United Nations
Environment
Programme

Distr.
LIMITED

UNEP/OzL.Pro/ExCom/12/33
21 February 1994

ORIGINAL: ENGLISH

Executive Committee of
the Multilateral Fund for the
Implementation of the Montreal Protocol

Twelfth Meeting
Montreal, 28-30 March 1994

REPORT ON STRATEGIC OPTIONS FOR RETROFITTING OF MOBILE AIR CONDITIONERS AND CHILLERS

Introduction

1. At its Eleventh Meeting (November 1993), the Executive Committee discussed an interim report prepared by the Fund Secretariat on "Retrofits of Mobile Air Conditioners and Chillers." Subsequently, the Committee requested the Secretariat to revise and expand the interim report, incorporating the comments made during the discussion and present it to the Twelfth Meeting of the Committee.

2. The main conclusion of the Interim Report was to defer development and consideration of project proposals on retrofits of Mobile Air Conditioners until the technology is firmed up; and to deal with retrofits of chillers on a case by case basis.

3. Some of the comments made during the meeting implied that conditions in Article 5 countries could favour consideration of retrofits of both MACs and chillers.

4. The present report is prepared in fulfilment of the Executive Committee's request.

5. In preparing this report the Secretariat consulted extensively with technology vendors, trade associations in industrialized countries and with industry representatives in Article 5 countries. The first draft of this report was circulated to some members of the Executive Committee whose countries have ongoing programmes in retrofits, and to the Implementing agencies.

Availability of Controlled Substances in Article 5 Countries

6. Availability of CFCs to Article 5 countries is one of the important factors determining CFC phase-out options to be applied in MAC and chiller sectors, and the time frame for their application. There are six Article 5 countries which are CFC producers. Some of them have excessive production capacity exceeding consumption under their national phase-out programmes. The issue of future demand for CFC in Article 5 countries has been addressed in the report prepared by the Secretariat. The Executive Committee considered the report at its Eighth meeting. The major conclusion of the report was that forecast demand for CFC-11 and CFC-12 can be met up to the year 2000 with 100 per cent utilization of production capacity in Article 5 countries. The report will be updated in 1995. There are also non-Article 5 countries which might wish to use provisions of the Montreal Protocol, as appropriate, to supply CFCs to Article 5 countries in the future. Analysis of the provisions of the Montreal Protocol may facilitate the assessment of future availability of CFCs to be used in MAC and chiller sectors in Article 5 countries.

7. The Montreal Protocol contains several provisions which, if implemented, should ensure the continuation of CFC supply to Article 5 countries after January 1, 1996, when CFC consumption will be banned in developed countries.

(a) The Montreal Protocol currently allows developed countries to produce up to ten per cent above their otherwise allowable level in order to satisfy the basic domestic needs of Article 5 countries. This allowance is increased to 15 per cent after 1996.

(b) Article 5 paragraph 1 of the Protocol also allows Article 5 countries to delay for ten years its compliance with the control measures set out in Article 2A to 2E and to continue production of CFCs.

(c) The Protocol also has a provision in paragraph 4 of Article 5 dealing with possible inadequate supply of CFCs to Article 5 countries. If an Article 5 country finds itself unable to obtain an adequate supply of CFCs, the Meeting of the Parties will consider the matter and decide upon appropriate action to be taken.

(d) However, according to paragraph 8 of Article 5, a Meeting of the Parties shall review, in 1995, the situation of Article 5 countries, including the effective implementation of financial co-operation and transfer of technology to them and adopt such revisions that may be deemed necessary regarding the schedule of control measures applicable to those Parties.

Mobile Air Conditioning Sector

Background

8. Mobile air conditioners are by far the largest consumers of CFC-12 within the air conditioning and refrigeration sector. Air-conditioned vehicles in Article 5 countries are estimated at about 25 million, of which about 2-5 million were produced in Article 5 countries during 1993. This represents about 10 per cent of world population of air-conditioned vehicles. The current rate of CFC-12 consumption is approximately 1.30 kg per vehicle (factory fill) for systems installed in Original Equipment Manufacturing (OEM), and about 1.00 kg per vehicle per year for servicing. The total annual CFC consumption in the MAC sector in Article 5 countries is estimated at 26,000 metric tonnes which represents about 15 per cent of total ODS consumption in Article 5 countries. On an annual basis, about 3,000 tonnes are used for initial charge (factory fill) and 23,000 tonnes for servicing.

9. Article 5 countries may be subdivided into three categories:

(a) Producers of MAC systems;
(b) Importers of MACs for car assembly;
(c) Importers of vehicles equipped with MAC systems.

10. Phase-out and/or phase-down of CFC-12 in the MAC sector may be achieved by one or more of the following paths:

(i) Recovery/recycling and better service
(ii) Conversion to HFC-134a refrigerant
(iii) Retrofitting

Factors that influence the choice of any one path include the availability of viable technology, cost-effectiveness, adequacy of supply of CFC-12 and experiences gained in developed countries among others.

