pumps offering up to 79% reduction in energy costs	Range of air -cooled chillers: largest model offers 1,265 kW	Bottle chillers
Mini bars	Water coolers	Wine cooler dispensers
Deli display cabinets	Chest chill cabinets	Glass door merchandiser
Multi-deck display cabinets	Ice cream conservators	Defrost type freezer chillers
		Freezers

The Danish manufacturer **Vestfrost** produces hydrocarbon display cabinet bottle coolers featuring a high efficiency Danfoss variable compressor. **Elstar** also manufactures hydrocarbon commercial drink cabinets. Similarly, **Carrier Commercial Refrigeration**, a United Technologies company, produces hydrocarbon-based refrigerated cases and displays. And **Husky** has deployed the Intelligenzia freezer cabinet that uses propane[4].

B.4 *Commercial Air-Conditioning with Natural Refrigerants*: There are numerous supermarkets, office buildings, public institutions and other commercial enterprises in various countries that have installed HCFC/HFC-free cooling technologies. HFC-free alternatives include, among others, carbon dioxide based coolers, hydrocarbon or ammonia based secondary cooling systems, desiccant cooling, evaporative cooling, and absorption cooling. Consumers of cooling technologies must ensure that they chose the best available solution for their specific needs.

Secondary cooling systems use coolants such as water, brine, glycols, silicon oils, or Flo-ice™ to circulate through refrigeration cabinets. The coolant itself is chilled, through a heat exchanger, by a primary refrigeration circuit using ammonia or hydrocarbons. The primary circuit is usually located in a safely isolated plant room in the back of the store. Non-fluorocarbon

[4] http://www.hydrocarbons21.com/content/articles/2009-06-02-husky-to-launch-r290-cabinet.php

refrigerants such as ammonia and hydrocarbons are used as the primary refrigerants. Using secondary cooling significantly reduces the volume of primary refrigerant needed.

B.5 *Hydrocarbon refrigerants in commercial cooling:* Hydrocarbons continue to gain market acceptance in commercial cooling applications. Hydrocarbon chillers are now available in a wide variety of sizes, with the largest being around 1000kW.

B.5.a Breakthrough hydrocarbon supermarket technology: On June 29, 2009 **Waitrose Supermarket** of the UK announced the development of a new, propane based refrigeration technology, which is expected to reduce the company's carbon footprint by 20%. The technology will be introduced in the new Waitrose Altrincham branch in 2010. The company states that this technology is a "breakthrough for the supermarket industry" as the installation is simple and servicing is easy for properly retrained engineers.[5]

B.5.b Earthcare Products Ltd. of the UK has installed split system air conditioning using hydrocarbon refrigerants in a wide variety of settings, including:

Middlesex University	Great Ormond Street Children's Hospital	University College in London
Pembury Hospital in Kent	Her Majesty's Customs and Excise offices	Confectionary Factory in York
Horsham Arts Centre	Government Laboratory in Birmingham	Alverston Library in Derby
London Transport in West Kensington	DVLA Oxford	Brighton Library
Shropshire County Council	DEFRA Whitehall	Pharmaceutical Company in Welwyn Garden City
Government Laboratory in Chepstow	DFT in Westminster	National Trust in Swindon

B.5.c Examples of companies and facilities that have installed hydrocarbon cooling systems:

Edeka Supermarkets (Germany)	Frucor Processors (Hastings, New Zealand)	Tip Top Bread (Auckland, New Zealand)
Kiwi Co-operative Diaries Ltd, (Hawera, New Zealand)	Bodo Airbase (Norway)	Backhammars Bruk (Sweden)
AG-Favor (Sweden	PUB Department Store (Sweden)	Sainsbury's Supermarkets (UK)
Tesco's Supermarkets (UK)	Out of This World Stores (UK)	Iceland Supermarkets (UK
National Trust (UK)	Royal Institute of British Architects (UK)	National Hospital (UK)
Chartered Society of Physiotherapy (UK)	London Transport (UK)	Esso Gas Station Supermarkets (UK)
Church of England (UK)	REWE Supermarket (Germany)	

B.5.d York (Johnson Controls) is producing a line of medium sized air-cooled hydrocarbon chillers with frequency-controlled screw compressor and V-coil condenser. The capacity range is from 80 kW to 560 kW.

B.5.e Recom Engineering of Australia in 2008 was preparing to market, in the near future, Chinese produced Fujin Airconditioners with hydrocarbons in split system commercial applications.

B.5.f Converting HCFC-22 installations to hydrocarbons: It is widely accepted that propane and other hydrocarbons are the optimal alternative replacements for HCFC-22. **Ecozone**, is a Netherlands based ecologically minded refrigeration company. **Energy**

[5] www.waitrose.presscentre.com June 29, 2009

Resources Group is an Australian company. Both companies have many years experience working in developing countries, and both have conducted numerous conversions from HCFC-22 to hydrocarbons in a wide variety of settings with different size chillers. The experience of these two companies vividly demonstrates that as long as routine safety standards are maintained, and work is performed by trained technicians, hydrocarbons are the most cost effective and most efficient substitutes for HCFC-22.

Partial List of Conversions from HCFC-22 to Hydrocarbons by Energy Resources Group:

Country	Installation Site	Type of Chiller	Energy Savings
Singapore	Far East Square Shopping Mall	York 200TR Water-cooled Reciprocal Chiller	16%
	Defence Science & Technology Agency	Carrier 1hp Air-cooled split unit	16%
	Dapenso Building	Carrier 21TR Water-cooled Packaged Unit	32%
	Watson's Stores	Daikin Air-cooled Split Unit	24%
	The Moomba Restaurant, Boat Quay	McQuay 8hp Air-cooled split unit	16%
Malaysia	7-eleven Stores Kuala Lumpur	Topaire Air-cooled Split Unit	24%
	Flairis Kota Tinggi	Water-cooled Packaged Unit	19%
	Nichicon Bangi	Topaire Water-cooled Packaged Unit	20%
	Sumiden Electronics Shah Alam	Topaire Air-cooled Split Unit	22%
	Hosiden Electronics Bangi	Air-cooled Split Unit	25%
	Alps Electric Nilai	Dunham-Bush Water-cooled Packaged Unit	17%
	Panasonic AVC Network Shah Alam	Air-cooled Split Unit	19%
	Venture Tebrau I Johor	Dunhan-Bush 65TR Water	47%
	Panasonic Communication Senai Johor	National 20hp Water-cooled Packaged	20%
	Celestica Electronics Tampoi Johor	Topaires 3 x 80TR Water-cooled Packaged	24%
	Menara Ansar Johor	Carrier 23TR Water-cooled Packaged	13%
	Bangunan PharmaCARE KL	Topaires 26TR Air-cooled Packaged	23%
	Sumitomo Electronics Tebrau II Johor	York 32TR Water-cooled Packaged	21%
	Taiko Electronics Senai Johor	York 21TR Water-cooled Packaged	20%
	GG Circuits Industries Tampoi Johor	Carrier 35TR Water-cooled Packaged	14%
	YKJ Industries Kulai Johor	Acson 4TR Air-cooled Split Unit	27%
	Tru-Tech Electronics Ulu Tiram Johor	York 20TR Air-cooled Packaged	19%
	Matsushita Electric Company Shah Alam	Carrier 35TR Water-cooled Packaged	15%
	Menara AmFinance KL	York 21TR Water-cooled Packaged	16%
	Li Tat Mfg Masai Johor	York 17TR Air-cooled Ducted Type Split Unit	29%
	OYL HQ (R&D Lab)	**New** 3TR split units	27%
	UiTM Shah Alam Campus	Hitachi screw chiller	19.7%
	Damansara Realty	Carrier 10TR Packaged units	32%
	Pantai Medical Centre Bangsar	York 80TR Heat Recovery Unit	24%
	Pantai Medical Centre Bangsar	York Air-cooled Chiller Packaged	18%
	Lam Wah Ee Hospital Penag	Carrier Water-cooled Packaged	20%
	Elecan SemiConductor Penang	Air-cooled Packaged	14.8%
	Comfort Engineering Puchong	Carrier Air-cooled Packaged	18.5%
	Cekap Rea Johor	National Air-cooled Split Unit	16.7%
Thailand	Carrier HQ Building	Carrier 150TR reciprocal chiller	14%
	Two 7-11 stores	split unit and walk-in-freezer	20%

