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SAFETY RELATED COSTS IN PROJECTS USING HYDROCARBON TECHNOLOGY

CONTENTS

INTRODUCTION

1. This paper is submitted in response to the Executive Committee Decision 17/14 regarding safety costs associated with conversion of domestic refrigeration plants to hydrocarbon technology, which reads as follows:

> "The Executive Committee, noting its decision at its Fifteenth Meeting to presume against the use of HCFCs in investment projects, recognizing the higher cost of hydrocarbon technologies, primarily due to safety factors, and desiring to ensure an equality between technology options consistent with that decision decided:
>
> (a) That for the purposes of calculating the cost-effectiveness value of projects utilizing such technologies, the numerator should be discounted by up to 35 per cent. It is expected that these figures will be adjusted in the light of experience and a study on safety matters to be conducted by the Secretariat;
>
> (b) To request the Secretariat to analyze projects in the pipeline for the commercial refrigeration sector and the rigid polyurethane sector where hydrocarbon technologies are used, and to inform the Executive Committee of the results at its Eighteenth Meeting."

STUDY ON SAFETY MATTERS

2. An examination of projects using hydrocarbon technologies showed that safety requirements in domestic refrigeration projects vary not only from country to country, but also from project to project even when the same technology is used. While the baseline situation regarding existing conditions at particular enterprises may be different, it is evident that there is scope for defining the general precautions required for safe operations involving hydrocarbon technologies in domestic refrigeration production.

3. Therefore, in accordance with the request of the Executive Committee, the Secretariat engaged an independent consultant to undertake a technical study on safety matters involved in conversions to hydrocarbons. The technical study has been undertaken in two parts. The first part addresses:

- basic safety concepts
- available international safety regulations
- risk calculations due to emission of flammable substances
- major changes in processes and equipment due to safety requirements
- training requirements and inspection and certification requirements on the basis of experience gained by enterprises in non-Article 5 countries converted to hydrocarbon technologies.

4. The second part of the study provides detailed information on the equipment required to implement a hydrocarbon project, based on the principles outlines in the first part. This includes cost estimates of all major equipment components involved in the conversion to hydrocarbons.

5. Copies of the study are available from the Secretariat upon request.

6. Following discussion of the study by the implementing agencies and the Secretariat, consideration will be given to whether changes to the templates which cover hydrocarbon projects are warranted. Any policy issues that might arise will be brought forward to the Executive Committee as they emerge.

DISCOUNTING BY 35%

7. The technical study provides a great deal of detailed information which is of direct relevance to the preparation of technical parameters such as those contained in project templates. However, the determination of cost-effectiveness for any project is dependent on the size of the project and the specific circumstances which apply for the enterprise concerned, especially the baseline situation. If this were not the case, all projects in a sub-sector could be expected to have similar cost-effectiveness values.. Clearly, this is not so. Therefore, the technical study does not provide a sound basis for verifying whether the 35% discounting factor is sufficient to cover necessary safety costs.

8. The approach adopted in this paper is a statistical analysis of the projects which were in the pipeline at the 17th Meeting and have now been approved by the Executive Committee. The analysis has also included all other projects approved in the domestic refrigeration sector. It thus provides an overall comparison of costs for conversion to hydrocarbon and non-hydrocarbon technologies. Such an analysis is valid because the difference in costs is primarily related to the additional measures necessary to achieve safe operation of the enterprise when hydrocarbon technologies are employed.

9. Decision 17/14 establishes a methodology for calculation of cost-effectiveness for projects using hydrocarbons. In particular, the decision states that the 35% discounting is to be applied to the numerator of the cost-effectiveness figure. The numerator consists of both capital and operating costs. Capital costs are higher because safety related equipment is needed; however, operating costs are lower because the substances used are less expensive. The objective of the statistical analysis is to examine both the capital and operating costs for hydrocarbon and non-hydrocarbon technologies, in approved projects and to determine whether the 35% discounting factor is sufficient to maintain parity between projects based on hydrocarbon and non-hydrocarbon technologies or, as a minimum condition, to enable projects with hydrocarbon technology to meet the cost-effectiveness threshold.