Technology

Recovery Recycling and Better Service

11. Since 1988, the mobile air conditioning industry in developed countries has established programmes to reduce the amount of CFC-12 used in servicing of vehicle air conditioners. New service procedures have been designed to minimize emissions. This, together with the rising cost of CFCs in those countries, has encouraged refrigerant recycling/reclamation and training of service personnel. These measures have been supported by Government regulation. As indicated in the Refrigeration Technical Option Committee Report, the application of these new improved containment, conservation and recycling/reclamation procedures during service has made possible a substantial reduction of the amount of CFC-12 used, up to 0.4 kg per vehicle per year. It is further indicated that with full implementation of adopted regulations, the amount of CFC needed for MAC servicing could be reduced to 0.24 kg/vehicle/year or even less with better containment practices applied by trained service personnel. A variety of recovery/recycling/reclamation equipment is available in the market. This technology is mature and is being transferred to Article 5 countries.

12. Consumption in Article 5 countries has been shown to be higher than 1 kg of CFC-12 per year to service a mobile air conditioner. It seems plausible that better containment programmes, recycling/reclamation and service personnel training efforts could achieve the target of 50 per cent reduction in the amount of CFC-12 used for MAC servicing. This might lead to 11,000 metric tonnes of CFC-12 saved. MAC recovery/recycling and training projects have been included in the country programmes of several countries. The Executive Committee has already approved two investment projects in MAC recycling in two Article 5 countries with a large population of air-conditioned vehicles for a total of US $1.8 million. The implementation of these two investment projects will save up to 620 tonnes of CFC-12, representing about 25 per cent of total demand for after-sale MAC market in these two countries. The cost-effectiveness of these two projects is US $2.90 per kg of CFC-12 saved.

13. Successful implementation of recycling/reclamation investment projects cannot be accomplished without coupling it with training and other technical assistance activities related to better containment practices, and with the enactment of appropriate government regulations. The major task in developing countries would be to train MAC service technicians to use recycling/reclamation equipment and better service procedures which would reduce consumption of CFCs. The appropriate guidelines, service procedures and training materials are available

and can be transferred to Article 5 countries. In this respect, the Executive Committee has approved a global MAC project which aims at developing projects in 13 Article 5 countries. The project includes management and implementation arrangements, training programmes and pilot recycling activities. Eight training and technical assistance projects covering five countries and two regions have also been approved, at a total cost of US $715,000 which will reinforce the investment activities.

14. The Three Year Plan and Budget approved by the Executive Committee emphasizes recycling, improved handling and better refrigerant containment. About US $20 million of allocations are expected in 1994-1996 for investment projects and supporting activities in 15 countries.

Conversion to HFC-134a Refrigerant

15. Some Article 5 countries have indicated in their country programmes that their MAC producers and automobile assemblers would switch to MACs that use HFC-134a as soon as possible but no later than 1996. The Executive Committee has already approved three projects in MACs production facility conversion to HFC-134a technology in two Article 5 countries at a total cost of US $5.7 million. About 130 tonnes of CFC-12 will be eliminated annually in factory filled MACs with the cost-effectiveness of US $44/kg of CFC-12 avoided.

16. Early implementation of projects on MAC manufacturer conversion to HFC-134a will facilitate the supply of HFC-134a MACs for vehicle assembly plants in Article 5 countries. As a consequence of this action, and the developed country conversions, the number of new autos with CFC-12 MACs entering developing country markets could be substantially reduced. This will result in substantial reduction in the demand for CFC-12 for initial refrigerant charging and a subsequent decrease in its use for servicing in Article 5 countries. The amount of CFC-12 which will be made available as a result of this conversion can be utilized for service of the remaining CFC-12 MAC fleet, which through attrition with each added year will be growing smaller. The availability of domestically manufactured vehicles with HFC-134a MACs would also facilitate the adoption of regulations banning the import of cars with CFC-12 MACs, and would provide the incentives and the requisite training for HFC-134a MAC repair shops.

Retrofitting

17. The Montreal Protocol ban on production of CFCs by 1 January 1996 in developed countries, will result in an increased number of vehicles with CFC-12 systems which will require retrofitting if consumers want to continue to service their air conditioners. It is estimated that between 130 and 170 million vehicles, in developed countries, may be candidates for retrofitting between now and the year 2000. A typical consumer will not voluntarily retrofit his air conditioning system until it no longer provides cooling. The cost of retrofitting the system will consist of two costs. One to repair the system (US $250 average cost), plus the cost of the actual retrofit requirements (US $228 average least-cost retrofit) for a total estimated average cost of at least US $475 per unit. Using the conservative estimated cost of US $400 per MAC retrofit,

retrofitting of the fleet in the developed countries will cost consumers between US $52 and US $68 billion. This represents a tremendous challenge to both car manufacturing companies and the air conditioning service industry, and an unprecedented financial burden for consumers.

18. A great deal of research work and tests have been done in respect of MAC retrofitting. Many major auto manufacturing and MAC service shops in the developed countries are actively involved in resolving the remaining technical issues associated with retrofits of MACs. The general retrofitting procedure consists of the following steps:

(a) Leak-check of the MAC system;
(b) Repairing leaks as appropriate and evacuation of CFC-12 refrigerant using recovery/recycling machine;
(c) Minimizing the amount of mineral oil remaining in the system (a possible requirement);
(d) Changing parts that are incompatible with HFC-134a and the synthetic oil;
(e) Replacing parts that are likely to leak, perform poorly or fail quickly at HFC-134a's higher pressure;
(f) Pulling a deep vacuum for about 45 minutes;
(g) Recharging with HFC-134a and the right amount of a suitable synthetic lubricant;
(h) Verifying performance; and,
(i) Installing new connectors and labels identifying the systems as an HFC-134a retrofit.