Partial List of Conversions from to Hydrocarbons by Energy Resources Group (Cont):

Country	Installation Site	Type of Chiller	Energy Savings
Philippines	Gaisano Country Mall	50tr Hitachi Screw Type Compressor	16%
	Park Square One (Ayala Mall)	7.5tr Frascold Semi - Hermetic Reciprocating Compressor	12%
	Delsa Chemicals Office	5tr Maneurop Hermetic Reciprocating Compressor	14%
	McDonalds Restaurant	7.5tr Maneurop Scroll Type Compressor	12%
	Legenda Hotel	2tr Matsushita Rotary Type Compressor	19%
	Federal Express (Fedex)	7tr Copeland Hermetic Reciprocating Compressor	21%
	Iglesia ni Cristo Church	3tr Copeland Scroll Type Compressor	15%
	INARP Research Inc.	2tr Matsushita Rotary Compressor	12%
	Building Care Corporation	5tr Copeland Hermetic Reciprocating Compressor	20%
	Mandarin Restaurant	40tr Century Screw Type Compressor	17%
Indonesia - Jakarta	Alfamart 649 stores	air-cooled split units	25%
	ITC Mangga Dua	208 tr Carrier reciprocal chillers	34.7%
	JW Marriott Hotel	132 tr York reciprocal chillers	25%
	Supermal Karawaci	60 tr Hitachi screw AHU	30%
	Mulia Hotel	Copematic chiller	13.3%
	Sol Elite Marabella Hotel	1.5 tr Sanyo split unit	24.4%
	Maspion Plaza	150 tr York reciprocal chiller	15%
	Kondominium Simpruk Teras	10 tr Fair packaged unit	22%
	Mal Kelapa Gading	200 tr Carrier reciprocal chillers	28%
	Darmawangsa Square	2 tr General split unit	24%
	Siloam Gleneagles Hospital	1 tr Mitsubishi split unit	45%
	Yayasan Pendidikan Permai	1 tr Gree split unit	22%
Indonesia - Bali	Maya Ubud Resort & Spa	n/a	41%
	Sahid Jaya Hotel	n/a	51%
	Ritz Carlton Hotel	n/a	28%
	Kartika Plaza Beach Hotel	n/a	55%
Indonesia - Lombok	Sahid Jaya Hotel	n/a	72%
	Oberoi Hotel	n/a	18%
	Novotel Hotel	n/a	39%
	Lombok Raya Hotel	n/a	27%
	Sheraton Senggigi Hotel	n/a	53%
	Senggigi Beach Hotel	n/a	36%
	Jayakarta Hotel	n/a	25%
	Intan Lombok Hotel	n/a	21%
	Holiday Inn Hotel	n/a	20%

B.6 ***Examples of commercial enterprises using CO2 refrigerants****:* CO_2 technology is rapidly gaining market share in the global cooling industry. Recent examples include:

- **Coca Cola** and **PepsiCo** are deploying new, high efficiency, CO_2 vending machines. According to CocaCola: “some of our suppliers achieved even better CO2 performance versus R134a under "D" conditions (40degrees C ambient)… and in all countries in the world yearly averages are in a range where CO_2 in beverage cold drink equipment performs better than 134a”. It has been reported that Coke’s CO_2 cooler made by **Haier** is 35% more efficient than the ordinary HFC ones. According to PepsiCo there was no penalty for CO_2 versus HFC-134a.

- In March 2006, several major UK supermarket chains announced their decision to phase-out their use of HFCs in cooling equipment and to convert to natural refrigerants such as carbon dioxide. **ASDA, Marks & Spencer, Sainsbury's, Somerfield, Tesco** and **Waitrose** emphasized that a further use of hydrofluorocarbons (HFCs) in commercial refrigeration was incompatible with increasing concerns over climate change.

- Europe's 3rd largest food trader **REWE** has announced that from 2008 on it will use CO2 (R744) refrigeration in new small-sized supermarkets in Germany[6].

- In 2008, **Drakes** supermarket in Australia installed a transcritical CO2-only cooling system without any back-up system in its North Adelaide store.[7] This is the first of its kind in Australia.

- Australia's largest food retailer, **Woolworths,** announced that it plans to install CO2 cascade systems in new stores after the success of its pioneer "green supermarket" in Sydney.[8]

- **Tesco Lotus** in Thailand is the first supermarket in Asia to have installed a cascade CO_2 system. It is built by the Australian company **Frigrite** and installed by **Carrier**.

- The Dutch bank **ABN Amro** uses a CO_2 system to cool 15 high-performance servers at the data centre of its London branch. To provide a controlled climate for this hardware, the refrigeration systems manufacturer Star Refrigeration designed and built a low-energy-consumption CO_2 refrigeration system to generate a total output of 300 kilowatts. The carbon dioxide is recondensed with water at 6℃ via an indirect chilling cycle. The cooling is handled by ventilator units on the back of the server cabinets, where the carbon dioxide evaporates at 14℃ and absorbs the h eat siphoned off by the fans.[9]

- **United States Cold Storage Company** is pioneering a new CO_2 refrigeration technology used in food storage facilities in Indiana, California, Pennsylvania and Florida [10]. The system uses ammonia and CO_2 in a cascade system that allows for lower operating pressures and confines ammonia to the machine room only.

- **Carrier Corp** has developed CO_2refrigeration systems for supermarkets and other large applications and plans to deploy a full-scale production rollout in 2009. Carrier developed a two-step technology with the refrigerant that allows the pressure on the supermarket shop floor to be kept at around 40 bar with only the plant areas requiring higher pressures[11].

