UNITED
NATIONS

EP

United Nations Environment Programme

Distr.
GENERAL

UNEP/OzL.Pro/ExCom/54/54/Add.1
1 April 2008

ORIGINAL: ENGLISH

EXECUTIVE COMMITTEE OF
THE MULTILATERAL FUND FOR THE
IMPLEMENTATION OF THE MONTREAL PROTOCOL
Fifty-fourth Meeting
Montreal, 7-11 April 2008

Addendum

PRELIMINARY DISCUSSION PAPER PROVIDING ANALYSIS ON ALL RELEVANT COST CONSIDERATIONS SURROUNDING THE FINANCING OF HCFC PHASE-OUT (DECISION 53/37 (I))

This addendum is being issued to:

- **Add** Annex IV as mentioned in para. 7 (c) of document UNEP/OzL.Pro/ExCom/54/54.

ANNEX IV

DETAILED ANALYSIS ON TECHNICAL AND COSTS ISSUES RELATED TO THE REFRIGERATION SECTOR

A. INTRODUCTION

1. Annex IV is meant to provide technical and cost considerations relevant when replacing HCFC-22 in the refrigeration and air-conditioning sector with alternatives, with support by the Multilateral Fund. HCFC-22 is by far the predominant HCFCs in the refrigeration and air-conditioning sector, with an estimated share of more than 97.2 per cent of the total HCFCs consumption (metric tonnes) in the refrigeration sector. Table 1 shows the estimated HCFCs consumption in the refrigeration and air-conditioning sector by substance.

Table 1: Estimated HCFCs consumption in the refrigeration and air-conditioning sector, by substance

Substance	**Consumption (metric tonnes)**	**Uses**	**Estimated consumption in the refrigeration sector**	
			(metric tonnes)	**(% of total)**
HCFC-22	247,200	Refrigeration, foam	217,610	97.2%
HCFC-123	3,700	Refrigeration	3,700	1.7%
HCFC-124	940	Refrigeration	940	0.4%
HCFC142b	31,230	Foam, refrigeration	1,640	0.7%

2. The Secretariat has assessed the use pattern of HCFCs in the refrigeration and air-conditioning sector. In Article 5 countries, HCFC-22 is in particular used for air conditioning and, to a somewhat smaller extent, for a wide range of applications subsumed under commercial refrigeration. There are a number of other HCFCs which feature in the refrigeration sector, in particular HCFC-123 in centrifugal chillers, and HCFC-124 and HCFC-142b in drop-in alternative refrigerants for CFC-12. Since it appears that there are no dedicated manufacturing capacities in Article 5 countries for products using these refrigerants, and since the quantities used in the servicing of refrigeration equipment are very small compared to HCFC-22, these HCFCs have not been further investigated in this paper.

3. There is insufficient consistent information available about the HCFC-22 use patterns in developing countries, in particular how much HCFC-22 consumption is associated with the different sub-sectors. Aside from issues related to the definition of sub-sectors, data which would allow an estimate is neither collected by the Fund Secretariat nor by the Ozone Secretariat, and is not available commercially or from associations. An estimate was attempted based on indicative market figures available for the trade in air-conditioning equipment in the year 2006. These figures suggest that the consumption in new air-conditioning systems might have amounted in the year 2006 to between 80,000 and 100,000 metric tonnes of HCFC-22. The

remaining consumption of about 130,000 metric tonnes might have been split approximately equally between commercial refrigeration manufacturing and service sectors.

4. This Annex will, after an introduction and a review of past experience, provide information on the different sub-sectors and some alternative technologies, before providing cost information and other considerations for the manufacturing and service sectors.

Experience

5. To date a total of 30,831.2 ODP tonnes of CFCs have been phased out from the domestic and commercial refrigeration sub-sectors through individual and umbrella projects, including 22,471.5 ODP tonnes of CFC-11 and 8,359.7 ODP tonnes of CFC-12. For some of the projects, HCFCs were used as alternatives to CFC. The refrigeration projects frequently had a component related to the insulation foam, where CFC-11 was often replaced by HCFC-141b.

6. Table 2 provides an overview of alternatives approved in Multilateral Fund conversion projects in the refrigeration manufacturing sectors, including domestic and commercial refrigeration.

Table 2: Alternative technologies in approved stand-alone Multilateral Fund refrigeration projects

Replacement	Projects	ODP tonnes phased out	%age total	ODP tonnes phased in
Refrigerant component				
Drop-in blend	5	137.0	1.6	2.52 (approx.)
HCFC-22	9	818.4	9.8	45.01
HFC-134a	439	6,188.9	74.1	0
HFC-152a	1	80.0	1.0	0
HFC-152a/HCFC-22	1	70.0	0.8	1.28 (approx.)
HFC-404a	2	0.6	0.0	0
Isobutane	22	983.3	11.8	0
Propane	1	11.5	0.1	0
R-401A	1	70.0	0.8	1.89
Total refrigerant component	481	8,359.7	100.0	50.7
Foam component				
Cyclopentane	120	14,260.9	63.5	0
HCFC-141b	336	8,210.6	36.5	903.17
Total foam component	456	22,471.5	100.0	903.17

7. In addition to projects in refrigeration manufacturing sectors, 42 projects for the conversion of CFC-12 compressors to alternative refrigerants in ten Article 5 Parties have been approved by the Executive Committee. Such compressor projects were supported on one hand in cases where the compressor was the technology-defining element in the production chain leading to CFC refrigeration equipment; this is often the case if small assemblers use compressors and other components to produce, frequently on site, refrigeration equipment. On the other hand these projects were supported when compression production was integrated with equipment production, in particular in the domestic refrigeration sector. In the particular case of China, the

Executive Committee agreed on a sector approach and funded the conversion of 24 compressor manufacturing enterprises to alternative refrigerants with an associated phase-out, on the understanding that the Government of China would not seek any assistance from the Multilateral Fund for the conversion of commercial refrigeration manufacturing plants. Of the 24 compressor projects in China, 18 were converted to HCFC-22 refrigerant with an associated phase-out of 361 ODP tonnes of CFC-12 (calculated phase-in: 19.86 ODP tonnes), and three were converted to HFC-134a with an associated phase-out of 253 ODP tonnes. The alternative refrigerant selected for the other 21 compressors projects were HFC-134a (18 projects), isobutane (two projects) and HCFC-22 (one project).

8. The total funding approved for stand alone training programmes for refrigeration service technicians and customs officers, recovery and recycling projects and RMPs in all Article 5 countries amounts to US $52.7 million (i.e., US $29.6 million for LVC countries and US $23.1 million for non-LVC countries). An additional US $235.0 million is associated with TPMPs for LVC countries and national/sectoral phase-out plans for non-LVC countries addressing the total remaining consumption of CFCs, mainly used in the refrigeration servicing sector[1] .

B. TECHNOLOGY

Characteristics of the Air-conditioning sub-sectors

General

9. Air-cooled air conditioners ranging in capacity from 2.0 to 700 kW are used in residential and commercial applications for cooling or heating (if combined with air-conditioning heat pumps), representing probably the largest sub-sector of HCFC-22 consumption in Article 5 countries. For the purpose of this document the sub-sector is further split between unitary equipment and chillers.

Unitary equipment

10. The majority of both the existing installed capacity and new production is of the unitary equipment type. Unitary air-conditioning equipment is a broad category of air-to-air air-conditioning systems, including:

(a) Room air conditioners (window-mounted, through-the-wall and mobile units). A unit has a capacity between 2 kW and 10.5 kW and contains between 0.5 and 2 kg of HCFC-22, with an average of 0.75 kg. These units are manufactured and charged typically in large plants with quality control and leak tests, leading to low leakage rates in the order of 2.0 to 3.0 per cent of the initial charge per year;

[1] Several national phase-out plans and a few TPMPs address small amounts of CFCs used in small foam and refrigeration manufacturing enterprises or small amounts of other ODSs, mainly CTC and/or TCA.