19. However, there are specific technical and practical issues that might differ from model to model. Among others, there are the issues of the performance of retrofitted refrigeration systems, the uncertainty with parts to be replaced, e.g., desiccants; compressor parts like seals, lubricant circuits, bearings and coatings; hoses; choice of synthetic lubricant and compatibility of residues of mineral oil; necessity of flushing; lifetime and performance of compressor and condenser under high pressure of HFC-134a; and, durability of the retrofitted MAC system as a whole. It was generally understood from the engineering standpoint that CFC-12 based MAC systems were designed to operate with CFC-12 and they should continue to use this refrigerant as long as it is available.

20. It is well recognized that HFC-134a is currently acceptable as a principal refrigerant for retrofitting mobile air conditioning systems. This refrigerant is endorsed by the majority of the world automobile manufacturers. There are also some blend refrigerants like HCFC-22, HFC-152a, HCFC-124 blend, which can be considered as candidates for retrofitting. Neither are "drop-in" refrigerants. They require retrofit of existing equipment, depending on the system design. It is also recognized that application of refrigerants other than HFC-134a might lead to additional problems. If a blend is introduced in the service practices, in addition to HFC-134a, the potential of cross-contamination will increase. The additional expenses of purchasing tools and equipment to handle each material will also increase significantly. Meanwhile, there is information available that an alternative "drop-in" refrigerant is currently under tests and evaluation. There are preliminary indications that this new refrigerant could be used with

minimal modifications to existing CFC-12 MACs. However, it is uncertain when all the tests, development and commercialization will be finalized.

21. There is information that certain lubricant additives are being evaluated and tested for use in retrofitting motor vehicle air conditioning systems. The additives are designed to enable HFC-134a to be used as a retrofit refrigerant with the existing mineral oil in CFC-12 systems. Retrofitting costs may be reduced by eliminating the need to change lubricants, rubber parts, seals and O-rings and modify the compressor. If the additives are successful, retrofitting procedures might be simplified and the transition to ozone-friendly refrigerant might be made easier. The industry, however, has decided what lubricant specifications are required to provide their expected system durability. Any new lubricant to receive system manufacturer approval requires extensive testing before entering the marketplace.

22. The use of HFC-134a in CFC-12 MAC systems sometimes requires increased condenser capacity, especially when the car is used under high ambient temperature. It can be done by installing a new higher efficiency condenser or an additional electric cooling fan at an additional retrofit cost. However, the latest research results demonstrated that when the additional pusher fan is integrated, faulty operations of the engine and air conditioner computer systems may occur requiring a recalibration of the compressor cutout system at a high additional cost.

23. In order for MAC retrofitting to be done, each major automotive company should provide retrofit kits and retrofit procedures which differ from model to model. Given the number of companies and models, the amount of retrofit kits required would be very large. Thus, one auto manufacturer has recently announced that about 60 different retrofit kits will be available on the market for their car models. Some manufacturers have already retrofit kits for each model. However, the development of the required amount of retrofit kits is still far from being completed. The maximum retrofit activities in developed countries are expected after 1995 when CFC-12 production ceases, and the stock is used up. The required inventories of HFC-134a compatible components might not be sufficient to fill all the needs.

Cost of Retrofitting In Developed Countries

24. Developed countries gained some experience in costing MAC retrofits. It is generally understood that the customer may require his MAC to be retrofitted at the time when the system is broken down. Retrofit costs consist of the cost of the retrofit kit and the cost of labour, including average repair costs. Retrofit trials conducted by different companies demonstrated that each retrofit could take 1½ to 4 hours, depending on the specific type and condition of the vehicle and whether flushing was needed.

25. The issue of retrofit costs has also been addressed in the revised report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (February 1994). The lowest average least-cost retrofit has been calculated at US $152; US $80 (part cost) and US $72 (labour cost). Higher cost scenarios, involving additional component replacements/additions (e.g., desiccant, hoses, compressor, condenser, condenser fan, and system control) are likely to be necessary for the majority of vehicles to maintain acceptable

durability and/or performance. Ultimately a retrofit must result in a MAC system durable enough to satisfy customer expectations.

26. The costs of retrofit in the developed countries are varied but they range from US $200-$600 depending on the car model, age and durability requirements. Given the labour cost of US $45 per hour in developed countries, the cost of labour can range from US $65-$180. The cost of retrofit kit is estimated at US $110-$420. Average repair costs are estimated at US $250 and should be added to retrofit costs.

Cost of Retrofitting in Article 5 Countries

27. In calculating the retrofit costs in developing countries, the cost of retrofit kit and labour should be considered. The cost of retrofit kit may be higher than the cost of the same kit in developed countries. However, the cost of labour is substantially lower. The components requiring replacement for retrofit are rarely, if ever, changed during normal service. As a result, retrofit costs are in addition to repair costs. However, repair costs cannot be considered as incremental and they should not be taken into account when calculating the retrofit costs. It is estimated that the cost of labour of retrofitting of one car may be in the range of US $15-$30. If the cost of retrofit kit is the same as in developed countries, the estimated cost of retrofitting might be within the range of US $125-$450. Given the amount of CFC-12 used for MACs, charged at the level of 1.3 kg per vehicle, the cost effectiveness of retrofitting would range from US $95-$350/per kg of CFC-12 saved.