B.7 *New developments in CO_2 Cooling Equipment:* CO_2 technologies exhibited at the 2008 Mostra Convegno Expocomfort in Milan included:[12]

- The Swedish supplier **SWEP** exhibited its CO_2 gas cooler for transcritical systems, which is already part of several supermarket installations all over Europe.
- This Italian SME (small to medium enterprise) **HPH** exhibited its own models of copper-based CO_2 heat exchangers for industrial applications.
- The Brazilian manufacturer **Embraco** showcased its CO_2 Compressor for light commercial applications, including the display of a cassette system for vending machines. At the same time, the company is working on electronic control of the system's performance (VCC), which helps improve efficiency by better monitoring the system.
- **Bitzer** exhibited its CO_2 Compressor range for refrigeration, covering all temperature ranges and suitable to different types of systems, including cascade and transcritical systems.

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[6] www.r744.com/news/news_ida260.php REWE Group Chooses Co2 for its new "City Markets"
[7] www.r744.com/news/news_ida302.php. Industry Visits Australia's first CO_2 only supermarket
[8] www.r744.com/news/news_ida302.php Industry Visits Australia's first CO_2 only supermarket
[9] eurammon: Example provided by eurammon, the European initiative for natural refrigerants, www.eurammon.com/ß
[10] http://www.uscoldstorage.com/newsletter/pdf/IN_March2009.pdf, Press Release "United States Cold Storage Scheduled to Open First Facility in Indiana" March 16, 2009.
[11] http://www.appliancedesign.com/CDA/Articles/Feature_Article/BNP_GUID_9-5-2006_A_10000000000000558309 Appliance Design, March 31, 2009
[12] www.r744.com/news/news_ida312,php Milan Expo features CO_2 Technology

- The Italian company **Lu-ve** showcased CO_2 gas coolers for large industrial installations.

- **Emerson** displayed compressors under the **Copeland** brand, for subcritical CO_2 systems. The company also confirmed its cooperation with **Rivalco**,an Italian supplier of commercial refrigeration equipment.

B.8 ***Ammonia Air-Conditioning in Commercial Enterprises:*** Ammonia has been used in refrigeration since 1850s. It has superior thermodynamic properties and is highly energy efficient. The most prominent example of the use of ammonia in air-conditioning is in the **international space shuttle**. Other examples from around the world include universities, hospitals, hotels, office buildings, convention centers, airports:

Examples of Ammonia Air-Conditioning in Commercial Enterprises

COUNTRY	**FACILITY**	TYPE OF ENTERPRISE
Canada	Campbell's Soup (Toronto)	Office building
Denmark	Hvidovre Hospital	Hospital
	Copenhagen University Rigshospitalet	Hospital
	Ilum Department Stores	Department store
	Magasin Department Stores	Department Store
	Scandic Hotel Copenhagen	Hotel
	SDC Bank	Data bank for financial institutions
	Copenhagen Airport	Airport
	Danish National Television	Television Studios
	SAS Building (Aarhuz)	Airline Office Building
Germany	Hannover Trade Fair Building (One of the largest commercial ammonia air-conditioning systems in the world, using two and a half tonnes of ammonia to generate 3.5 megawatts of cooling)	Trade Fair Building
	Leipzig Trade Fair Building	Trade Fair Building
	Lindplatz Centrum-Berlin	Shopping center
	Casino & Supermarket (Monsdorf)	Casino & Supermarket
Japan	Ashai Brewery (Nogano)	Brewery
Luxembourg	Palais Grande Ducal and Parliament	Parliament building
	Cactus Supermarket	Supermarket
	Match Supermarket	Supermarket
	IBM Luxembourg	Office building
	ASTRON Building	Office building
	Imprimerie St. Paul	Office Building
	City Concorde	Shopping Center
	Banque Van Lanschot	Bank
	Dresdner Bank	Bank
	Husky	Office building
	Amro Bank	Bank
Norway	Oslo Airport	Airport
	Kodak Norge Office	Office building
Spain	Carlos III University in Leganes	University
Sweden	Arlanda Airport-Stockholm	Airport
	KF Stores	Stores
United Kingdom	Middlesex University	Univewrsity
	Roche Products/UK (Welwyn Garden City)	Company headquarters office building
	Heathrow Terminal 5 (4 systems, cooling capacity of 6.6MW each, ammonia charge of 1300kg each)	Airport
United States	Biosphere II Oracle (Tucson, AZ)	Demonstration center (space A/C)
	McCormick Place Convention Center (Chicago)	Convention Center
	Stanford University (Palo Alto, CA,)	University –district cooling / multiple sites
	Montgomery College (Germantown, MD)	College- district cooling of multiple sites
	USF&G (Baltimore)	Office building
	Rockford Arts & Science Museum (Rockford, IL)	Museum
	University of Miami	Marine studies center
	Blue Cross Blue Shield (Chicago)	Office tower
	Xerox Office Complex, (Los Angeles)	Office tower
	Montgomery County College (Maryland)	College
	Tempest Inc, Cleveland	Office building

B.9 ***Examples of Recently Installed Applications of Ammonia in Refrigeration and Freezing:***[13]

- **Grasso GmbH** spiral chiller with finless evaporator for food freezers: Usually heat transmitters have fins that increase the evaporator's surface. However, this also facilitates the deposition of microorganisms and makes the facility harder to clean. Thus, there is demand for finless alternatives offering the same level of efficiency in the foods industry. The heart of the prototype is a spiral chiller equipped with a finless evaporator. The evaporator is tested by cooling 8,000 regular ice packs from ambient temperature to -37 degrees Celsius in 30 minutes. The refrigeration energy is furnished by an ammonia/ CO_2 cascade: ammonia for the high-temperature cycle, CO_2 for the low-temperature cycle. The advantage: only 40 kg of ammonia is used, and it remains confined to the central machine room while the freezer is supplied with CO_2.

- **Kältetechnik Dresen + Bremen** system for a poultry producer in Germany: New production facilities, with a total floor space of approx. 5,000 m², were to be equipped with a number of different refrigeration and processing rooms. The spectrum of required temperatures extended from -30℃ to 7℃. Kältetechn ik Dresen + Bremen built a three-stage ammonia refrigeration plant with a glycol cycle. Four screw compressors and one piston compressor were used to control the various temperature level requirements of the system, which was charged with 2,850 kg of ammonia. The deep-freeze warehouse and the shock-freeze rooms with a refrigeration output of 410 kW at -40℃ are directly supplied with ammonia. An ethylene glycol cycle with a flow temperature of -12℃ cools the production rooms, e.g. filleting, fresh storage and packaging rooms, and an integrated ventilation system with a total refrigeration output of 2,190 kW. In a spray humidified chilling tunnel that is also linked into the cycle, roughly 9,000 chickens per hour are cooled down to a temperature of 2℃.

- Process refrigeration for a confectionery: A leading German confectionery manufacturer erected a new production building in Halle/Westphalia, Germany. Here **Dresen + Bremen** installed a refrigerating plant for process refrigeration and air-conditioning, using the natural refrigerant ammonia. Process refrigeration is responsible for controlled heat removal during the production of chocolate, sweets and fruit gums, and for cooling the machines. The focal element of the central plant consists of four frequency-controlled screw compressors. The consumers are supplied with refrigeration via two liquid circuits at temperatures between 5℃ and 11℃. The process r efrigeration circuit uses cold water, while the air-conditioning system works with a propylene glycol circuit.