(b) Ductless split systems, both mini-splits for one room and larger systems, have usually multiple indoor evaporator/fan units connected to a single outdoor unit, 4 kW refrigerating capacity and above. These air conditioners have average HCFC-22 charge about 1.2 kg per system. These systems are normally produced in large manufacturing plants as well, with the associated quality control and leak tests. However, the systems are installed on-site using pre-charged lines and connectors, which lead to a higher average leak rate for these systems;

(c) Residential split ducted central air-conditioning systems and heat pumps consist of a condensing unit (compressor/heat exchanger) installed outside of conditioned space, that supplies refrigerant to one or more indoor heat exchangers installed within the building's air duct system. The refrigerating capacity of such systems is generally between 5 kW and 18 kW containing on average about 3.25 kg of HCFC-22 per system; and

(d) Packaged air-to-air systems and split systems for commercial air-conditioning, ranging in refrigerating capacity from 10 kW to more than 350 kW. Commercial rooftop air conditioners fall into this category. The average HCFC-22 charge is about 10.8 kg per system.

11. Representative leakage rates for the last three categories of split systems are in the literature mentioned to be 4-5 per cent of the nominal charge per year although anecdotal evidence suggests emissions as high as 15 per cent of the annual charge. The higher leak rates are related to the limitations of installation into existing buildings, including a higher number of connections.

Chillers

12. Chillers are compact refrigeration systems designed to cool down water or a brine for the purpose of air-conditioning or, less often, process cooling for manufacturing of goods or chemicals. The cool water or brine is distributed to the cooling equipment, in case of air-conditioning to heat exchangers distributed throughout a building. The refrigerating capacity ranges from 7 kW for water cooled chillers equipped with reciprocating and scroll compressors to chillers of about 700 kW and above, which are usually built as centrifugal chillers. Centrifugal chillers, which use a turbo-compressor and have been only rarely built using HCFC-22 as refrigerant, are not considered in this document. HCFC-22 has been used for manufacturing virtually all non-centrifugal chillers with screw, scroll and reciprocating compressors. While chillers based on R134a, HFC-407C and R 410A have started penetrating the market in non-Article 5 countries, users in Article 5 countries continue to be supplied with HCFC-22 chillers. Since chillers are often manufactured and quality controlled in large plants, and since their operating conditions tend to be very favourable, chillers can last for several decades before being in need to be replaced. While the HCFC-22 needs for service and repair are normally small per system, the large number of chillers and their long lifetime prolongs the dependence of countries on HCFC-22.

Characteristics of the commercial refrigeration sub-sector

13. Commercial refrigeration systems are a broad category of refrigeration systems. The sub-sector covers refrigerated equipment found in retail food sector such as supermarkets, convenience stores, restaurants, and other food service establishments. In the context of the Multilateral Fund, every commercial use of refrigeration systems which did not belong to another sub-sector (industrial, chiller, air-conditioning, transport, domestic) was subsumed under commercial refrigeration. Commercial refrigeration systems in Article 5 countries are often locally or regionally made products, catering to the specific need of one or a small group of users. In other cases, products like water fountains, chest or bottle coolers might be produced in medium, sometimes even large quantities as commercial refrigeration products. Commercial refrigeration equipment can be sub-divided into the following broad categories: stand-alone equipment, condensing units and centralized refrigeration systems.

14. The category of stand-alone equipment consists of serial products where all the components are integrated, produced and typically charged in manufacturing facilities and plants. It includes, e.g., commercial-sized refrigerators and freezers, water coolers, chest coolers, ice cream freezers, ice making machines, display cabinets, and hotel mini bars. Currently, HCFC-22 is still widely used as the refrigerant in manufacturing of stand-alone equipment in Article 5 countries. Along with R 134a and HFC-404, in recent years, hydrocarbons (isobutane and propane) have been introduced to the market for stand-alone units up to 1 kW capacity. The small filling and the opportunity to undertake leak testing and quality control at the manufacturers premises leads to typically reasonable or better quality of production and only relatively small leakage.

15. CFC-12 had been the most important refrigerant in stand-alone equipment in Article 5 countries. The conversion of manufacturing of stand-alone equipment in those countries to non-CFC technology has been addressed through approval of more that 260 investment projects and activities by the Executive Committee. The Secretariat has used its experience gained in reviewing the above projects in assessments of possible incremental costs related to the manufacturing of HCFC-22 – based equipment.

16. Condensing units are the main component of split refrigeration systems. Such a unit, comprising a compressor, a condenser, and a receiver holding the refrigerant in the liquid phase, is typically being pre-manufactured in medium to large quantities, but not charged. On site, such a unit is located typically in a way that the condenser can be cooled by outside air, and is connected via refrigerant-containing tubing to the cooling equipment. This may include one or several display cabinets and walk-in cold rooms or other refrigeration uses. Several condensing units can be installed side-by-side in a machinery room to cool different equipment, reaching up to 50 kW refrigeration capacity. The use of several condensing units is less energy efficient than the installation of one specifically designed centralized system, while the installation of centralized systems requires more expensive compressors of larger capacity, and more design and engineering know-how.

17. The use of condensing units is a preferred solution for many end-users in Article 5 countries because these systems are technically simple and easy to install and maintain, locally available and attractive in terms of low initial investments. HCFC-22 remains the refrigerant of choice in manufacturing condensing units in Article 5 countries. Condensing units

are suitable for HFC refrigerants, while the use of hydrocarbons is problematic because of the distance between condensing unit and equipment, which increases refrigerant filling and requires certain site-specific safety considerations.

18. Centralized refrigeration systems are similar to condensing units, only that one unit with normally several compressors serves a large number of parallel sets of cooling equipment, often on several different temperature levels. Such systems are used in particular in medium and larger super markets, to lower energy consumption and increase redundancy. In a configuration similar to the one used for HCFC-22, they are suitable for HFC refrigerants, and the use of CO_2 is under development for moderate climatic conditions. In comparison to condensing units, centralized refrigeration systems have challenging leak testing and large refrigerant filling. These make centralized refrigeration systems in their standard configuration no suitable candidate for hydrocarbon use.

19. There are alternative configurations for centralized systems which allow using refrigerants such as hydrocarbons or ammonia. One can for example use for refrigerating applications (at around 4°C) a cold brine, which reduces the amount of refrigerant and contains it in the machine room, greatly simplifying leakage and safety issues and allowing use of hydrocarbons or ammonia, but on the expense of higher investment cost, increased complexity, and an increase in energy consumption of 5 per cent to 10 per cent. It should be noted that anecdotal evidence suggests that in several industrialized countries, the overall greenhouse emissions of such a system using e.g. a hydrocarbon would still be lower than that of a standard configuration HFC-404A system, which is the commonly used non-HCFCs refrigerant for centralized systems in non-Article 5 countries. For deep-freezing applications (i.e. for keeping goods at -18°C) it is possible to use CO_2 in a cascade system, where another refrigerant provides cooling at around 4°C, and a CO_2 cycle is used as a booster to supply deep-freezing temperatures. The necessary know how for these systems is complex and so far not wide spread, although a number of systems are running in Europe. It appears doubtful if the necessary know how and infrastructure will be available in Article 5 countries in time for any significant contribution of these technologies to the 2013 and 2015 compliance requirements.

Characteristics of other sectors

20. Decision 31/45 defined the sub-sector for assembly, installation and charging of the refrigeration equipment. This sub-sector covers activities related to installation of condensing units and centralised systems as well as the predominant part of the industrial and transport refrigeration sectors, and establishes eligibility exclusively for capital incremental costs. The guidelines contain an element relating to a cut-off date of July 1995, and might therefore be in need of endorsement should a separate cut-off date be established.

21. Since there are no indications for significant use of HCFC-22 in the industrial and transport refrigeration sectors, this document does not introduce the related sectors further.

Alternative refrigerants to HCFC-22 and suitability considerations

Introduction

22. HCFC-22 has been used since the 1930s as a refrigerant, predominantly for air-conditioning systems. It remains in this sector by far the predominantly used technology world wide until to date. When the consumption of CFC, in particular CFC-12 was reduced and subsequently phased out under the Montreal Protocol, HCFC-22 was one of several possible replacement technologies.

23. This document considers a number of alternatives for the replacements of HCFC-22, namely several HFC, ammonia, carbon dioxide and hydrocarbons. The list has been assembled using the criteria of commercial and widespread use or large scale prototype use in the field in sub-sectors with a significant use of HCFC-22 as refrigerant. Further, the criteria for technical suitability specified in the next paragraph had to be fulfilled. A number of technically possible alternatives have therefore not been included in this document because they did not fulfil these criteria. It should also be noted that these assessments, despite representing best efforts and based on broad exchange with experts, still are the result of a subjective judgement; that is similarly true for the selection of whether a refrigerant is suitable for a given application or not. The Secretariat is prepared to extend the lists of alternatives or reassess the applicability if requested by the Executive Committee.