10. Hydrocarbon technologies were first introduced in projects in the domestic and commercial refrigeration sectors in 1994. Since then the implementing agencies and the

Secretariat have been gaining experience in dealing with this technology. The data base of approved projects was not extensive enough to prepare the analysis before the 18th Meeting of the Executive Committee. Therefore, this paper has been prepared for the 20th Meeting.

DOMESTIC REFRIGERATION

Background

11. Two controlled substances are used in manufacturing domestic refrigeration appliances. CFC-11 is used as a blowing agent for insulation foam, and CFC-12 is used as a refrigerant in the cooling system.

12. The replacement of CFC-11 started with the introduction of reduced CFC-11 formulations. The Executive Committee approved several projects based on a 50% reduction of CFC-11. After a very short period of time this approach was replaced with the introduction HCFC-141b which was applied in Article 5 countries prior to 1994. A number of projects approved with CFC-11 reduced technology, were later reformulated to use HCFC-141b as a blowing agent. However, HCFCs became controlled substances for Article 5 countries in 1995. In addition, the Executive Committee has taken several decisions regarding the use of HCFCs. In particular the 17th Meeting of the Executive Committee emphasized a presumption against HCFCs when preparing projects for Article 5 countries and requested that where HCFC projects were proposed, the choice of this technology should be fully justified including an estimate of the potential future costs of second stage conversion. The 19th Meeting further reinforced this decision.

13. A technology based on the hydrocarbon cyclopentane as a foam blowing agent, was developed and introduced in Article 5 countries at the beginning of 1994. Since that time, a total of 59 projects using cyclopentane blowing agent have been approved, which represents 57% of total projects approved by the Executive Committee in the domestic refrigeration sector.

14. HFC-134a is the predominant substitute for CFC-12 refrigerant in projects submitted. However, introduction of a new technology based on the hydrocarbon isobutane as a refrigerant commenced in 1995. Eight projects using isobutane refrigerant have been approved to-date.

Scope and Methodology

15. The analysis used for the domestic refrigeration sub-sector covers 104 projects approved by the Executive Committee for conversion of domestic refrigeration plants in Article 5 countries since the inception of the Fund.

16. The approach which has been adopted is to calculate a theoretical average cost-effectiveness for projects with similar technologies and to compare the hydrocarbon and non-

hydrocarbon figures with each other and with the established cost-effectiveness threshold for the sector, US $13.76 per kilogram. Theoretical cost-effectiveness figures were calculated rather than using actual project values, so projects with varying operating cost durations, export percentages and foreign ownership percentages could be compared. The comparison is thus related directly to the physical, or engineering, characteristics of the projects, rather than their financial characteristics.

17. The data analyzed consisted of:

(a) capital costs including safety related costs (using the total eligible safety related costs for each project.)
(b) operating costs
(c) actual production output (i.e. number of units produced by an enterprise per year)
(d) amount of grants approved
(e) deductions due to foreign ownership and export to Article 5 countries.
(f) project cost

18. The theoretical average cost-effectiveness was calculated in a two stage process. The first stage was to calculate the incremental cost per unit of production, that is, the incremental costs for one refrigerator. This cost is equivalent to the numerator in the cost-effectiveness formula and can be converted into capital and operating costs for a project of any size by multiplying by the number of units per year that the enterprise produces.

19. This methodology enables a clear comparison of both capital and operating costs for each technology, and shows how lower operating costs for hydrocarbon partially offset higher capital costs. Capital costs for each project were recalculated to include all costs relating to export or foreign ownership and operating costs were standardized to 6 months duration, prior to the calculation of theoretical cost-effectiveness.

20. In the second stage of the calculation, the average incremental costs per unit were converted to theoretical average cost-effectiveness figures, by dividing by the average ODP consumption of one unit (refrigerator), which was also derived directly from project data.

Analysis

21. The 104 approved projects were classified into the following three categories, based on the technology used:

Category 1: Conversion from CFC-11 to HCFC-141b blowing agent and from CFC-12 to HFC-134a refrigerant, (non-hydrocarbon);

Category 2: Conversion from CFC-11 to cyclopentane blowing agent and from CFC-12 to HFC-134a refrigerant, (part-hydrocarbon);

Category 3: Conversion from CFC-11 to cyclopentane blowing agent and from CFC-12 to isobutane refrigerant, (all-hydrocarbon).

