Social and Economic Implications of Controlling the Use of Chlorofluorocarbons in the EEC

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Social and Economic Implications of Controlling the Use of Chlorofluorocarbons in the EEC

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PREFACE

The primary purpose of this study of the social and economic implications of chlorofluorocarbon regulation in the EEC is to assist the Commission of the European Communities when it re-examines the fluorocarbon-ozone depletion issue towards the end of 1978, and in the light of the latest evidence and advice then available considers whether restrictions on the manufacture and use of chlorofluorocarbons in the Community are necessary and, if so, what forms and timescales of regulation should be proposed.

The study was initiated and supervised on behalf of the Commission by the Environment and Consumer Protection Service, and was conducted in two stages. In the first, attention was concentrated on the main applications of fully halogenated chlorofluorocarbons and the feasibility of replacing them with other substances free from environmental risks, or with other products or systems capable of fulfilling the same functions. On the basis of the interim findings, decisions were taken on the regulatory scenarios to be evaluated and other questions to be examined in the second stage of the study.

Readers for whom this report is mainly intended are likely to be acquainted with the scientific, technological and socio-economic context, and it has been assumed unnecessary to include lengthy and detailed explanations, for example, of the ozone depletion theory, or the chemical nature of fluorocarbons.

UNITS AND TERMINOLOGY

1. Metric Units are used throughout, and a ton is therefore a metric ton (or 'tonne') of 1000 kilograms.

2. Monetary Values are generally quoted in terms of UCE units of account, and values originally advised to Metra in terms of national currencies have been converted to UCE by applying the official conversion rates obtaining in June 1978. For the member states of the Community and for the USA these rates were as follows:

Country and National Currency Unit		National Currency Equivalent of 1 UCE in June 1978
Belgium	BFR	) 40.2458
Luxembourg	FLux	)
West Germany	DM	2.57318
Netherlands	HFL	2.75838
United Kingdom	UKL	0.672698
Denmark	DKR	6.92859
France	FF	5.65196
Italy	LIT	1065.0
Ireland	IRL	0.672698
U.S.A.	USD	1.23236

3. Fluorocarbon: a general term for compounds of carbon and fluorine, which may also contain other halogens and hydrogen.

4. Chlorofluorocarbon: a general term for compounds of carbon, chlorine and fluorine, which may also contain hydrogen. This report is mainly concerned with chlorofluorocarbons which are members of two series of chlorofluoroalkanes:

chlorofluoromethanes, general chemical formula $CH_aCl_bF_c$, where a+b+c = 4

chlorofluoroethanes, general chemical formula $C_2H_xCl_yF_z$, where x+y+z = 6

5. CFC : an abbreviation signifying a chlorofluorocarbon.

6. Fluorocarbon Reference Number System

Specific fluorocarbons and azeotropic mixtures of fluorocarbons are designated by the letter F followed by a number indicating the chemical identity. The internationally accepted numbering system is used, and the ground rules for the two and three digit numbers representing the individual chlorofluoromethanes and chlorofluoroethanes are as follows:

The first digit on the right is the number of fluorine atoms in the molecule.

The second digit from the right is the number of hydrogen atoms plus one.

The third digit is the number of carbon atoms minus one, and is omitted if zero - i.e. when the molecule contains only one carbon atom.

For the chlorofluoroalkanes, the number of chlorine atoms is the difference between the sum of the numbers of hydrogen and fluorine atoms in the molecule, and the total number of hydrogen or halogen atoms needed for saturation, i.e. 4 in chlorofluoromethanes, and 6 in chlorofluoroethanes.

Hence, F-12 represents dichlorodifluoromethane (CCl_2F_2); F-114 represents dichlorotetrafluoroethane ($C_2Cl_2F_4$), and F-22 is monochlorodifluoromethane($CHClF_2$).

Other rules come into play to deal with isomers, azeotropes, cyclic and unsaturated compounds, and compounds containing halogens other than chlorine and fluorine.

Where appropriate in the text, the chemical names and formulae are added for clarification.

7. Aerosols and Propellants

In this report the term aerosol normally signifies a complete aerosol dispenser, defined as a non-reusable container made of metal, glass or plastic and fitted with a valve or other release device allowing the contents to be expelled in a controlled manner by the action of an internal source of pressure when the valve is operated.

The internal pressure source is most commonly a gas, termed the propellant, which may be compressed, liquefied or dissolved under pressure, in current EEC regulations the term aerosol dispenser is restricted to pressurised packs in which a propellant gas is used. Technically, however, the above definition of an aerosol includes packages in which the internal pressure is provided mechanically, for example by a spring or elastomeric bag, but it excludes devices which must be pumped or squeezed by externally applied force.

An aerosol unit is a single, filled and ready-to-use aerosol dispenser, irrespective of value, dimensions or content.

SUMMARY

Statistics for the production and end-use of the chlorofluorocarbons F-11, -12, -113 and -114 in the EEC in 1976 and 1977 are analysed and compared with data for the rest of the world.

The impacts of three regulatory scenarios on the chlorofluorocarbon manufacturing and allied industry sectors and on the aerosol industry are examined:

(1) A ban on the use of perhalogenated chlorofluorocarbons in aerosols other than those exempted on 'essential use' grounds, effective 3 years from the end of 1978.

(2) A ban as in (1) but coming into effect 5 years from the end of 1978.

(3) Reduction of CFC usage in aerosols over a 3-year period to 50% of the usage in an earlier selected year, followed by a ban as in (1) and (2) after a further two years if warranted by the prevailing status of the ozone depletion theory.

The other main applications of chlorofluorocarbons, for refrigeration and air conditioning, foam plastic manufacture and cleaning solvents are reviewed from the standpoint of the potential substitution or reduction of release into the atmosphere.

CONCLUSIONS

A. Chlorofluorocarbon Production and Use Statistics

A.1 Collated statistics provided by independent accountants to whom all CFC manufacturers submitted returns show that EEC production and imports of F-11, 12, 113 and 114 in year 1977 totalled 343 thousand tons, a reduction of 7 thousand tons on the 1976 total. Imports probably did not exceed 10 thousand tons in either year.

A.2 Sales of the four CFCs in 1977 amounted 339 thousand tons, of which 87 thousand (25.6%) were exported outside the EEC, and F-11/12 sales accounted for 92.6% of the total.

A.3 Distribution of EEC sales by end use in 1977 was as follows:

	F-11/12	F-113/114
Sales in EEC - thousands of tons	233.0	19.3
Distribution	%	%
Aerosol propellants	69.8	27.2
Refrigeration and air-conditioning	8.7	1.2
Foam plastics	19.4	5.1
Solvent and other uses	2.1	66.5
	100.0	100.0

A.4 Sales for aerosols in the EEC fell from 182.1 thousand tons in 1976 to 167.8 thousand tons in 1977, a drop of 7.8%. Refrigeration sales showed little change at 20.9 and 20.5 thousand tons respectively in 1976 and 1977, but sales for foam plastics rose from 42.5 to 46.2 thousand tons, an increase of 8.7%. Significant growth also occurred in the solvent and other uses category, from 16.0 to 17.7 thousand tons, a rise of 10.4%.

A.5 Sales of F-11/12 in the EEC in 1977 were 10 thousand tons above the consumption reported by OECD for 1974; in that year EEC consumption accounted for 31.8% of that of the OECD countries total, and the USA for 51.5%.

A.6 The 1977 EEC sales of F-11 and F-12 represented one third of the world sales of 698 thousand tons by the 20 CFC manufacturing companies reporting under a scheme administered by the MCA (U.S. Manufacturing Chemists Association), and whose sales amounted to 92.5% of the estimated world production in 1977 of 755 thousand tons of F-11/12.