Reliability

28. Retrofitting means altering the original system design. Doing so means service industry does not usually know prior usage and maintenance profile of the air conditioning system. The useful life of system components not changed during retrofit will likely be shortened. It means that the risk of secondary failure does really exist and significantly greater additional costs may be involved at a later stage. The servicing shops can not provide any period of guarantee of retrofit done. The engineering estimates made by one company show that the retrofitted system durability may vary from one year to four years depending on the complexity of work done.

29. Retrofits at the special cost of US $60-$90 have been reported, consisting of recovering CFC-12, adding a fill of synthetic oil, and recharging with HFC-134a. This type of least cost solution may seem to be very attractive for developing countries. However, the most recent information published in US MACS Report demonstrated negative results in the application of this approach. Sixty cars were retrofitted using just the base job with no new parts. Within a matter of months there was an unacceptable compressor failure rate (reportedly 25 per cent). The tests were carried out under the conditions of a hot climate in an urban area, similar to those conditions prevalent in most developing countries. Hence, it appears that in the case of Article 5 countries, a low-range retrofitting cost cannot be considered when determining the reliability of retrofits.

Possible Government Actions

30. In order to ensure the success of implementation of recycling programmes, governments in Article 5 countries should take concrete actions, e.g., enactment of legislation to ban venting of CFC-12 during servicing. In addition, governments should provide information and regulations to address the following issues: leakage and venting control measures, certification of service personnel, compatibility of service refrigerants with existing recycling/recovery equipment, procedures to avoid cross-contamination of refrigerants during recovery/recycling, guidelines for proper service procedures during recovery and reclamation. The appropriate knowledge and expertise in this respect exists in developed countries and after certain evaluation can be transferred to Article 5 countries.

31. The retrofitting of a large fleet of vehicles within a country should be done in accordance with unified standards regarding component design, material compatibility, systems chemical stability, and other factors. Many developed countries are in the process of formulating and adopting regulatory measures related to the retrofitting of mobile air conditioning systems. As soon as these activities are finalized, the available information could be transferred to Article 5 countries.

32. Developed countries' automobile industry is committed to eliminating the use of CFC-12 as a vehicle air conditioning refrigerant by the end of 1995. All the leading car manufacturers are aggressively pursuing this policy. Given the fact that many developing countries import used cars from developed countries, the continuous import of such cars with CFC-12 MACs may complicate the implementation of CFC-12 phase-out programme in the MAC sector in those countries. However, it is encouraging to note that some Article 5 countries have indicated in their country programmes the necessity of adopting regulatory measures to prevent the import of CFC-12 MAC vehicles from developed countries after a certain date.

CONCLUSIONS AND RECOMMENDATIONS

33. Recovery/recycling/reclamation and better servicing, coupled with technical assistance, continues to be the most cost-effective approach to thus far substantial reduction in the use of CFC-12 in MAC sector in Article 5 countries. The current CFC-12 consumption rate in MAC service can be reduced at least 50 per cent, making available CFC-12 for servicing of the remaining CFC-12 MAC vehicles in Article 5 countries. Also, activities of Article 5 countries in the industry's conversion to HFC-134a should be encouraged and supported by the Multilateral Fund.

34. It is recommended that Article 5 countries be encouraged to pursue a more aggressive recycling and reclamation programme in MAC sector, and to convert their CFC-12 MAC production plants to HFC-134a technology for new vehicles. Implementing agencies should be requested to intensify their efforts in the implementation of investment projects and technical assistance activities already approved by the Executive Committee and to prepare new investment projects in these areas.

35. Early development and adoption of regulatory measures on containment and recycling, unified standards, material compatibility and others, by the respective Governments of Article 5 countries could provide guidance to both local car manufacturing and the air conditioning service industry as prerequisites for successful ODS phase-out activities. Relevant experience and knowledge can be easily transferred from developed countries with assistance from the Fund.

36. It is recommended that Article 5 countries be encouraged to develop and adopt regulatory measures for better containment and recycling and conversion of MAC manufacturing to HFC-134a technology. Implementing agencies should provide the necessary assistance in transferring the available knowledge and experience for this particular area within their technical assistance activities.

37. The technology of MAC retrofitting is not yet sufficiently mature to be transferred to Article 5 countries. Costs associated with MACs retrofit in Article 5 countries are estimated to be in the range of US $125-$450. Given the average amount of CFC-12 used for charge of air-conditioning systems at 1.3 kg, the cost-effectiveness of retrofits runs from US $95-$350/per kg, making them excessively costly. So far, only a limited number of retrofit kits which have been developed by car manufacturing companies for some car models, are available in the market. MAC retrofitting is under serious consideration in developed countries. There are indications that progress in retrofitting technology and research and development could provide substantial improvements and some reduction in costs. Developing countries still will be able to obtain CFC-12 under the Montreal Protocol through the agreed grace period. A strong case can be made for a decision to await further development of the retrofitting technology until retrofitting is mature enough for transfer to the Article 5 countries.