- **Danone** dairy produce n France: Danone, a producer of fresh dairy products headquartered in Paris, operates a plant for manufacturing yoghurt and cottage cheese in Fèrrieres en Bray, Northern France. The refrigeration system consists of liquid chilling units using ammonia, which supplies 400 cubic meters per hour of chilled water at 1℃. The chilled water is conducted to various consumers like cold stores and specific rooms through a piping network. As the demand for cold energy varies over the day, **Axima Refrigeration France** supplied an ice storage tank that stores the extra cold energy and releases it again when demand is high.

- **Edeka** meat processing plant in Germany: A system consisting of refrigeration and deep-freeze rooms that would meet all technical requirements while remaining efficient and inexpensive was needed. Johnson Controls Systems & Service realised a two-stage ammonia system involving screw compressors. It produces refrigeration output of 5,500 kW with a refrigerant charge of 10,000 kg. The cooling fluid piped through the processing rooms is ethylene glycol (34%).

[13] eurammon: Examples provided by eurammon, the European initiative for natural refrigerants, www.eurammon.com/ß

- **Zipf** brewery in Austria: The Zipf brewery, a Brau Union Österreich AG brand, relies on an ammonia plant with slurry ice as coolant for its refrigeration needs. The retrofit was realised by Austria's **KWN Engineering GmbH**. The existing refrigeration system was kept, but the coolant cycle as well as part of the ammonia pump system was replaced with slurry ice – a mix of ice, refrigerants and anti-corrosives. Most of the existing pipelines were kept, as were the heat exchangers on the beer tanks and in the refrigeration rooms. New installations included two 230 kW ice generators and air coolers supplied by **Güntner**. A 110 m³ silo with a refrigeration capacity of 2,800 kW was added to serve as an ice bank.

- The **Guinness** Brewery in Dublin: Guinness planned to increase the production volume of its world-famous Guinness Stout beer to twelve million barrels per year. **Star Refrigeration** extended the 5 MW system up to 8.9 MW, which complements the existing facilities perfectly. The refrigeration specialists installed six additional variable speed drive glycol pumps and increased the condenser capacity. The modernised system now has a refrigeration capacity of 8.9 megawatts at an evaporating temperature of -4.5 degrees Celsius, without noticeably increasing the ammonia refrigerant charge in the system.

- **Asda** distribution center in Lutterworth, UK: Beginning in 2002, the British supermarket chain Asda has had **Star Refrigeration** replace all refrigeration units that use the hydrochlorofluorocarbon (HCFC) R22 at its distribution centers, as part of a long-term modernisation programme. Star Refrigeration designed a central refrigeration system that supplies liquid carbon dioxide at -31℃ to six air coolers in the cold store. It also supplies carbon dioxide as a volatile secondary refrigerant at -5℃ to 20 air coolers in three chill rooms. The cascade facility's low temperature circuit yields a refrigerating capacity of 820 kW, while the high temperature circuit produces 2,700 kW.

- **Recheis Teigwaren GmbH** past company in Austria: For the manufacturing of filled fresh and frozen pasta, and to store the raw materials that go into them, the Austrian market leader Recheis Teigwaren GmbH required conditioned storehouses, regular and deep-freeze storehouses and a combined spiral/freezer-cooler. The company required an economical and environmentally friendly refrigeration facility that complies with Austria's F-Gases regulation. To furnish all the cold energy demand without using HFCs, the **KWN Engineering-Gesellschaft mbH** designed a refrigeration facility using the natural refrigerant ammonia. A CO_2 cascade was additionally installed for the deep-freeze storehouse and the spiral freezer and cooler

- **Roche** healthcare facilities: The Swiss healthcare company, in a commitment to rid itself by 2015 of chemicals that harm the ozone layer or cause global warming, is installing ammonia cooling in its new facilities in Germany, Ireland and the US. At Roche's Indianapolis facilities fluorocarbon chillers are in the process of being replaced with ammonia in the facility's16,000 m^2 chiller plant building. In Ireland, a similar replacement reduces Roche's CO_2 emission by 575 tonnes annually. In Germany, the company is using a mixture of ammonia, propane and CO_2.

B.10 ***Ammonia Chillers in small applications****:* Ammonia is typically associated with larger cooling installations. However, York Company of Denmark produces smaller ammonia chillers with a single piston compressor, plate heat exchanger, liquid separator, automatic oil return, and electronic control in front panel. These have been applied in radio studios, computer centres and offices. It would be technically possible to build ammonia chillers for domestic use. However, there would need to be economies of scale to make these commercially feasible.

C. DESICCANT, EVAPORATIVE AND ABSORPTION COOLING IN THE UNITED STATES

C.1 *Desiccant cooling* is widely used in the United States by supermarkets, chain departments stores such as WalMart, restaurants, hospitals, community centers, and office buildings. These systems use materials that attract moisture, thereby picking up humidity from incoming air and discharging it to the outdoors.

In 2007, **Wal-mart** partnered with **Munters Corporation** to develop and implement a desiccant dehumidification system for its first "High-Efficiency Store" in Kansas City, Missouri. The system utilizes reclaimed heat from the refrigeration system to reactivate the desiccant system, thus allowing the normal air conditioning equipment to run at a higher operating point. The system is expected to increase overall store energy-efficiency by roughly 2% and it is now being rolled out across the industry[14].

C.2 *Evaporative water coolers* are another of several alternatives to current models of refrigerators and air conditioners. These units use heat in ambient air to evaporate water, which in turn cools the surrounding air. They are especially efficient in dry climates, where the installation and operating costs can be significantly lower than a traditional refrigerant system. Direct, or single-stage, evaporative coolers are used on tens of thousands of homes in the western US, as well as thousands of commercial establishments-shops, restaurants, dry cleaners, offices, warehouses, factories. They are also sold as small, portable units to cool individual rooms.

In the United States more than 70 companies manufacture evaporative air conditioners for residential, automotive, commercial and industrial markets. The U.S. Department of Energy reports that 122,000 commercial buildings in the U.S. use this type of cooling application.[15]

Indirect-Direct, or two-stage, evaporative air conditioning systems are also used in numerous applications such as; schools, office buildings, commercial buildings, and homes. These systems pre-cool air in the first stage by running it through a heat exchanger, thus the final cooled air has less humidity than in a direct or single-stage system.

C.3 *Absorption cooling systems* use a heat source, such as natural gas or propane, instead of electricity. They are used in a wide variety of commercial settings, including banks, airports, office buildings, apartment buildings, hospitals, convention centers, and large residences. They typically use water as the refrigerant and lithium bromide as the absorber. Most of the installations noted use natural gas-fired chillers, though an increasing number use solar energy as the heat source.

European countries, such as Spain, Germany and Greece, have been leaders in implementing large-scale solar absorption coolers. The largest system is owned by **Gr.Sarantis S.A.**, a cosmetics company that uses the system to cool its manufacturing facility in Viotia, Greece[16].

D. CO-GENERATION COOLING

Air-conditioning technologies based on the use of waste heat from on-site electricity generation have the potential to greatly reduce energy consumption. This eliminates HFC use in many large-scale applications immediately.