A.7 A comparison of the 1977 sales category patterns within and outside the EEC reveals substantial differences: aerosol propellants accounted for 70% of F-11/12 sales in the EEC but only 38% of non-EEC sales. The proportions for foam plastics were similar at around 18%, but while refrigeration and air conditioning accounted for 8.7% of EEC sales, they made up 34% of the non-EEC total. Reasons for these disparities include the slump in USA aerosol sales due to the ozone depletion issue which has not been parallelled in the EEC, and to the greater use of refrigeration and air conditioning in certain countries outside the EEC, especially in the USA where automotive air conditioning is a significant CFC consumer.

The effectiveness of any regulatory action designed to reduce CFC release to the atmosphere could be affected by changes in the CFC consumption pattern, because reductions secured by restrictions on particular compounds and uses could be nullified by growth in other CFC production and application sectors. Although the MCA monitoring system is invaluable in a global context, the analysis in this study shows that CFC usage can vary considerably from one region to another. It is believed, therefore, that EEC production, use, imports and exports of CFCs should be monitored for as long as the possibility of regulation exists, and also during the time during which any enacted regulation remains in force.

B. The Fluorocarbon Manufacturing Industry

B.1 Chlorofluorocarbons are manufactured in the EEC by ten companies in five countries: France (2), West Germany (3), Italy (1), Netherlands (2) and the UK (2). All the producers are members of major multi-national groups and the output of one of the West German producers is marketed by another. Because there are no more than two producer-marketers in any one country there is a reluctance to disclose production and sales data except for aggregation on an EEC basis as was done for this study.

B.2 Total CFC production capacity in the EEC is estimated at about 422,000 tons per year and output in 1977 is thought to represent less than 80% of capacity.

B.3 CFCs are produced by the catalytic fluorination of chlorocarbons with hydrogen fluoride made from sulphuric acid and acid grade fluorspar. The principal chlorocarbon precursor is carbon tetrachloride, mostly made by chlorinating either methane, or propylene derived from naphtha cracking. By-product hydrochloric acid arises from the chlorination and fluorination processes.

B.4 Over half the 1977 CFC sales were in producers' home markets and over half the balance was exported outside the EEC. The total value of 1977 sales volumes of F-11, 12, 113 and 114 at mid-1978 prices is assessed at UCE 177 million, and the added value of the export sales is estimated at about UCE 48 million.

B.5 Sales projections based on a number of assumptions as to growth rate and exportation indicate that bans on the use of CFCs in most aerosols in 1982 or 1984 would reduce sales of F-11/12 to 41.5% and 51.0% respectively of the 1977 sales volume. This would reduce average plant utilisation to less than 40%, which is below viable levels for continuous process CFC plants. In the context of the regulatory scenarios it is concluded that reduction in operating capacity would be inevitable, and that collaborative action would be desirable to rationalise manufacture so as to minimise production and distribution costs.

B.6 The forecast of strong growth in F-113 sales for solvent applications could lead to demand for F-113/114 being higher from 1982 onwards under regulation than in 1977 despite the loss of the F-114 aerosol market.

B.7 The regulatory scenarios would cause major imbalances in demand for the two pairs of compounds, and the F-11/F-12 sales ratio could move from 52 : 48 in 1977 to 76 : 24 under Scenario (1) in 1982, or 72 : 28 under Scenarios (2) and (3) in 1984. It is believed, however, that there is sufficient process flexibility to cope with such variations.

B.8 From considerations of price-demand elasticity, alternative marketing policies and possible competition from outside the EEC, it is believed that relatively moderate price increases would ensue specifically from regulation. It is projected that the added value of CFC exports could fall from the estimated 1977/78 level of UCE 48 million to UCE 23 million and 28.6 million respectively under the 1982 and 1984 ban scenarios, and to UCE 31.4 million in 1982 under the 50% reduction scenario.

B.9 Direct employment in CFC manufacture and dependent processes in the EEC, excluding marketing, distribution and ancillary services is estimated to be about 2300. It is thought unlikely that this figure would fall below 1500 in the event of restrictions on the use of CFCs in aerosols.

B.10 Other sectors of the chemical industry would be affected by a major cutback in CFC production. In particular, the chlorine-caustic soda and related sectors could be disturbed by reductions of the order of 5% in the demand for chlorine, and in the availability of hydrochloric acid; and reduced consumption of carbon tetrachloride would cause problems with processes in which it is co-produced with perchloroethylene, including the utilisation of vinyl chloride monomer production by-products. Outside the CFC production complexes, however, the effects of regulation would be disturbance rather than disruption.

B.11 The fluorspar mining and processing industry has already lost much of its acid grade spar export market due to CFC regulation in the USA, and regulation in Europe would almost certainly result in mine and plant closures since CFCs typically account for more than 60% of the acid spar output of at least 14 mines and works in France, Germany, Italy, Spain and the UK. The number of jobs at risk may not exceed 2000, but nearly all the mines are in rural areas with little alternative employment opportunity.

C. Aerosols

C.1 The aerosol industry is the largest consumer of CFCs in the EEC, and accounted for 167.8 thousand tons of F-11, 12, 113 and 114 in 1977, - 66.5% of the total sales of these compounds in the Community. Production in 1977 was 1867 million units, and only slightly lower than the 1976 total of 1874 million despite the impact of the ozone controversy.

C.2 The personal products sectors - mainly hairsprays, anti-perspirants, de-oderants, colognes and perfumes - represented 56.8% of fillings in 1977. These sectors (together with the medicinal, pharmaceutical and veterinary product) are currently the most heavily dependent on CFC propellants, which are used in 80 to 100% of all the units in these categories in all EEC countries.

C.3 Although there is scope for greater use of the dissolved gas propellants, carbon dioxide and nitrous oxide, the most realistic alternatives to CFC propellants for the majority of aerosols, and particularly in the personal product categories, are liquefied hydrocarbon gases - mainly propane and butane. The main drawbacks to hydrocarbons are their high flammability and relatively inferior solvent properties, and there are difficulties in re-formulating personal products with hydrocarbons so as to achieve equivalent product quality while keeping the content of flammable material below the 45% limit, above which the packs must be labelled as flammable and then incur marketing disadvantages.

C.4 Experience in the USA, where most production is already converted to non-CFC propellants - mainly hydrocarbons - coupled with the advent of developments such as valves which permit the use of hydrocarbon-water mixtures in personal products and others in which water was once considered unacceptable suggest that the industry can successfully adapt to non-CFC propellants, providing it is given enough time for research and conversion, for the great majority of products. If dimethylether satisfies tests currently being conducted by the industry this could be a useful alternative to hydrocarbons because of its better solvent properties, miscibility with water and lower flammability.

C.5 The regulatory time-scale would be crucial to successful adaptation. Three years notice of prohibition is thought somewhat too short a period for a smooth changeover, whereas five years notice including the intermediate case of a 50% reduction in CFC usage should be adequate.

C.6 Excluding the CFC and allied sectors, employment in the industry is approximately 43,000. Net job loss due to regulatory action on CFCs is unlikely to exceed 3000. Job disturbance might affect more than twice this number because some fillers would not be able to convert to inflammable propellants or would have to relocate their plants. The overall result would be that contract fillers and large filler-marketers would expand their businesses at the expense of some of the smaller concerns.

C.7 The total value of retail and export sales for the EEC is assessed at approximately UCE 2100 million for the 1977 sales volume, and this figure is only slightly higher than the actual added value. It is believed that the maximum annual loss of added value would not exceed 10% of this figure, or UCE 210 million, under the 3-year ban scenario, or 5% - UCE 105 million under either of the 5 year scenarios.

D. Refrigeration and Air Conditioning

D.1 The great majority of refrigeration and air conditioning equipment employs the vapour-compression system, for which fluorocarbon refrigerants are used almost exclusively except for some large industrial systems using ammonia. The only alternatives to fluorocarbon refrigerants in vapour-compression systems are substances such as ammonia, sulphur dioxide and methyl chloride which have long been discarded for general application because of toxicity, flammability or poor thermodynamic efficiency.