38. It is recommended that approval of projects in MAC retrofitting be delayed until the retrofitting technology is proven, cost-effective and is adequately mature to be transferred to Article 5 countries. The Executive Committee may wish to request the Secretariat to follow closely the progress in the development of retrofitting technology in the developed countries and to report to the Executive Committee on the state-of-the-art situation.

39. The increasing import of used vehicles with CFC-12 MACs to the Article 5 countries may have a negative impact on the implementation of CFC phase-out programmes in the MAC sector. The pertinent regulatory measures should be adopted in Article 5 paragraph 1 countries in cooperation with developed countries to prevent this situation.

40. It is recommended that the Executive Committee should encourage Article 5 countries to adopt necessary measures to regulate import of vehicles with CFC-12 based MACs.

Chillers

Background Information

41. The air conditioning industry uses two distinct forms of systems:

(a) Direct-expansion systems which cool and dehumidify air via heat transfer to cold refrigerant;

(b) Chilled water systems which cool the water with a refrigerant and then circulate that water through a heat exchanger to cool and dehumidify the air in the conditioned spaces.

42. The key component of a chilled water system is the water chiller, and like direct-expansion systems the chiller can use air or water for heat rejection. There are several different types of compressors used in water chillers. In chillers using positive displacement type compressors HCFC-22 is the common refrigerant. In larger size chillers centrifugal compressors are used, and common refrigerants for centrifugal applications have been CFC-11, HCFC-22 and CFC-12. CFC-11 is used in low pressure systems, CFC-12 and HCFC-22 are used in high pressure equipment.

43. Approximately 8,000 CFC-11 and 2,000 CFC-12 units are currently in service in Article 5 countries. These chillers use about 1000 tonnes of CFC-11 and about 200 tonnes of CFC-12 to make up for leakage and losses during servicing, an average of 120 kg/per chiller/per year. About 700 chillers are being installed annually in Article 5 countries. About 300 tonnes of CFC are being consumed annually for charging new installed chillers. The installed population of chillers in Article 5 countries contain approximately 4,000 tonnes of CFCs. The total annual consumption of Article 5 countries in the chiller sector amounts to 1,500 metric tonnes of CFC-11 and CFC-12 which represents about one per cent of total CFC-11 and CFC-12 consumption in these countries.

44. Some Article 5 countries manufacture CFC-11 and CFC-12 chillers. The total production is estimated at 200 chillers per year. The amount of CFC-11 and CFC-12 required to charge new chillers for operation is estimated at 100 tonnes of CFCs per year.

45. CFC phase-out in the chiller sector may be achieved by combination of the following options:

(a) Improved refrigerant containment and service practices to minimize CFC emissions and conserve the existing refrigerant;

(b) Replacement of CFC based equipment with non-CFCs alterative;

(c) Retrofit (convert) existing chiller to a non-CFC alternative; and

(d) Conversion of manufacturing facilities producing CFC based chillers to non-CFC based chillers.

46. When considering the options available, the following factors should be taken into account which may determine the priorities between and within the choices:

(a) Availability of proven CFC phase-out technology;
(b) Availability of CFCs and alternative refrigerants;
(c) Type and amount of alternative refrigerant required;
(d) Energy consumption;
(e) Equipment refrigeration capacity;
(f) Safety and risk in use;
(g) Ozone depletion potential (ODP);
(h) Total equivalent to the warming impact (TEWI);
(i) Cost-effectiveness; and
(j) Regulatory implications.

47. Existing CFC-11 and CFC-12 water chillers can be replaced with chillers operated with HFC or HCFCs. For the purpose of retrofit, HCFC-123 is the only replacement for CFC-11 and HFC-134a is the only replacement of CFC-12. The technology is proven and is readily available. Several companies in developed countries supply water chillers in a broad range of capacity with HFC-134a, HCFC-123 or HCFC-22.

48. HFC-134a is a long-term alternative refrigerant. It is easily available. HCFC-123 and HCFC-22 are controlled substances under the Montreal Protocol and they are supposed to be phased out by 2030 in developed countries. Recent European Union regulations call for a HCFC phase-out by 2015. The HCFC phase-out schedule for Article 5 countries will be determined in 1995. Given the chiller average useful life of 25-30 years, new HCFC-123 or HCFC-22 chillers installed in Article 5 countries could run their useful lifetime before these refrigerants will be totally phased out.

49. All refrigerants pose health risks at levels above allowable exposure limits, although alternative refrigerants have received particular attention in this regard. Currently, one chemical manufacturer has raised its recommended exposure level for HCFC-123 from 10 parts per million, to 30 parts per million. Other manufacturers have deferred decisions on revising their recommendations pending completion of further testing. Nevertheless, current toxicity tests demonstrate that HCFC-123 can be used safely in centrifugal chillers where exposures are kept in the range of 10-30 parts per million, while HFC-134a can be used safely where exposures are kept below 1000 parts per million. The appropriate safety guidelines should be followed where any refrigerant is installed.

50. When selecting the refrigerant for a water chiller, apart from ODP values of alternative refrigerants, energy consumption should be taken into consideration. Though power consumption is very dependent on age, type and application of the chillers, an average chiller consumes a substantial amount of energy. Even a small percentage of efficiency improvement can lead to

significant savings in energy cost. The potential theoretical energy efficiency data for different refrigerants provide the basis for optimization of refrigerant selection.