24. To establish the technical suitability of the different alternatives, the following aspects were taken into account:

(a) Likely availability of the refrigerant in the mid- and long term;

(b) Suitability for the temperatures for air-conditioning, refrigerating (around 4°C) and deep-freezing (-18 °C) of food;

(c) Available experience with the use of the refrigerants in actual applications;

(d) Influence of the technology onto equipment cost;

(e) Necessary requirements towards manufacturers and service companies;

(f) Safety related aspects;

(g) Energy consumption;

(h) Environmental aspects;

(i) Capability to be used at high ambient temperatures; and

(j) Status of development and current availability of technology making the refrigerant a candidate to contribute to achieving compliance with the 2013 and 2015 HCFCs consumption reduction requirements.

25. Table 3 provides an overview of some important characteristics related to HCFC-22 and its replacements.

Table 3: Properties of zero-ODP refrigerants and HCFC-22

Refrigerant	Type and/or name	GWP (100a)[2]	Safety classification[3]	Temperature-glide [K]	Condensing temperature at 26 bar [°C][4]
HCFC-22	*HCFCs*	*1810*	*A 1*	*0*	*63*
HFC-134a	HFC	1430	A 1	0	80
HC-290	Propane (HC)	20	A 3	0	70
HFC-404A	HFC-blend	3900	A 1	0,7	55
HFC-407C	HFC-blend	1800	A 1	7,4	58
HFC-410	HFC-blend	2100	A 1	0	43
R-417A	HFC-HC blend (Drop-in)	2300	A 1	5,6	68
R-422A	HFC-HC blend (Drop-in)	3100	A 1	2,5	56
R-422D	HFC-HC blend (Drop-in)	2700	A 1	4,5	62
HFC-507A	HFC-blend	4000	A 1	0	54
HC-600a	Isobutane (HC)	20	A 3	0	114
R-717	Ammonia	0	B 2	0	60
R-744	CO_2	1	A 1	0	-11
HC-1270	Propylene (HC)	20	A 3	0	61

Alternative refrigerants

26. For refrigeration and air-conditioning, presently the most widely used HFC options for HCFC-22 replacement in new equipment are HFC-134a, HFC-404A, HFC-407C, and HFC-410A. All these HFC and HFC blends are non-toxic, non-flammable and require the use of different compressor lubricants as compared to HCFC-22 to ensure satisfactory operation and durability; typically, these are synthetic polyolester-based (POE) oils. These lubricants have a higher cost than those used for HCFC-22, and need more careful handling to avoid contamination. The related issues (training and equipment needs) are known from the introduction of HFC-134a into the market as part of the CFC-12 phase-out efforts. Due to incompatibility with the oils used for HCFC-22, the need for a new lubricant also implies that these refrigerants cannot be used as drop-ins for existing equipment, but would require a

[2] According to the 2006 Report of the Refrigeration, Air-conditioning and Heat Pumps Technical Options Committee

[3] Toxicity:
Class A: refrigerants for which toxicity has not been identified at concentrations less than or equal to 400 ppm; Class B: refrigerants for which there is evidence of toxicity at concentrations below 400 ppm.
Flammability: Class 1: no flame propagation; Class 2: lower flammability limit of more than 0.10 kg/m3 and heat of combustion of less than 19 kJ/kg; Class 3: lower flammability limit of less than or equal to 0.10 kg/m3 or a heat of combustion greater than or equal to 19 kJ/kg

[4] Common upper working pressure for refrigeration equipment

complex retrofit procedure in order to be used in existing equipment. In comparison to HCFC-22, the HFC and HFC blends mentioned have the following characteristics:

27. HFC-134a is globally available, and can be used for refrigerating at around 4°C in commercial refrigeration, in small units (up to 2 kW to 4 kW capacity) for commercial refrigeration / deep-freezing and for smaller room air conditioners, as well as where previously CFC-12 has been used and where HCFC-22 has been only an interim solution. There is considerable practical experience in its application in Article 5 countries. In comparison to HFC blends and propane / propylene, HFC-134a requires larger compressors and larger tubing. The energy consumption is similar to HCFC-22 equipment, while the direct greenhouse gas emissions are expected to be lower due to lower GWP, lower pressures and lower risk of pressure oscillations in the tubing[5]. HFC-134a is suitable for very high ambient temperatures.

28. HFC-404A and HFC-R507A are very similar and can therefore be assessed jointly. Both refrigerants have been used in non-Article 5 supermarkets for a number of years and are well suited for refrigerating and deep-freezing applications, in particular in condensing units and centralized commercial plants. While the medium term availability is certain because of the needs of the installed equipment base and the continuous use of these refrigerants, the long term availability depends strongly on the policies regarding industrial greenhouse gas emissions since both substances have a particularly high GWP. The costs of assembly of centralized commercial plants using R404A/R507 are similar to HCFC-22, while the refrigerant costs are higher. In order to use these refrigerants in on-site installations, experience to reduce pressure oscillations in high pressure tubing are meaningful. The energy consumption is slightly higher than with HCFC-22 equipment for refrigerating, slightly lower for deep-freezing. The high GWP leads to a higher emission of greenhouse gases as compared to HCFC-22. In case of very high ambient temperatures the equipment might have to be built for higher than standard working pressures.

29. HFC-407C is a refrigerant with a significant temperature glide and is therefore not suitable for equipment with a large refrigerant filling or accumulators, such as condensing units, centralized systems and certain chillers; in other applications, the temperature glide still needs to be taken into consideration in design and service. It is widely used in Europe as HCFC-22 replacement in air-conditioning equipment, and will therefore likely be available in the medium to long term. The costs of manufacturing HFC-407C equipment are very similar to the costs for HCFC-22 equipment except for the higher costs for refrigerant and refrigeration oil. In case of very high ambient temperatures the equipment might have to be built for higher than standard working pressures. The GWPs of HCFC-22 and HFC-407C are similar, therefore the overall emissions of greenhouse gases attributed to the equipment should remain similar.

30. HFC-410A is a commercially available refrigerant blend used in newly designed air-conditioning equipment, which has been commercially available within the capacity range of 2 kW to 175 kW from major manufacturers for a number of years. It seems likely that this

[5] Pressure oscillations on the high pressure side of refrigeration equipment depend on the outdoor temperature and can lead to vibrations, resulting potentially in material fatigue of the tubing and subsequent ruptures. These might take place after a relatively short operating time of some days, and would lead to the emission of the full refrigerant charge. As compared to HCFC-22, the risk increases with HFC-404A and HFC-507A, and increases further with HFC-410A. A trial and error approach to avoid these risks can be used for equipment produced in a series. For on-site installations, experience, training and marksmanship of the technician are the factors reducing the risk of such ruptures.

refrigerant will be available in the medium to long term. The high refrigerating capacity permits often small, more compact components to be used. A typical hermitic or semi-hermetic compressor designed for HCFC-22 cannot be used with HFC-410A, which might also be true for some other components in the system. The costs information provided for HFC-410A systems suggests a cost increase for the components, which might also include costs for design upgrades independent of the refrigerant. While the higher operating pressure can be addressed in the design of new systems, this refrigerant is inappropriate for retrofit of existing HCFC-22 systems. Units using HFC-410A have demonstrated higher energy efficiency than HCFC-22 units; it should be noted that this might include the effort of optimisation of components and upgrading of technology as part of the development of newly designed systems. HFC-410A is not universally accepted for use in high ambient temperatures due to its elevated pressures and relatively low critical point, which might lead to lower energy efficiency at such temperatures as compared to e.g. HFC-134a or HC-290.