D.2 Sales of F-11, 12, 113 and 114 refrigerants in the EEC amounted to 20.5 thousand tons in 1977, representing only 8.1% of the EEC total and less than half the usage in foam plastics. The bulk of these sales were of F-12 (87%) and F-11 (12%). A small decrease on the 1976 total of 20.9 thousand tons may be due to the trend towards greater use of F-22 (which is not perhalogenated and is not considered a threat to the ozone layer), especially in packaged air conditioning units, and of F-502 (an azeotrope of F-22 and F-115) in retail food display cabinets.

D.3 The use of the less thermally efficient absorption type refrigeration systems employing waste heat instead of electro-mechanical energy may grow, but no serious competitor to the vapour-compression system is likely to emerge for many years.

D.4 It is believed that, for most applications, systems currently using perhalogenated CFC refrigerants could be re-designed to use F-22 or F-502, but existing installations could not readily be converted and stationary refrigeration equipment normally has a long life-time.

D.5 Because of the importance of refrigeration in the developed world - especially in food storage and transportation, the large volume of installed capacity and the impracticability of any rapid switch to alternative manufacture, no restrictions on the use of perhalogenated CFC refrigerants have been considered. The preferred approach is to concentrate on the elimination of preventable emissions from existing and new equipment, and to encourage the use of non-perhalogenated CFC refrigerants where practicable. It is estimated that some 70% of refrigerant sales are for replacement purposes due to leakage and contamination, and that avoidable losses occur in the manufacture, testing and installation of new equipment. Technology and procedures are available for substantially reducing these emissions.

D.6 The cost of emission reduction measures would probably not be fully compensated by savings in refrigerant consumption and would tend to raise the cost of new equipment and servicing, with possible adverse effects on the growth rate of the industry.

D.7 Detailed analysis of refrigerant usage, trends and socio-economic factors in the refrigeration and air conditioning industry in the EEC is seriously hampered by the lack of adequate and up-to-date statistics.

E. Foam Plastics

E.1 General Foam plastics manufacture has become the second largest application of CFCs in the EEC, in contrast to the rest of the world market in which it ranks below refrigeration. The major proportion is of F-11 as a blowing agent for flexible (open cell) and rigid (closed cell) polyurethane foams, which are estimated to account for 87% of the 46 thousand tons of F-11, 12, 113 and 114 in this EEC sales category in 1977, and nearly 16% of the total EEC sales.

E.2 Flexible polyurethane foam

E.2.1 Flexible polyurethane foam is now the principal material for furniture and automotive upholstery, and is also used extensively in bedding, clothing laminates, insulation and packaging. In the EEC, chlorofluorocarbons - mainly F-11 - are used exclusively as the secondary blowing agents needed to augment the action of the chemically released carbon dioxide to make the lower density grades of foam. If CFCs were not available, there would be no viable option at present but to restrict manufacture to the higher density grades (above 22 kg/m^3); these account for less than half of total production, are typically 30% more expensive to use and have unsuitable physical properties for many of the purposes for which the low density grades are employed.

E.2.2 All the CFC used for blowing flexible open cell foams is rapidly released into the atmosphere, so in the ozone depletion context there is a strong case for developing alternatives and, given time, this may be feasible. Methylene chloride is a potential substitute: it is being used to some extent in the USA but is unlikely to be acceptable to operatives in EEC plants unless minimal exposure to the vapour can be assured. Formulation improvement may reduce the CFC requirement. CFC recovery and vacuum blowing are possibilities but have not yet been demonstrated to be economic in practice.

E.2.3 Custom produced slab or block flexible foam represents about 70% of manufacture, and this sector employs some 13,000 people and produced over 272 thousand tons of foam in 1976, with a value of approximately UCE 500 million. Other production is accounted for by custom moulders and by in-house production, especially in the automotive industry. The independent conversion sector is also a substantial employer. Growth of production is assessed to be running at about 3% annually.

E.2.4 Without low density polyurethane foam, users would have to resort to combinations of the more costly higher density grades with alternative upholstery materials and systems demanding completely different manufacturing techniques and entailing extensive re-deployment of labour. Higher production costs and prices would ensue, and unless a common policy on CFC control were to be adopted universally, major inequalities in competitiveness would be generated.

E.3 Rigid polyurethane foam

E.3.1 CFC blown rigid polyurethane foam combines mechanical, thermal insulation and adhesive properties conferring technical and economic advantages as an energy conserving structural material in building construction, domestic appliances such as refrigerators and freezers, and for transport and industrial insulation. The majority of the CFC blowing agent is retained in the closed cells of the foam during its useful life, and the low thermal conductivity of the CFC gas makes an essential contribution to the insulation characteristics.

E.3.2 No alternatives to fluorocarbons are known which would provide comparable insulation value, and the only potential substitutes for the existing CFC blowing agents are other fluorcarbons not yet commercially available or fully evaluated.

E.3.3 If CFC blowing agents could not be employed the rigid polyurethane foam industry would be substantially extinguished and a high performance insulation material would cease to be available. Equivalent insulation using alternative materials would entail greater thicknesses with consequent dimensional and weight penalties, and the inevitable compromises in many applications would increase energy losses. Refrigerator cabinets, for example, would have to be made with much thicker and heavier panels in place of the present slim light gauge steel/foam sandwich construction, and they would cease to be competitive in export markets in which corresponding restrictions did not apply.

E.3.4 Rigid polyurethane foam production in the EEC exceeded 150 thousand tons in 1977, and the raw materials value was over UCE 180 million. Growth at around 8% annually is likely to continue for several years and in the absence of CFC restrictions could accelerate due to the increasing importance of energy conservation.

E.3.5 Custom manufacture of slab and board is a much smaller sector than in the flexible foam industry, and there are numerous insulation contractors, pre-fabricated panel makers, moulders and in-house users. Employment is not readily assessable because of the diffuse nature of the industry. If rigid foam could not be made alternative materials would have to be used, and the overall socio-economic penalties would be those attaching to higher fabrication costs for insulation generally, probable declines in some specific export markets, especially refrigeration, and poorer energy saving performance.

E.3.6 The problem of CFC usage for rigid polyurethane foam is less urgent in respect of the threat of ozone depletion than prompt release applications, but the amount of CFC trapped in rigid foam is accumulating. More research is needed on the rate and mechanism of CFC release during the life of rigid foam and when it is ultimately scrapped or destroyed.

F. Solvent Cleaning Applications

F.1 Solvent cleaning is the principal application in the 'other use' category to which 4.9 and 12.8 thousand tons respectively of EEC sales of F-11 and F-113 were allocated in 1977; it probably accounted for at least 90% of the total F-113 sales of 16.7 thousand tons, but the proportion for F-11 was not established.

F.2 F-113 solvent cleaning systems find increasing application in technical, industrial and dry cleaning in preference to much cheaper chlorinated and other solvents because F-113 has a unique combination of suitable physical properties with good safety characteristics, high chemical stability and cleaning activity, and compatability towards a wide range of materials.

F.3 Applications fall into two broad categories : those where F-113 is advantageous in terms of safety and performance but for which reasonably effective alternatives are available, and those for which F-113 is indispensable or nearly so. The former include dry cleaning - especially of delicate fabrics and furs, the latter include the manufacture of certain types of electronic and electrical components and assemblies, (e.g. the defluxing of printed circuit boards), and of precision engineering and optical equipment.

F.4 Some scope exists for reducing the need for F-113 solvents, for instance by eliminating fluxes in miniature electronics. Also, the release of F-113 from the hot liquid and vapour rinse systems in which it is mostly used could be cut down by taking extra precautions to minimise drag-out losses and vapour escape.

F.5 Many users of CFC solvent cleaning systems would be able to make out a good case for exemption from regulation on 'essential use' grounds, and the reduction in CFC release achievably by regulation would be less than 5% of the EEC total. The value of the CFC solvent cleaning supply industry in the EEC is put at about UCE 30 million, but a much greater value lies in terms of service to the electronic and other important EEC industries.