51. The selection of refrigerants has important environmental consequences in another area, global warming. According to the UNEP Refrigeration Option Committee Report, "refrigerants affect global warming in two ways:

(a) **direct effect** - refrigerant molecules which escape into the atmosphere absorb infrared radiation from the sun and directly help to heat the atmosphere; direct effect is determined by global warming potential (GWP) value of the refrigerant.

(b) **indirect effect** - refrigerants which make cooling equipment less efficient increase power consumption. As a result, power plants generate more carbon dioxide and nitrous oxides in the atmosphere for many years while the equipment is in service. These combustion products absorb infrared radiation and heat the atmosphere."

Recent studies show that indirect effect is related to energy efficiency of the refrigerant. Indirect global warming effect is dominant and considerably in excess of the direct effect. The combined direct and indirect effects can be calculated and expressed as a total equivalent to the warming impact (TEWI). This characteristic can be used in the process of refrigerant selection. According to industry experts, the direct effect accounts for 2 per cent and the indirect effect accounts for 98 per cent of the TEWI factor. It makes the energy efficiency characteristics more important when considering the global warming issue.

52. On the average, the cost of an installed chiller with 400 tonnes of refrigeration capacity is estimated to be about US $160,000 on the basis of several CIF price quotations in Article 5 countries, which represents a serious investment for any building owner. Given the number of choices available in the chiller sector i.e., containing the refrigerant, replacing the chiller, retrofitting existing chillers with an alternative refrigerant, it is imperative to have an elaborated country strategy. This strategy should be aimed at reduction of ozone depletion and global warming potential, minimizing costs and providing service during the transitional period.

53. The strategy should give consideration to chiller age and remaining life, availability of currently used refrigerant, hours of use, maintenance and repair history, refrigerant supply and possible alternatives, energy and capacity history, equipment enhancements, operational and maintenance practices, and building modernization schedules. The necessary elements of this strategy should include:

(a) Improved operations and maintenance practices and modifications to lessen refrigerant loss;

(b) Life-cycle costing studies to determine which chiller to retain on existing CFC refrigerants and which to retrofit to other alternatives and extend useful chiller life;

(c) Replacement schedule for older less efficient chillers with new CFC free chillers.

The conversion of chiller manufacturing facilities should be another element of country strategy for Article 5 countries which have their own chiller production plants.

54. The elaboration of national strategy for Article 5 countries can be conducted with assistance from implementing agencies as part of project preparation and technical assistance activities. Assessment of financial implication for the Multilateral Fund and for the Article 5 countries together with ODS reduction, should in itself constitute a part of this strategy. The Executive Committee has approved allocations for project preparation activities in three Article 5 countries in the chiller sector.

Refrigerant Containment and Better Operations and Maintenance Practices

55. The average CFC-11 chiller with 400 tonnes of refrigeration capacity contains about 500 kg of refrigerant. Up to 25 per cent of the initial charge or 120 kg of refrigerant per chiller is required annually to replace refrigerant losses in Article 5 countries. It is assumed that about 50 per cent of the loss is associated with equipment leakage, and 50 per cent is due to improper servicing, purging and to maintenance operations. The existing operation and maintenance practices in Article 5 countries have a great potential for improvement. Most of a chiller charge is simply vented off to the atmosphere if major service work is required. It is possible to reduce leakage rate up to 2 per cent of initial charge per year on low pressure chillers and to one per cent on high pressure chillers, i.e., from 120 kg to 5-10 kg of refrigerant per chiller per year, by applying better operations and maintenance practices and installing refrigerant containment devices.

56. Improvement in operations and maintenance practices should lead to significant reduction in refrigerant losses. Developed countries have gained substantial experience in developing operations and maintenance manuals, procedures and regulations. The essential aspects of operations and maintenance practices generally include:

(a) General operations and equipment performance;
(b) Preventive maintenance requirements;
(c) Records keeping and analysis;
(d) Leak diagnosis when records indicate need;
(e) Training and certification of personnel;
(f) Contracted service and repair; and
(g) Recovery, recycling and reclamation of refrigerant.

57. Information on operations and maintenance practices and recovery and recycling equipment is readily available in developed countries and are being transferred to Article

5 countries with the assistance of implementing agencies or directly from developed countries on a bilateral basis. The Executive Committee has already approved four projects at a cost of US $619,500 for training and technical assistance activities in the chiller sector in four Article 5 countries.

58. The vast majority of chiller owners in Article 5 countries have their in-house general maintenance crew. Major equipment makers can offer annual service contracts through their agents in Article 5 countries. It is assumed that less than 20 per cent of chiller population in Article 5 countries is covered by contracted service and repair. The average annual cost of a contract with monthly visit, is about US $1,000 to US $2,000 per year per chiller, excluding spare parts. Contract services may prove to be a good vehicle to provide training and certification programmes to technicians in Article 5 countries.

59. Refrigerant containment is associated with modifications of existing equipment, which reduce refrigerant loss or risk of loss during operation. These modifications may be different for CFC-11 low pressure and CFC-12 high pressure chillers. Low pressure chillers represent the major portion of water chiller population in Article 5 countries and may require the following low pressure full containment equipment:

(a) High efficiency purge;
(b) Back-up relief valve;
(c) Refrigerant storage tank;
(d) External oil filter and isolation/service valves;
(e) Pressurizing system;

60. The containment package for high pressure chiller typically consists of the following items:

(a) Isolation and service valve;
(b) Storage tank; and
(c) Leak check and reduction.