22. Within each category a further classification based on the size of production was also made because costs per unit can vary according to the size of the enterprise. A production level of 100,000 units was selected as the mid-point. This figure represents a reasonable statistical division of projects . It is also consistent with the accepted definitions of higher and lower production level in this sub-sector. Table 1 summarizes all the projects included in the analysis, broken down by category and size.

TABLE 1

	Number of projects approved		
Units per year	Category 1 Conversion to HCFC-141b/ HFC-134a	Category 2 Conversion to cyclopentane / HFC-134a	Category 3 Conversion to cyclopentane / isobutane
<100,000	23	38	4
>100,000	18	17	4
TOTAL	41	55	8

23. For each technology category and each of the two projects size groups, the average capital cost and average operating cost were calculated using data from individual projects, taking into account the parameters listed in paragraph 17 above. The findings are presented in Table 2, which compares Category 1 (non-hydrocarbon) with Category 2 (part-hydrocarbon) technology, and Table 3, which compares Category 1 (non-hydrocarbon) with Category 3 (all-hydrocarbon) technology.

TABLE 2

Comparison of unit costs for Category 2 projects (part-hydrocarbon) and Category 1 projects (non-hydrocarbon)								
	HCFC-141b/HFC-134a			Cyclopentane/HFC-134a				
	US $/unit			US $/unit			Percentage increase	
Unit/yr.	Capital costs	Operating costs	Total costs	Capital costs	Operating costs	Total costs	Capital costs	Total costs
<100,000	21.9	4.5	26.4	27.53	3.25	30.78	25.71%	16.80%
>100,000	3.98	4.5	8.48	9.16	3.25	12.41	130.15%	46.30%

24. Table 2 shows increases of 26% and 130% respectively in the capital costs/unit for cyclopentane/HFC-134a projects in enterprises producing less than 100,000 units per year and enterprises producing more than 100,000 units per year, compared to the projects using HCFC-141b/HFC-134a technology. However, when six months of operating costs are taken into consideration (as shown in the "operating cost" column) the net increase in total project cost is reduced to 16.8% and 46.3% respectively. The difference reflects the impact of lower operating costs in the case of cyclopentane technologies, which partially offset the capital costs associated with safety.

TABLE 3

Comparison of unit costs for Category 3 projects (all-hydrocarbon) with Category 1 projects (non-hydrocarbon)								
	HCFC-141b/HFC-134a			Cyclopentane/isobutane				
	US $/unit			US $/unit			Percentage increase	
Unit/yr.	Capital costs	Operating costs	Total costs	Capital costs	Operating costs	Total costs	Capital costs	Total costs
<100,000	8.47	4.5	12.97	19.37	0.75	20.12	128.7%	55.1%
>100,000	3.98	4.5	8.48	9.06	0.75	9.81	127.6%	15.60%

25. Table 3 demonstrates a similar increase in capital costs per unit of cyclopentane/isobutane technology compared to HCFC-141b/HFC-134a technology. This increase amounts to 128.7% for enterprises producing less than 100,000 units per year, and 127.6% for enterprises with a production output of more than 100,000 units. However, when six months of operating costs are included the net increase in total project costs amounts to 55.1% and 15.6% respectively.

26. In order to examine the equality between technology options in relation to the policies of the Executive Committee, the average cost-effectiveness figures for each technology category and enterprise size are needed. These were obtained directly from the average cost per unit value in Tables 2 and 3 using the average ODP consumption of one refrigerator (foam plus refrigerant) of 0.97 kg, derived from project data. The figures obtained are presented in Tables 4 and 5.

TABLE 4

Comparison of cost-effectiveness of Category 2 projects (part-hydrocarbon) with Category 1 projects (non-hydrocarbon) and with threshold value				
Production	C.E. threshold US $/kg	Theoretical average C.E. US $/kg		Percentage increase in theoretical average C.E.
Unit/Year		HCFC-141b/ HFC-134a	Cyclopentane/ HFC-134a	
<100,000	13.76	27.2	31.73	16.6%
>100,000	13.76	8.74	12.79	46.3%

