



COOL TECHNOLOGIES: WORKING WITHOUT HFCs- 2010

Examples of HFC-Free Cooling Technologies in Various Industrial Sectors¹

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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 (CO₂, 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 nearly all those human needs that were formerly met by fluorocarbons.² (please see disclaimer below)

HFC-free technologies exist in nearly 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-froging 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 fluorocarbon chemical industry’s monopoly over their choice of technology.

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A. GREENFREEZE DOMESTIC REFRIGERATION

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. The term Greenfreeze refers to refrigerators and freezers that contain no fluorocarbons. Typically they use cyclopentane for the foam and isobutane (R-600a) for the refrigerant. The refrigerant charge of 30 to 100 grams varies according to the size and special features 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. 75% of new domestic refrigerators in China use R-600a.³ It is also produced in Latin America, in Argentina and Brasil. Greenfreeze has not yet entered the North American market in the USA or in Canada but it is available in Mexico.

The 2010 Technology and Economic Assessment Panel (TEAP) Progress Report writes: “It is predicted that at least 75 percent of global new refrigerator production will use hydrocarbon refrigerants in 10 years.”⁴

¹ A report under the same title was published by Greenpeace in 2000 , 2008 and 2009 and it continues to be updated. Greenpeace welcomes receiving information regarding new examples of HFC-free technologies. Please forward them to jmate@telus.net

² 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.

³ Cox, Nicholas “Low-Carbon Cooling: Hydrocarbons- Challenges and Opportunities”- RAC Magazine: October, 2009

⁴ UNEP Technology and Economic Assessment Panel 2010 Progress Report: “Assessment of HCFCs and Environmentally Sound Alternatives” , p.37

Table 1: Partial list of companies producing Greenfreeze Domestic Refrigerators		
COMPANY	COUNTRY	NOTES
AEG	Germany	
Arcelik	Turkey	
Bauknecht	Germany	
Bosch	Germany	
Bosch Siemens Hausgerate BSH Russia	Russia	
Bosch Siemens Hausgerate BSH Mexico	Mexico	Begins marketing in March, 2009, in cooperation with retailer Sears Mexico. First penetration of hydrocarbon technology into a North American market.
Candy Group	Italy	
Bosch Siemens Hausgerate BSH Russia	Russia	
Electrolux	Sweden	
Electrolux	Hungary	
Electrolux	Australia	
Email	Australia	
FisherPaykel	New Zealand	
General Electric	USA	In October 2008, General Electric announced that the company has formally requested the approval of the US Environmental Protection Agency, under the Significant New Alternatives Policy (SNAP) program, for the production of hydrocarbon refrigerators for the US market. Initial plan called for beginning of production in 2010.
Godrej	India	
Gorenje Deutschland	Germany	
Gram	Denmark	
Haier	China	
Hartono Istana Electronics	Indonesia	
Hitachi	Japan	
Husky Deutschland	Germany	
Indesit Deutschland	Germany	
Inpud	Cuba	
Kelon	China	
Koh-I-Noor	Argentina	
LG Electronics Inc.	South Korea	
Liebherr	Germany	
Matsushita	Japan	
Miele	Germany	
Panasonic	Japan	
Palfridge	Swaziland	Palfridge in Swaziland is converting in 2010 its entire production line to hydrocarbons with the support of GTZ ProKlima.
Quelle	Germany	
Sanyo	Japan	
Sharp	Japan	
Siemens Home	Germany	
Thompson	France	
Toshiba	Japan	
Vestfrost	Demark	Vestfrost also produces SolarChill vaccine coolers
Voltas	India	
Whirlpool	Italy	
Whirlpool	Argentina	
Zanussi Electrolux	Italy	

A.1 SolarChill⁵ : solar powered, storage battery free, hydrocarbon based vaccine cooler and food refrigerator

SolarChill is a breakthrough technology in vaccine cooling and domestic and small commercial refrigeration. Ten years in the making, the SolarChill vaccine cooler operates with a Danfoss direct current compressor powered directly by sunlight. Instead of storing electrical energy in a led battery, the refrigerator stores thermal energy in an “ice battery”. A thermostat maintains the vaccine temperatures between the required +2 to +8°C. In low-sun situations or with power completely disrupted, the insulated “ice battery” maintains acceptable temperatures for up to five days. An intelligent fan enhances the convection circulation of the cold air and is operated by a small rechargeable battery, which is recharged by the solar power. The current generation of SolarChill (Vestfrost model MKSO44) has WHO PQS qualification for +20 to +32 °C ambient temperatures. However, in field tests, the units have operated under lower and higher ambient temperatures ranges of +10 to +42°C.

⁵ The SolarChill Project partner organizations are: the Danish Technological Institute (DTI), the German Government Development Agency (GTZ ProKlima) , Greenpeace International, Program for Appropriate Technology in Health (PATH), United Nations Environment Programme (UNEP), United Nations Children's Fund (UNICEF) World Health Organization (WHO) and the World Bank . SolarChill Industry Participants include Vestfrost and Danfoss. Please see www.solarchill.org “Contacts” for the names and contact information of individual representatives.

The SolarChill vaccine cooler is now commercialized by Vestfrost. The food refrigerator model is still in the R&D phase. In 2010, PalFridge company of Swaziland launched three new SolarChill prototypes: vaccine cooler, domestic and commercial food refrigerators.⁶

B. COMMERCIAL REFRIGERATION WITH NATURAL REFRIGERANTS

Commercial refrigeration represents 40% of total annual refrigerant emissions. It is the refrigeration subsector with the largest CO2 equivalent refrigerant emissions.⁷ There are three main types of commercial refrigeration equipment: (a) stand alone plug-in equipment, (b) condensing units; (c) centralized systems.

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.

Table 2: Use of natural refrigerants in point -of –sale cooling equipment by member companies of Refrigerants, Naturally!

COMPANY	APPLICATION	NOTES																																	
Coca Cola	Food & everage	Since 2000 Coca Cola has developed a new, high efficiency, CO₂ technology for vending machines. On December 3rd, 2009, Coca Cola announced that 100 percent of their new vending machines and coolers will be hydrofluorocarbon-free (HFC-free) by 2015. Coca Cola will have 135,000 coolers and vending machines using natural refrigerants worldwide by the end of 2010. According to CocaCola: "some of our suppliers achieved even better CO2 performance versus R134a under "D" conditions (40 degrees C ambient)... and in all countries in the world yearly averages are in a range where CO₂ in beverage cold drink equipment performs better than 134a". It has been reported that Coke's CO₂ cooler made by Haier is 35% more efficient than the ordinary HFC ones.																																	
Carlsberg	Food & Beverage	Carlsberg has deployed in Denmark, Sweden and Switzerland over 3,500 coolers using hydrocarbon technology.																																	
McDonald's	Food & Beverage	In 2003 McDonald's opened the "first fluorocarbon free restaurant" in Vejle, Denmark. On January 16, 2003 McDonald's opened the world's first HFC-free restaurant in Vejla, Denmark. This pilot project realized CO₂ emission reduction of approximately 27% to a comparable control McDonald's restaurant .⁸ The test equipment included: <table><tr><th>EQUIPMENT</th><th>CURRENT REFRIGERANT</th><th>ALTERNATIVE REFRIGERANT</th></tr><tr><td>Soda Machine (Post Mix Type)</td><td>HFC-404a</td><td>R290 (propane)</td></tr><tr><td>Juice Dispenser</td><td>HFC-404a</td><td>R290 (propane)</td></tr><tr><td>Milkshake & Ice Cream Machine</td><td>HFC-404a</td><td>R290 (propane)</td></tr><tr><td>Meat Freezer</td><td>HFC-404a</td><td>R290 (propane)</td></tr><tr><td>Wall-hung Freezer</td><td>HFC-404a</td><td>R290 (propane)</td></tr><tr><td>Ice Cube Machine</td><td>HFC-404a</td><td>R290 (propane)</td></tr><tr><td>Salad Refrigerator</td><td>HFC-134a</td><td>R600a (isobutane)</td></tr><tr><td>Refrigerating Room</td><td>HFC-134a</td><td>R290 & CO₂</td></tr><tr><td>Freezing Room</td><td>HFC-404a</td><td>R290 & CO₂</td></tr><tr><td>Air conditioning & heating</td><td>HFC-407c</td><td>CO₂</td></tr></table> The company has not reported any further progress towards meeting its public commitments to phase out HFCs.	EQUIPMENT	CURRENT REFRIGERANT	ALTERNATIVE REFRIGERANT	Soda Machine (Post Mix Type)	HFC-404a	R290 (propane)	Juice Dispenser	HFC-404a	R290 (propane)	Milkshake & Ice Cream Machine	HFC-404a	R290 (propane)	Meat Freezer	HFC-404a	R290 (propane)	Wall-hung Freezer	HFC-404a	R290 (propane)	Ice Cube Machine	HFC-404a	R290 (propane)	Salad Refrigerator	HFC-134a	R600a (isobutane)	Refrigerating Room	HFC-134a	R290 & CO ₂	Freezing Room	HFC-404a	R290 & CO ₂	Air conditioning & heating	HFC-407c	CO ₂
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PepsiCo	Food & Beverage	Pepsi has over 8000 vending machines around the world using hydrocarbons or CO₂ technologies. About 5,000 of these are hydrocarbon units .⁹ The company has pioneered the testing of CO₂ and hydrocarbon equipment in the United States. Starting in 2009, all new Pepsi coolers in Turkey are HFC-free. According to PepsiCo, there is no efficiency penalty with CO₂ equipment compared to similar HFC-134a equipment. The new hydrocarbon units contain R290 (propane) refrigerant that cuts direct greenhouse gas emissions by 99%. In terms of energy efficiency, the new units use on average 44% less energy than 2008 models, and 20% less energy than Energy Star requirements."¹⁰																																	
Unilever	Food & Beverage	By 2009 Unilever had placed over 400,000 hydrocarbon ice-cream coolers around the world, including South Africa, China, Europe, Brasil and the United States. These coolers contain approximately 100 grams of hydrocarbons, and have a 9% energy savings over their HFC counterparts.¹¹ In an industry precedent setting move, Unilever pioneered the testing of hydrocarbon ice-cream freezers in the United States in its Ben & Jerry's ice cream stores. The company requested from the EPA 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.																																	

⁶ PalFridge developed its SolarChill prototypes with the cooperation of GTZ ProKlima.

⁷ IPCC/TEAP, 2005 as reported in TemaNord. 2007: "Potent Greenhouse Gases: Ways of Reducing Consumption and Emission of HFCs, PFCs 7 SF6": report prepared for the Nordic Council of Ministers p. 32

⁸ UNEP DTIE OzonAction : HCFC Help Centre : www.unep.fr/ozonaction/topics/hcfc_case-studies.htm : McDonalds' : world's first free HFCs restaurant

⁹ <http://www.hydrocarbons21.com/content/articles/2009-03-31-pepsico-uses-hydrocarbons-in-5000-vending-machines.php>

¹⁰ PepsiCo Press release: <http://www.pepsico.com/PressRelease/PepsiCo-Debuts-Energy-Efficient-HFC-Free-Cooler-at-Super-Bowl02022010.html> : February 2, 2010

¹¹ <http://www.unilever.com/ourvalues/environment-society/case-studies/climate-change/hydrocarbon-ice-cream-cabinets.asp>

B.2 Companies working with cooling equipment using natural refrigerants

Increasing number of companies around the world are making the business decision to opt for natural refrigerants to meet their cooling needs.