31. HFC-417A, HFC-422A and HFC- 422D are relatively recent developments based on HFC mixtures with some isobutane, allowing drop-in conversion of existing HCFC-22 refrigeration equipment, using the same refrigeration oil. They are unlikely to find widespread use for new refrigeration equipment due to certain compromises regarding their overall properties and performance. These HFC refrigerants have a temperature glide and are therefore not suitable for equipment with large refrigerant filling or accumulators, such as condensing units, centralized systems and certain chillers. HFC-422A can be used for refrigerating and deep-freezing, HFC-417A and HFC-422D for refrigerating. The practical experiences with all three refrigerants are so far very limited. Experience of service technicians with refrigerants with temperature glide is necessary. In case of very high ambient temperatures the equipment might have to be built for higher than standard working pressures; the GWPs of all three refrigerants is higher than that of HCFC-22. It should be noted that despite wide encouragement, drop-in replacements for CFC-12 have established themselves only in very few markets in Article 5 countries, therefore the situation with drop-in replacements for HCFC-22 might well be similar. Consequently, the short-term availability for specific markets is not known, and the availability of these fluids beyond the mid-term remains unlikely due to their transitory nature.

32. Ammonia, NH3 (R717) has been used for more than 100 years as refrigerant, and is common in many countries in large industrial and food processing applications. It is toxic, but usually easily avoidable because of its stench well below the toxicity level. Due to their capacity and specific characteristics, these applications fall under the sub-sector “industrial refrigeration”, not commercial refrigeration. Since industrial refrigeration has not systematically used HCFC-22 as refrigerant, it is not further assessed as part of this paper, although it should be noted that the use in industrial refrigeration ensures the refrigerants long-term availability. Ammonia as refrigerant is suitable for refrigerating, less well for deep-freezing. It can be used in large centralized commercial refrigeration plants and in large chillers; the refrigerant is less well suited for deep-freezing temperatures. The installation costs of ammonia plants are significantly higher than for HCFCs or HFC plants, since parts, assembly and the necessary brine cycles and require different and more complex manufacturing skills, in particular welding. According to experts, there is some possibility that ammonia could extend from the industrial refrigeration sector into chillers or the commercial refrigeration sector, but only if the technology has already a strong technician base in the country. Despite the good energetic performance characteristics for most except very hot climates, the need to use brines increases energy consumption as

compare do HCFC-22 direct cooling applications. Since ammonia has a GWP of 0, the overall greenhouse gas emissions are usually more favourable than with HCFC-22.

33. HC-290 (Propane), HC-1270 (propene) and HC-600a (isobutane) are hydrocarbons and have in several aspects similar characteristics. Isobutane is suitable for small stand-alone refrigerating units, HC-290 and HC-1270 both for refrigerating as well as for deep-freezing applications in stand alone units up to about 1 kW refrigeration capacity and in centralized supermarket systems using brines. While as such very good refrigerants, the flammability of these substances is a problem which requires additional efforts in design, manufacturing and service of the equipment. The flammability leads to a tendency to use hydrocarbons only in small or equipment with relatively small refrigerant filling, or in systems where a brine is being used. While for the production of stand-alone equipment the safety requires only limited efforts and therefore the associated costs are also limited, centralized equipment leads to substantially higher investment costs for the brine cycle and the safety equipment, and requires a high degree of experience with flammable substances. The energy consumption for stand-alone units tends to be similar or lower than with HCFC-22, while for the centralized systems the brine cycle leads to increased energy demand as compared to HCFC-22. The overall climate impact is likely to be lower than with HCFC-22 equipment, in case of stand-alone equipment significantly lower. HC-290 is also well suited for high ambient temperatures.

34. Carbon dioxide, CO_2, as refrigerant has been used in a limited number of centralised commercial systems, also in food processing, and on a medium scale in light commercial applications (vending machines) and for hot water heat pumps. It is suitable both for refrigerating and deep freezing applications. For deep freezing the refrigerant can be used in a cascade system, limiting the working pressures of the equipment. Should the condenser of CO_2 equipment be cooled with ambient air, then working pressures will be above 75 bar and different components will be needed. For outdoor temperatures above 20°C, the performance of CO_2 equipment is lower than HCFC-22 equipment, and the performance tends to decrease more rapidly with increasing temperatures, which can lead to more than a doubling of energy consumption as compared to HCFC-22 at high ambient temperatures. Since the working principle differs significantly from that of other refrigerants, and because of the very high working pressures about six times above those for HCFC-22, manufacturing and service has to undergo major changes in equipment, practices and know-how in order to use this technology. A component supply base does not currently exist for manufacturing CO_2-based air-conditioning systems, and therefore the costs for CO_2 equipment other than cascade systems is presently significantly higher than for HFC or HCFCs systems; this is expected to change should there be market acceptance, subsequently leading to high quantities of standardized components. Cascade systems might have similar costs than HCFC-22 systems.

35. Due to the low performance in warm climates for air cooled systems, the limited applicability for centralized cascade systems in Article 5 countries, and the only slowly emerging market for components, CO_2 as a replacement for HCFC-22 has been seen as unlikely to contribute to reaching the 2013 and 2015 compliance requirements and has therefore not been considered in the costing part of the document.

Suitability overview

36. It appears that at least for the initial stage of HCFCs phase-out, the above presented alternatives will represent all of the potential choices. Developments are reported for some low GWP refrigerants with no flammability and low toxicity, but presently it remains unclear when these will be available and if they will actually eventually be commercialised. CO_2 is under development as an alternative refrigerant for the last 20 years, and is presently used in demonstration trials. It remains unclear if and under which circumstances it will be used on a larger scale, since it has fundamentally different design, component and, in particular, service characteristics than other refrigerants. The analysis of the above factors will lead to the selection of the appropriate technology by the different manufacturers in Article 5 countries. Table 4 shows an indication for the suitability of alternative refrigerants for widespread use in new equipment in Article 5 countries; the use of the transitory drop-in refrigerants HFC-417A, HFC-422A and HFC- 422D has not been considered since they are meant to be used in existing, not new equipment. The typical applications for HC-1270 and HC-600a do presently not appear to be manufactured on a significant scale in Article 5 countries; therefore they are not further shown in Table 4.

Table 4: Suitability of alternative refrigerants for widespread use in new equipment in Article 5 countries

	Suitability of alternative refrigerants for widespread use in new equipment (indicative only)						
	HFC-134a	HFC-404A / 507C	HFC-407C	HFC-410A	HC-290	R717 Ammonia	CO_2
Commercial							
Commercial stand-alone	+	+	o	o	+	-	o/-
Commercial condensing	+	+	+	o	o	-	-
Commercial centralized systems	+	+	+	o	o/-	o/-	-
Commercial deep freezing - one stage	-	+	-	o	-	-	-
Commercial deep freezing - two stage/supermarket	-	+	-	o	o	o	o
Air-conditioning							
Room A/C	o	-	+	+	+	-	-
Ductless split systems	o	-	+	+	o/-	-	-
Residential split ducted central air-conditioning systems	o	-	+	+	o/-	-	-
Packaged air-to-air systems and split systems for commercial air-conditioning	-	-	+	+	-	-	-
Small chiller (scroll)	-	-	+	+	o/-	-	-
Large chiller (screw)	+	-	+/o	+	-	+	-

C. GENERAL ISSUES RELATING TO INCREMENTAL COST IN THE REFRIGERATION SECTOR

37. The Multilateral Fund has assisted many domestic refrigerator and freezer companies and a number of commercial refrigeration companies in Article 5 countries in converting their manufacturing process to HFC-134a and hydrocarbon refrigerants within the stand-alone projects. The experience gained in the review of such projects formed the basis for the following first assessment of the incremental costs associated with the phase-out of the use of HCFC-22 in the manufacturing of refrigeration and air-conditioning equipment.

38. This assessment had to be developed based on a limited set of information. The incremental capital costs for an individual project are typically influenced by:

(a) The existing equipment in a manufacturing facility; or alternatively

(b) What could be expected as a minimum to be existing;

(c) The need of upgrade or replacement of or amendment to this equipment; and

(d) The cost of the associated activities, in particular the costs for hardware.

39. At the present point in time, information is not accessible about typical levels for the first three factors. In order to overcome this shortcoming, the Secretariat decided to define model enterprises, meant to represent what might turn out to be typical conversion cases for the different sub-sectors, or what might demonstrate the level and spread of costs for conversions. Consequently, the calculation of incremental costs in the refrigeration manufacturing sector in Article 5 countries has been undertaken on the basis of model enterprises in the sub-sectors air-conditioning, chiller and the commercial sector. Each of these activities, sectors and sub-sectors had to be considered individually to make it possible to apply existing Executive Committee policies for better presentation of associated incremental costs.