TABLE 5

Comparison of cost-effectiveness of Category 3 projects (all-hydrocarbon) with Category 1 projects (non-hydrocarbon) and with the threshold value.				
Production	C.E. threshold US $/kg	Theoretical average C.E. US $/kg		Percentage increase in theoretical average C.E.
Unit/Year		HCFC-141b/ HFC-134a	cyclopentane/ isobutane	
<100,000	13.76	13.37	20.74	55.1%
>100,000	13.76	8.74	10.11	15.6%

Discussion of Results

Cyclopentane/HFC-134a Technology

27. For enterprises with a production level of more than 100,000 units per year, the average theoretical cost-effectiveness is 12.79, (Table 4) that is, below the threshold of 13.76. This is sufficient to ensure equality between technology options without the application of any discounting factor since all projects below the threshold are eligible for funding and in current circumstances, all such projects approved by the Executive Committee are funded without significant delay.

28. For enterprises with a production level of less than 100,000 units per year, the average theoretical cost-effectiveness is 31.73 (Table 4). This is 16.6% more than the average theoretical cost-effectiveness of non-hydrocarbon projects, which has a value of 27.2. It should be noted however, that this theoretical cost-effectiveness figure includes adding-in items discounted from normal project calculations. Thus, it is to be expected that an average theoretical cost-effectiveness will be higher than the actual cost-effectiveness of approved projects and can be higher than the threshold values.

29. In these circumstances, equality of applicants will be achieved if the theoretical average cost-effectiveness of hydrocarbon technology is no greater than the theoretical average cost-effectiveness of the non-hydrocarbon technology, even if both are above the threshold value for the sub-sector. In this case, since the difference between hydrocarbon and non-hydrocarbon technologies is only 16%, application of a 35% discount will be sufficient to maintain parity.

Cyclopentane/Isobutane Technology

30. While the analytical methods adopted for analysis of all-hydrocarbon projects are the same as those used for part-hydrocarbon technology, the statistical sample is very small. Only 8 projects, 4 large (>100,000 units production) and 4 small (<100,000 units), have been approved. The results described below may be indicative of the possible situation with projects using this

technology, but the margin for error is high. The results therefore do not represent a reliable basis for decision making.

31. For enterprises with a production level of more than 100,000 units per year, the difference in average theoretical cost-effectiveness values between all-hydrocarbon and non-hydrocarbon technologies is 15.6% (Table 5), which is well below the 35% discounting factor. Additionally, the average theoretical cost-effectiveness figure is below the threshold for the sub-sector. This indicates that all projects in this sub-category, both the hydrocarbon and non-hydrocarbon, are likely to be eligible for approval by the Executive Committee. The trend, therefore, is that large all-hydrocarbon projects may not be disadvantaged by a 35% discounting factor and, in fact, might be able to compete equally without any discounting.

32. For enterprises with a production level below 100,000 units per year, comparison of theoretical average cost-effectiveness values was derived from non-hydrocarbon projects in the range of 31,000-100,000 units, to provide a basis for comparison with the 4 all-hydrocarbon projects in the same consumption range. Table 5 indicates that the theoretical average cost-effectiveness for all-hydrocarbon projects is US$ 20.74 per kilogram, which is 55.1 % higher than non-hydrocarbon projects at US$ 13.37 per kilogram. This may indicate a trend that small projects using cyclopentane/isobutane technology could be disadvantaged in comparison to HCFC-141b/HFC-134a projects.

CONCLUSIONS FOR DOMESTIC REFRIGERATION

33. There has been a learning curve in adapting ODS phase out technologies for Article 5 countries, in domestic refrigeration. The first project with cyclopentane based technology was approved in November 1993. Since that time the maturity of hydrocarbon technology has been growing rapidly. The number of conversions to hydrocarbon technologies and the experience gained in non-Article 5 countries is leading to improvement in technology transfer and a better understanding of safety concepts. As demand for equipment associated with conversions to non-CFC technologies grows, the cost of equipment, including safety equipment, has been declining. The implementing agencies in co-operation with the Secretariat have undertaken the preparation of templates to standardize capital costs including safety costs. The Secretariat and implementing agencies are in the process of monitoring the effectiveness of the templates. The Study on safety associated with hydrocarbon technologies will contribute further to the process of standardization of incremental costs associated with safety.