Table 3: Examples of companies using cooling equipment working with hydrocarbons and CO₂ natural refrigerants

COMPANY	APPLICATION	NOTES
Nestlé	Food & Beverage	Nestlé, the world's largest food processing company, is committed to phasing-out all fluorocarbon refrigerants. On October 1, 2001 the company announced 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...". Today, besides extensively relying on natural refrigerants in its food processing, the company has several thousand hydrocarbon coolers in Germany.
Danone	Dairy Products	Danone has 1000 coolers using hydrocarbon technology in a number of countries, including Denmark, Mexico and Germany.
Tesco	Supermarket	In 2009 Tesco had five stores in the UK using CO ₂ based refrigeration systems. By the end of 2012, Tesco plans to have 150 stores using CO ₂ refrigeration. Outside the UK, Tesco has installed or is testing CO ₂ refrigeration in stores in Korea, Thailand, Hungary, USA, Turkey and Malaysia.
Tesco Lotus	Supermarket	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.
Auchan	Supermarket	Auchan supermarket has two stores in Hungary fitted with CO ₂ /ammonia cascading systems. Reported energy savings are at least 35% better than with comparable R404a air cooled systems. ¹²
Sainsbury's	Supermarket	By 2010, Sainsbury's plans to have 9 stores in the UK using CO ₂ refrigeration systems.
Morrisons	Supermarket	By the end of 2009, Morrisons planned to have 20 of its 418 UK stores using CO ₂ refrigeration.
Marks & Spencer	Supermarket	Starting in 2010, Marks & Spencer plans to have all its new supermarkets in the world using CO ₂ refrigeration. The company is training technicians in developing countries in the use of natural refrigerants.
Metro	Supermarket	Metro has 5 stores in Germany and Denmark using CO ₂ refrigeration technology.
REWE	Supermarket	Europe's 3 rd largest food trader announced in 2006 that from 2008 on it will only use CO ₂ (R744) refrigeration in new small-sized supermarkets in Germany. ¹³
Drakes	Supermarket	In 2008, Drakes supermarket in Australia installed a transcritical CO ₂ -only cooling system without any back-up system in its North Adelaide store. ¹⁴ This is the first of its kind in Australia
Aldi Sud	Discount Supermarket	The giant German food discount chain, Aldi Sud, announced in December 2009, that as of January 2010 the company will only install CO ₂ refrigeration systems in all new stores in Germany. The company opens around 150 new stores each year. Aldi contracted Carrier to install the CO ₂ systems.
Waitrose	Supermarket	The UK company Waitrose currently has seven stores using propane based refrigeration technology. The company plans to install propane refrigeration in all new and retrofitted stores, so that by 2020 all Waitrose stores will be HFC-free. ¹⁵ The company estimates that the propane refrigeration technology will reduce its carbon footprint by 20%. The system is based on a combination of high efficiency air-cooled chillers supplied by Klima-therm and manufactured by Geoclima that utilise R290 propane and uses water as the condensing medium to supply the Carter Retail Equipment integrated cabinets operating on R1270 propene hydrocarbon-based scroll compressors. It makes use of split coils to keep the propene charge under 400 g, together with liquid pump amplification and floating head pressure and conventional free cooling below 18°C. The system design allows for the harnessing of heat from the integral refrigeration units to deliver warmth into the space between cabinets, in order to offset the in store "cold aisle" effect. This helps boost efficiency and overcomes the need for a separate heating system. ¹⁶
Woolworths	Food Retailer	Australia's largest food retailer, Woolworths, announced that it plans to install CO ₂ cascade systems in new stores after the success of its pioneer "green supermarket" in Sydney. ¹⁷

¹² www.r744.com 2010-03-01

¹³ www.r744.com/news/news_ida260.php REWE Group Chooses Co2 for its new "City Markets"

¹⁴ www.r744.com/news/news_ida302.php Industry Visits Australia's first CO₂ only supermarket

¹⁵ www.hydrocarbons21.com, 2010-03-29

¹⁶ *ibid* 2009-08-12

¹⁷ www.r744.com/news/news_ida302.php Industry Visits Australia's first CO₂ only supermarket

B.3 Companies producing and/or marketing commercial cooling equipment using natural refrigerants:

With the growing global demand for sustainable cooling equipment there is a steady growth in the number of companies producing and marketing equipment with natural refrigerants.

Table 4: Examples of companies producing and/or marketing cooling equipment with natural refrigerants

COMPANY	COUNTRY	EQUIPMENT DETAILS																														
Vestfrost	Denmark	The large Danish cooling equipment manufacturer has a vast array of commercial equipment using natural refrigerants. The majority of the company's products are available with hydrocarbons (R-600a and hydrocarbon blends), with "more to come".																														
		<table><tr><th>EQUIPMENT</th><th>REFRIGERANT & Net Capacity</th><th>NOTES</th></tr><tr><td>Chest Freezers 11 models</td><td>R-600a 189 - 464 litres</td><td>Heavy duty cabinet maintains temperature under extensive use. All in energy class A+ provides low running costs. Temperature range -17 to -24 C.</td></tr><tr><td>Display Freezers 5 models</td><td>R-600a 265-492 litres</td><td>Storage for ice cream and frozen food. Sliding glass top. temperature range -17 to -24 C.</td></tr><tr><td>Low Temperature Freezers 8 models</td><td>R-600a 133-476 litres</td><td>Maintains temperature as low as -30 to -60 C. Designed for laboratories and hospitals. Equipped with alarm if temperature rises.</td></tr><tr><td>Upright Freezers</td><td>R-600a 282 - 310 litres</td><td>Glass doors. No frost. Temperature range -16 to -25 C.</td></tr><tr><td>Upright Bottle Coolers 6 models</td><td>R-600a 281-379 litres</td><td>Large display coolers . Temperature range 3-10 C. Glass doors. Movable shelves. Maintains temperature even under difficult conditions.</td></tr><tr><td>Chest Display Cooler</td><td>R-600a 210-307 litres</td><td></td></tr><tr><td>Off-grid Freezers (battery operated) 2 models</td><td>R-290 106 - 206 litres</td><td>100 mm insulated freezer. Danfoss 12/24 BD compressor. Temperature ranges: 0 to 10 C and -10 to -18 C.</td></tr><tr><td>SolarChill MKSO44 Vaccine Cooler WHO Approved Solar energy stored in ice</td><td>R-600a Vaccine storage capacity 19.5 litres</td><td>Maintains storage temperature at required +2-+8 C. Autonomy time:147 hours Hold overtime: 114 hours Cool down time: 96 hours Ambient temperature: +20 to +32 C Minimum power: 160 watts at 6.0 kWh/m²/day Danfoss BD35K compressor</td></tr><tr><td>Wine cabinets 8 models</td><td>R-600a 140-368 litres</td><td>Equipped with fan, low vibration compressor, temperature setting, frost protection, built-in heating element, lockable smoked glass door, variable temperature zones</td></tr></table>	EQUIPMENT	REFRIGERANT & Net Capacity	NOTES	Chest Freezers 11 models	R-600a 189 - 464 litres	Heavy duty cabinet maintains temperature under extensive use. All in energy class A+ provides low running costs. Temperature range -17 to -24 C.	Display Freezers 5 models	R-600a 265-492 litres	Storage for ice cream and frozen food. Sliding glass top. temperature range -17 to -24 C.	Low Temperature Freezers 8 models	R-600a 133-476 litres	Maintains temperature as low as -30 to -60 C. Designed for laboratories and hospitals. Equipped with alarm if temperature rises.	Upright Freezers	R-600a 282 - 310 litres	Glass doors. No frost. Temperature range -16 to -25 C.	Upright Bottle Coolers 6 models	R-600a 281-379 litres	Large display coolers . Temperature range 3-10 C. Glass doors. Movable shelves. Maintains temperature even under difficult conditions.	Chest Display Cooler	R-600a 210-307 litres		Off-grid Freezers (battery operated) 2 models	R-290 106 - 206 litres	100 mm insulated freezer. Danfoss 12/24 BD compressor. Temperature ranges: 0 to 10 C and -10 to -18 C.	SolarChill MKSO44 Vaccine Cooler WHO Approved Solar energy stored in ice	R-600a Vaccine storage capacity 19.5 litres	Maintains storage temperature at required +2-+8 C. Autonomy time:147 hours Hold overtime: 114 hours Cool down time: 96 hours Ambient temperature: +20 to +32 C Minimum power: 160 watts at 6.0 kWh/m ² /day Danfoss BD35K compressor	Wine cabinets 8 models	R-600a 140-368 litres	Equipped with fan, low vibration compressor, temperature setting, frost protection, built-in heating element, lockable smoked glass door, variable temperature zones
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Earthcare Products Ltd.	UK	Earthcare Products Ltd. is marketing a wide range of commercial cooling equipment using hydrocarbons:																														
		<table><tr><td>Range of wall mounted and ceiling mounted split air conditioners</td><td>Water coolers</td><td>Glass door merchandiser</td></tr><tr><td>Dehumidifiers</td><td>Chest chill cabinets</td><td>Sliding door display coolers</td></tr><tr><td>Range of air-cooled chillers: largest model offer 1,265 kW</td><td>Ice cream conservators</td><td>Defrost type freezer chillers</td></tr><tr><td>Mini bars</td><td>Bottle chillers</td><td>Freezers</td></tr><tr><td>Deli display cabinets</td><td>Wine cooler dispensers</td><td>Multi-deck display cabinets</td></tr></table>	Range of wall mounted and ceiling mounted split air conditioners	Water coolers	Glass door merchandiser	Dehumidifiers	Chest chill cabinets	Sliding door display coolers	Range of air-cooled chillers: largest model offer 1,265 kW	Ice cream conservators	Defrost type freezer chillers	Mini bars	Bottle chillers	Freezers	Deli display cabinets	Wine cooler dispensers	Multi-deck display cabinets															
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Frigoglas	Greece	The Greek manufacturer Frigoglass in 2009 launched its Ecocool range of cold drink dispenser equipment, using natural refrigerants R290, R600a or R744. as well as the use of natural substances in the insulation. According to the company, the Ecocool coolers consume up to 50% less energy than equivalent units produced 10 years ago.																														
		The company has a client base of 15 countries around the world, and customers include Coca-Cola bottlers (Coca-Cola Hellenic, Coca-Cola Enterprises, Coca-Cola Amatil, Coca-Cola Sabco), international brewers (Heineken, Carlsberg, SAB Miller, ABInbev, Efes) and dairy companies (Nestle, Danone).																														
		With a market share in 2008 reaching 20%, Frigoglass is the global market leader in commercial refrigeration with operations in 15 countries across four continents. Frigoglass has production hubs in Romania, Russia, Turkey, India, China, Indonesia, South Africa and Nigeria. ¹⁸																														

¹⁸ www.hydrocarbons21.com/content/articles/2009-07-10-greek-firm-launches-complete-hfc-free-coolers.php

Table 4 Continued: Examples of companies producing and/or marketing commercial cooling equipment with natural refrigerants