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[14] http://walmartstores.com/FactsNews/NewsRoom/6213.aspx Wal-mart Press Release, "Wal-Mart to Open First High-Efficiency Store; Supercenter Expected to Use 20 Percent Less Energy" January 18, 2007.
[15] U.S. Department of Energy, Energy Information Administration. Consumer Commercial Buildings Energy Consumption Survey (CBECS) 2003 http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html
[16] http://esttp.org/cms/upload/pdf/070202_4_EUSEW_Henning.pdf. Hans-Martin Henning, Presentation for Solar Energy Week,

- The **Banque Generale du Luxembourg** has installed a gas fired co-generation system that produces 90% of the Bank's energy needs and 100% cooling and heating. The cooling is provided with three absorption chillers using lithium bromide as the absorbent. The bank estimates that it saves 1 million dollars in energy costs, and reduces CO_2 emissions by 6500 tons a year. The system is American designed and installed by Trane.

- **Ashai** Brewery announced in 1999 that the company was installing a co-generation energy system at the Nagoya plant, using ammonia absorption for air-conditioning and hydrocarbons for the beer vending machines. The company expects to save 400 million yen a year from the resultant energy savings.

E. DISTRICT COOLING SYSTEMS (DCS)

"District cooling system (DCS) distributes thermal energy in the form of chilled water or other media from a central source to multiple buildings through a network of underground pipes for use in space and process cooling. The cooling or heat rejection is usually provided from a central cooling plant, thus eliminating the need for separate systems in individual buildings."[17]

District Cooling Systems today rely on a variety of cooling agents, including HFCs, ammonia, water, or the use of absorption chillers. However, the use of HFCs for DCSs is unnecessary since natural refrigerants, are available and can be safely applied in large chillers. And DCSs using absorption chillers can use mixture of lithium bromide and water, "which is a more environmentally benign alternative than the cooling agents used in building-specific compressor plants, is used as a cooling agent in absorption chillers."[18]

Regardless of the refrigerant used, District Cooling Systems are a highly efficient way of delivering cooling services with potential to reduce consumption of electricity for cooling purposes by as much as 90%.[19] A centralized cooling system provides greater quality control in maintenance and servicing, reducing the rate of refrigerant leakage.

"District cooling systems displace peak electric power demand with district cooling and storage using ice or chilled water. This benefits the local power grid by reducing peak power demand and alleviating power congestion due to power transmission limitations in cities. So district cooling not only helps cool cities, it helps alleviate the challenges posed by high electric consumption. The economic benefits can be experienced by both the owner and the tenant, where the capital costs of control panels, internal power distribution, annual maintenance and power consumption inside the building are reduced and the cost of chillers are eliminated."[20]

Benefits of District Cooling include:

* Better quality of cooling
* Maximum cost effectiveness
* Capital cost elimination
* Space saving
* Decrease in sound pollution
* Environmentally friendly

"Common applications involve District Cooling utilities that sell chilled water to numerous customers, as well as single owner-operator-customer systems such as universities, hospitals, airports and industrial facilities. DCSs often facilitate the use of other beneficial technologies,

[17] National Climate Change Committee, Singapore : www.nccc.gov.sg/building/dcs.shtm
[18] www.helsinginenergia.fi/kaukojaahdytys/en/os4_1.html
[19] www.helsinginenergia.fi/kaukojaahdytys/en/os4_1.html
[20] www.tabreed.com/districtCoolingDistrictCoolingBenefits.aspx

such as non-electric and hybrid (electric and non-electric) chiller plants, cogeneration and trigeneration, and Thermal Energy Storage."[21]

District Cooling Systems exist in many parts of the world. There are about 100 District Cooling systems in Europe[22]. In the U.S. there are approximately 2,000 district cooling systems, which cool 33,000 commercial buildings, plus numerous schools, institutions, and residences.[23] They have also been installed in the Middle East and in Singapore.

E.1 ***Examples of District Cooling Installations:***

- **Cool Solutions**, a company based in Lisle, Illinois, USA has participated in the installation of DC systems in Chicago, Illinois (21,000 tons), Cincinnati, Ohio (7,500 tons), Lansing, Michigan (12,000 tons), Oklahoma City, Oklahoms (18,500 tons), Orange County, Florida (21,000 tons), Orlando, Florida (5,700 tons), Washington, D.C. (10,000 tons).[24]

- **Baltimore Aircoil Company** has completed more than 2500 installations worldwide of high efficiency [34℉ (1℃) supply water] ice stor age systems for district cooling. BAC has supplied ice storage systems for a wide range of projects, including office complexes, hospitals, universities, sports arenas, as well as utility districts (some as large as 125,000 ton-hours).[25]

- District Cooling Systems can be found in the **Changi Business Park** and **Changi Naval Base** in Singapore.

- **Palm District Cooling Co**. of Dubai is working on several DCS projects in Dubai for Nakheel (a large Dubai development company), which when completed will provide combined 500,000 refrigerated tonnage. Nakheel DCS projects include Palm Jumeirah, Jumeirah Lake Towers, Jumeirah Village, Discovery Gardens and Dubai Metals and Commodities Centre, Ibn Battuta Shopping Mall and Furnished Apartments.[26]

- The **National Central Cooling Co**. (PJSC) – Tabreed, a United Arab Emirates public joint stock company established in June 1998, is now one of the world's largest district cooling utilities. Tabreed provides district cooling services throughout the GCC countries with offices in Dubai, Abu Dhabi, Ras Al Khaimah, Doha, Manama, Khobar and Muscat."[27]

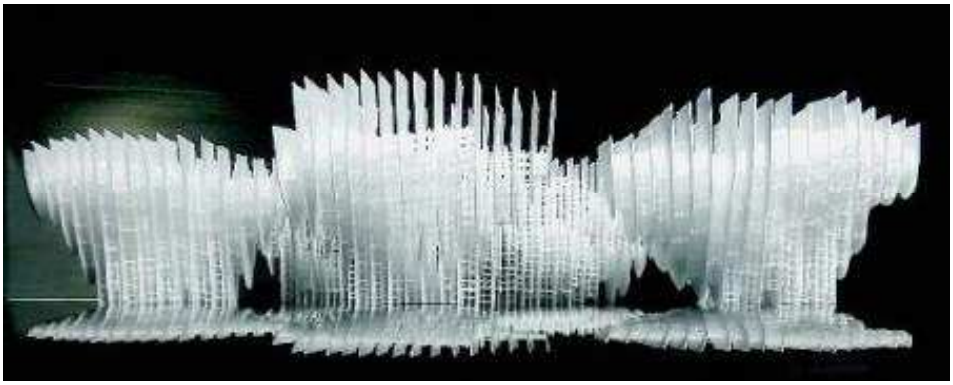
- **Helsinki Energy** in Finland has provided cooling from its district cooling plant at the Salmisaari power plant site since 1998. The output has been 10 MW since the first stage of the cooling plant project was completed. The cooling plant has two absorption chillers and chilled water storage for evening out peak loads. Cooling energy is transmitted via a pipe network to the districts of Ruoholahti and Kamppi. In addition, the outputs of the Pitäjänmäki absorption chillers and the transportable compressor cooling units in the district of Sörnäinen total 5 MW.[28]