34. The statistical analysis of all domestic refrigeration projects, including projects in the pipeline at the 17th Meeting indicates that:

(a) There is an increase in both the capital and total cost per unit for all-hydrocarbon technologies compared to HCFC/HFC based technologies. The increase in the total project cost (capital plus operating cost) ranges between 15.6% to 55.1% for different categories of projects.

(b) Discounting the numerator by 35% is sufficient to maintain parity between HCFC-141b/HFC-134a and cyclopentane/HFC-134a technology options in the domestic refrigeration sector.

(c) The number of projects approved for cyclopentane/isobutane technology is not sufficient to enable reliable conclusions to be drawn.

COMMERCIAL REFRIGERATION

Background

35. Similarly to the domestic refrigeration sector, two controlled substances are used in manufacturing commercial refrigeration products. CFC-11 is used as a blowing agent for insulation foam, and CFC-12 is used as a refrigerant in the cooling system.

36. HFC-134a is the only substitute which has been used in commercial refrigeration projects to replace CFC-12 refrigerant. Two substitutes are available for replacement of CFC-11; HCFC-141b and cyclopentane. These two substances have been used in commercial refrigeration projects since 1994. Of the 58 projects approved in this sector, 19 projects are based on cyclopentane technology. Cyclopentane is a flammable substance and precautionary measures are required to ensure safe operations.

37. The salient feature of the commercial refrigeration sector is the large variety of products manufactured by enterprises. Typically, these products can be classified as unitary or non-unitary commercial refrigeration equipment. Unitary equipment includes display cabinets, chest and vertical freezers, bottle coolers, commercial refrigerators, ice makers, and drinking fountains. Non-unitary equipment includes walk-in freezers, cold rooms, cold stores, and refrigerated trucks. Commercial refrigeration enterprises can also produce insulation panels to be assembled outside the factory.

38. The average size of enterprises for which projects have been funded is about 20,000 units per year. The cost-effectiveness threshold established by the Executive Committee for the commercial refrigeration sector is US $15.21/kg. The foam part of the projects is predominant in

commercial refrigeration because commercial refrigeration units generally require more foam than domestic refrigerators.

Scope, Methodology and Analysis

39. Projects were sub-divided into the following two categories:

1. Projects for conversion to HCFC-141b and HFC-134a; and

2. Projects for conversion to Cyclopentane and HFC-134a.

There are 39 projects in Category 1 and 19 projects in Category 2.

40. Capital costs for all projects have been recalculated and any costs deducted for foreign ownership and export to non-Article 5 countries have been re-instated. This provides a basis for comparing actual project costs. Operating costs have also been recalculated for projects in both categories to reflect equal one-year durations.

41. Give the variety of products and the variations in the size (and the cost and consumption), it was not feasible to use cost per unit to compare the technologies. Rather, after standardizing the capital and operating costs as indicated above, cost-effectiveness values were determined separately for each project and the theoretical average values calculated for each project category.

42. Additionally, the theoretical average cost-effectiveness was calculated in the same way using only the standardized capital cost, to demonstrate the effect of operating costs on the overall cost-effectiveness of projects in this sub-sector. The results of the analysis are presented in Table 6.

TABLE 6

Cost-effectiveness threshold US$/kg	Cost-effectiveness based on capital costs only			Cost-effectiveness based on full (capital + operating) costs		
	HCFC-141b/ HFC-134a	Cyclopentane/ HFC-134a	Percentage increase	HCFC-141b/ HFC-134a	Cyclopentane/ HFC-134a	Percentage increase
15.21	11.31	14.66	29.6	14.14	15.37	8.7

Discussion of Results

43. The theoretical average cost-effectiveness of projects using cyclopentane-based technology based only on capital costs exceeds the similar value for non-hydrocarbon based technology by 29.6 per cent. This reflects the increase in capital costs arising from funding for the safety measures needed for cyclopentane foam. The increase is offset by lower operating costs.

Table 6 shows that the theoretical average cost-effectiveness for cyclopentane based technology, taking both capital and operating costs into account, is 8.7 per cent greater than HCFC-141b based technology.

44. The theoretical average cost-effectiveness of both hydrocarbon and non-hydrocarbon technologies differs by less than 10 per cent, and the figure for hydrocarbon technology is within one per cent of the threshold established for the commercial refrigeration sector.