COMPANY	COUNTRY	EQUIPMENT DETAILS
Carrier Corp	US/Global	Carrier Corp has developed CO ₂ refrigeration 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 ¹⁹ .
Carrier Commercial Refrigeration	US/Global	A United technologies Company, Carrier produces hydrocarbon based refrigerated cases and display cabinets.
United States Cold Storage Company	United States	United States Cold Storage Company is pioneering a new CO ₂ refrigeration technology used in food storage facilities in Indiana, California, Pennsylvania and Florida ²⁰ . 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.
Caravell	Denmark	Markets a 74 litre hydrocarbon open top bottle cooler. ²¹
Gram Commercial	Denmark	Produces hydrocarbon commercial refrigeration kitchen equipment (refrigerators and freezers) which are marketed in Sweden, Denmark and Norway. ²²
Haglund Industri	Sweden	Produces hydrocarbon professional kitchen refrigerators and freezers. ²³
Kuvatek	Denmark	Produces hydrocarbon based tap water coolers and beer coolers. ²⁴
Husky Group	UK/Global	The Husky Group markets hydrocarbon based ice cream displayed cabinets , and upright and under the counter bottle coolers. In 2009 the company introduced the highly efficient Intelligenza freezer cabinet that uses propane, and features new electronics with soft start compressor technology. ²⁵ The company also upgraded its top-of-the-range open-fronted multideck chiller cabinets to using propane. This provides “smaller retailers and convenience stores the same advantages as large supermarkets... to minimize both direct and indirect emissions associated with their refrigeration.” ²⁶
Williams Refrigeration	UK	Commercial refrigerator for the food service and bakery industry. The product contains 100 grams of propane, and with the use of “CoolSmart” intelligent controllers and self closing doors can realize energy savings of up to 15%. ²⁷
AHT UK	UK	In 2009 AHT launched its propane Multidecks, open-fronted display coolers for snack foods, soft drinks and dairy products. AHT Cooling Systems is one of the largest UK wholesalers of commercial refrigeration products. ²⁸
AHT Austria	Austria	AHT company of Austria is a major manufacturer of plug-in-type supermarket cabinets. The company is producing a 724 litres net freezer cabinet using 120 grams of R290. In 2007 the company designed a similar cabinet with fresh food compartment. ²⁹
Elstar	UK	Commercial drink cabinets for bars, restaurants and hotels.
George Barker & Co.	UK	Manufacturer of integral and indirect display cases mainly for food and beverages.
Interlevin Group	UK/Europe	Largest commercial cabinet wholesaler in Europe. Has produced hydrocarbon equipment since 1995.
Foster Refrigeration Ltd.	UK	Cabinet makers primarily for food industry. Operate worldwide with offices in UK, France, Germany, Italy, Austria, Spain. Has produced hydrocarbon equipment since 1996. Reports up to 15% energy savings with natural refrigerants in stand alone equipment.
Koxka (part of Ingersoll Rand companies)	Global	Outlets in North & South America, Europe, Asia, south East Asia. Has tested and launched in 2009 a CO ₂ compatible island display cabinets in supermarkets. The company is also developing CO ₂ based refrigeration systems. ³⁰
Recom Engineering	Australia	In 2008 the company was preparing to market Chinese produced Fujin Airconditioners with hydrocarbons in split system commercial applications.
blupura	Italy	R290 FONTEMAGNA water cooler: “well insulated ice-bank for high volume supply of cold, still and sparkling water, with a capacity of 15 litres per hour”. ³¹

¹⁹ http://www.appliancesdesign.com/CDA/Articles/Feature_Article/BNP_GUID_9-5-2006_A_1000000000000558309 Appliance Design, March 31, 2009

²⁰ 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.

²¹ TemaNord. 2007: “Potent Greenhouse Gases: Ways of Reducing Consumption and Emission of HFCs, PFCs 7 SF6”: report prepared for the Nordic Council of Ministers p. 27

²² TemaNord. 2007: “Potent Greenhouse Gases: Ways of Reducing Consumption and Emission of HFCs, PFCs 7 SF6”: report prepared for the Nordic Council of Ministers p. 29

²³ Ibid. P.29

²⁴ Ibid. P.29

²⁵ <http://www.hydrocarbons21.com/content/articles/2009-06-02-husky-to-launch-r290-cabinet.php>

²⁶ www.hydrocarbons21.com 2009-10-07

²⁷ ibid. 2010-03-04

²⁸ ibid. 2009-04-27

²⁹ TemaNord. 2007: “Potent Greenhouse Gases: Ways of Reducing Consumption and Emission of HFCs, PFCs 7 SF6”: report prepared for the Nordic Council of Ministers p. 31

³⁰ www.r744.com 2009-09-04

³¹ www.hydrocarbons21.com 2010-03-01

Table 4 Continued: Examples of companies producing and/or marketing commercial cooling equipment with natural refrigerants

COMPANY	COUNTRY	EQUIPMENT DETAILS
Sanyo Electric	Japan/Global	-Sanyo sells hydrocarbon domestic and commercial refrigerators. -Since 2004, Sanyo is selling CO ₂ vending machines, show cases and heat pumps. -The company reports that since 2005 almost all beverage companies in Japan are purchasing vending machines using natural refrigerants (CO ₂ or HC) and there are over 30,000 CO ₂ vending machines in the Japanese market today. -Sanyo produces a “hot and cold” CO ₂ vending machine that provides both hot and cold beverages in one machine. -Sanyo produces CO ₂ heat pump water heater under the brand name EcoCute. With a market volume of over 1 million units a year, this represents the largest market for CO ₂ refrigerants in the world. ³²
Verco	UK	Producer of commercial hydrocarbon based display cabinets, including open chill and glass door ranges. The company reports 15-20% energy savings. ³³
Embraco	Brasil/Global	Embraco produces CO ₂ compressors 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. ³⁴
HPH	Italy	Produces copper-based CO ₂ heat exchangers for industrial applications. ³⁵
Bitzer	Germany/Global	CO ₂ Compressor range for refrigeration, covering all temperature ranges and suitable to different types of systems, including cascade and transcritical systems. ³⁶
Lu-ve	Italy	CO ₂ gas coolers for large industrial installations. ³⁷

³² UNEP DTIE OzonAction : HCFC Help Centre : www.unep.fr/ozonaction/topics/hcfc_case-studies.htm :

“CO₂ Vending Machines “ by Sanyo Electric Co. Ltd

³³ www.ver.co.uk/

³⁴ www.r744.com/news/news_ida312.php Milan Expo features CO₂ Technology

³⁵ Ibid.

³⁶ Ibid.

³⁷ Ibid.

Table 5: Examples of compressor manufacturers using natural refrigerants

COMPANY	COUNTRY	EQUIPMENT DETAILS	
Bitzer	Germany/Global	Bitzer C1-C2 Octagon (sub-critical) and C3-C4 (trans-critical) - Bitzer has developed a semi-hermetic reciprocating compressor series for subcritical CO ₂ cascade applications with a maximum operating pressure of 42 bar.. The compressor series is suitable for a wide range of applications and various system configurations and has high energy efficiency	
Bock	Germany/UK	Series of CO ₂ Compressors – Transcritical and Subcritical options. Bock has developed a complete semihermetic, electrical driven compressor-series for transcritical R744 applications like industrial and commercial refrigeration or air-conditioning.	
Danfoss	Denmark/Global	Refrigerant HC	Full line of energy-optimised R600a compressors for all size applications including household appliances and commercial equipment. They are available in a range of voltage ratings. Some are designed specifically for tropical conditions or for direct current solar power or difficult electrical supply connections.
		CO ₂	CO ₂ Compressor, type TN - tailored for light commercial applications and heat pumps, the ultra-efficient new CO ₂ reciprocating compressor was created in response to increasing customer interest in alternative refrigerants, especially for bottle coolers, vending machines and heat pumps. The trans-critical system operations required meant Danfoss had to create not only a capable compressor, but also a new system control strategy and heat exchanger concept. Advantages: Low noise level, Environmentally friendly natural refrigerant, Low energy consumption, High cooling capacity, High COP, High product quality, Technology innovation, low running cost
Dorin	Italy	Series of Semi-Hermetic Piston CO ₂ Compressor. Dorin's SCC series is able to operate in sub-critical conditions. It is suitable for cascade/brine commercial and industrial refrigeration systems.	
Embraco	Brasil/Global	Embraco has developed a CO ₂ compressor series for light commercial applications and heat pumps. 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. ³⁸ All models are based on a new platform concept. Suitable for light commercial (vending machines, bottle coolers, ice cream freezers), ice machines, heat pumps, dryers. The design is a single stage reciprocating compressor for M/HBP (Medium/High Back Pressure).	
Emerson	Global	Produces a series of scroll compressors under the Copeland brand, for subcritical CO ₂ systems. The company also cooperates with Rivalco, an Italian supplier of commercial refrigeration equipment. ³⁹	
FRASCOLD	Italy	Semi-hermetic CO ₂ Compressor A 1.5 4 SK subcritical	
ixetic	Germany	R744 Compressor LAK. Suitable for all vehicle classes	
Johnson Controls		HPO/HPC high-pressure reciprocating CO ₂ compressor	
Obrist	Austria/Global	C99 CO ₂ Compressor : Variable displacement - externally controlled with a swept volume of 20ccm - 40ccm. It is designed to be a simple and reliable mechanism with a reduced number of parts.	
Sanyo	Japan/Global	- Rotary 2-Stage CO ₂ Compressor Sanyo has been producing hermetic rotary compressors for transcritical CO ₂ cycles since 2001. Main applications of its 2-stage compressor are heat pump water heaters and vending machines.	
Qianjiang Compressor	China	Founded in December 1994, Hangzhou Qianjiang Compressor Co. is specialized in the production of a range of hydrocarbon hermetic compressors for refrigerators, freezers and various household appliances.	

³⁸ www.r744.com/news/news_ida312.php Milan Expo features CO₂ Technology

³⁹ Ibid

C. Domestic & Commercial Air-Conditioning with Natural Refrigerants

The need for environmentally sustainable domestic and commercial air-conditioning technology is immediate. Demand in this cooling sector is exponentially growing in both industrialized and developing countries as we experience ever increasing temperatures around the world due to global warming.

There are numerous supermarkets, office buildings, public institutions and other commercial enterprises in various countries that have installed HCFC/HFC-free cooling technologies using natural refrigerants. Natural refrigerant based air-conditioning include carbon dioxide based coolers, hydrocarbon primary systems, 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 refrigerants such as ammonia and hydrocarbons are used as the primary refrigerants. Using secondary cooling significantly reduces the volume of primary refrigerant needed.

C.1 Hydrocarbons and carbon dioxide in commercial air-conditioning

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.

Table 6: Examples of hydrocarbon & CO2 air-conditioning in commercial and public buildings

COMPANY	COUNTRY	NOTES		
Earthcare Ltd.	UK	Earthcare has installed split system air conditioning using hydrocarbon refrigerants in a wide variety of settings, including:		
		Middlesex University	Great Ormond Street Children's Hospital -8 split systems installed	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
		South Downs Health Authority	Medway Health Authority	
ABN Amro	Netherlands	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°C 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°C and absorbs the heat siphoned off by the fans. ⁴⁰		

Table 7: Examples of commercial and public facilities equipped with hydrocarbon air-conditioning

FACILITIES USING HYDROCARBON AIR CONDITIONING	FACILITIES USING HYDROCARBON AIR CONDITIONING	FACILITIES USING HYDROCARBON AIR CONDITIONING
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)	Supermarket (Germany)	McDonald's – Philippines : conversion

⁴⁰ eurammon: Example provided by eurammon, the European initiative for natural refrigerants, www.eurammon.com/ß

Table 8: Examples of companies producing domestic & commercial air-conditioning equipment with natural refrigerants

COMPANY	COUNTRY	EQUIPMENT DETAIL			
De'Longhi	Italy	DeLonghi has been producing a range of hydrocarbon based domestic air-conditioners in the European market since 1995. The DeLonghi range includes a variety of portable units for varying room sizes. Portable air-conditioners can be moved to cool individual rooms. DeLonghi also produces split-system wall mounted units. Examples of De'Longhi Products			
		Type	Refrigerant	Cooling Capacity	Specifications
		Maestro CPA 30 AR-E290 Heat Pump Ready to Install Wall Mounted Air Conditioner	Propane (R290)	11.253 Btu/hr 3.3 Kw	-low noise level (36 db indoor, 45 dB outside), compressor outside -indoor unit weight 9Kg with size -outdoor unit weight 35Kg -remote control with 3 fan speeds -plugs into normal 13amp socket
		Pinguino PAC T 105 ECO Portable Split system air conditioner	R290	8,000 Btu/h	-dehumidifies while cooling, removing 25l/d of excess moisture -electronic humidistat -2 speed ventilation + quite mode -autofan function
		Pinguino PAC T06eco	R290	10,000 Btu/h	-energy efficiency class A --dehumidifies while cooling, removing 45l/d of excess moisture --electronic humidistat -Air Cleaning System removes particles --2 speed ventilation + quite mode
Elstar Company	UK	Pinguino PAC T90 ECO	R290		-energy efficiency rating A
Benson Air Conditioning	Australia	Since 1996, producer of a variety of hydrocarbon based split-air conditioners for both home and office use.			
		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	kW Cooling Size	Energy Star Rating	Hydrocarbon Charge
		Wall Mounted Split Systems	2.31/2.6	4.5/5.5	300 g
			3.4/3.4	4.5/4.5	
			5.1/5.6	4/3.5	
			6.3/6.6	4/4	
			8.2/8.4	4/3	
		Ducted Systems			
		Single Phase	10.3/10.4	3/3.5	
			12.3/12.1	5/4.5	
			16.3/16.2	3.5/4	
		Three phases	12.8/12.8	4.5/4.5	
			17.5/17.1	4/5	1.2 kg