[21] www.coolsolutionsco.com/district_cooling.htm
[22] www.euroheat.org/
[23] U.S. Department of Energy, Energy Information Administration. Consumer Commercial Buildings Energy Consumption Survey (CBECS) 2003 http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html
[24] www.coolsolutionsco.com/district_cooling.htm
[25] www.baltimoreaircoil.com/english/products/ice/district/index.html
[26] www.palmdistrictcooling.com
[27] www.tabreed.com/aboutus.aspx
[28] www.helsinginenergia.fi/kaukojaahdytys/en/os3_1.html

- **Cornell University** in Ithaca, New York delivers 20,000 tons of DCS cooling to its campus by pumping cold water into a heat exchanger from nearby Lake Cayuga. The City of Toronto is currently installing a similar system that will deliver 50,000 tons of DCS cooling from the waters of Lake Ontario.[29]

F. PASSIVE COOLING

The architectural redesign of new buildings to make use of natural ventilation, coupled with efficient insulation, can eliminate or reduce the need for mechanical air-conditioning and thus save energy.



Swabhumi Hotel complex (model) in Kolkata, India, designed by architectural firm Morphogenesis, uses innovative building design that simulates the way trees trap winds to deliver cooling services. The firm also designed a Jaipur fashion school where classrooms are cooled to around 25 degrees Centigrade without air-conditioners while ambient temperatures are nearly double outside.

G. MOBILE AIR-CONDITIONING (MACS) AND TRANSPORT COOLING

G.1 ***Environmental Impacts of HFC Mobile Air-Conditioning****:* Approximately 50% of global HFC-134a production is for automotive air conditioning, 15% for domestic refrigeration, and most of the remaining 35% for commercial and residential air-conditioning and supermarket refrigeration. A 1997 study by Atlantic Consulting reveals that the HFC-134a leakage from the air-conditioning of cars sold in 1995 in Western Europe alone will generate the CO_2 equivalent emissions of five new power plants, while the HFC-134a leakage from automobiles sold in Japan in 1995 will contribute the CO_2 equivalent of ten power plants, or approximately 16 million tonnes of CO_2.

Though there is substantial variation in estimate of annual leakage rates from MACs, one thing is certain though, the rates are substantial. The US Department of Energy's Energy Information Agency website claims that "Automobile air conditioners are subject to leakage, with sufficient refrigerant leaking out (15 to 30 percent of the charge) over a 5-year period to require servicing."[30] The site also claims that major US car manufacturer General Motors (GM) estimates annual leakage rates of 10 percent per year. "With GM vehicles accounting for about one-third of the U.S. light-duty fleet, the GM emissions estimate implies that total U.S. HFC-134a emissions from mobile air conditioners were equal to about 4,500 metric tons in 1996. Emissions from this source are expected to continue to increase in the near future, as the replacement of vehicles using CFCs proceeds at a rapid pace."[31]

[29] Information provided by Mr. John Andrepont of Cool Solutions www.coolsolutions.com
[30] http://www.eia.doe.gov/oiaf/1605/archive/gg98rpt/halocarbons.html
[31] http://www.eia.doe.gov/oiaf/1605/archive/gg98rpt/halocarbons.html

In the U.S., the Environmental Protection Agency has found that vehicles are the largest source of HFC emissions, accounted for 56% of annual total HFC emissions in the US[32]. These emissions have increased by 274% from 1995 to 2000, and are the largest source of emissions of high GWP gases (i.e., HFCs, PFCs or SF6). Air conditioning accounts for over 7% of a vehicle's total GHG emissions: 4.3% from direct HFC emissions through leaks, and 3.1% from CO_2 emissions related to energy use. These emissions are not taken into consideration in fuel-economy standards, thus they are completely unregulated.

A study by the School of Chemical Engineering and Industrial Chemistry, University of New South Wales, indicates that hydrocarbon automobile air-conditioners are almost 35% more efficient than HFC air conditioners. They also found that, if countries in Asia used hydrocarbons instead of HFCs in automobile air-conditioners, there would be 3.7 billion tonnes less cumulative CO_2 emissions by the year 2020.[33]

G.2 *Carbon Dioxide based Mobile Air-Conditioning (MACs)*

German carmakers announce the selection of CO_2 refrigerants to replace HFC-134a in MACs: In response to the European Union's decision to phase out high GWP, HFC-134a in mobile air-conditioning by 2011, in August of 2007 the German car industry decided to use carbon dioxide as the replacement refrigerant.[34] CO_2 was selected over several low GWP HFCs proposed by the Chemical companies, DuPont, Honeywell and Ineos, known in the MAC industry as DP1, Fluid H and AC1. In October 2008 the German carmakers reconfirmed their decision to opt for CO_2, although indications are that there is still on-going discussion among the German manufacturers.

Since 2007 DP1, Fluid H and AC1 products have been withdrawn from consideration by their producers, and DuPont and Honeywell have introduced HFO-1234yf. The verdict is still out on this new refrigerant. Environmental and toxicity concerns, including the release of TFA and lethal hydrofluoric acid, exist as well as concerns over the high cost of the chemical and reduced efficiency.

The energy efficiency benefits of CO_2 systems have been known for several years. Extensive measurements carried out at the University of Illinois in 1999 showed that CO_2 MACs have at least 30% lower TEWI than HFC systems.[35] Other studies reporting on trials comparing CO_2 prototypes against state-of-the-art HFC-134a system in real situations indicate that the COP of the CO_2 system was typically 25% greater than that of the R134a system.[36] Tests by Visteon and Behr, two of the world's leading MAC suppliers, demonstrate that CO_2 systems reduce fuel consumption by between 0.3L and 0.5L per 100km, compared to HFC-134a. This is equivalent to a 25-30% reduction in indirect emissions of the MAC system.[37,38] Based on the Life Cycle Climate Performance (LCCP), a recent study by SINTEF research institute, compared MAC systems' total contribution to global warming in a cradle to grave approach, highlighting several benefits of CO_2 MAC concerning environmental performance, costs and future potential. Namely, that CO_2 MACs produced up to 40% less emissions in hot climates (India and China) than HFC-134a.[39] In July 2009, Obrist Engineering used real-life testing data in the GREEN-MAC LCCP model and

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[32] http://www.epa.gov/climatechange/anpr.html Regulating Greenhouse Gas Emissions under the Clean Air Act, Advance Notice of Proposed Rulemaking, July 2008

33 Pham, Tuan and Aisbett, E.: Natural Replacements for Ozone-Depleting Refrigerants in Eastern and Southern Asia: School of Chemical Engineering and Industrial Chemistry, University of New South Wales: to be published by the International Journal of Refrigeration- in press 1998.

[34] UNEP, 2006 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, 2006 Assessment

[35] (Yin, 1999) need full ref

[36] Notes from Calor Gas reporting on studies by Walter & Krauss, 1999; Walter 1999; DKK 1998) and confirmed on Mercedes (Daimler-Benz web site (http://www.daimler-benz.com/ind_gfnav_e.html?/research/text/80331_e.htm

[37] Wieschollek, F., Heckt, R., "Improved Efficiency for Small Cars with R744." Visteon. Presentation prepared for VDA Alternative Refrigerant Winter , February 13-14, 2008, Saalfelden, Austria.