40. This first attempt to calculate incremental costs has focused on what was perceived to be likely refrigerant choices while at the same time representing cost issues which could be, if needed, relatively easily be transferred to several other refrigerants. The refrigerants choices assumed when calculating incremental cost were HFC-410a, HFC-407C and HC-290 (propane) refrigerants.

41. A higher significance than expected is associated with the incremental operating costs, which are paid based on the incremental, eligible cost difference in the operating cost of the manufacturing plant and are therefore proportional to the duration for which they are being paid. The Executive Committee defined different durations for the incremental operating costs for different sectors and sub-sectors. These ranged from zero months to 48 months; guidelines assigned duration to the commercial sector of 24 months, but the decision specified that guidelines would not be valid for HCFCs phase-out projects. For the air-conditioning and chiller sub-sectors, durations were never determined. Therefore, for the refrigeration and air-conditioning sector all incremental operating costs calculations have been carried out on the basis of one year, i.e. as incremental operating costs per annum, of to allow easy conversion to

any duration of incremental operating costs that the Executive Committee might consider. The Secretariat would like to explicitly point out that this is the exclusive reason to show this specific duration, and that there is no reason to prefer this duration to any other duration the Executive Committee might wish to consider.

42. It should be noted that for the refrigeration and air-conditioning sub-sectors, the estimation of incremental operating costs at the present time associated with very high uncertainties is highly problematic. While in this paper significant efforts have been undertaken to arrive at realistic estimates, e.g. by using historical data, the error margin in the estimates of incremental operating costs for this Annex remains significant, and the values should only be looked at as indicative. Better data will only be available once the Secretariat can actually fully assess cost data, e.g. during the review of a project proposal.

43. It should be noted that for the use of several alternative technologies, calculation of incremental operating costs for components (compressor, heat exchangers, etc.) in the context of this paper cannot sufficiently take into account the issue of energy efficiency. For example, for the new technology of HFC-410A, the technological gap between previous (HCFC-22) designs and the newly developed (HFC-410A) technology is considerably larger than in the case of CFC-12 to HFC-134a. In order to achieve comparable energy efficiency, or to increase energy efficiency, the balance between the characteristics of the various components need to be established anew, and changes in several components might be necessary. For the purpose of this paper, cost-effective solutions with an assumed likeliness of achieving similar energy efficiency have been used, based on discussions with experts. However, this presents a considerable uncertainty because of two reasons:

(a) The actual costs experienced and reported in publicly accessible documentation combine costs related to the conversion with the cost for technological upgrades. It is difficult to separate out the different cost elements, in particular because the cost know-how forms an important part of the intellectual property of an enterprise; and

(b) Paragraph 11 (b) of decision XIX/6 of the Meeting of the Parties requested the Executive Committee, when developing and applying funding criteria for projects and programmes, to give priority to cost-effective projects and programmes which focus on, *inter alia*, substitutes and alternatives that minimize other impacts on the environment, including on the climate, taking into account global-warming potential, energy use and other relevant factors. As pointed out above, conversions which did take place in Article 5 countries for export to non-Article 5 countries have achieved gains in energy efficiency on the expense of higher operating costs. It remains so far unknown whether and how the Executive Committee will deal with the issue of incremental operating costs if those are related to, *inter alia*, energy efficiency improvements.

44. The incremental cost of compressor is an important component of overall production cost. The Executive Committee dedicated a great deal of attention to the issue of incremental cost for compressors while dealing with CFC phase-out in the refrigeration sector. The existing policy allows an Article 5 country to claim either incremental operating costs of the compressor or the cost of conversion of its compressor manufacturing facilities, or both on a proportional

basis. The Article 5 country has to make a decision regarding its approach and inform the Executive Committee. Currently, several Article 5 countries have compressor production facilities for air-conditioning equipment. Related compressor manufacturing conversion costs are not assessed in this paper.

<u>Incremental cost in manufacturing room and mini-split air-conditioning units</u>

45. As an example, a hypothetical conversion of a production line manufacturing 250,000 units per year of room/mini-split air-conditioners of 4 kW cooling capacity has been considered for calculation of incremental capital costs and incremental operating costs, assuming a conversion to HFC-410A, R-407C and R-290 (propane) refrigerants. It is assumed that production is set up for three shifts, 250 working days in a year. All the costs are estimates made on certain assumptions and judgments on the basis of experience from conversion from CFC-12 to HFC-134a in the domestic refrigeration sector.

Conversion to HFC-410A refrigerant technology

46. Incremental capital costs associated with the replacement and/or adaptation (retrofit) of production equipment will not vary significantly in production of room and split ductless air-conditioning units. Therefore, these two categories of product are considered as one case study. Incremental capital costs are related to the cost of model redesign, investment in new refrigerant and leak detecting equipment, retooling of the production line, including adaptation of the evacuation system, technology transfer, training, commissioning and engineering. incremental capital costs are calculated in the range of US $275,000 (Scenario 1) to US $950,000 (Scenario 2) depending on the availability of the new design, the baseline and set-up of the production line.

47. Incremental operating costs (IOC), however, are closely related to the capacity of the air-conditioning units increasing with higher capacity due to the increased size and cost of the compressor, amount of the refrigerant charge and additional material used. Incremental operating costs will need to be adjusted to reflect particular characteristics of the manufactured product. Incremental operating costs in the manufacturing of ducted commercial and packaged air conditioners may be significantly different from residential air conditioners. The border line between residential and commercial applications is established by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) at 19 kW of cooling capacity. These units are being typically installed by contractors, including the charging of the system after the ducting and piping was completed according to the customer requirements. While the manufacturer therefore does not incur incremental costs associated with higher priced refrigerant, there is incremental cost associated to the higher price of compressors.

48. Incremental operating cost is calculated on the basis of the following assumptions:

(a) The average charge in the room air-conditioner is 1.35 kg of HCFC-22 similar to the charge used in the HCFCs Study for China;

(b) The baseline cooling capacity is 4 kW;

(c) The price of HCFC-22 is US $1.4/kg (HCFCs Study for China);

(d) The charge of HFC-410A will be 10 per cent less than the baseline (1.21 kg);

(e) The price of HFC-410A is US $13.8/kg (HCFCs Study for China);

(f) Savings in the cost of material due to reduction in size of heat exchanger are estimated and included; and

(g) Incremental cost of compressor is estimated at US $5.00 on the basis of consultations with industry experts (Scenario 1). The incremental cost of compressor in the HCFCs Study for China is calculated as a surplus of US $27.62 in the price of HFC-410A/HFC-407C compressor over the average price of HCFC-22-based compressor (Scenario 2).

49. The energy efficiency ratio (EER) of HFC-410A-based unit exceeds the EER of a HCFC-22 unit by about 5 per cent (an average conservative estimate). There is a potential for further improvements in the system efficiency and costs through use of smaller diameter tubes, use of micro-channel technology, additional compressor optimization and reducing of charge. Energy savings have not been calculated as part of incremental operating costs.

50. Incremental operating costs for duration of 12 months will range from US $2,660,000 (Scenario 1) to US $8,320,000 (Scenario 2). The following table shows the results of calculations of incremental costs:

<u>Table 5: Incremental cost of conversion of the production line of 250,000 unit per year to HFC-410A refrigerant (estimate)</u>

Category of incremental cost (US $)	Scenario 1	Scenario 2
Incremental capital cost	275,000	950,000
Incremental operating cost/year	2,660,000	8,320,000

Conversion to HFC-407C refrigerant technology

51. Since the working pressure of HFC-407C is very close to HCFC-22 refrigerant, only minor changes are expected in the design of the product and the manufacturing process. Incremental capital costs associated with the replacement and/or adaptation (retrofit) of production equipment will not vary significantly in production of room and split ductless air-conditioning units. The incremental capital costs for conversion of a production line of 250,000 unit/year capacity to HFC-407 blend have been calculated to be within the range of US $190,000 to US $250,000, depending on the local availability of testing facilities at the enterprise. For comparison, the incremental cost of conversion (rebuilding) of the production line of 500,000 unit/yr capacity to HFC-410A/HFC-407C refrigerants is estimated to be US $104,000 in the HCFCs Study for China, excluding costs of model redesign.