CONCLUSIONS FOR COMMERCIAL REFRIGERATION

45. On the basis of the above analysis, there is no need for the introduction of a discounting factor to account for the additional safety costs needed for hydrocarbon technology in the commercial refrigeration sector, because on average, projects using hydrocarbon technologies are within one per cent of the cost-effectiveness threshold for the sector and therefore will not be disadvantaged for consideration for funding.

RIGID POLYURETHANE FOAM

Background

46. CFC-11 was the predominant foam blowing agent in the rigid polyurethane foam sub-sector. This sub-sector covers a variety of applications in which polyurethane foam is used as an insulating material. These applications include the manufacture of thermoware, water heaters, ice-boxes, insulation boards, panels and blocks, pipe insulation and in-situ applications as a spray and cavity filling foam.

47. There are several replacement technologies in projects approved by the Executive Committee. They are based on HCFC-141b, HCFC-22/HCFC-142b, water and carbon dioxide, and hydrocarbons (N-, iso-, and cyclo-pentane). Hydrocarbons are flammable and require safety considerations. Therefore, investment costs for hydrocarbon technology projects are typically higher than those using HCFC or water carbon dioxide based formulations. At the same time operating costs for hydrocarbon based technologies are lower, reflecting the lower cost of the materials used. The cost-effectiveness threshold established by the Executive Committee for rigid polyurethane foam is US$ 7.83/kg.

Scope, Methodology and Analysis

48. Projects were divided into two categories as follows:

1. Projects for conversion to HCFC-141b, other ODS chemicals, or to water and carbon dioxide.

2. Projects for conversion to hydrocarbons.

49. The analysis included 18 non-hydrocarbon projects and 12 hydrocarbon projects: of the non-hydrocarbon projects, only 3 employed the water and carbon dioxide technology, which was insufficient for a separate analysis.

50. Using a similar methodology to that adopted for the commercial refrigeration sub-sector, capital costs for all projects have been recalculated and any costs deducted for foreign ownership and export have been re-instated. This provides a basis for comparing actual project costs. Operating costs have also been recalculated for projects in both categories to reflect equal two-year durations, the norm in this sub-sector during the period when most of the projects analyzed were approved.

51. Again, given the variety of products in the sub-sector, cost per unit of production was not used. Using standardized project costs, as indicated above, cost-effectiveness values were determined separately for each project and the theoretical average value calculated for each project category. This was done on the basis of capital costs only, and total (capital plus operating) costs, to demonstrate the effect of operating costs on the overall cost-effectiveness.

52. The theoretical average cost-effectiveness value was derived for all non-hydrocarbon projects with a CFC-11 consumption higher than 50 ODP tonnes, to provide a basis for comparison with all the hydrocarbon projects, which were in the same consumption range. The results of the analysis are presented in Table 7.

TABLE 7

Cost-effectiveness threshold US$/kg	Cost-effectiveness based on capital costs only			Cost-effectiveness based on full (capital and operating) costs		
	Non-hydrocarbon	Hydrocarbon	Percentage increase	Non-hydrocarbon	Hydrocarbons	Percentage increase
7.83	3.22	5.57	72%	5.13	6.08	18.5%

Discussion of Results

53. Using capital costs only, the theoretical average cost-effectiveness of rigid polyurethane foam projects based on hydrocarbon technology is 72% higher than the similar value for non-hydrocarbon technology, reflecting the funding of safety-related equipment items. The use of cyclopentane follows the established pattern of having much lower operating costs than non-hydrocarbon technologies. Thus when operating costs are added to produce the overall theoretical average cost-effectiveness, the difference between hydrocarbon and non-hydrocarbon technologies is decreased to 18.5%.

54. Again, the theoretical average cost-effectiveness for each technology is below the actual threshold for the sub-sector of 7.83 US$/kg.

CONCLUSIONS FOR RIGID POLYURETHANE FOAM

55. There is no need for the introduction of a discounting factor to account for the additional safety costs for hydrocarbon technology in the rigid polyurethane foam sub-sector, because the above statistical analysis shows that on average, projects using hydrocarbon technology are already below the cost-effectiveness threshold for the sector, and thus will not be disadvantaged for consideration for funding.