A variety of add-on products and accessories related to refrigerant containment is available from major chiller manufacturing companies. An optimized containment package may cost between US $10,000 and US $15,000 for a low pressure chiller; between US $5,000 and US $10,000 for a high pressure chiller, depending on the manufacture. An addition of a containment package to a well serviced chiller can reduce refrigerant loss to between 1-2 per cent of initial charge. Thus, refrigerant loss can be reduced from 120 kg to 5-10 kg of refrigerant per chiller per year. The containment equipment would be compatible with new non-CFC chillers and can continue to be used after the replacement.

61. Responsible refrigerant management can save substantial amounts of CFC. One can expect significant CFC savings from improvement in operations and maintenance practices and better containment, including recycling/reclamation from the existing chiller population and from disposal of older chillers as they are retired and replaced. Thus, the continuing supply of saved

refrigerants, will significantly contribute to service existing CFC chillers throughout their useful lives. The containment strategy might also provide the time, so the Article 5 countries will be able to take advantage of future technological development of refrigerant and equipment manufacturers. It is estimated CFC emissions could be reduced by up to 400 tonnes per year of the CFC consumption in the chiller sector, when containment and better operations and maintenance practices including recovery/recycling/reclamation are fully introduced for two thirds of chiller population in Article 5 countries. The estimated cost of this programme is about US $10-$15 million, with a cost-effectiveness of US $25-$35 per kg CFC saved.

Conversion of CFC-Based Chiller Manufacturing Facilities to Substitute Refrigerant

62. The Executive Committee has approved a project on conversion of a CFC-11 centrifugal chiller manufacturer to HCFC-123 technology. The technology will be obtained under technical transfer agreement from a major centrifugal chiller producing company. Manufacturing facilities will be modified for production of 25 new HCFC-123 centrifugal chillers per year. The cost of the project is US $567,000.

Replacement of CFC-Based Chillers with Equipment that Operates with Substitute Refrigerants

63. When considering the proper course of action the decision to replace or retrofit existing equipment should be made only after a careful look at the actual costs involved, and taking into account the desirability of limiting capital abandonment to the greatest extent possible. The guidelines and methodology of evaluation of possible options are well-known and available.

64. Currently, replacement chillers use one of four technologies:

(a) Low pressure chillers with HCFC-123 refrigerant;
(b) High pressure chillers with HFC-134a refrigerant;
(c) High pressure chillers with HCFC-22;
(d) Absorption chillers; and
(e) Ammonia chillers.

The latter two options are not considered in this paper. HCFC-123 low pressure, HFC-134a and HCFC-22 high pressure chillers are major candidates for replacement. These three types of chillers are commercially available in the broad range of refrigeration capacity.

65. The Executive Committee approved the project on substitution of HFC-134a for CFC-12 in central air conditioning systems for Venezuela. The incremental costs have been calculated by the World Bank at US $15,000 per chiller replaced, or 10 per cent of the cost of a new HFC-134a chiller of equivalent capacity.

66. The replacement option provides an unequal share of financial burden between an Article 5 country and the Multilateral Fund, except when an old chiller must be replaced anyway. The Article 5 country would finance about 90 per cent of capital costs. However, new

chillers are much more efficient than the chillers of 20 to 30 years ago. Frequently, the improved performance of today's chillers can generate a payback in investment, based on energy savings and less refrigerant losses due to built-in containment devices. Energy and refrigerant savings will depend on efficiency and capacity of a new chiller and current and future costs of electricity and refrigerant, while the potential payback period must be determined on the basis of the specific circumstances in each country. For example, efficiency of the early 1970's version of water-cooled centrifugal chiller is in the range of 0.8-1.0 kwH/ton. Today's water-cooled centrifugals are available with efficiency in the range of 0.55-0.70 KwH/ton. It means that about 30 per cent of energy costs can be saved annually. In one developed country with the cost of energy US $0.05 per kw hour, annual energy savings per chiller might represent about US $15,000. The calculation is based on a typical office building application in a moderate climate with operating conditions at 2000 hours per year. The savings could be much higher in a hospital or process-cooling application in a hot climate where the chiller equipments runs up to 24 hours a day. The difference in efficiency can result in a three-to-four-year payback.

Retrofitting Existing Chiller to Utilize an Alternative Refrigerant

67. Both CFC-11 and CFC-12 water centrifugal chillers can be retrofitted to use HCFC-123 and HFC-134a refrigerants respectively. Although the technology of retrofitting is proven and commercially available, a decision to retrofit the chiller should be made only after careful consideration of the items outlined in paragraph 53.

68. Refrigeration capacity and energy efficiency are the important factors which have to be taken into consideration in retrofitting to HCFC-123. A typical retrofitting of CFC-11 chiller is accompanied by 7 per cent loss in capacity and up to 6 per cent loss in efficiency. Retrofitting of CFC-12 high pressure chillers to HFC-134a usually leads to 4 per cent loss in capacity and 2 per cent in efficiency. However, each case should be examined in detail since various options are available on each retrofit. The cost of retrofitting will depend on whether capacity and efficiency problems are going to be addressed during the retrofitting. Both capacity and efficiency can be optimized by introducing some changes in the chiller design.