Table 8 Continued: Examples of companies producing natural refrigerant domestic & commercial air-conditioning equipment					
COMPANY	COUNTRY	EQUIPMENT DETAIL			
Gree Electric Appliances	China	Gree, is the largest manufacturer of residential air-conditioners globally. In cooperation with GTZ ProKlima, Gree has developed a propane (R-290), highly efficient, domestic air-conditioner: COP of 3.52 to 3.55, energy efficiency 15% better than corresponding HCFC-22 unit, and total hydrocarbon charge less than 300 grams. R-290 units are cheaper to produce than R-22, R 407C and R 410A units because: R-290 uses narrower tubes in condenser and evaporator, R290 has better heat transfer properties, and lower pressure drop. Gree R-290 air-conditioners conform to all EU regulations, and refrigerant charge is lower than required by international standards (IEC 60335-2-40). The units include a refrigerant leak alarm system that turns off the compressor, keeps fans operating, and sets off an alarm and flashing light. Production to start in 2010.			
		Capacity Kw (Btu)	COP w/w	Charge gram	Max noise Inside Db
					Max noise Outside Db
		2.7 (9K)	3.55	265	38
		3.2 (11K)	3.54	310	41
		3.5 (12K)	3.52	330	41
COP rating is better than the “A” rating of the EU efficiency labeling for air-conditioners					
Godrej & Boyce	India	In cooperation with the German Development Agency, GTZ ProKlima, Godrej & Boyce is converting its line of HCFC air-conditioning systems to hydrocarbons. The production is to start in 2011.			
	Conversion project	This project has drawn the interest of three other Indian manufacturers as hydrocarbon air-conditioners may achieve higher energy star ratings.			
Sanyo	Japan/Global	* Since 2001 Sanyo has been selling CO ₂ heat pump/water heater in the Japanese market. * Since 2004, Sanyo has been selling CO ₂ heat pump/water heater in Nordic markets * Since 2004, Sanyo is selling CO ₂ vending machines and show cases * CO ₂ compressors for heat pumps, vending machines, show cases			
York (Johnson Controls)	Denmark/Global	York 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.			
Recom Engineering	Australia	In 2008 the company was preparing to market Chinese produced Fujin Airconditioners with hydrocarbons in split system commercial applications.			
MAYEKAWA	Japan	Developed a central air-conditioning and hot water supply system using hydrocarbon zeotropic blend of isobutane and propane. The “system uses air and water as both the heat sources and heat sink to provide cooling, heating and hot water production”. ⁴¹			
Frigadon	Sweden	Frigadon has developed a range of hydrocarbon packaged air-conditioners using R1270 (Propylene). The range of chillers covers capacities between 29 to 208 kW at +7°C flow temperature and 15.6 kW at -8 °C flow temperature. Low temperature chillers up to 88kW at -31°C are also available. All units come with complete controls and electrics, as well as built in hydraulic kit with inverter drive circulation pump. Reference Frigadon installations are in the UK and Ireland with companies such as Sainsbury’s, COOP Bank, British Land, Cooplands Bakery, Nsetle, Dunnes Stores, Braehead Foods, BP, and Welcome Break Motorway Services. ⁴²			

⁴¹ www.r744.com 2010-02-25

⁴² www.srs-comp.com/index.html

C2. Conversion of HCFC-22 air-conditioning installations to hydrocarbons

It is widely accepted that propane and other hydrocarbons are the optimal alternative, nearly drop-in replacements for HCFC-22. Companies like **Ecozone** of the Netherlands, **Energy Resources Group** of Australia, **Nat Energy Resources Private Limited** of Singapore, **Maple Edge Sendirian Berhad** in Malaysia, **APL ASIA Co** in Thailand, as well as **Econergy Engineering Services Ltd** and **Rexham Engineering Services Ltd.** in Jamaica have completed numerous conversions of R-22 installations to hydrocarbons with significant energy savings. These conversions of used equipment demonstrate that hydrocarbons can be safely applied, and should be an incentive to equipment manufacturers to produce new air conditioning units with propane and other hydrocarbons.

The advantage of converting to hydrocarbon refrigerant is that it is environmentally friendly and little or no changes need to be made to the retrofitted air conditioning units.

C2.a Conversion project at the University of West Indies, Mona Campus: Econergy Engineering Services in cooperation with **Rexham Engineering** as a sub contractor converted nearly 4,000 air-conditioning units from HCFC-22 to R-290 on the Mona Campus of the University of West Indies, Jamaica. These included window, mini-split and central air-conditioning units. The energy reductions due to the superior efficiency of propane, average between 15 to 20% per unit. In addition, the hydrocarbon units require less maintenance and repair. These two factors combined results in very significant cost benefits to the university.

- There have been numerous other conversions, in both commercial and private residential settings, to hydrocarbons completed in Jamaica. Examples include:
- Petroleum Corporation of Jamaica** where 140 ton chiller was converted for 2 years before replacement
 - Lascelles DeMercado** a large privately owned distributive company had all their 40 units converted to HC including mini splits and central units
 - University of Technology Refrigeration Lab** where all the demonstration models have been converted to hydrocarbons

Table 9: Partial list of conversions from HCFC 22 to hydrocarbons by Energy Resources Group of Australia (ERG) and Nat Energy Resources Private Limited of Singapore (NER)

Country	Installation Site	Type of Chiller	Energy Savings	Installer
Singapore	Far East Square Shopping Mall	York 200TR Water-cooled Reciprocal Chiller	16%	NER
	Defence Science & Technology Agency	Carrier 1hp Air-cooled split unit	16%	ERG
	Dapenso Building	Carrier 21TR Water-cooled Packaged Unit	32%	NER
	Watson's Stores	Daikin Air-cooled Split Unit	24%	NER
	The Moomba Restaurant, Boat Quay	McQuay 8hp Air-cooled split unit	16%	ERG
	Panasonic Refrigeration	20 hp Mitsubishi water-cooled package unit	26%	NER
	Summit Building	20 hp Hitachi water-cooled package unit	20%	ERG
	Kato Spring	60 hp Carrier water-cooled package unit	20%	NER
	ATI	53 hp Daikin VRV2 split-unit	17%	NER
	Panasonic Semiconductor	50 hp Daikin water cooled package unit	15%	NER
	SignPost	5 hp Daikin air-cooled split unit	17%	NER
	Herbal Science	5 kw Bitzer cold room	19%	NER
	Orchard Hotel	3 hp Tecumseh cold room	19%	NER
	Ngee Ann Polytechnic	Air cooled split unit (demo)	19%	NER
	Hitachi Chemical	23.5 hp water-cooled package unit (demo)	13%	NER
	National University-Eusoff Hall	2.8 hp air-cooled split unit (demo)	17%	NER
	Singapore Food Industries	25 hp Bitzer cold room (demo)	16%	NER
	Singapore Food Industries	25 hp Bitzer cold room (demo)	16%	NER
	Panasonic Electronics devices	18.5 hp Hitachi air-cooled package unit (demo)	13%	NER
	GSK Beecham Pharmaceuticals	5 hp Daikin air-cooled split unit	15%	NER
	NUS Temasek Hall	3 hp Sanyo air-cooled split unit (demo)	19%	NER
	Juron Shipyard	11 hp McQuay air-cooled split unit (demo)	12%	NER
	Borneo Motors	11 hp Carrier air-cooled split unit (demo)	13%	NER
	Ceva Freight	150 tonR York recip chiller (demo)	17%	NER
	Certis Cisco	10 hp Carrier air-cooled split unit (demo)	14%	NER
Malaysia	7-eleven Stores Kuala Lumpur	Topaire Air-cooled Split Unit	24%	ERG
	Flairis Kota Tinggi	Water-cooled Packaged Unit	19%	ERG
	Nichicon Bangi	Topaire Water-cooled Packaged Unit	20%	ERG
	Sumiden Electronics Shah Alam	Topaire Air-cooled Split Unit	22%	ERG
	Hosiden Electronics Bangi	Air-cooled Split Unit	25%	ERG
	Alps Electric Nilai	Dunham-Bush Water-cooled Packaged Unit	17%	ERG
	Panasonic AVC Network Shah Alam	Air-cooled Split Unit	19%	ERG
	Venture Technocom System Tebrau II, Johor	65-100 hp Dunham-Bush water-cooled packaged unit	23%	NER
	Sumitomo Electric Interconnect	1-30 hp York, National & Topaire air-cooled, split-unit & water-cooled package unit	21%	NER
	Panasonic Communication Senai Johor	National 20hp Water-cooled Packaged	20%	ERG
	Celestica Electronics Tampoi Johor	Topaires 3 x 80TR Water-cooled Packaged	24%	ERG
	Menara Ansar, Johor	Carrier 23TR Water-cooled Packaged	13%	ERG