1. INTRODUCTION

1.1 Background to the Study

1.1.1 The fluorocarbon-ozone depletion theory

This study of the social and economic implications of restricting the use of certain fluorocarbons in the EEC stems from the concern that continuing unrestricted release of these substances into the atmosphere could deplete the stratospheric ozone layer and reduce its effectiveness as an ultra-violet radiation shield, with harmful consequences for life on earth.

The need to increase knowledge about the effects of man's activities on the atmosphere led to the initiation in the early 1970s of a number of nationally and internationally sponsored research programmes on stratospheric processes. It became apparent that a number of man-made and naturally occurring chemical species, including certain industrially produced chlorine compounds, could be of importance in this context, and in 1974 Rowland and Molina published their well-known hypothesis that chlorofluorocarbons could be a potential cause of stratospheric ozone depletion.

The principal compounds involved are the chlorofluoromethanes F-11 (CCl_3F) and F-12 (CCl_2F_2), which are widely used as aerosol propellants, refrigerants, and in the manufacture of foam plastics. The combined world production of these two compounds reached a peak of over 851 thousand metric tons in 1974, and it is estimated that by the end of 1977 production since the beginning of manufacture had totalled nearly 10 million tons, of which 8.6 million had been released into the atmosphere (Reference 1.1). To put the EEC contribution in perspective, sales in 1977 of F-11 and F-12 within the EEC accounted for one third of total sales recorded by all the significant producers in the non-Communist world. (Data presentation in Section 2.3.4.)

The essence of the fluorocarbon-ozone depletion theory is that because of their chemical stability and the large quantities being released, appreciable amounts of chlorofluorocarbons ('CFCs') are escaping decomposition and removal by rain in the troposphere and are being conveyed into the stratosphere where they are broken down by radiation, resulting in the formation of chlorine atoms and chlorine oxides which can catalyse the decomposition of ozone (O_3) into ordinary oxygen (O_2). If enough of this reactive chlorine is present it may disturb the existing equilibrium of a variety of natural processes causing the formation and decomposition of stratospheric ozone, and reduce the average thickness of the layer.

The stratospheric ozone layer filters out a large proportion of the potentially harmful ultra-violet component of solar radiation, and any mechanism which reduces the effective thickness of the layer can result in more ultra-violet radiation reaching the earth's surface. It is known that UV radiation intensity is linked with the incidence of human skin cancers, and it is possible that sustained above average levels of UV radiation could have other adverse biological results and cause climatic changes.

Publication of the fluorocarbon-ozone theory in 1974 was followed by extensive and prominently reported comment and controversy which generated considerable public anxiety, particularly in the USA. One outcome was that a large volume of new research was initiated and existing programmes expanded throughout the world to cover every aspect of stratospheric modification and its consequences. The most recent comprehensive review of the scientific knowledge amassed on the problem is contained in an Interim Report published in December 1977 by the US National Academy of Sciences (Reference 1.2), and a further report specifically relating to the effects of chlorofluoromethanes may be available in the autumn of 1978.

It is no part of our brief to assess any of the scientific evidence relating to ozone depletion and its consequences, but it is impossible to divorce completely the question of regulatory measures on CFCs from the current scientific status of the fluorocarbon-ozone theory. In the context of possible regulation, therefore, it seems important to make the following points:

a) No concensus of opinion has yet emerged as to the overall validity of the fluorocarbon-ozone depletion theory, i.e. as to whether CFC release has yet caused or is actually causing a net decrease in stratospheric ozone.

b) It is now recognised that the whole issue is much more complex than was originally appreciated, and that there are a large number of competing processes affecting ozone concentration. New contributions on the subject are constantly appearing, and some years are likely to elapse before clear pictures can be discerned. To illustrate the present difficulty of drawing conclusions from the present array of conflicting data and hypotheses, it has recently been predicted that the increase of carbon dioxide in the atmosphere due to the burning of fossil fuels could raise the ozone concentration, and that by the year 2030 this rise could roughly equal the fall attributable to chlorofluoromethanes if they continue to be released at the 1973 rate. (Reference 1.3).

c) Taking the potential effect of CFCs on ozone concentration in isolation, the latest estimates cited by the NAS are that ozone depletion of 11 to 16 percent would be reached over a period of several decades at the 1974 chlorofluoromethane release rate. This extent of depletion has to be considered in relation to the wide variations and fluctuations normally found in the thickness of the ozone column over the earth, there being, for example, a daily mid-latitude variation of ± 25%. For this and other reasons it is difficult to detect small trends, and the predicted rate of change due to CFCs might not be detectable with certainty for a number of years.

d) Notwithstanding the substantial uncertainties attaching to the fluorocarbon-ozone theory as a whole, some of the main components are still unshaken: CFCs are entering the stratosphere where they can cause the depletion of ozone; a thinning of the ozone layer would allow more UV radiation to reach the earth; and UV radiation can be harmful to health. In its December 1977 Interim Report the NAS stated that "At present, the major threat to the ozone layer is from the releases of F-11 and F-12 ......". However, while advocating continued monitoring of CFC production, use and release, the report does not express or imply an opinion that immediate action to curtail CFC emissions is advisable.

e) In reading many commentaries on the issue, it has been noted how readily selective citations from scientific papers and reports can be used to support widely divergent views on the need for CFC emission control and the form it should take.

1.1.2 Attitudes to CFC regulation

In March 1977 a meeting of the United Nations Environment Programme (UNEP) on the ozone layer was held in Washington and attended by experts designated by Governments, Inter-Governmental and Non-Governmental Organisations. A World Plan of Action on the Ozone Layer was agreed, and in addition to endorsing the need for further co-ordinated scientific research it was agreed that:

> 'studies of the socio-economic impact of the predicted ozone layer depletions and of alternative courses of action to limit or control identified ozone depleting emissions to the atmosphere should be supported at national and international levels.'

At this conference and at others two opposing attitudes towards CFC regulation became evident:

Pro-regulation:

Advocates of prompt and radical measures to reduce CFC release argue that despite the uncertainties and lack of overall proof, a potential threat to health and the environment has been identified, and every addition to the quantities of CFCs emitted constitutes an increase in the hazard to future generations. It is also argued that the largest source of CFC emission is their use as aerosol propellants and that the great majority of aerosols are not essential to society since, even where the products dispensed are important, alternative dispensing systems are available, and alternatives to CFC propellants. Therefore, it is urged, immediate steps should be taken to ban the use of CFCs in most aerosols, and longer term measures actively considered regarding other CFC applications.

Anti-regulation:

Opponents of early regulation stress that progressive depletion of the stratospheric ozone layer by CFC emissions (or any others) has not yet been demonstrated, and that the predicted rate and extent of depletion are so low that no significant adverse effect could occur for some years at present release levels. There is ample time, it is reasoned, to wait for the results of current research and monitoring programmes, and to base decisions on facts instead of theory. It would be premature to take action now which could seriously affect major industries, and deprive the public of goods and services for which a large and continuing demand has been well established. Also, to take regulatory action without reasonable proof of danger sets a precedent which could lead to other products being banned on the basis of groundless suspicion, resulting in extensive economic damage and social deprivation.

In the USA the pro-regulation view has prevailed and regulations made by the Environmental Protection Agency, the Consumer Product Safety Commission and other Federal Agencies effectively prohibit the use of CFC propellants in most aerosols from the end of 1978. (Reference 1.4)

The EPA is not currently proposing to regulate other uses of CFCs, but it has already held a number of public meetings on the question of controlling or reducing CFC emissions from non-aerosol applications, and has commissioned the Rand Corporation to carry out an extensive investigation of the economic impact of possible regulation of non-aerosol CFC emissions. (Reference 1.5)

Canada is likely to follow the US lead by banning the CFC propellants in the main toiletry sectors: hair sprays, anti-perspirants and deodorants.