52. Incremental operating costs for the category of room and split ductless air-conditioning products is calculated on the following assumptions:

(a) The average charge in the room air-conditioner is 1.35 kg of HCFC-22 similar to the charge used in the HCFCs Study for China;

(b) The baseline cooling capacity is 4 kW;

(c) The price of HCFC-22 is US $1.4/kg (HCFCs Study for China);

(d) The charge of HFC-407C will be 5 per cent less than the baseline (1.28 kg);

(e) The price of HFC-407C is US $10.77/kg (HCFCs Study for China); and

(f) The incremental cost for HFC-407C compressor of US $5.0/unit has been used in the incremental operating costs calculations as an indicative only. HCFCs Study for China indicates to a significantly higher surplus of R407C compressor over HCFC-22 compressor. This scenario has not been considered. The existing price difference for HCFC-22 and HFC-407C compressors needs further investigation.

53. The annual incremental operating costs will be US $4,250,000. Table 6 shows calculations of incremental costs:

Table 6: Incremental cost of conversion of the production line of 250,000 units per year to HFC-407C refrigerant (estimate)

Category of incremental cost (US $)	**Scenario 1**	**Scenario 2**
Incremental capital cost	190,000	250,000
Incremental operating cost/year	4,250,000	4,250,000

Conversion to hydrocarbon alternative technology

54. For the purpose of calculation of incremental costs, the conversion of production of a small room air-conditioner of 1 kW cooling capacity is considered from HCFC-22 to HC-290 (propane) refrigerant. The refrigerant charge would be about 150 g which might be acceptable in some countries meeting the established safety standards. The capacity of a production line is assumed to be 250,000 units a year. It is assumed that compressors equipped with the necessary electrical features are commercially available.

55. The incremental capital costs will cover the cost of model redesign or alternatively the technology transfer fee, new refrigerant charging boards incorporating the necessary safety features, a refrigerant transfer system, the installation of gas detecting and ventilation systems, new leak detectors, refrigerant storage, training and safety inspection. Incremental capital costs are calculated within the range of US $545,000 and US $670,000.

56. Incremental operating costs for the small room air-conditioner are calculated on the following assumptions:

(a) The average charge in the room air-conditioner is 1.0 kg of HCFC-22;

(b) The baseline cooling capacity is 1.0 kW;

(c) The price of HCFC-22 is US $1.4/kg (HCFCs Study for China);

(d) The charge of HC-290 will be 0.15 kg;

(e) The price of HC-290 (refrigeration grade) is US $27.6/kg (HCFCs Study for China). The high price of refrigeration grade propane in China is due to low demand and is likely to be substantially reduced in the future if R290 technology is widely accepted and commercially used;

(f) The incremental cost of the HC-290 compressor plus the incremental cost to upgrade electrical components to meet safety requirements amount to US $15/unit, based on information received by a manufacturer; and

(g) The incremental operating costs for duration of 12 months amounts to US $4,312,000.

57. The result of an estimation of the total incremental cost of the conversion of a production line of 250,000 units' capacity to R290 refrigerant is shown in Table 7.

Table 7: Incremental cost of conversion of the production line of 250,000 unit per year to HC-290 refrigerant (estimate)

Category of incremental cost (US $)	Scenario 1	Scenario 2
Incremental capital cost	545,000	670,000
Incremental operating cost/year	4,312,000	4,312,000

Conversion of manufacturing of ducted commercial and packaged air-conditioners

58. Incremental capital costs have been calculated for the conversion of a manufacturing facility producing 1000 units of ducted split residential and commercial air conditioners of an average 15 kW cooling capacity and 100 units of packaged commercial units of 70 kW cooling capacity. Two HFC alternative refrigerants are considered: HFC-410A and HFC-407C. Ducted commercial and packaged air-conditioners are being typically installed by contractors with charging the system after the ducting and piping was completed according to the customer requirements

Conversion to HFC-410A refrigerant technology

59. Incremental capital costs for conversion of a production line of ducted commercial and packaged air conditioners to HFC-410A refrigerant primarily will involve costs associated with redesign, prototyping, pilot scale production and test trials to accommodate a higher working pressure of a new refrigerant in the design as well as cost for retooling, leak detector, and adaptation of the evacuation system. No or low cost will be associated with refrigerant charging equipment since no refrigerant charging operations are entailed on a production site.

60. The incremental capital costs are calculated in the range of US $145,000 and US $245,000.

61. The manufacturer will not incur incremental costs associated with higher priced refrigerant. There will be savings in the cost of heat exchanger material. The incremental cost for compressors, new filter/dryer and new expansion valve will be part of the incremental operating costs. The incremental operating costs for both parts of production are estimated to be

US $36,000. The results of an estimation of the incremental costs are shown in the following table.

Table 8: Incremental cost of conversion of manufacturing of ducted commercial and packaged air-conditioners to HFC-410A

Category of incremental cost (US $)	Scenario 1	Scenario 2
Incremental capital cost	145,000	245,000
Incremental operating cost/year	36,000	36,000

Conversion to HFC-407C refrigerant technology

62. Since the working pressure of HFC-407C is very close to HCFC-22 refrigerant, there are limited changes in the design of the product and the manufacturing process. This factor might be especially important for conversion of the higher capacity range equipment. The incremental capital costs are calculated to be in the range US $80,000 to US $100,000.

63. Incremental operating costs involve higher price of compressors, and a new filter/dryer, amounting to US $30,000. The incremental costs are shown in the following table.

Table 9: Incremental cost of conversion of manufacturing of ducted commercial and packaged air-conditioners to HFC-407C (estimate)

Category of incremental cost (US $)	Scenario 1	Scenario 2
Incremental capital cost	80,000	100,000
Incremental operating cost/year	30,000	30,000

Chillers

Conversion of manufacturing of chillers to HFC-410A refrigerant

64. The conversion of the manufacturing line of HCFC-22 500 kW water cooled chillers equipped with screw compressors is considered as an example. The direct expansion evaporator is assumed to the part of the system design. The alternative refrigerant is HFC-410A. The annual output is assumed to be 200 units.

65. Incremental capital costs for conversion of a production line of screw chillers of 500 kW capacity has been calculated using assumed costs since the Secretariat has never assessed the conversion of chiller production. The incremental capital costs include the cost of redesigning, prototyping, pilot scale production, test trials, set of equipment for manufacturing the HFC-410A prototype and training. The incremental capital costs are estimated between US $80,000 and US $300,000 depending on the source of the new design.

66. These units are typically being installed by contractors, with charging of the system after the ducting and piping is completed according to the customer’s requirements. Therefore, the manufacturer does not incur incremental costs associated with higher priced HFC-410A refrigerant. The incremental cost for compressors is the major incremental operating cost item. In manufacturing of units of about 500 kW cooling capacity, the components will need to have a

higher pressure rating than for HCFC-22. This moderate additional cost is likely to be offset by the lower cost for the screw compressor. The total incremental operating costs per unit for this category of air-conditioning will therefore be likely zero. Consequently, the annual incremental operating costs resulting from conversion of production of 200 units would be also zero. The incremental costs are shown in Table 10.

Table 10: Incremental cost of conversion of manufacturing of ducted commercial and packaged air-conditioners to HFC-407C (estimate)

Category of incremental cost (US $)	Scenario 1	Scenario 2
Incremental capital cost	80,000	300,000
Incremental operating cost/year	0	0

Commercial refrigeration - stand-alone equipment

67. As an example, the incremental cost has been calculated for the conversion of manufacturing of stand-alone commercial-sized freezers of 1.0 kW cooling capacity to HFC-404A refrigerant and beverage vending machines to propane refrigerant.

Conversion of manufacturing of stand-alone commercial-sized freezers to R-404A refrigerant

68. HFC-404A is the preferred choice for medium and low temperature applications. The conversion of a production line of 1,000 units per year will entail capital incremental cost for model redesign, prototype trials, a new refrigerant charging board, a leak detector, adaptation of the vacuum system, training and technical assistance amounting to US $35,000. Incremental operating costs will cover the additional cost of new refrigerant with the charge 0.75 kg/unit, compressor, capillary, and filter/dryer, amounting to US $15,000 per year.