Table 9 Continued: Partial list of conversions from HCFCs to hydrocarbons by Energy Resources Group of Australia (ERG) and Nat Energy Resources Private Limited of Singapore (NER)				
Country	Installation Site	Type of Chiller	Energy Savings	Installer
Malaysia	Bangunan PharmaCARE KL	Topaires 26TR Air-cooled Packaged	23%	ERG
	Sumitomo Electronics Tebrau II Johor	York 32TR Water-cooled Packaged	21%	ERG
	Taiko Electronics Senai, Johor	York 21TR Water-cooled Packaged	20%	ERG
	GG Circuits Industries Tampoi Johor	Carrier 35TR Water-cooled Packaged	14%	ERG
	YKJ Industries Kulai Johor	Acson 4TR Air-cooled Split Unit	27%	ERG
	Tru-Tech Electronics Ulu Tiram Johor	York 20TR Air-cooled Packaged	19%	ERG
	Matsushita Electric Company Shah Alam	Carrier 35TR Water-cooled Packaged	15%	ERG
	Menara AmFinance KL	York 21TR Water-cooled Packaged	16%	ERG
	Li Tat Mfg Masai Johor	York 17TR Air-cooled Ducted Type Split Unit	29%	ERG
	OYL HQ (R&D Lab)	New 3TR split units	27%	ERG
	UiTM Shah Alam Campus	Hitachi screw chiller	19.7%	ERG
	Damansara Realty	Carrier 10TR Packaged units	32%	ERG
	Pantai Medical Centre Bangsar	York 80TR Heat Recovery Unit	24%	ERG
	Pantai Medical Centre Bangsar	York Air-cooled Chiller Packaged	18%	ERG
	Lam Wah Ee Hospital Penag	Carrier Water-cooled Packaged	20%	ERG
	Elecan SemiConductor Penang	Air-cooled Packaged	14.8%	ERG
	Comfort Engineering Puchong	Carrier Air-cooled Packaged	18.5%	ERG
	Cekap Rea Johor	National Air-cooled Split Unit	16.7%	ERG
	Nichicon (M) Sdn BHD (Bangl, Selangor)	10-30 hp Dunham-Bush & Topair water-cooled packaged unit	21%	NER
Malaysia	Shinko Electronics Shah Alam, Selangor	25-36 hp Dunham-Bush water –cooled packaged unit	16%	NER
	Beyonics Precision Machining	280 tonR Dunham-Bush air-cooled chiller unit	11%	NER
	Koa Denko	35-50 hp Carrier water-cooledpackaged unit	18%	NER
	Panasonic Refrigeration Devices Cheng, Melaska	5-20 hp National & Panasonic air-cooled, split unit & water –cooled packaged unit	15%	NER
	Tsuritani Bt Berendam, Melaka	1-15 hp Topair, National, Fujitsu & York air-cooled, split-unit & water-cooled packaged unit	17%	NER
	Jusco Melaka Shopping Centre Ayer Keroh, Melaka	75-95 hp Carrier water-cooled packaged unit	19%	NER
	Sumiden Electronics Materials Shah Alam, Selangor	1-30 hp York, Carrier water-cooled packaged unit	22%	NER
	Flairis Sdn Bhd Kota Tinggi, Johor	10-40 hp York, Carrier water-cooled packaged unit	19%	NER
	TSB Industries, Johor	40 hp York air-cooled split unit	14%	NER
	Tiong Nam Logistic Solutions, Johor	2 hp Acson air-cooled split unit	13%	NER
	Hitachi Cable, Johor	25 hp Dunham-Bush water-cooled packaged unit	20%	NER
	Panasonic AVC Networks, Johor	1-60 hp Carrier Dunham-Bush air-cooled, split unit & water cooled packaged unit	21%	NER
	Digi Telecommunications, Selangor	12,5 hp Trane air-cooled split unit	21%	NER
	IDS Manufacturing, Selangor	30 hp Carrier air-cooled split unit	13%	NER
	Panasonic Compressor, Selangor	4-72 hp York & National air-cooled, split unit & water-cooled packaged unit	16%	NER
Thailand	Carrier HQ Building	Carrier 150TR reciprocal chiller	14%	ERG
	Two 7-11 stores	split unit and walk-in-freezer	20%	ERG
Philippines				ERG
	Gaisano Country Mall	50tr Hitachi Screw Type Compressor	16%	ERG
	Park Square One (Ayala Mall)	7.5tr Frascold Semi - Hermetic Reciprocating Compressor	12%	ERG
	Delsa Chemicals Office	5tr Maneurop Hermetic Reciprocating Compressor	14%	ERG
	McDonalds Restaurant	7.5tr Maneurop Scroll Type Compressor	12%	ERG
	Legenda Hotel	2tr Matsushita Rotary Type Compressor	19%	ERG
	Federal Express (Fedex)	7tr Copeland Hermetic Reciprocating Compressor	21%	ERG
	Iglesia ni Cristo Church	3tr Copeland Scroll Type Compressor	15%	ERG
	INARP Research Inc.	2tr Matsushita Rotary Compressor	12%	ERG
	Building Care Corporation	5tr Copeland Hermetic Reciprocating Compressor	20%	ERG
Indonesia - Jakarta	Mandarin Restaurant	40tr Century Screw Type Compressor	17%	ERG
	Alfamart 649 stores	air-cooled split units	25%	ERG
	ITC Mangga Dua	208 tr Carrier reciprocal chillers	34.7%	ERG
	JW Marriott Hotel	132 tr York reciprocal chillers	25%	ERG
	Supermal Karawaci	60 tr Hitachi screw AHU	30%	ERG
	Mulia Hotel	Copematic chiller	13.3%	ERG
	Sol Elite Marabella Hotel	1.5 tr Sanyo split unit	24.4%	ERG
	Maspion Plaza	150 tr York reciprocal chiller	15%	ERG
	Kondominium Simpruk Teras	10 tr Fair packaged unit	22%	ERG
	Mal Kelapa Gading	200 tr Carrier reciprocal chillers	28%	ERG
	Darmawangsa Square	2 tr General split unit	24%	ERG

Table 9 Continued: Partial list of conversions from HCFCs to hydrocarbons by Energy Resources Group of Australia (ERG) and Nat Energy Resources Private Limited of Singapore (NER)				
Country	Installation Site	Type of Chiller	Energy Savings	Installer
Indonesia Jakarta	Siloam Gleneagles Hospital	1 tr Mitsubishi split unit	45%	ERG
	Yayasan Pendidikan Permai	1 tr Gree split unit	22%	ERG
Indonesia - Bali	Maya Ubud Resort & Spa	n/a	41%	ERG
	Sahid Jaya Hotel	n/a	51%	ERG
	Ritz Carlton Hotel	n/a	28%	ERG
	Kartika Plaza Beach Hotel	n/a	55%	ERG
Indonesia - Lombok	Sahid Jaya Hotel	n/a	72%	ERG
	Oberoi Hotel	n/a	18%	ERG
	Novotel Hotel	n/a	39%	ERG
	Lombok Raya Hotel	n/a	27%	ERG
	Sheraton Senggigi Hotel	n/a	53%	ERG
	Senggigi Beach Hotel	n/a	36%	ERG
	Jayakarta Hotel	n/a	25%	ERG
	Intan Lombok Hotel	n/a	21%	ERG
	Holiday Inn Hotel	n/a	20%	ERG

Table 10: Examples of conversion projects from fluorocarbons to natural refrigerants carried out by GTZ ProKlima		
Country	Technology Conversion	Notes
SouthAfrica	From HCFC-22 to ammonia	The German Government Development Agency (GTZ ProKlima) together with the South African Government are converting two stores, one in Cape Town and one in Johannesburg from HCFC-22 to cascade systems with ammonia as the primary refrigerant and glycol-water solution circulating inside the stores.
Mauritius	CFC-12 and CFC-11 to ammonia	The German Government Development Agency (GTZ ProKlima) together with the Ministry of Environment of Mauritius are converting the air-conditioning of two government buildings. Existing CFC-12 and CFC-11 chillers are to be replaced with ammonia chillers. The project is designed to demonstrate the feasibility and enhanced energy efficiency of ammonia chillers in tropical climates. The project will provide technical and safety training to engineers and service technicians. ⁴³
Swaziland	HFC-134a & HFC-404a to hydrocarbons	The German Government Development Agency (GTZ ProKlima) working with the refrigeration equipment manufacturer Palfridge will convert the entire production of domestic and commercial refrigeration appliances from fluorocarbons to hydrocarbons. This is the first demonstration of hydrocarbon technology in the Southern African region. ⁴⁴

D. AMMONIA IN AIR-CONDITIONING & COMMERICAL REFRIGERATION

D.1 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.

Table 11: 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
	Illum 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
Germany	SAS Building (Aarhuz)	Airline Office Building
	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

⁴³ ibid. 2009-10-13
⁴⁴ GTZ ProKlima 2009 Fact sheet, www.gtz.de/proklima

Table 11 Continued: Examples of Ammonia Air-Conditioning in Commercial Enterprises		
COUNTRY	COMPANY	TYPE OF ENTERPRISE
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	University
	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

D.2 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.

D.3 Industrial Use of Ammonia Cooling: Ammonia is widely used in a variety of industrial cooling application.

Table 12: Examples of recent developments in ammonia technology and industrial applications of ammonia in refrigeration and freezing: ⁴⁵	
COMPANY	EQUIPMENT DETAILS
Grasso GmbH	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 Dresden + Bremen	Kältetechnik Dresden + 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°C to 7°C. Kältetechnik Dresden + 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°C are directly supplied with ammonia. An ethylene glycol cycle with a flow temperature of -12°C 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°C.

⁴⁵ eurammon: Examples provided by eurammon, the European initiative for natural refrigerants, www.eurammon.com/B

Table 12 Continued : Examples of recent developments in ammonia technology and industrial applications of ammonia in refrigeration and freezing

COMPANY	EQUIPMENT DETAILS
Dresen + Bremen	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°C and 11°C. The process refrigeration circuit uses cold water, while the air-conditioning system works with a propylene glycol circuit.
Axima Refrigeration France	Danone dairy produce in France: Danone, a producer of fresh dairy products headquartered in Paris, operates a plant for manufacturing yoghurt and cottage cheese in F��rri��res 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°C. 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.
Johnson Control Systems	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%).
KWN Engineering	Zipf brewery in Austria: The Zipf brewery, a Brau Union ��sterreich 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 G��ntner . A 110 m�� silo with a refrigeration capacity of 2,800 kW was added to serve as an ice bank.
Star Refrigeration	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.
Star Refrigeration	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°C to six air coolers in the cold store. It also supplies carbon dioxide as a volatile secondary refrigerant at -5°C 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.
KWN Engineering-Gesellschaft	Recheis Teigwaren GmbH pasta 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�� cascade was additionally installed for the deep-freeze storehouse and the spiral freezer and cooler.
Roche	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�� chiller plant building. In Ireland, a similar replacement reduces Roche's CO�� emission by 575 tonnes annually. In Germany, the company is using a mixture of ammonia, propane and CO��.

E. DESICCANT, EVAPORATIVE AND ABSORPTION COOLING

Dessicant, evaporative and absorption cooling technologies offer alternatives to typical vapour compression systems in refrigeration and air conditioning.

E.1 Desiccant Cooling

Desiccant cooling systems are basically open cycle systems, using water as refrigerant in direct contact with air. The thermally driven cooling cycle is a combination of evaporative cooling with air dehumidification by a desiccant, i.e. a hygroscopic material. For this purpose, liquid or solid materials can be employed. The term ‘open’ is used to indicate that the refrigerant is discarded from the system after providing the cooling effect and new refrigerant is supplied in its place in an open-ended loop. Therefore only water is possible as refrigerant with direct contact to the surrounding air.⁴⁶

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 industry⁴⁷.

Table 13: Examples of Dessicant Cooling in the United States

TYPE OF FACILITY	NAME & LOCATION OF FACILITY	EQUIPMENT SUPPLIER
Supermarket	Super Rite Foods, Inc. Baltimore, MD	
Supermarket	Cub Foods, Atlanta Georgia	
Supermarket	ShopRite, Newton, New Jersey	
Supermarket	First National Supermarket, Windsor Locks, Connecticut (33 stores)	
Supermarket	Shaw's Supermarkets, Seabrooke New Hampshire	
Supermarket	Harris Teeter Stores, Charlotte, North Carolina	
Supermarket	Baker's Supermarkets, Omaha, Nebraska	
Supermarket	Big Bear Supermarkets, Westerville Ohio	
Supermarket	H.E.B. Supermarkets, San Antonio, Texas	
Mega Store	Wal-Mart Stores Benton, AK (Season's 4)	Munters
Mega Store	Wal-Mart Stores (various locations nationwide)	Munters
Department Store	JC Penny Department Store, White Plains, NY	Engelhard/ICC
Restaurant	Burger King, Tampa, FL	Advanced Thermal Technologies
Restaurant	Denny's Restaurant, Clearwater, FL	Advanced Thermal Technologies
Housing	Ft. McNair Commissary, Wash. DC	Engelhard/ICC
Housing	Ft. Campbell Commissary, Ft. Campbell, KY	Engelhard/ICC
Medical Center	Willis-Knighton Medical Center, Shreveport, LA	Munters
Hospital	Northeast Baptist Hospital, San Antonio, TX	Munters
Care Facility	Jewish Home for the Elderly, Fairfield, CT	Robur
Hospital	University Hospital, Augusta, GA	SEMCO
College	The Medical College of Georgia, Augusta, GA	SEMCO
Theme Park	Walt Disney World Swan, Orlando, FL	Munters
Hotel	Park Hyatt Hotel, Wash. DC	Englehard/ICC
Clothing Manufacturer	Liz Claiborne Inc. Montgomery, AL	Englehard/ICC
Pharmaceutical	Powers Pharmaceutical Co. Brockton, MA	Munters
Housing	Nowlin Residence, Minneapolis, MN	Comfort Solution

⁴⁶ www.solair-project.eu

⁴⁷ <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.

E.2 Evaporative Cooling

Evaporative water coolers use heat in ambient air to evaporate water, which in turn cools the surrounding air. An evaporative cooler produces effective cooling by combining a natural process - water evaporation - with a simple, reliable air-moving system. Fresh outside air is pulled through moist pads where it is cooled by evaporation and circulated through a house or building by a large blower. As this happens, the temperature of the outside air can be lowered as much as 30 degrees.⁴⁸ Sweating is a form of evaporative cooling of the body.