In Western Europe a more cautious approach has predominated. A number of countries have considered regulation but so far only Sweden has introduced prohibitory measures, by banning CFCs in aerosols from 1st January 1979. The action being taken in the EEC is reviewed in the next sub-section, 1.1.3.

1.1.3 EEC Approach to the CFC Regulation Question

Governments of the EEC Member States have independently considered the fluorocarbon-ozone issue and some have seriously contemplated adopting measures to regulate the use of CFCs, including the Netherlands Government, which in 1976 commissioned Metra to examine the economic implications. (Reference 1.6).

Throughout the Community there is considerable public awareness of the issue. Organisations concerned with environmental protection have been particularly prominent in urging early regulatory measures, especially against CFC aerosol propellants, and the whole question has become a focus of political interest.

There have been discussions between Government and Industry on the technical and economic aspects of reducing CFC emissions. In West Germany the aerosol industry has voluntarily undertaken to reduce its use of CFC propellants by 25% in 1979, and in the United Kingdom the principal user industries are currently reporting to the Department of the Environment on the possibilities and problems of curtailing their CFC consumption.

At the EEC level, consultations between Member States early in 1977 produced a common position which the Commission represented at an international meeting on CFC regulation in Washington in April 1977, arranged by the U.S. Environmental Protection Agency. This view, which was shared by the majority of all delegations, was that before the question of regulation could be settled more research was needed to clarify some of the uncertainties on the effects of CFCs on the ozone layer and on the impact of ultra-violet radiation on health and the environment, and that the problem should be re-examined in the second half of 1978.

The EEC Commission decided to undertake a Community wide study of the economic and social implications of possible regulatory measures, and to consider the results in conjunction with its evaluation in the second half of 1978 of the latest scientific evidence on the fluorocarbon-ozone theory. The socio-economic study was assigned to Metra in October, 1977.

On the basis of the views of Member States, the Commission developed a Proposal for a Council Recommendation, of which details were published in August 1977. (Reference 1.7). This Proposal advocated intensification of the Community's research effort on the fluorocarbon question, coupled with action to step up investigations into alternatives for F-11 and F-12 in the aerosol and plastic foam industries; to eliminate leakages of F-11 and F-12; and to assure that F-11/12 production capacity in the Community would not be increased. In February 1978 the Commission amended its proposal that Community production capacity for F-11 and F-12 should not be increased, to include any substitute product of direct or indirect danger to human health.

The Proposal was the subject of Opinions given by the European Parliament (Reference 1.8) and the Economic and Social Committee (Reference 1.9), and was finally considered by the Council of the European Communities which adopted the following Resolution on 30th May 1978 (Reference 1.10).

1. The problems of the effects of fluorocarbons on the ozone layer and of ultra-violet radiation on health cannot be ignored. Insofar as Member States are carrying out research on these problems nationally, it is desirable that they should cooperate on a Community basis in planning this research and in making available and interpreting the results. The Community of course recognises the overall coordinating role of UNEP (United Nations Environment Programme) in relation to research.

2. Immediate steps should be taken to encourage all the aerosol and plastic foam industries using chlorofluorocarbons F-11 (CCl_3F) and F-12 (CCl_2F_2) to intensify research into alternative products and to promote the development of alternative methods of application.

3. Immediate steps should be taken to encourage the manufacturers and users of equipment containing chlorofluorocarbons F-11 and F-12 to eliminate the discharge of these compounds.

4. All appropriate measures should be taken to ensure that the industry situated within the Community does not increase its production capacity in respect of chlorofluorocarbons F-11 and F-12.

5. In the second half of 1978 the effect of fluorocarbons on the environment will be re-examined in the light of the information then available with a view to arriving at a Community policy.

1.2 Objectives and Scope of Study

The primary objective of the study is to examine in detail the social and economic implications of measures designed to reduce or to control the production, use or release of chlorofluorocarbons within the EEC.

The study is to consider:

a) The existing structure, in quantitative terms, of the chlorofluorocarbon manufacturing, using and related industries, including those supplying raw materials and intermediates, plant, equipment and services.

b) Alternative regulatory measures, having regard to the type and field of application of the measures; the time-scale for implementation; and the viability of substitute chemicals, processes and products in the EEC, taking potential health hazards and environmental impacts into consideration.

c) The social and economic implications of selected regulatory scenarios, in terms of the effects on employment, added value, prices, balance of payments, environmental impact and other potential socio-economic costs or benefits, taking into account the ability of the manufacturing sectors to comply with the regulatory requirements within the alternative time-scales and costs, and with particular reference to the effects upon individual EEC countries.

The Environment and Consumer Protection Service requested that in conducting the study and preparing the report the Consultants should:

- give particular emphasis to the prospects for the substitution of perhalogenated chlorofluorocarbons by other compounds, processes and products, and other measures for reducing CFC release.

- endeavour to form and express positive views and conclusions, notwithstanding the numerous provisos which might have to be attached.

<u>Comment</u>: It will be apparent that, although the study nominally concerns the socio-economic consequences of CFC regulation, it has a very high technological content because the terms of reference require the feasibility of substitution to be examined, both in developing regulatory options and in evaluating selected scenarios. This technical bias was increased during the study when the decision was taken to evaluate regulatory scenarios for the aerosol industry only, and to consider how the question of emission reduction could be approached in the other main CFC application fields.

1.3 Programme

The study programme, which began in October 1977, was divided into two distinct consecutive phases: instead of predetermining the regulatory scenarios to be evaluated these were selected by the Environmental and Consumer Protection Service (ECPS) after completion of the first phase of the study, in which we:

- determined, in consultation with the ECPS, the particular chlorofluorocarbons and applications on which the study should concentrate

- developed a general philosophy on the criteria and factors to be taken into account in devising regulatory scenarios

- examined the CFC manufacturing and main user industries and identified ancillary industry sectors which could also be significantly affected by CFC regulation

- initiated data collection exercises, mainly in collaboration with trade and industry associations

- appraised the feasibility for CFC substitution in the Community, interpreting that term to include all alternative means of obtaining equivalent or similar products or results

- reviewed possible regulatory options and their merits in the light of present and foreseeable circumstances

- drew up a short list of regulatory scenarios for consideration by the ECPS

- submitted a statement of interim findings and recommendations to the ECPS at the end of February, 1978.

During March 1978, having considered our interim submissions, the ECPS advised us of its selection of regulatory scenarios relating to the use of CFCs in aerosols, and of the approach to be adopted to the non-aerosol uses.

The second phase of the study, in which the chosen scenarios were evaluated and the other investigations completed, was carried out over the period March - June 1978. A draft final report was completed in September 1978.

1.4 Principal Chlorofluorocarbons and Applications Considered.

The fluorocarbons believed to be particularly potent as stratospheric ozone depleters are the fully halogenated ('perhalogenated') chlorofluoromethanes and chlorofluoroethanes because of their long atmospheric lifetimes and the scale on which they are being manufactured, used and released. Of these, the chlorofluoromethanes F-11 (CCl_3F) and F-12 (CCl_2F_2) currently account for around 90% of the sales of fully halogenated CFCs in the EEC, and preliminary enquiry established that the balance is largely comprised of F-113 ($C_2Cl_3F_3$) and F-114 ($C_2Cl_2F_4$). For the main purposes of this study, therefore, and with the assent of the ECPS, we concentrated on these four compounds and their principal applications as aerosol propellants, refrigerants, plastic foam blowing agents and cleaning solvents, which together account for 98% or more of their EEC sales.

Other commercially produced fluorocarbons in the same family, and which might therefore be caught by any regulations specifying classes of compound rather than unique substances, include F-13 ($CClF_3$) and F-115 (C_2ClF_5) which are used as refrigerants, and F-13B1 ($CBrF_3$) - used mainly as a fire extinguishing agent, but the tonnages involved are relatively small.