Conversion of manufacturing of beverage vending machines to isobutane (R-600a) refrigerant

69. Beverage coolers and small commercial refrigeration equipment based on hydrocarbon (HC) refrigerants such as isobutene (HC-600a), propane (HC-290) or HC blends have been developed in several non-Article 5 countries. Through developmental efforts, it was possible to reduce the refrigerant charge to limits required by safety standards in several non-Article 5 countries. An example of conversion of a manufacturing facility with an annual output of 10,000 units was used for the calculation of incremental cost. The cooling capacity of the refrigeration system is assumed to be 0.25 kW with the refrigerant charge of 0.25 kg.

70. The incremental capital costs will cover the cost of model redesign or alternatively a technology transfer fee, new refrigerant charging boards incorporating the necessary safety features, a refrigerant transfer system, the installation of gas detecting and ventilation systems, new leak detectors, refrigerant storage, training and safety inspection. The incremental capital costs are estimated to be within the range of US $500,000 to US $800,000.

71. The incremental operating costs will be associated with the higher price of the refrigerant, new compressor and the cost of safety features in the design. The overall incremental operating costs will be dependent on the source and availability of hydrocarbon compressors and

refrigerant. The annual incremental operating costs will be in the range US $150,000 to US $200,000.

Table 11: Incremental cost of the conversion of manufacturing of beverage vending machines to isobutane (R-600a) refrigerant

Category of incremental cost (US $)	Scenario 1	Scenario 2
Incremental capital cost	500,000	800,000
Incremental operating cost/year	150,000	200,000

Commercial refrigeration - condensing units

72. Currently, HFC-404A is the leading choice of refrigerant in manufacturing new condensing units. HFC-134a is also used mainly for medium temperature applications. The incremental capital costs are estimated for the conversion of a production line of 1,000 condensing units a year. The cost will be associated with the redesign and testing of the new product and the cost of new production equipment and retraining the personnel to handle more hygroscopic lubricant. It is assumed that middle-sized companies have the in-house technical expertise to cope with the redesign challenge. The estimated cost is within the range of US $25,000 and US $30,000, depending on the baseline.

73. In order to be eligible for both capital and operating costs from the Multilateral Fund, the production at the particular enterprise needs to be recognized as one belonging to the manufacturing sector. In its decision 31/45, the Executive Committee established Guidelines for definition of the sub-sector for assembly, installation and charging of the refrigeration equipment and the calculation of incremental operating costs. It is assumed that the company is considered under the rules pertaining to the commercial refrigeration sector and eligible for incremental operating costs. The cooling capacity of condensing units varies from 5 to 20 kW. For this cost estimation, the assumed compressor size is 5 kW, and the average charge to be 1.5 kg per system. The incremental operating costs for one year duration are estimated in the range of US $24,000 to US $27,000 depending on the source of supply of new compressors. Table 12 presents the results of the estimation of incremental costs.

Table 12: Incremental cost of the conversion of the manufacturing of commercial refrigeration – condensing units (estimate)

Category of incremental cost (US $)	Scenario 1	Scenario 2
Incremental capital cost	25,000	30,000
Incremental operating cost/year	24,000	27,000

D. SERVICE SECTOR

General considerations

74. Consumption of HCFC-22 in the service sector is likely to take place in every Article 5 country that has HCFC-22 equipment. In particular, HCFC-22 room air conditioners can be assumed to exist in every but very few countries. Therefore it is safe to assume that, with potential minor exceptions, every Article 5 country uses HCFC-22 for servicing.

75. On an enterprise basis, the distinction between the service sector and the sub-sector for assembly, installation and charging of the refrigeration equipment is very blurred. It can be assumed that a large number of smaller enterprises fall into both categories and are likely to be addressed only through service sector activities such as training and equipment support. Service sector activities were for most Article 5 countries addressed together with awareness, legislative and enforcement activities in RMPs and TPMPs. This section of Annex IV is therefore also covering to some degree those activities.

76. The service sector is particular in its very broad spectrum of enterprises covered, their often informal structure, the large amount of enterprises and the small consumption per enterprise. The service is predominantly performed at the customers' site, i.e. not at the premises of the service enterprise. Contrary to activities in the manufacturing sector, where the ODS consumption of the beneficiary can be monitored, these characteristics make it virtually impossible to monitor whether an enterprise phased out the use of HCFCs; the problem that their customers might be dependent on continued use of HCFCs in the service of their equipment is a sub-set of this issue. Experience indicates that instead of direct phase-out enforcement, refrigerant supply and, in particular, refrigerant costs are the main drivers leading to phase-out of ODS use in the service sector.

77. Experience in the phase-out of CFCs suggests that if refrigeration manufacturing enterprises and the service sector compete for a limited supply of refrigerant, the service sector is likely to be able to pay higher refrigerant costs since it is easier to pass the costs onto the consumer. This might indicate that in countries where both HCFC-22 refrigeration manufacturing and servicing sectors are present, the contribution of the service sector for phase-out will initially be low, and phase-out will predominantly be achieved in the manufacturing sectors. This is particularly important when planning phase-out activities to meet the compliance targets of 2013 and 2015, and might lead to a differentiation in activities in the service sector between countries with and without a HCFC-22 refrigeration manufacturing sector.

78. Approaches to reduce supply are performed on a national level by restricting imports or requesting that a certain minimum amount of ODS produced has to be exported. Such restrictions on the national level have become increasingly effective in the last few years. Verification reports reviewed by the Secretariat demonstrate significant improvements in the co-ordination between the NOU, licence issuing bodies, customs and importers. The monitoring of imports is also improved greatly, and more and more countries are using a computerised data basis for customs. It appears therefore likely that governments can control successfully the

HCFCs imports into their countries, and thus achieve compliance with their phase-out obligations. Nevertheless, this can not be interpreted as removing the need for assistance to the service sector because of two reasons:

(a) The service sector is eligible for funding of incremental cost. The eligibility has been established in the indicative list of incremental cost ("cost of providing technical assistance to reduce consumption and unintended emission of ozone depleting substances"), as well as in the practice and guidelines of the Executive Committee; and

(b) It might be viewed as a precondition before a government takes regulatory action to reduce the supply of HCFCs that there is an understanding that the country will be able to cope with the reduced supplies. Activities for the service sector provide the necessary assurance to governments.

79. Some Article 5 countries have already completely phased out CFC consumption, the remaining are implementing CFC phase-out activities in the servicing sector. These activities are i.e., customs officers and technicians are being trained; training centres are being properly equipped; refrigeration associations and project monitoring units have been established; and recovery/recycling, retrofits and other technical assistance programmes are also under implementation. Activities in the service sector related to HCFCs phase-out commencing at about the time of the CFC phase-out will maintain the momentum gained and capacity established beyond 2010 and will thus facilitate the cost effective phase-out of HCFCs.

80. Every HCFC-22 dependent refrigeration system imported into an Article 5 country will lead to a broadening of the HCFC-22 dependent equipment base and will subsequently lead to the need of HCFC-22 for service, to the need for retrofit or to premature retirement. It is therefore meaningful to consider how to avoid growth of and, subsequently, reduce the size of the HCFC-22 equipment base. This might require import restrictions, taxing of equipment and/or subsidies/tax breaks for equipment operating with HCFC-22 alternatives. The earlier such restrictions and incentives are decided upon by a government, the easier will be the transition away from HCFC-22 consumption in the service sector. Such legislative measures can be effective only under the circumstances when HCFCs-free refrigeration equipment is made available at a competitive price. Timely conversion of refrigeration equipment manufacturing facilities existing in some Article 5 countries might facilitate meeting the demand for non-HCFCs equipment and reduce the dependence on HCFC-22 refrigerant in all Article 5 countries.

81. A number of activities in the service sector, in particular the non-investment activities, are recurring activities. Customs officers and, on a slower rate, refrigeration technicians are rotating out of their jobs, new arrivals need to be trained. In addition, training might need repetition or amendments relating to new developments. During CFC phase-out, service sector activities occurred on a large scale from about 1995 on, i.e. from 15 years before the final phase-out. Due to the need to achieve significant consumption reductions in the service sector in more than 70[6] of the Article 5 countries from 2010 onwards to comply with the 2013 and 2015

[6] There are 70 Article 5 countries with HCFC-22 consumption below 150 metric tonnes (8.25 ODP tonnes) which is believed to be predominantly or exclusively used in the refrigeration servicing sector.

reduction steps, such activities will commence 30 years before the final phase-out date. The recurring nature of many activities and the long duration until final phase-out might suggest assessing which might be the best approaches to achieve sustainable, cost effective support for the service sector; these might differ from previously used approaches.