Evaporative cooling is 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.⁴⁹

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.

Table 14: Examples of Evaporative Cooling Installations in the United States

FACILITY	FACILITY
America West Airlines Technical Support Facility (Phoenix AZ)	Intersil/GE Office Building (Cupertino CA)
Golden Hill Office Complex (Denver, CO)	Camelback Hospital (Scottsdale, AZ)
Colorado Springs School District, Colorado Springs, CO (multiple schools)	Cherry Creek School Districts, Aurora, CO (multiple schools)
Vacaville State Prison, Vacaville, CA	Anaconda Copper Laboratory (Tucson, AZ)
US Postal Service Bulk Mail Facility (Denver, CO)	

E.3 Absorption cooling

Absorption 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, Greece⁵⁰.

The examples below are coded by the type of absorption system installed. Where only the manufacturer’s name is indicated the building uses a single-effect absorption chiller and where “2x” is indicated a double-effect absorption chiller is used. In either case, the refrigerant is water and the absorber is lithium bromide. Most of the installations noted use natural gas-fired chillers, some use high pressure steam.

Table 15: Examples of Absorption Air-Conditioning Installations in the United States

TYPE OF FACILITY	NAME & LOCATION OF FACILITY	EQUIPMENT SUPPLIER
Commercial/Retail/Office	Reliance Federal Savings, Garden City, NY	Carrier-2x
Bank	Canadian Imperial bank of Commerce, Toronto, Ont	Carrier-2x n
Commercial/Retail/Office	Toyota Motor Sales USA, Torrance, CA	McQuay-2x
Commercial/Retail/Office	Oklahoma Natural Gas Co. Oklahoma City, OK	McQuay-2x
Commercial/Retail/Office	Ecology and Environment Offices, Buffalo, NY	Trane
Commercial/Retail/Office	Owensboro National Bank, Owensboro, KY	Robur
Commercial/Retail/Office	Yankee Gas Services Co., Stonington, CT	Robur
Commercial/Retail/Office	Union Central Life Insurance, Cincinnati, OH	Trane-2x
Commercial/Retail/Office	AT&T, St. Louis, Mo	York-2x
Commercial/Retail/Office	Merck & Co. Pharmaceuticals Headquarters, Readington NJ	York-2x
Commercial/Retail/Office	National Audobon Society, New York, NY	York-2x
Commercial/Retail/Office	US Air, Laguardia International Airport Terminal, New York, NY	York -2x
Commercial/Retail/Office	Pratt & Whitney, East Hartford, CT	Carrier
Educational Institution	Illinois Mathematical and Science Academy, Aurora, IL	Carrier
Educational Institution	Brandies University, Waltham, MA	Carrier-2x
Educational Institution	Texas A&M University, College Station, Texas	Carrier-2x
Educational Institution	Doane College, Crete, NE	McQuay-2x

⁴⁸ www.consumerenergycenter.org
⁴⁹ 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
⁵⁰ http://esttp.org/cms/upload/pdf/070202_4_EUSEW_Henning.pdf. Hans-Martin Henning, Presentation for Solar Energy Week,

Table 15 Continued: Examples of Absorption Air-Conditioning Installations in the United States

TYPE OF FACILITY	NAME & LOCATION OF FACILITY	EQUIPMENT SUPPLIER
Educational Institution	University of Toronto, Toronto, Ont.	McQuay-2x
Educational Institution	Dixon University Center, Harrisburg, PA	McQuay
Educational Institution	Oak Hill School for the Blind, Hartford, CT	Robur
Educational Institution	Estrella Mountain Community College, Phoenix, AZ	Trane
Educational Institution	Union Community College, Elizabeth, NJ	Trane
Educational Institution	Viterbo College, LaCrosse, WI	Trane-2x
Educational Institution	Northbrook Junior H.S., Northbrook, IL	York
Educational Institution	Winston Campus School, Palatine, IL	York-2z
Educational Institution	The Learning enter, Queens, NY	York-2x
Educational Institution	Walter and Lois Curtis School, Allen, TX	York-2x
Educational Institution	Rockwall H.S., Rockwall, TX	York-2x
Government Buildings	City of Mesquite, Recreation Center, Mesquite, TX	Yazaki
Government Buildings	Federal Energy Regulatory Commission HQ (FERC) Wash. DC	Trane-2x
Government Buildings	Cook County Dept. of Corrections, Chicago, IL	Trane
Government Buildings	US Courthouse and Federal Building, Phoenix, AZ	York-2x
Government Buildings	Aurora Municipal Justice Center, Aurora, CO	York-2x
Government Buildings	State of Illinois Building, Chicago, Il	York-2x
Government Buildings	Department of Employment and Training, Boston, MA	York-2x
Government Buildings	The Ohio Statehouse, Columbus, OH	York-2x
Hospitals & Health Centers	Resurrection Medical Center, Chicago, IL	Carrier
Hospitals & Health Centers	Sherman Hospital, Elgin, IL	Carrier
Hospitals & Health Centers	Little Company of Mary Hospital, Evergreen Park, IL	Carrier
Hospitals & Health Centers	Loyola Medical Center, Maywood, IL	Carrier
Hospitals & Health Centers	Jamaica Hospital Medical Center, Queens, NY	Carrier
Hospitals & Health Centers	Claremont Manor, Claremont, CA	McQuay
Hospitals & Health Centers	Scripps Clinic, San Diego, CA	York
Hospitals & Health Centers	St. Joseph Medical Center, Wichita, KS	McQuay-2x
Hospitals & Health Centers	Our Lady of Mercy Medical Center, Bronx, NY	McQuay
Hospitals & Health Centers	Rapid City Regional Hospital, Rapid City, SD	McQuay
Hospitals & Health Centers	Alexian Brothers Medical Facility, Elk Grove, IL	Trane-2x
Hospitals & Health Centers	BroMenn Regional Medical Center, Normal, IL	Trane-2x
Hospitals & Health Centers	St. Joseph Medical Center, Joliet, I	Trane-2x
Hospitals & Health Centers	Anne Arundel Medical Center, Annapolis, MD	Trane
Hospitals & Health Centers	Dept. Of Veteran's Affairs Hospital, Bronx, NY	Trane
Hospitals & Health Centers	Montefiore Medical Center, Bronx, NY	Trane-2x
Hospitals & Health Centers	Craven Regional Medical Center, New Bern, NC	Trane-2x
Hospitals & Health Centers	St. Luke's Hospital, Maumee, OH	Trane-2x
Hospitals & Health Centers	The Toledo Hospital, Toledo, OH	Trane
Hospitals & Health Centers	Baptist Medical Center, Little Rock, AK	York-2x
Hospitals & Health Centers	Copely Hospital, Aurora, IL	York-2x
Hospitals & Health Centers	St. Francis Hospital, Evanston, IL	York-2x
Hotel	Guest Quarters Suites, Chicago, IL	York -2x
Office Building	Loctite Corp. Rocky Hill, CT	Trane Co-generation
Office Building	Nestle Quality Assurance Laboratory, Dublin, OH	York-2x
Office Building	Nestle, New Lehigh Valley, PA	York-2x
Residential	Apartment Building, Chicago, IL	York-2x
Theatre	IMAX Theater, Dallas, TX	Yazaki
Airport	Norfolk International Airport, Norfolk, VA	McQuay-2x
Zoo	Jungle World, Bronx, NY	York
Convention Center	Pennsylvania Convention Center, Philadelphia, PA	York

F. 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.

Table 16: Examples of co-generation installations

COMPANY	DETAILS
Banque Generale du Luxembourg	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	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.

G. 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.”⁵¹

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.”⁵²

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%.⁵³ 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.”⁵⁴

Benefits of District Cooling include:

Better quality of cooling	Capital cost elimination	Decrease in sound pollution
Maximum cost effectiveness	Space saving	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, such as non-electric and hybrid (electric and non-electric) chiller plants, cogeneration and trigeneration, and Thermal Energy Storage.”⁵⁵

District Cooling Systems exist in many parts of the world. There are about 100 District Cooling systems in Europe⁵⁶. In the U.S. there are approximately 2,000 district cooling systems, which cool 33,000 commercial buildings, plus numerous schools, institutions, and residences.⁵⁷ They have also been installed in the Middle East and in Singapore.

Table 17: Examples of District Cooling Installations

INSTALLATION	LOCATION	SYSTEM DETAILS
Cornell University	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. ⁵⁸
City of Toronto	Ontario, Canada	Delivers 50,000 tons of DCS cooling by pumping cold waters from Lake Ontario into a heat exchanger. ⁵⁹
Helsinki Energy	Finland	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. ⁶⁰
National Central Cooling Co.	United Arab Emirates	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.” ⁶¹

⁵¹ National Climate Change Committee, Singapore : www.nccc.gov.sg/building/dcs.shtm

⁵² www.helsinginenergia.fi/kaukojaahdytys/en/os4_1.html

⁵³ www.helsinginenergia.fi/kaukojaahdytys/en/os4_1.html

⁵⁴ www.tabreed.com/districtCoolingDistrictCoolingBenefits.aspx

⁵⁵ www.coolsolutionsco.com/district_cooling.htm

⁵⁶ www.euroheat.org/

⁵⁷ 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

⁵⁸ Information provided by Mr. John Andrepont of Cool Solutions www.coolsolutions.com

⁵⁹ Ibid.

⁶⁰ www.helsinginenergia.fi/kaukojaahdytys/en/os3_1.html

⁶¹ www.tabreed.com/aboutus.aspx

Table 17 Continued: Examples of District Cooling Installations

Palm District Cooling Co.	Dubai	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. ⁶²
Baltimore Aircoil Co.	USA/Global	Baltimore Aircoil Company has completed more than 2500 installations worldwide of high efficiency [34°F (1°C) supply water] ice storage 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). ⁶³
Cool Solutions	Illinois, USA	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, Oklahoma (18,500 tons), Orange County, Florida (21,000 tons), Orlando, Florida (5,700 tons), Washington, D.C. (10,000 tons). ⁶⁴
Business Park & Naval Base	Singapore	District Cooling Systems can be found in the Changi Business Park and Changi Naval Base in Singapore.

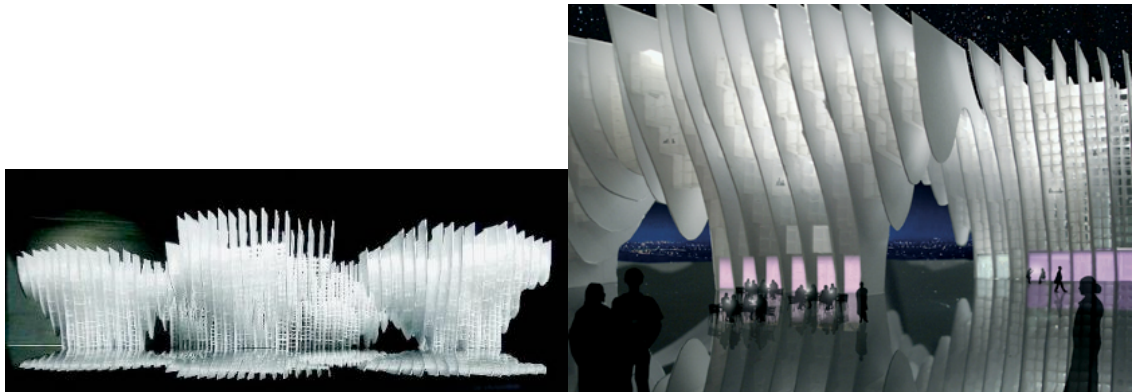
⁶² www.palmdistrictcooling.com

⁶³ www.baltimoreaircoil.com/english/products/ice/district/index.html

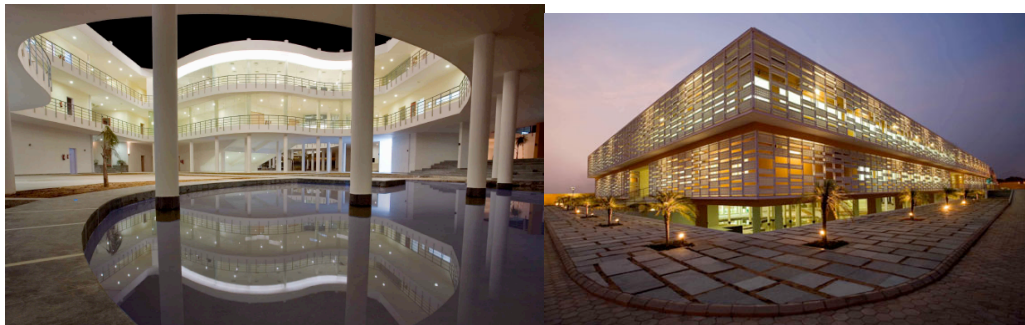
⁶⁴ www.coolsolutionsco.com/district_cooling.htm

H. **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 the Pearl Academy of Fashion (shown below) in Jaipur where classrooms are cooled to around 25 degrees Centigrade without air-conditioners while ambient temperatures are nearly double outside.⁶⁵



Office building in Seattle, Washington, USA designed by Weber & Thomson requires no air-conditioning. The building has green-tinted glass shades (or sunglasses) that shield windows from heat, while still allowing light into the building. Heat-reflective coating on the windows also reduce temperatures. The 40,000 square foot structure has a central courtyard, which allows cross breezes to enter all parts of the building, and allows more natural light into the building.⁶⁶

⁶⁵ Vancouver Sun: Reuters report, March 12, 2008 and www.metaefficient.com

⁶⁶ www.metaefficient.com

I. MOBILE AIR CONDITIONING AND TRANSPORT COOLING

I.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.