A fluorocarbon being manufactured in large tonnages but which is not fully halogenated is F-22, used mainly as a refrigerant and also having a captive application as the starting material for the synthesis of polytetrafluoroethylene ('PTFE') plastic. In 1976, world sales of F-22 were approximately 10% of the combined sales of

F-11, F-12 and F-22 and consumption was showing a strong upward trend, but because F-22 is readily attacked by hydroxyl (OH) radicals in the troposphere it is not currently considered a serious threat to stratospheric ozone. If production continued to rise, and if the fluorocarbon-ozone theory were to be validated, F-22 could become a problem in the future, but it has not been considered in the regulatory context of this study other than as a potential substitute for fully halogenated CFCs, particularly for F-12 in refrigeration.

1.5 Approach to Regulatory Scenario Development

1.5.1 Need for Set of Guiding Principles

At an early stage in the initial phase of the study it was necessary to develop a general philosophy on the question of possible regulatory scenarios, to be applied in guiding our approach to information collection and allocation of study resources, and in developing the options to be submitted to the ECPS.

Many representatives of the fluorocarbon manufacturing and using industries we encountered disliked discussing possible regulatory scenarios because they thought this begged the question by assuming that regulation was inevitable, when they strongly disputed its necessity. It must be pointed out again, perhaps, that it was not an aim of this study to reach conclusions about the need for regulation, but it was essential to hypothecate restrictions on CFCs in order to assess their potential consequences. In postulating restrictions, however, it is also important to consider what would be practicable in the prevailing circumstances under which the EEC is likely to have to make its decisions.

In the following section we list and comment upon the factors we believe to have an important bearing on regulatory action, and which we took into account in developing our interim submissions. The factors are not listed in an order signifying importance or priority.

1.5.2 Key factors in Scenario Selection.

1.5.2.1 Status of the Fluorocarbon-Ozone Depletion Theory.

This bears on the need and urgency for regulation and the scenarios should reflect the views likely to obtain when the Commission prepares proposals and these are considered by the various EC bodies.

In its Interim Report of December 1977 (Reference 1.2) the NAS Committee on the Impacts of Stratospheric Change points out that although the latest estimates of ozone depletion due to CFC release at the 1974 rate are roughly twice the earlier values, the central figures of 11 to 16 percent are still within the previously estimated range of 2 to 20% reduction as the ultimate result after many decades; and the report makes no recommendations on curtailment of CFC release.

More evidence may be available to the Commission in 1978, and the NAS has promised a further report, but the indications are that the key questions will not be much closer to resolution than they were at the time of the Washington Conference on CFC regulation in April 1977, and it is unlikely, therefore, that any proposals calling for the very early introduction of regulatory action would gain the immediate and unanimous support of all the EEC Member States.

Accordingly, we believe that there is little point in evaluating scenarios based on regulation of CFC usage at an earlier date than would be likely with the normal pace of EEC legislation, and a good case for considering extended time-scales. There is also a case for contemplating limiting rather than prohibitory action, pending availability of a clearer picture of the ozone situation.

1.5.2.2 Minimum Legislation Timescales

It is understood that in the absence of special urgency the time elapsing between the initial submission of proposals by the Commission and the final step of implementation by Member States is unlikely to be less than three years, and this does not provide for a period of notice between enactment and application in a national context.

1.5.2.3 Contribution to CFC Release Reduction

Restrictions on any particular source of emission must be considered in relation to the proportionate reduction effected in the total release from EEC sources: little practical benefit will be gained by restrictions on an application which contributes only a few percent to the total, and for this reason we thought it especially important to obtain reliable end-use data (Section 2).

The reduction need not necessarily be considered relative to global release, because if the EEC introduces regulation it is presumably with the hope that the rest of the uncommitted world will follow suit.

1.5.2.4 Socio-Economic Effects in Relation to CFC Release Reduction.

The magnitude and nature of any adverse social and economic consequences of regulation need to be weighed against the gain in terms of the CFC release reduction achieved and the significance of this reduction in relation to ozone depletion. These factors will also have to be taken into account in deciding upon relative priorities and urgencies.

Although difficult to quantify, social value assessments will have to be made in determining whether a particular use within a general field of application should be exempt from restriction, e.g. an aerosol medical product.

1.5.2.5 Availability of Substitutes and Alternatives

The availability of substitutes for CFCs or alternative products can affect decisions to regulate a specific application and the timescale. If it is shown that economic and employment losses and other hardships can be substantially ameliorated by giving an industry four years to adapt instead of two, the view may be taken that a high degree of urgency for reducing CFC release to this extent must be demonstrated to justify imposing the earlier scenario.

1.5.2.6 Cost and Practicability of Implementation

In appraising alternative regulatory means of reducing CFC release due to a particular use or procedure, the relative costs and ease of administration should be considered. For example, as discussed in Section 5 on Refrigeration, there are possible procedures for reducing CFC release in the servicing of refrigeration and air conditioning equipment, but some of these would be very difficult indeed to enforce.

1.5.2.7 Regulatory Action by Individual Countries

In considering legislation for the EEC as a whole it is likely that some attention will be paid to action taken or proposed by individual countries within and outside the Community, and to any lessons which can be learned from the experience gained.

To date, positive steps towards restrictive regulation on CFCs in aerosols have been taken in three countries: the USA, Canada and Sweden.

USA

Aerosols containing CFCs must now carry a warning label stating that the CFC may harm public health and the environment by reducing ozone in the upper atmosphere.

Under Federal Regulations registered by the Environmental Protection Agency, the Consumer Product Safety Commission and the Food and Drug Administration in March 1978 (Reference 1.4), a three-step schedule for eliminating CFCs (defined as fully halogenated chlorofluoroalkanes) will begin in October 1978:

From October 15, 1978 no company may manufacture CFCs for use as a propellant in non-essential aerosol products.

From December 15, 1978 the use of CFCs as propellants in non-essential aerosols must cease.

From April 15, 1979 products containing CFC propellants may not be introduced into inter-state commerce.

A number of exemptions are specified including certain medical products, some flying insect sprays and a mine safety warning device.

(The State of Oregon introduced a ban on CFC aerosol propellants effective from March 1, 1977).

Canada

In 1976 the Canadian aerosol industry voluntarily undertook to reduce the use of F-11 and F-12 in aerosols by 50% by the end of 1977 and it is understood that this was achieved.

The Canadian Government anticipates publishing regulations by September 1978 to prohibit the use of F-11 and F-12 in specified aerosol products, particularly hairsprays, de-oderants and anti-perspirants, from April 15, 1979, thus co-ordinating with the final phase-out of CFC aerosol propellants in the USA.

This approach is of particular interest because by banning CFCs in specific product sectors the major proportion of CFC usage in aerosols can be eliminated without the controversy and legislative complexities attendant on trying to specify 'essential' exempt categories, which caused the US Federal Authorities much difficulty in framing their more comprehensive prohibitions.

Sweden

Regulations banning the manufacture and import of aerosols containing fully halogenated chlorofluoroalkanes take effect from June 30, 1979, and there is provision for exempting medical and other products on special grounds.

Other countries have considered regulations against CFCs in aerosols but it now appears that these are unlikely to act prior to publication of the next NAS report, or until a lead is given by the EEC.

Two points should be made here regarding possible regulation by or within the EEC:

a) It has been strongly represented to us that unilateral action on regulation by individual EEC Member States would lead to an awkward and inequitable trading situation, giving some countries an export advantage over others.

b) No country has regulated or is currently planning to regulate non-aerosol uses of CFCs although, as noted in Section 1.1.2, the USA is actively studying the problems involved. The EEC would therefore be taking an initiative ahead of the rest of the world if it proposed to regulate non-aerosol applications at this juncture.