[38] Behr, "R744 A/C Systems: Test Stand and Field Test Experience". Published in ATZ 07-08I2008, volume 110.

[39] http://www.r744.com/news/news_ida095.php

determined that CO_2 will not only lead to the lowest greenhouse gas emissions in MACs in a European scenario, but will also outperform current refrigerants at the global scale[40].

In addition to their environmental benefits, CO_2 systems provide a servicing cost benefit as well, since there is no need to recover and recycle the refrigerant at the end of life.[41]

Manufacturers Ready to Produce CO_2 Equipment: Several mobile air-conditioning manufacturers are ready to produce CO_2 systems. These include **Behr, Valeo, Calsonic Ka**nsei, and **Denso**. Reportedly, Calsonic and Denso have already launched CO_2 systems in hybrid vehicles in Japan.

Numerous CO_2 MAC system and component manufacturers have also announced their availability for production, such as **Ixetic, Behr, Visteon, Modine, Hydro** or **Doowo**n.[42] In addition, at the international MAC industry gathering in February 2008, the German Car manufacturers and their suppliers announced major steps towards serial production of CO_2 MAC systems.[43]

Carbon Dioxide Air-Conditioning for Buses: **Konvekta**, the leading German manufacturer of thermal systems for commercial vehicles has begun to install CO_2 vehicle air conditioning. Type P 7744, to be used with the natural refrigerant CO_2 (R744), features a cooling capacity of 33 kW, and a heating capacity of 38,000 Q 100. Since 1996, it has been running successfully in test fields with a German bus operator to prove its everyday suitability. The operational experience has shown that, compared to the current refrigerant HFC134a, CO_2 is competitive in terms of efficiency and capacity due to a better compressor performance and heat transfer, as well as a lower effect in case of pressure losses. In addition, CO_2 units in reversed circulation can be used for heating purposes, unlike HFC-134a. After more than 6,000 operating hours of the CO_2 prototypes, Konvekta is now preparing for the serial production of its CO_2 cooling unit.[44]

The **Berlin Public Transport Society** for the City of Berlin ("Berliner Verkehrsbetriebe Gesellschaft", BVG) has been testing a bus with a Konvekta/Spheros CO_2 MAC system since 2007. The company reports fewer technical problems, better efficiency and higher reliability. The company has decided to purchase more CO_2 systems in the coming years, with the intention of making CO_2 a compulsory part of their bus purchases as of 2012/ 2013. [45]

G.3 Hydrocarbons in Primary MAC Systems: Millions of mobile air-conditioning units in cars in Australia, United States and Canada have been converted without regulator approval from CFC-12 and HFC-134a to hydrocarbons. In 2002, the Mobile Air Conditioning Society (MACS) performed a survey that found 2% of vehicles presented for repair in the US were charged with hydrocarbon refrigerants, which equates to over 4.2 million vehicles.[46] Similarly, a study by the University of New South Wales estimated that 4.7 million U.S. vehicles were charged with hydrocarbons as of 2004[47]. The same study also documented extensive use of hydrocarbons in Australian vehicles. There is no report of accidents or injury resulting from hydrocarbon refrigerants in these cars.

***G.4 Hydrocarbons in Secondary Loop MAC Systems*:** The application of a secondary loop system would further overcome any outstanding safety concerns. Designed to accommodate a hydrocarbon, the secondary loop system would completely eliminate HFC-134a use (and emissions). It would be expected to use about 10% more energy for operation than the current

[40] http://www.r744.com/articles/2009-07-07-green-mac-lccp-finds-r744-to-perform-best.php
[41] Multisectorial Initiative on Potent Industrial Greenhouse Gases (MPIGGs) newsletter, 2004: www,mipiggs.org
[42] A good overview of these latest industry developments can be found on R744.com
[43] http://www.r744.com/news/news_ida298.php
[44] http://www.r744.com/news/news_ida319.php
[45] Berliner Verkehrsbetriebe (BVG) May 12, 2009
[46] MACS Releases Refrigerant Survey Results. Mobile Air Conditioning Society Worldwide, October 29, 2002
[47] Maclaine-cross, I.L. "Usage and risk of hydrocarbon refrigerants in motor cars for Australia and the United States" International Journal of Refrigeration 27(2004) 339–345

system, but would still represent a net savings of at least 80% of equivalent green-house gas emissions associated with current HFC-134a systems that are operated without proper recovery and recycle during service and vehicle disposal.

One noteworthy aspect of using propane, the best hydrocarbon choice for secondary loop systems, is its availability. Propane is used universally for heating and cooking. As a result, its safe handling is widely understood and practiced by the general population in most countries, whether literate or not. This could be an advantage in the developing countries. For systems using propane, the charge for a mid-size vehicle would be relatively small, on the order of 200 grams, based on the molecular weight of the refrigerant and the lower refrigerant charge required by the secondary loop system.[48]

TransAdelaide Bus Company in Australia has installed hydrocarbon air conditioning in the drivers' compartment, while the passengers compartment is cooled by desiccant cooling.

G.5 Evaporative Cooling for Buses: Nearly 500 buses (in Colorado, Utah, California and Texas) and additional buses in Adelaide and Perth, Australia use evaporative or adiabatic air conditioning systems. Companies using evaporative cooling in transport include: Regional Transportation District, Denver, CO; Denver International Airport, Denver, CO; Utah Transit Authority, Salt lake City, UT; University of California at Berkeley, Berkeley, CA; Sacramento Regional Transit, Sacramento, CA; Pacific Gas & Electric Co. CA.

H. FOAMS

A major cause for concern in the foam sector is the pending switch from HCFC-141b for blowing Rigid Polyurethane foam (PUR) insulation to potent global warming gases such as HFC-245fa, HFC-365mfc, and whether those alternative prove to be inferior, to HFC-134a.

H.1 Construction Foams:

PUR is commonly used in construction as insulating foam. There are a number of different kinds of foam that are all rigid PUR, most notably, boardstock, sandwich panels and spray foams.

- Boardstock is prominently used in roof and wall insulation in commercial buildings. Sandwich panels, where the foam is sandwiched between facing materials such as steel and aluminium, are used for insulating cold stores, cold rooms and doors. Spray foams are made at the point of use and are literally sprayed into place. They are highly suitable for the insulation of uneven or inaccessible surfaces and are used in storage tanks, pipe work and refrigerated trailers.