The U.S. Environmental Protection Agency found that vehicles are the largest source of HFC emissions. They account for 56% of annual total HFC emissions in the US. Air conditioning accounts for over 7% of a vehicle's total greenhouse gas emissions: 4.3% from direct HFC emissions through leaks, and 3.1% from CO₂ emissions related to energy use. The US Department of Energy's Energy Information Agency website states 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."⁶⁷

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 CO₂ equivalent emissions of five new power plants, while the HFC-134a leakage from automobiles sold in Japan in 1995 will contribute the CO₂ equivalent of ten power plants, or approximately 16 million tonnes of CO₂. 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 CO₂ emissions by the year 2020.⁶⁸

1.2 Hydrocarbon in MACs

Conversion of CFC and HFC MACs to Hydrocarbons: Hydrocarbons offer reliable alternatives to HFCs in mobile air-conditioning (MACs). Though at the present there are no hydrocarbon based mobile air-conditioners on the world market, an estimated 7 million cars have been converted, outside of regulatory framework, from CFCs and HFCs to hydrocarbons. Such routine drop-in conversion are taking place in Australia, United States, Canada, Philippines and elsewhere.

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. 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. The same study also documented extensive use of hydrocarbons in Australian vehicles.

Since hydrocarbons are flammable, conversion from HFCs to hydrocarbons must follow standard safety procedures.

Direct Systems MAC Cooling: Hydrocarbons could be safely used in direct systems in new MAC equipment specifically designed for their usage. This would encompass keeping hydrocarbons away from spark and heat sources, automatic switch offs in case of leaks, leak detection devices and ventilation systems.

Secondary Loop Hydrocarbon 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 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."⁶⁹

⁶⁷ . <http://www.eia.doe.gov/oiaf/1605/archive/gg98rpt/halocarbons.html>

⁶⁸ 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.

⁶⁹ 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

I.2 Carbon Dioxide in MACs

The energy efficiency benefits of CO₂ systems have been known for several years. Extensive measurements carried out at the University of Illinois in 1999 showed that CO₂ MACs have at least 30% lower TEWI than HFC systems.⁷⁰ Other studies reporting on trials comparing CO₂ prototypes against state-of-the R134a system in real situations indicate that the COP of the CO₂ system was typically 25% greater than that of the R134a system.⁷¹ 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 R744 MAC concerning environmental performance, costs and future potential. Namely, that R744 MAC produced up to 40% less emissions in hot climates (India and China) than R134a.⁷²

In addition to their environmental benefits, CO₂ systems provide a servicing cost benefit as there is no need to recover and recycle the refrigerant at the end of life.⁷³

Table 18: Examples of Hydrocarbon, CO₂ and Evaporative Cooling Bus Air-Conditioning

TECHNOLOGY	COMPANY	NOTES
Hydrocarbons with Evaporative Cooling	TransAdelaide Bus Company	TransAdelaide Bus Company in Australia installed hydrocarbon air conditioning in the drivers' compartment, while the passengers compartment is cooled by dessicant cooling.
Carbon Dioxide	Konvekta	Konvekta, the leading German manufacturer of thermo 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 R-134a, R744 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 R-134a. After more than 6,000 operating hours of the CO2 prototypes, Konvekta is now preparing for the serial production of its R744 cooling unit. ⁷⁴
Evaporative Cooling	US and Australian companies	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.

⁷⁰ (Yin, 1999) need full ref
⁷¹ 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_gfnave.html?research/text/80331_e.htm)
⁷² http://www.r744.com/news/news_ida095.php
⁷³ Multisectorial Initiative on Potent Industrial Greenhouse Gases (MPIIGGs) newsletter, 2004: www.mipiggs.org
⁷⁴ http://www.r744.com/news/news_ida319.php

I.3 HFC-1234yf (HFOs) in MACs

Due to rising concerns regarding the high global warming HFCs currently on the market, the chemical industry is now rolling out a new generation of low GWP HFC products, called HFOs. or "hydrofluoro-olefins".

HFC-1234yf is slated to be the first HFO refrigerant to be marketed. It is to replace HFC-134a in mobile air-conditioning. Other HFO refrigerants are in the pipeline for various cooling applications. HFOs do not deplete the ozone layer and have low global warming potential, but there are significant environmental and human safety risks associated with these new substances.

Table 19: Environmental, Human Safety and Financial Concerns regarding HFC-1234yf (HFOs)

CONCERN	NOTES
Direct & Embedded GWP	The stated direct GWP of HFC-1234yf is 4. However the embedded GWP of any given substance also needs to be considered. For example, the embedded GWP of HFC-134a is 35 and that of CO ₂ is 0.5, when emissions during production, as well as energy use for extraction of raw materials, heat for reactions, and so on, are considered. The embedded GWP of HFC-1234yf is not yet reported.
HCFC ingredients	A key production ingredient of HFOs is HCFCs. This means that the production of HCFCs will need to be maintained in perpetuity to produce HFOs.
Trifluoroacetic Acid (TFA)	TFA is a by-product when most HFCs breakdown. HFC-1234yf produces 4 to 5 times more TFA than the same amount of HFC-134a. The concentration of TFA in fresh water bodies around the world could have dramatic effects on plants and animals and human health.
Toxic flammability	HFC-1234yf is flammable. When it burns, it releases hazardous substances such as hydrogen fluoride (HF). HF is very toxic and potentially lethal to humans in unventilated spaces. While the flammability of a substance is not an impediment for its use as a refrigerant, the toxic byproduct of a substance when it burns is of great concern to human safety.
Reduced efficiency	HFC-1234yf has been tested to be at least 10% less efficient than HFC-134a, the substance it is meant to replace. And HFC-134a is typically 7 to 10% less efficient than hydrocarbons.
Higher costs	HFC-1234yf is expected to be more than ten to twenty times more expensive than HFC-134a. High costs will provide incentives for service technicians to revert back to HFC-134a.

The vigorous promotion of this new generation of F-gases is delaying the large scale uptake of natural refrigerants, even though they are environmentally safe, technologically proven, relatively inexpensive and provide the long term solution to meeting our cooling needs.

J. FOAMS produced with natural foam blowing agents

Natural blowing agents such as pentane or CO2 can be used in all types of foam production. The technology has been successfully used by several large manufacturers for many years to produce high-quality products⁷⁵. As demand for foam rises, due in large part to improved insulation for housing and buildings, it is increasingly important that foam be manufactured without high-GWP refrigerants.

J.1 Rigid extruded polystyrene (XPS):

Extruded polystyrene is used as a rigid board stock, where its moisture resistance and strength make it suitable for below ground construction insulation, for example, in foundations and basement walls. Developed countries commonly use HFCs and developing countries are still primarily using HCFCs as blowing agents, but many alternatives are emerging and being increasingly used worldwide. Water based blowing agents and hydrocarbons are now commonly used.

Table 20: Examples of natural blowing agents in XPS foams

Company	Country	Blowing Agent	Application
Hamed Moussa	Egypt	propane	
Dow Chemical	USA	CO2	
BASF	Germany	CO2	

J.2 Flexible Foams

Compared to rigid foams, flexible foams can be deformed when exposed to pressure, a characteristic required, for example, in mattresses and other furniture. In the 1990s, new techniques were developed to produce flexible foam without CFCs, including Variable Pressure Foaming (VPF) which creates CO2-based foam from the reaction of isocyanate and water. No blowing agents are required in this process.

⁷⁵ See Proklima, Natural Foam Blowing Agents: Sustainable Ozone- and Climate-Friendly Alternatives to HCFCs. For more information: <http://www.gtz.de/de/dokumente/gtz2009-en-proklima-nat-blow-agents.pdf>

Flexible foams are often used for non-cooling products – like furniture, automotive applications, safety devices and noise insulation. Many manufacturers have already switched to this process. For example, in 1998 the Multilateral Fund helped fund the conversion of 4 companies in Argentina from CFC-12 to carbon dioxide based foam for mattresses, accounting for 90% of the Argentinean market.

Table 21: Examples of natural blowing agents in flexible foams

Company	Country	Blowing Agent	Application
Brdr.Foltmar	Denmark	CO2	
KBE	Denmark	CO2	
Danfoam	Denmark	CO2	
Urepol Oy	Finland	hydrocarbons	insulated steel-faced and flexible faced panels
Baxenden Scandinavia	Denmark	Isopentane	Flexible integral foam
Ecco/Bayer	Denmark/Germany	CO2	Flexible integral foam for shoe soles

J.2 Rigid PUR

A major cause for concern in the foam sector is the pending switch from HCFC-141b for Rigid Polyurethane (PUR) foam blowing to potent global warming gases such as HFC-245fa, HFC-365mfc or HFC-134a. However, this concern is unnecessary since there are natural blowing agents to replace HCFC-141b in most foaming applications. In 2005 hydrocarbons were expected to represent over 55% of global blowing agent usage.⁷⁶

Rigid polyurethane (PUR) insulating materials are closed-cell, rigid plastic foams that are available in many forms. Most often, this type of foam is used in construction, as in flexible-faced laminates, sandwich panels, slabstock or boardstock, spray foams and pipe insulation. It is also used in appliance insulation. Today hydrocarbons have become the most widely applied technology in the world for PU foams. Whereas it is sometimes reported that hydrocarbons do not have as good thermal performance as HFCs in foams, current technology has been optimized to the point where hydrocarbon foams now have performance equal to that of HFC-based foams⁷⁷.

J.2.a Appliances

Appliance insulation foam is used to insulate refrigeration appliances, hot water storage tanks and similar products. With the exception of the North American market, cyclopentane is the standard choice for the rigid PUR in domestic appliances and small commercial equipment.

Germany has been a leader in converting to cyclopentane in appliances, and has fully converted to this technology in domestic refrigerators. General Electric in the U.S. might soon be the first to enter the North American market with cyclopentane foam in new refrigerator-freezers set for production next year.

In the commercial sector, Electrificio in Brazil switched to cyclopentane based foam for refrigerated displays for chilled and frozen foods and cold stores for large supermarkets back in 1996.

J.2.b Flexible-face laminates

Flexible-faced laminates are used as insulating panels in the housing sector to insulate floors, saddle roofs or under floor heating systems. Until 2004, HCFC-141b was mainly used. Today, rigid PUR insulating panels for building construction are often foamed with pentane. In Germany, 90% of flexible laminates use pentane.