69. The cost of retrofitting can also be substantially affected by the type of compressor motor in low pressure chillers, i.e. hermetic, semi-hermetic or open drive. The cost of retrofitting also depends on the age of the chiller. Many CFC-11 centrifugal chillers of 3 years of age and less have features built into the design providing compatibility with HCFC-123 refrigerant. The cost of retrofitting of these chillers is about 15 per cent of the total installed cost of a replacement chiller. Conversion to HFC-134a chiller typically does not have compatibility problems. In general the cost of retrofitting of a chillers of 7 to 20 years of age, usually considered as the best candidate for retrofitting, might be estimated in the range of 20 to 60 per cent of the total installed cost of a replacement chiller. The total installed cost of an average 400 tonnes chiller is estimated at US $160,000 in an Article 5 country. Consequently, the retrofit cost is assumed in the range from US $30,000 to US $90,000 including the cost of labour which is typically about 20 per cent of the total retrofit cost in Article 5 countries. The cost effectiveness of chiller retrofitting may vary from US $48 to US $145 per kg CFC saved.

70. The Executive Committee approved the project on chiller retrofitting in Venezuela submitted by the World Bank for retrofitting of 27 high pressure CFC-12 chillers with the average capacity of 200 tonnes of refrigeration. The average incremental cost of a single retrofitting was calculated at about US $42,000 including labour cost at 25 per cent of the total retrofit cost. The cost-effectiveness is determined at US $135 per kg CFC saved.

71. It is anticipated that 30 per cent of the chiller population in Article 5 countries or 3,000 units are 7-20 years of age. The cost of retrofitting these chillers is estimated to be in the range of US $90 million to US $270 million.

CONCLUSIONS AND RECOMMENDATIONS

72. Technologies of CFC phase-out in the chiller sector, based on several alternatives, are commercially available and can be transferred to Article 5 countries.

73. It is recommended that consideration be given to the Total Equivalent Warming Impact (TEWI) in selecting alternative technology in the chiller sector, which would include both direct effects (refrigerant global warming potential) and indirect effects (system energy efficiency), and to human health and safety aspects.

74. Refrigerant containment and better operation and maintenance practices, including recovery, recycling and reclamation, deserve full attention and can be immediately introduced in Article 5 countries. This would lead to reduction of CFC emissions of up to 400 tonnes of CFCs annually. The cost of this programme is estimated at US $15-20 million. This programme can be implemented within the next three years according to the Three Year Plan and Budget for 1994-1996 approved by the Executive Committee.

75. It is recommended that the Executive Committee approves refrigerant containment and better operation and maintenance practices, including recovery/recycling/reclamation as a strategic option in ODS phase-out in the chiller sector in Article 5 countries. Article 5 countries should be encouraged to pursue a more aggressive refrigerant containment programme including recovery/recycling/reclamation. The implementing agencies should be requested to intensify their efforts in formulation of new investment project in this area.

76. The technology for conversion of CFC-based chiller manufacturing facilities is available and can be transferred to Article 5 countries. Projects to convert CFC-based chiller manufacturing facilities in Article 5 countries to substitute refrigerants can be initiated within the same period of time, which would result in the elimination of 100 tonnes of CFC annually. The implementation of these projects will also prevent the production of new CFC-based chillers, reducing future ODS phase-out costs.

77. It is recommended that the Executive Committee approves conversion of CFC-based chiller manufacturing facilities as a strategic option of ODS phase-out in the chiller sector.

The implementing agencies should be requested to increase their activities in identifying and preparing project proposals in this area.

78. It is recognized that replacement of CFC-based chillers with non-CFC chillers is the most cost-effective solution if energy savings are taken into consideration, and can start immediately. About 350 chillers could be replaced in Article 5 countries, resulting in savings of about 200 tonnes of CFCs.

79. It is recommended that the Executive Committee approves the replacement of CFC chillers as a first priority of strategic options in ODS phase-out in the chiller sector. Implementing agencies should be requested to focus their activities on the replacement options in addressing ODS phase-out in the chiller sector. Energy savings should be taken into consideration when calculating the incremental costs of replacement.

80. Chiller retrofit may be unattractive due to the costs involved. The costs of retrofitting of one-third of the chiller population in Article 5 countries would be within the range of US $90 million to US $ 217 million. Such an expenditure would draw funds away from projects which could achieve over ten times the level of reduction envisioned. Also, it may be of limited application due to expected unavailability of qualified manpower in the immediate future. The situation of CFC supply for Article 5 countries is not yet critical enough to initiate extremely costly actions. There will likely be individual cases when retrofitting is justified e.g., high cost-effectiveness, building conditions cannot allow the chiller replacement.

81. It is recommended that the Executive Committee defer consideration of projects to retrofit chillers, except in very special cases. considered.

82. Projects on CFC phase-out in the chiller sector approved by the Executive Committee, should be coupled with regulatory measures undertaken by the respective governments in Article 5 countries.

83. It is recommended that the Executive Committee encourages the governments in Article 5 countries to give full consideration to appropriate regulatory and legislative actions facilitating the implementation of CFC phase-out projects in the chiller sector. These should include an immediate cessation in the installation of new CFC chillers.