- Increasingly, companies are using the hydrocarbon pentane as an alternative blowing agent for both board stock and sandwich panels. In 2005 hydrocarbons were expected to represent over 55% of global blowing agent usage.[49]

- Major US building insulation producing companies, such as **Atlas Roofing, Firestone, RMAX,** and **Johns Manville** have shifted from HCFC-141b to using pentane and fiberglass. They have concluded that pentane is less costly than HFC-245fa or HFC-365 mfc and that, given the high GWP of these substances, pentane is environmentally more sustainable. Water blown foams are also now available on the market: Canadian

[48] S.O. Andersen, U.S. Environmental Protection Agency, Washington DC, USA, W. Atkinson & J.A. Baker Technical Advisors to the Mobile Air Conditioning Climate Protection Partnership " Existing and Alternate Vehicle Air Conditioning Systems

[49] IPCC (2005)

company **Icynene, Inc**. and US companies **Earthane** and **Bio-Based Insulation** manufacture water-blown, soy-based polyurethane foam.[50,51]

- A similar situation is occurring in Europe. **Thanex** in Denmark has used a mechanical process for producing PUR insulating foam. Recticel (Belgium), the largest manufacturer of PUR foams in Europe, and **Bayer**, have been producing hydrocarbon blown foams for construction applications for a number of years. The French company **Efisole** has also switched to using pentane for various polyurethane foam production. German companies have been using hydrocarbons for nearly a decade.

- Alternatively, CO_2 is currently being used as the blowing agent by **ICI** and **Liquid Polymers Group** in the UK, **ResinaChemie** and **BASF** in Germany and **Nassau Doors** in Denmark. Carbon dioxide blowing, in combination with process changes, as demonstrated by **Windsor** Doors in Norway, is a proven technology for spray foams.

- **Alternatives to foams:** Often the best alternatives to polyurethane boardstock are not foams at all. Magnesium carbonate, as produced by **Darchem** in the UK, can be made into an insulation product for use in power stations and oil installations. Products such as mineral fiber and fiberboard have always been in competition with polyurethane. Mineral fiber is dominant in insulation products in the UK. Meanwhile, the Swiss company **Isofloc** and US company **Greenfiber** both produce boardstock panels made out of cellulose. The panels are made out of recycled materials, such as newsprint. Extruded polystyrene is also used as a rigid boardstock, where its moisture resistance and strength make it suitable for below ground construction insulation, for example, in foundations. **Dow Chemicals** and **BASF** use carbon dioxide technology to produce extruded polystyrene. The product is sold in many European countries.

H.2 ***Refrigerator and Freezer Insulation:*** In most markets, with the exception of North America, the hydrocarbon cyclopentane has now become the standard choice for the blowing rigid polyurethane foams, which continue to be the dominant insulation used in domestic refrigerator-freezers and small commercial equipment. Alternative foam blowing agents include water and CO_2.

H.3 ***District heating pipes:*** More than half of the world production of pre-insulated district heating pipes takes place in Denmark, by four companies: **ABB District Heating (I C Moller), Logstor Ror, Tarco Energy and Starpipe (Dansk Rorindustri)**. As from January 1993 CFCs were no longer allowed for the blowing of insulation foam for district heating pipes in Denmark. HCFCs, as a transitional solution, and CO_2 had been used instead. Now all four companies have developed systems based on cyclopentane or other hydrocarbons. Two of the companies also continue producing CO_2-based pipes.

H.4 ***Portals, industrial doors:*** Two Danish companies, **Nassau Doors** and **Windsor Door**, produce industrial portals and doors with sandwich panels containing polyurethane foam. They are now using CO_2.

H.5 ***Rigid integral foam:*** The Danish firm **Tinby A/S** has a considerable production of rigid integral foam for industry, especially in the graphical industry. They stopped using CFCs in 1993 and have since used CO_2 in the major part of the production, and HCFCs in a minor part.

H.6 ***Jointing foam:*** **Baxenden Scandinavia** produces canister foam sealant (jointing foam) and has, since 1987, produced cans with propane/butane propellant for the Scandinavian market and cans with HCFC for the European market.

[50] http://www.biobased.net/products/index.php
[51] http://www.icynene.com/products/

H.7 *Flexible integral foam:* Baxenden Scandinavia has also developed systems for producing flexible integral foam with isopentane as a blowing agent. Additionally, **Ecco**, a large shoe producer, has, in cooperation with **Bayer**, developed a technology for producing shoe soles of flexible integral foam using CO_2 rather than ODSs.

H.8 *Flexible foam:* Three Danish companies (**Brdr.Foltmar, KBE and Danfoam**) are producing flexible slabstock foam at four localities. They stopped using CFCs in 1991 and use CO_2 for most production. **Urepol Oy** is a Finnish company manufacturing polyurethane insulated steel-faced and flexible faced panels, and one-component PUR foam insulation. The company is now using hydrocarbons to produce products which were previously manufactured with CFCs and HCFCs

H.9 *Vacuum insulation:* Vacuum insulation panels, which offer superior insulation for appliances and provide significant energy savings are increasingly being applied. These vacuum panels are filled with e.g. silica, fiberglass, or ceramic spacers.

- NoFrost Co. of the UK launched a new line of hydrocarbon freezers in 1999 using vacuum panels that were developed in cooperation with ICI for insulation, and hydrocarbons for the refrigerant.

- Vacuum panels in appliances are used by General Electric and Owens-Corning in the USA.

- In Japan, Sharp combines the use of vacuum panels with PUR foam blown with cyclopentane in domestic refrigerators. AEG in Germany has introduced some vacuum panel insulated fridges

- The Swiss Ecofridge Project uses vacuum insulation, where the vacuum is filled with diatomaceous earth. The thermal conductivity is about 0.005.

I. HYDROCARBON REFRIGERANT PRODUCTION

Hydrocarbon refrigerants are produced from naturally occurring gases and have minimal impact on the environment. Their global warming contribution is very small, they are efficient, reliable, have no chemical or acid reactions, and are less costly then their fluorocarbon counterparts. Furthermore, hydrocarbons cannot be patented, and they are therefore readily available. Typically, cooling systems require one-third the charge with hydrocarbons than is needed with fluorocarbons.

I.1 **HyChill Company of Australia** has been producing hydrocarbon refrigerants for the international market since 1999. HyChill distributes its products in Australia, Japan, Taiwan, Phillippines, China, Thailand, India, Sri Lanka, Malaysia, Singapore, Indonesia, South Africa, Europe, the Middle East and the USA. The company's products are widely used in car air-conditioning as drop in replacement for HFC-134a, as well as in refrigerated containers and transports, domestic refrigerators and freezers, drink dispensers, supermarket cooling units and display cabinets, and in domestic air conditioning systems.[52]

I.2 **AS Trust & Holding** in the US is marketing a new hydrocarbon blend of refrigerant, R-188C. As of December 2008, the US EPA issued a letter allowing sales of R-188s for use in residential refrigerators and air conditioning. This is the first hydrocarbon refrigerant to gain tentative approval for use in domestic refrigerators in the US. EPA expects to issue a final rule and use conditions for the refrigerant in mid-2009. Tests commissioned by the refrigerant

[52] www.hychill.com.au/

manufacturer on a residential refrigerator show better performance, smaller charge size, and significant energy savings compared to HFC-134a[53].

CONCLUSION

There are many more examples around the world where natural working fluids (e.g ammonia, CO_2, hydrocarbons, water) along with other non-fluorocarbon based technologies are accomplishing the job of providing sustainable, low-GWP, reliable and safe cooling. The above survey is to demonstrate the "possible". Now is the time to leave behind the fluorocarbon era, and to embrace technologies that do not unnecessarily harm the climate or the environment.

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[53] http://www.hcr188c.com/default.aspx