J.2.c Boardstock

Boardstock is mainly used as roof and wall insulation in commercial buildings, and companies are increasingly using pentane as a blowing agent in these panels. Currently, hydrocarbon foams are mainly used in developed countries, whereas developing countries are still using HCFCs.

J.2.d Sandwich panels

Sandwich panels usually have foam sandwiched between materials such as steel and aluminium, and are often used to insulate roofs and walls in industrial refrigerated warehouses and cold stores. Cyclopentane is now commonly used as a blowing agent in sandwich panels, and the process has been optimized to the point where the thermal insulation is better than that of most HFCs. By 2002, 4 of the 6 large panel foam manufactures in Argentina switched from CFC-11 to pentane as their foam blowing agent.

Two Danish companies, Nassau Doors and Windsor Door, produce industrial portals and doors with sandwich panels containing CO₂ blown polyurethane foam .

⁷⁶ IPCC (2005)
⁷⁷ UNEP Technology and Economic Assessment Panel. Task Force Decision XX/8 Report: Assessment of Alternatives to HCFCs and HFCs and Update of the Teap 2005 Supplement Report Data. 2009.

Table 22: Examples of Natural Foaming Agents in Construction Foams		
FOAMING AGENT	COMPANY (COUNTRY)	APPLICATION
Hydrocarbon Pentane	Atlas Roofing (USA) Firestone (USA) RMAX (USA) Johns Manville (USA)	Major US building insulation producing companies have shifted from HCFC-141b to using pentane. They have concluded that pentane is less costly and more sustainable than HFC-245fa or HFC-365 mfc
Hydrocarbon Pentane	Recticel (Belgium)	The largest manufacturer of PUR foams in Europe uses pentane for foam manufacturing.
Hydrocarbon Pentane	Bayer (Germany)	Producer of hydrocarbon construction foam.
Hydrocarbon Pentane	Efisol	Uses pentane for a variety of polyurethane foams.
Mechanical process CO ₂	Thanex (Denmark) ICI (UK) Liquid Polymers Group (UK) ResinaChemie (Germany) BASF (Germany) Nassau Doors (Denmark) Windsor Doors (Norway)	Uses a mechanical process for producing PUR insulating foam Using CO ₂ as blowing agent for PUR foams.

J.2.e Spray foams

Spray foams now increasingly use CO2, and the performance of this while not quite equivalent to HFCs and HCFCs it replaces, is still improving and already suitable for many applications.

J.2.f Pipe insulation

Pipe insulation can now be manufactured with cyclopentane, and has the same performance as HFC-365mfc, the common refrigerant used. 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). All four companies are now producing insulation using cyclopentane or other hydrocarbons. Two of the companies also produce CO₂-based pipes.

J.3 Alternatives to Foam

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 produces boardstock panels made out of cellulose. The panels are made out of recycled materials.

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.

CONCLUSION

There are many more examples around the world where natural working fluids (e.g ammonia, CO₂, 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.

GREENPEACE INTERNATIONAL

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APPENDIX A: EFFICIENCY OF HYRDOCARBON AND CO₂ TECHNOLOGIES IN COMPARISON WITH HCFCs AND HFCs

Contrary to the HFC industry’s claims, systems using natural refrigerants are often more energy efficient than those using HFCs. Of course there are many factors to be considered when comparing the efficiency of cooling equipment, but many studies have revealed that systems using natural refrigerants often display greater energy efficiency.

Table 23: Sample survey of studies comparing the efficiency of hydrocarbons and fluorocarbons

APPLICATION	REFERENCE	NOTES
Domestic refrigeration	Efficiency of hydrocarbons in domestic refrigeration	In 2005-2006 “the Danish Electricity Saving Trust conducted a campaign where 1000 DKK (approximately \$200 US) were given to customers buying “A++” refrigerators and freezers (the most energy efficient models in the European labeling specification).” Among the 78 different appliances approved for inclusion in the campaign, 100% were based on hydrocarbon technology. ⁷⁸
Residential air-conditioning	Efficiency of hydrocarbons in residential air-conditioning in comparison to HCFC-22	A 2007 comprehensive enquiry into the use of hydrocarbons in residential air-conditioning has shown an energy efficiency increase of up to 5.7% over R22. ⁷⁹ This is accompanied with a decrease in refrigerant charge of up to 55% due to the smaller density of hydrocarbons. ⁸⁰
Residential air-conditioning	DeLonghi	The Italian manufacturer De’ Longhi produces small AC systems using propane as refrigerant. The cooling capacity ranges from 500 to 3200 W and the refrigerant charge is 100–500 g. The systems are found to have 5–10% higher efficiency than with HFCs. ⁸¹
Refrigerants	Efficiency of new hydrocarbon blends	2008 studies with new hydrocarbon blends, such as R-433A ⁸² (30% propylene, 70% propane), and R-432A ⁸³ (80% propylene, 20% dimethylether) have shown increases in energy efficiency of up to 7.6% and 8.7% respectively (both these blends are ommercialized by Korean manufacturer MK Chemical).
Refrigerants	CoP comparison of HFC-245ca with hydrocarbons	A 2006 study comparing the coefficients of performance (CoP) for hydrocarbon mixtures and HFC-245ca in a spray evaporator found a 6% increase in CoP when the hydrocarbon mixture was used. ⁸⁴
Refrigerants	Survey of studies comparing CoPs of hydrocarbon and HFC refrigerants	A study analysed various papers to draw comparisons between hydrocarbons and F-gas refrigerants. They found that in 90% of the cases reviewed hydrocarbons offered higher CoPs than their F-gas counter parts, with an average improvement of 10% of the CoP. ⁸⁵
HCFC-22 replacements	Comparison of HFCs and hydrocarbons as replacements for HCFC-22	HFCs, compared with hydrocarbons, are seen as poor substitutes for HCFC-22 in heat pumps. “For example, the critical temperature of HFC-R410A is only 72°C, far less than for the previous generation HCFC-R22, which had a critical temperature of 96°C. However, propane, R290, has a critical temperature of 97°C, making it the ideal replacement for heat pump applications that would previously have used R22.” ⁸⁶
HCFC-22 replacements	R-22 installations Retrofitted with propane	Conversions of R-22 installation to propane typically report 15-20% energy savings. See Section C.2 page 10 of this report.
Air-conditioning	Comparison of hydrocarbons and fluorocarbons in compression refrigeration systems	In a 2008 study on a vapour compression refrigeration system (the most widely used method in refrigeration and air-conditioning today), a blend of R290 and R600a (propane and isobutane) gave an increase in energy efficiency of up to 25.1% at low temperatures (circa -18°C) and up to 17.4% at higher temperatures (circa +2°C). ⁸⁷ This was compared to CFC-12. R134a was even less efficient than R12.
Ice cream freezers	Unilever	By 2009 Unilever had placed over 400,000 hydrocarbon ice-cream coolers around the world, including South Africa, China, Europe, Brasil and the United States. These coolers contain approximately 100 grams of hydrocarbons, and have a 9% energy savings over their HFC counterparts. ⁸⁸

⁷⁸ TemaNord, 2007 : “Potent Greenhouse Gases: Ways of Reducing Consumption and Emission of HFCs, PFCs & SF6” : report prepared for the Nordic Council of Ministers

⁷⁹ Park K.J., Jung D “Thermodynamic performance of HCFC22 alternative refrigerants for residential air-conditioning applications”, Energy and Buildings (2007), 675-680

⁸⁰ Maclaine-cross I.M, Leonardi E, “Why do hydrocarbons save energy?” Australian AIRAH Journal 51 (1997) 33–37.

⁸¹ *Supra* no.1, private communication with Aloisi A., De’ Longhi, 2007

⁸² Park K.J. et al. “Performance of R433A for replacing HCFC22 used in residential air-conditioners and heat pumps” Applied Energy 85 (2008) 896–900

⁸³ Park K.J. et al. “Experimental performance of R432A to replace R22 in residential air-conditioners and heat pumps” Applied Thermal Engineering (2008)

⁸⁴ Tadros, A., J.W. Clark, I.L. Maclaine-Cross and E. Leonard, (2006) “Replacing fluorocarbons with hydrocarbon mixtures in centrifugal water chillers” Presented to 7th IIR Gustav Lorentzen Conference on Natural Working Fluids, Trondheim, Norway.

⁸⁵ D. Colbourne and K. O. Suen, (2000) “Assessment of Performance of Hydrocarbon Refrigerants”

⁸⁶ Cox, N., (2006) “Sustainable Cooling: Refrigerants Beyond the Crisis”, presented to the EU Commission, Brussels, Belgium

⁸⁷ Mani K, Selladurai V, ‘Experimental analysis of a new refrigerant mixture as drop-in replacement for CFC12 and HFC134a’, International Journal of Thermal Sciences (2008)

⁸⁸ <http://www.unilever.com/ourvalues/environment-society/case-studies/climate-change/hydrocarbon-ice-cream-cabinets.asp>

Table 23 Continued: Sample survey of studies comparing the efficiency of hydrocarbons and fluorocarbons

APPLICATION	REFERENCE	NOTES
Restaurant Equipment	McDonald's	In 2003 McDonald's opened, as a pilot project, the world's first HFC-free restaurant in Vejle, Denmark . The company reported that "according to TEWI calculation, during summertime (4 months) / wintertime (8 months) the emission (kgCO ₂) from the restaurant in Vejle were 19%/32% lower than the conventional [HFC based control] restaurant in Esbjerg. The company projected that the lifetime emissions from the Vejle restaurant cooled by natural refrigerants "will be approximately 27% lower." ⁸⁹
Commercial Food Refrigeration	Foster	This UK based company has been producing hydrocarbon based commercial refrigeration equipment since 1996. Reports up to 15% energy savings with natural refrigerants in stand alone equipment.
Supermarket	Waitrose	Waitrose Supermarket of UK has announced plans to only use hydrocarbons in all new refrigeration. Designed to EN 378, the company is using a hydrocarbon chilled water circuit (at 10° C) with water cooled condensing units in display cabinets. The company reports 20% energy savings.

Table 24: Sample comparison of efficiency of CO₂ cooling with that of fluorocarbons

APPLICATION	REFERENCE	NOTES
Mobile Air-conditioning	TEWI and LCCP studies comparing CO ₂ and R134a	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. ⁹⁰ Other studies reporting on trials comparing CO ₂ prototypes against state-of-the R134a system in real situations indicate that the COP of the CO ₂ system was typically 25% greater than that of the R134a system. ⁹¹ 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 R744 MAC concerning environmental performance, costs and future potential. Namely, that R744 MAC produced up to 40% less emissions in hot climates (India and China) than R134a. ⁹²
Vending Machines	Coca Cola	Coca Cola has developed a new, high efficiency, CO ₂ technology for vending machines. Energy savings with these units average 26%. According to CocaCola: "some of our suppliers achieved even better CO ₂ performance versus R134a under "D" conditions (40 degrees 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.
Vending Machines	Sanyo Electric	In 2004, Sanyo conducted field tests in Australia, comparing a CO ₂ vending machines with an existing HFC based machine. The CO ₂ system was optimized to replicate the operational factors of the HFC system. "The results showed "17% lower energy consumption by the CO ₂ system...compared to the R134a system during the summer season." ⁹³

⁸⁹ UNEP DTIE OzonAction : HCFC Help Centre : www.unep.fr/ozonaction/topics/hcfc_case-studies.htm : McDonalds': world's first free HFCs restaurant

⁹⁰ (Yin, 1999) need full ref

⁹¹ 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

⁹² http://www.r744.com/news/news_ida095.php

⁹³ UNEP DTIE OzonAction : HCFC Help Centre : www.unep.fr/ozonaction/topics/hcfc_case-studies.htm : "CO₂ Vending Machines " by Sanyo Electric Co. Ltd>

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