1.5.2.8 Scope for Voluntary Action

There are many examples of industries introducing codes of practice and other voluntary restrictions in order to maintain and cultivate customer confidence and goodwill, and to avoid incurring the imposition of more onerous legislative action. From the viewpoint of government such codes are often welcome because they avoid or postpone the need to introduce complicated legislation which would be difficult and expensive to enforce. Within the EEC, codes of practice already exist in the aerosol and refrigeration industries in some countries, and mention has already been made of the voluntary action in Germany to reduce the usage of CFCs in aerosols by at least 25% in 1979, and the discussions between the CFC using industries and the Department of the Environment in the UK.

The Commission may not favour the voluntary approach because it is not a positive method of control and not all Member States would necessarily cooperate. It could be a useful policy, however, if it is decided that an interim period of limitation rather than prohibition is desirable, and in industries such as refrigeration where outright bans may not be practicable in the short or medium term.

1.5.2.9 Response to Regulatory Proposals

There is ample evidence that even the distant prospect of legislation induces and stimulates contingency research and development on means of adapting to it, and that once regulation appears likely conversion to alternatives is often incepted well ahead of enactment and implementation.

In Europe, for example, many aerosol manufacturers are already researching alternatives to CFC propellants, and in the USA substantial conversion to non-CFC propellants and pump-sprays has already been effected although the ban on CFCs in aerosols is not fully operative until April 1979.

When setting regulatory timescales, therefore, it must be appreciated that CFC release rates will fall well before the latest date for compliance.

1.5.2.10 Labelling as a Regulatory Measure

As mentioned above, the United States requires aerosols containing CFCs to bear a warning label, pending the ban on use of CFC propellants in most aerosols from the end of 1978. In the EEC, the Netherlands Government has considered introducing labelling but has suspended action for the time being.

We have formed the opinion that labelling is an unsatisfactory type of measure, for the following reasons:

- USA experience indicates that labelling does depress CFC propellant usage, both directly by its effect on public attitudes and indirectly by stimulating manufacturers to adopt alternative propellants and systems. However, the public is often unable to distinguish between aerosol products and one of their possible constituents, so that a warning about a particular propellant causes disquiet about aerosols in general. This may please those who disapprove of aerosol packaging altogether, but it seems unfortunate to confuse the issue to the detriment of the industry.

As an example of the way the press may mislead the public on this aspect, when Sweden announced a ban on F-11/12 propellants one of the most responsible newspapers in the EEC carried the entirely erroneous headline: 'Sweden Bans Aerosols'.

- in effect, labelling transfers responsibility for action to reduce CFC release from government to the public at large. But if a government has concluded that CFC release should be curtailed in the interests of world health it should surely take direct regulatory action and not rely on a public relations exercise. If it has not reached a firm conclusion, with access to expert advice, it seems an evasion of responsibility to try to persuade the public to act in a way in which government cannot make up its mind to act.

- if labelling is introduced as a prelude to a CFC propellant ban it will have the result of accelerating the decline in usage. This in turn may cause aerosol manufacturers and marketers to speed up conversion to alternatives - principally to hydrocarbon propellants - with possible adverse results in terms of product quality and safety. If the regulatory timescale has been set with a view to giving industry reasonable time in which to adapt to alternatives, it does not seem sensible to introduce a supplementary measure which effectively shortens this time.

1.5.3 Summary of Guidelines Adopted for Preparing Scenario Proposals

The following guidelines represent views formed independently by Metra and none of them is necessarily shared by the

Commission or its Departments, including the ECPS.

1.5.3.1 When reviewed in the second half of 1978, the scientific evidence on the fluorocarbon-ozone theory is unlikely to result in unusually rapid action to regulate CFC usage in the EEC, and three years is the shortest period likely for implementation throughout the Community.

1.5.3.2 It is also unlikely that the EEC will find grounds for moving ahead of the USA and other CFC regulating countries by introducing measures prohibiting the use of CFCs in non-aerosol applications at this time.

1.5.3.3 Pending clarification of the ozone issue there is a case for limitation rather than a complete ban on CFC usage in any field of application.

1.5.3.4 In deciding the scope, mode and timescale of possible regulatory measures, account should be taken of:

- the impact on total CFC release in the EEC
- the socio-economic penalties in relation to the CFC release reduction gained
- the availability of substitute materials and products and the cost and time entailed in conversion
- the cost and practicability of implementing and enforcing proposed restrictions

1.5.3.5 In seeking to limit and reduce CFC release the merits of voluntary action by industry should not be overlooked.

1.5.3.6 The labelling of aerosols containing CFCs is an unsatisfactory substitute for direct action to reduce CFC release.

1.6 Report Presentation

Because some of the investigations initiated in the first stage of the study were completed or supplemented in the second, it would not be helpful to split this report into two parts corresponding to the two study periods. Instead, each subject section contains the findings from the study as a whole.

The presentation also relates to the decisions taken at the end of the first phase of the study on the directions the rest of the work should take, and on how the main topics should be treated in the report. These decisions are recorded in Section 1.7 below, so that readers will be aware of them before proceeding to the main subject matter.

1.7 Advice Tendered and Decisions Taken at End of First Stage of Study.

1.7.1 Interim Advice Submitted to ECPS

In brief, we advised the Environment and Consumer Protection Service:

a) that in the aerosol industry, aside from the availability of pump sprays, and other non-pressurised packaging and dispensing systems, adaptation to non-CFC propellants is commercially feasible in most product sectors, including toiletries, given reasonable time to deal with the technical problems involved in redesign and re-formulation, and to effect plant conversion and expand the supply of alternative propellants. Emphasis was placed on the fire and explosion risks associated with the main alternatives to CFC propellants: liquefied hydrocarbon gases, and the obstacles these hazards would present to conversion, coupled with the market resistance they might engender.

A short list of possible regulatory scenarios was provided, comprising bans on the use of CFCs in 'non-essential' aerosols after 3, 4 or 5 years, and an option in which CFC propellant usage would be reduced by 50% over a 3-year period, held at that limit for a further two years, and then prohibited in non-essential aerosols if that final step were to be justified by the status of the ozone depletion theory prevailing at the time.

b) that for the applications of CFCs in refrigeration and air conditioning, plastic foam manufacture and cleaning solvents we could not recommend evaluating regulatory scenarios involving bans on the use of fully halogenated CFCs. This conclusion was reached by applying the guidelines summarised in Section 1.5.3, and particularly on the basis of relative contribution to CFC release, socio-economic value and the absence of any early prospect of substitution.

Instead, we recommended that appreciations should be prepared of the problems and possibilities of eliminating or reducing CFC emissions from these sources, and of the further research required in these areas to quantify the potentialities.

1.7.2 Decisions on Content of Second Stage

After consideration of our interim submissions by the ECPS, it was agreed that we should proceed as follows:

1.7.2.1 Fluorocarbon Manufacturing and Allied Industries.

Socio-economic consequences to be assessed of production cutbacks corresponding to the regulatory scenarios to be evaluated for the aerosol industry.

1.7.2.2 Aerosol Industry

Comparative socio-economic assessments to be made of three cases:

a) A ban on fully halogenated CFC propellants in aerosols except for essential uses, effective 3 years from the end of 1978, i.e. on 1st January 1982.

b) A ban as in (a) but effective 5 years from the end of 1978, i.e. from 1st January 1984.

c) Reduction of CFC usage in aerosols over a 3-year period to 50% of the usage in an earlier selected year, followed by restriction to this reduced level for a further two years at the end of which a ban on CFCs in aerosols except for essential uses would take effect if justified by the prevailing status of the ozone depletion theory.

Note: The difficulty of defining an 'essential use' is appreciated and the term is to be taken as implying that there would be provision for granting exemption from regulation on special grounds. The ECPS asked Metra to provide an opionion as to the criteria on which exemption should be granted.

1.7.2.3 <u>Refrigeration and Air Conditioning</u>

No regulatory scenarios on the use of CFC refrigerants to be evaluated.

An appreciation to be provided of how preventable CFC release elimination and reduction could be approached in the EEC.