Existing experience

82. Phasing out CFC use in the refrigeration servicing sector has long been one of the Executive Committee's priorities. The Executive Committee was approving training programmes for refrigeration technicians, and recovery and recycling projects for this purpose as early as 1991. Since then, recovery and recycling projects and stand-alone training programmes have been replaced by refrigerant management plans (RMPs) and more recently by national/terminal phase-out management plans (NPPs/TPMPs) which has been a tool used by Article 5 countries to achieve compliance with the control measures established by the Montreal Protocol[7].

83. At its 31st Meeting, the Executive Committee decided on the modalities for approving funding for the preparation and implementation of RMP projects (decision 31/48). Subsequently, at its 45th Meeting the Executive Committee decided to approve further funding for phasing out CFC consumption post-2007 period (i.e., 15 per cent of the CFC consumption baseline) in LVC countries through the preparation and implementation of terminal phase-out management plans (TPMPs) (decision 45/54). Through this decision, the Executive Committee, *inter alia*, established maximum funding levels on the basis of the CFC baseline consumption of LVC countries on the understanding that individual project proposals would still need to demonstrate that the funding level was necessary to achieve complete phase-out of CFCs.

84. The total funding approved for stand alone training programmes for refrigeration service technicians and customs officers, recovery and recycling projects and RMPs in all Article 5 countries amounts to US $52.7 million (i.e., US $29.6 million for LVC countries and US $23.1 million for non-LVC countries). An additional US $235.0 million is associated with TPMPs (for) LVC countries) and national/sectoral phase-out plans for non-LVC countries addressing the total remaining consumption of CFCs, mainly used in the refrigeration servicing sector.[8]

Good practices in refrigeration

85. The Multilateral Fund has invested significant funding in the improvement of refrigeration servicing practices of CFC-based systems through the implementation of RMP and TPMP activities. Though servicing practices for CFC and HCFCs based systems are very similar, there are additional measures that could be considered on a case-by-case basis as a short-term priority to reduce HCFCs emissions.

[7] At its 31st Meeting, the Executive Committee decided on the modalities for approving funding for the preparation and implementation of RMP projects to achieve the 2005 and 2007 allowable levels of CFC consumption (decision 31/48). Subsequently, at its 45th Meeting the Executive Committee decided to approve further funding for phasing out CFC consumption post-2007 period (15 per cent of the CFC consumption baseline) in LVC countries through the preparation and implementation of terminal phase-out management plans (TPMPs) (decision 45/54).

[8] Several national phase-out plans and a few TPMPs address small amounts of CFCs used in small foam and refrigeration manufacturing enterprises or small amounts of other ODSs, mainly CTC and/or TCA

(a) In many Article 5 countries preventive maintenance of air-conditioning and refrigeration equipment is not a routine practice. Regular preventive maintenance and repair of the system can significantly reduce the leakage rate; and

(b) Substantial resources have been allocated for introduction of recovery and recycling operations in Article 5 countries. Despite the introduction predominantly for the purpose of CFC recovery and recycling, many countries report higher HCFCs recovery/recycling than CFC; this might be related to the fact that even small air-conditioning systems have significant refrigerant content and that room air conditioners are often transported to a repair location, where equipment is available. It could be assessed whether additional efforts are meaningful to optimise the usefulness of recovery and recycling of HCFC-22; these might include better monitoring and creating appropriate incentives for owners of equipment and servicing technicians.

<u>Retrofit and replacement activities in end-user sector</u>

86. The HCFC-22 equipment base can be reduced by retrofit of HCFC-22 equipment, reducing future service demand and, in certain cases, making recovered HCFC-22 from the converted equipment available to the service sector. This is particularly relevant for equipment in commercial refrigeration. Conversions and retrofit activities in the end-user sector have been defined in decision 32/28. This decision refers to relevant circumstances which must prevail before priority will be accorded to end-user conversions and establishes certain pre-conditions prior to funding retrofitting activities.

87. In order to assess whether a retrofit is meaningful, the remaining life-time of each system needs to be considered and a cost-benefit analysis should be performed. Since HFC alternatives are presently more costly than HCFC-22, there is a significant risk of a reverse retrofit back to HCFC-22. There are several possibilities to provide incentives against a reverse retrofit, which need to be integrated into the design of the retrofit scheme; these would include long-term subsidies and long-term monitoring of the equipment. The retrofit schemes currently used would similarly subsidize the installation of new equipment with alternative technologies.

88. The administration of retrofit incentive projects is complex since inherently they provide a large incentive for inappropriate use, and require therefore careful monitoring of activities related to relatively small amounts of funding to ensure eligibility and sustainability. The Secretariat calculated in detail the costs associated with retrofits and came to a cost effectiveness of between US $300/kg ODP and US $650/kg ODP (US $16.50 and US $35.75/kg, respectively) for the actual retrofit alone, i.e. without accounting for administrative procedures. This figure is based on the assumption that the Multilateral Fund would cover 50 per cent of the costs, and the equipment owner the remaining, as is the case in existing retrofit schemes.

<u>Cost information</u>

89. The costing of HCFCs phase-out plans in the refrigeration servicing sector is influenced significantly by the prevailing circumstances in the country concerned, such as the size of the country in terms of population and surface area and the geographical distribution of the main economic activities; the actual amounts of HCFCs consumed in the servicing sector by type of

equipment; and the characteristics of the refrigeration servicing sector including the number of service workshops and their geographical distribution. At present, some of this basic information is not available, and will only be known when Article 5 countries submit their HCFCs phase-out plans.

90. In spite of the limitations in the availability of information, the Secretariat has attempted a preliminary estimate on the incremental costs based on the Multilateral Fund experience in CFC phase-out activities.[9] The estimation is meant to cover the funding needs for service sector activities and other non-investment activities until the 2015 reduction step. It was assumed that the service sector activities would be targeted to enable a reduction of consumption in the service sector proportional to the necessary national consumption. The level of detail in which the information is provided would allow also understanding the financial implications if countries with a HCFC-22 equipment manufacturing capacity would not commence service sector related activities immediately, but would rather concentrate on their manufacturing sectors. The following estimate assumes providing additional funding for reviewing ODS legislation, as well as training programmes at a level of funding estimated according to the level of HCFCs consumption in the year 2006. Further, funding for technical assistance estimated at US $18.20/kg ODP (US $1.00/kg) of consumption, and additional funding (about 20 per cent of the total costs) for monitoring and reporting are assumed. The details of this estimate are presented in Table 13 below.

Table 13: Cost estimate for the refrigeration service sector as well as legislative, enforcement and monitoring activities to comply with the 2013 and 2015 HCFCs reduction steps, by national HCFC-22 consumption in 2006 in metric tonnes

	HCFC-22 consumption in 2006							
Consumption (metric tonnes):	Below 30	Up to 100	Up to 300	Up to 500	Up to 1,000	Up to 5,000	Up to 8,000	Above 8,000
Activities (in US $):								
Legislation	10,000	10,000	10,000	20,000	30,000	50,000	50,000	80,000
Custom training	20,000	40,000	50,000	60,000	80,000	120,000	140,000	160,000
Technicians training	30,000	60,000	70,000	100,000	160,000	240,000	300,000	400,000
Technical assistance	30,000	100,000	300,000	500,000	1,000,000	5,000,000	8,000,000	11,000,000
Monitoring	20,000	40,000	90,000	140,000	250,000	1,000,000	1,700,000	2,300,000
Total (in US $)	**110,000**	**250,000**	**520,000**	**820,000**	**1,520,000**	**6,410,000**	**10,190,000**	**13,940,000**

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[9] Since the inception of the Fund, the total funding approved by the Executive Committee for stand alone training programmes for refrigeration service technicians and customs officers, recovery and recycling projects and RMPs in all Article 5 countries amounts to US $52.7 million (i.e., US $29.6 million for LVC countries and US $23.1 million for non-LVC countries). An additional US $235.0 million is associated with TPMPs (for LVC countries) and national/sectoral phase-out plans for non-LVC countries addressing the total remaining consumption of CFCs, mainly used in the refrigeration servicing sector. Several national phase-out plans and a few TPMPs address small amounts of CFCs used in small foam and refrigeration manufacturing enterprises or small amounts of other ODSs, mainly CTC and/or TCA.