1.7.2.4 <u>Foamed Plastics</u>

No regulatory scenarios to be evaluated.

A review to be provided on the use of CFCs as blowing agents for foamed plastics, together with a general appreciation of the consequences of eliminating the use of CFC blowing agents in the manufacture of flexible (open cell) polyurethane foams and of the technical studies needed to enable alternatives to be evaluated.

1.7.2.5 <u>Solvent Applications</u>

No regulatory scenarios to be evaluated.

A review to be provided of solvent cleaning applications of CFCs, the sources of release to the atmosphere and the investigations that would be needed to assess the possibilities for reducing emission.

1.8 Allocation of Resources

Approximately 75% of the study effort was allocated to the fluorocarbon manufacturing and aerosol industries, including ancillary sectors, and the balance to the non-aerosol applications of CFCs.

Non-aerosol uses could not have been properly considered with a smaller allocation, and although we concluded on other grounds that ban type scenarios should not be considered in these fields, we had to advise the ECPS at the interim stage that budgetary limitations would not permit restrictive scenario examinations for non-aerosol uses except in very general terms.

Regarding the allocation of time to the Member States of the Community, we made visits in all except Luxembourg, and the distribution was governed largely by the locations of trade association headquarters and relevant centres of industry and technology, which do not relate directly to territorial area and population.

It was also necessary to make contacts in countries outside the EEC, and we visited Switzerland to see two companies with major interests in the fluorocarbon and aerosol industries in the Community, and North America, where there has been so much activity relating to CFC regulation.

1.9 Sources of Information

Large numbers of firms are involved in the industries directly and indirectly connected with fluorocarbon production and use, for example there are over 430 members of the seven national aerosol trade associations in the Community.

For budgetary and other reasons limits had to be placed on the numbers of organisations contacted. Selection was preferred to sampling in order to maximise the input to the study, and the approach was to:

- make use of national and international trade associations as sources of data wherever practicable; also as channels for obtaining information from member firms and for help in identifying organisations and individuals for consultation

- arrange personal and telephone interviews with executives in selected companies representing a range of interests, concentrating on those whose knowledge and willingness to communicate were likely to yield a material contribution

- draw on official and other published sources of information within and outside the EEC. Of particular value were some recent and continuing studies in the USA sponsored by Federal agencies, trade associations and individual firms.

Over 120 organisations gave information directly to us, most of these contacts involving at least one personal discussion, and many more firms provided information through trade associations.

Where a major source of information was a government department or an association it is identified in the text. In general, however, individuals and companies are not identified because many of them did not wish to be associated with particular opinions or statistics.

By special invitation a member of the project team attended the Spring 1978 Meeting in Mainz of the Federation of European Aerosol Associations, and the 1978 Mid-Year Meeting in Chicago of the U.S. Chemical Specialties Manufacturers Association.

We were accorded excellent cooperation in almost every quarter where we sought assistance, but while it was generally easy to obtain qualitative facts and opinions it often proved difficult to obtain quantitative information, especially economic data. Sometimes this was due to reluctance to reveal information of possible value to competitors, but often because the figures needed did not exist and could not have been assembled within the time and resources available.

1.10 Acknowledgment

The Metra Group and the members of the project team gratefully acknowledge the extensive help received from many organisations and individuals in the course of the study. In some instances this entailed a considerable amount of time and effort in gathering, checking and collating data from a number of sources, and we greatly appreciate all the trouble taken to provide the contribution we sought.

References in Section 1

1.1 World Production and Release of Chlorofluorocarbons 11 and 12 Through 1977. July 17, 1978. Calculation by E.I. du Pont de Nemours and Company from data published in Alexander Grant and Company Report "1977 World Production and Sales of Fluorocarbons FC-11 and FC-12" of June 26, 1978. Manufacturing Chemists Association.

1.2 Response to the Ozone Protection Sections of the Clean Air Act Amendments of 1977: An Interim Report. National Academy of Sciences, Washington D.C., December 1977.

1.3 K.S. Groves, S.R. Mattingley and A.F. Tuck Nature, 273, 711-715, (June 1978).

1.4 U.S. Federal Register. Vol. 43, No. 53, March 17, 1978. Certain Fluorocarbons (Chlorofluorocarbons) in Food, Drug, Cosmetic etc. Products as Propellants in Self-Pressurised Containers: Prohibition on Use.

1.5 Non-Aerosol Chlorofluorocarbon Emissions: Evaluation of EPA-Supplied Data. G.C. Eads et al. Rand Corporation Working Note for the Environmental Protection Agency. Ref. No. RAND/WN-10043-1-EPA. February 1978.

1.6 The Implications of the Control of Fluorocarbons in the Netherlands. Report for the Ministerie van Volksgezondheid en Milieuhygiene by Metra Consulting Group Ltd., December 1976.

1.7 EEC Document COM (77) 387 final, Brussels 8.8.77.

1.8 EEC Official Journal No. C 6, 9.1.78, p.140.

References in Section 1 continued

1.9 EEC O.J. No. C 101, 26.4.78, p.29.

1.10 EEC Document R/1031/78 (ENV 68).

2. CHLOROFLUOROCARBON PRODUCTION AND USE STATISTICS

2.1 Importance of CFC Usage Data

The availability of reliable, up-to-date and detailed statistics on the production and use of CFCs is of paramount importance for adequate consideration of regulatory measures and their consequences. Such data is essential for estimating the potential, both in absolute and relative terms, for reducing CFC release to the atmosphere by regulatory action in respect of specific compounds and applications. It also forms the starting point for gauging the effect of regulation on the CFC industry itself, since any measures resulting in CFC production curtailment must affect the economics of CFC and precursor materials manufacture, irrespective of the effects on CFC users, some of whom may be able to turn to alternatives.

Accordingly, one of the first steps in this study was to ascertain the data already available and put in hand action to fill the gaps found in statistics relating to the EEC.

The statistical picture is presented at this early stage in the report because the perspective of CFC usage in the EEC provides the principal background criteria against which possible regulatory measures in the Community must be examined.

2.2 Scope and Limitations of Published Statistics

2.2.1 MCA Data

Under an arrangement incepted and administered by the MCA - the USA Manufacturing Chemists Association - twenty fluorocarbon producers representing over 95% of total world production of fluorocarbons, including all EEC production, have submitted production and sales data, including information on the activities of their subsidiaries and affiliates, to a U.S. firm of independent accountants, Alexander Grant and Company, for all the years from the start of production through to 1977. This data has been supplemented by returns from several other small producers and by estimates of production in Communist countries. The resultant aggregate data has been analysed by E.I. du Pont de Nemours and Company, and is believed to reflect more than 99% of world production of F-11 and F-12 to an accuracy of better than ± 5% (Refs. 2.1, 2.2 and 2.3).

From 1956 onwards tabulations are available for end-use sales in four categories: hermetically sealed and non-hermetically sealed refrigeration; blowing agents for closed cell plastic foams; and a category covering aerosols, open cell foams and other uses. For the years prior to 1956 extrapolations have been made back to the year 1931 when commercial production of fluorocarbons began. By making some assumptions on the rates of release of CFCs from the 'non-prompt' emission sources - refrigeration and closed cell foams - the annual and cumulative releases to atmosphere from 1931 to 1977 have been calculated.

Of the 9946 thousand tons of F-11 and F-12 produced up to the end of 1977, it is estimated that 8582 thousand tons, or 86.3%, have been released.

An abstract of the MCA/du Pont data for F-11 and F-12 is given in Table 2.1, showing how production climbed steeply after 1960 to a peak of 851 thousand tons of F-11/12 in 1974.

TABLE 2.1 : TOTAL WORLD PRODUCTION OF F-11 AND F-12 FROM 1931 TO 1977

Thousand Metric Tons

Year	F-11	F-12	Total F-11/12
1931	0.0	0.5	0.5
1935	0.0	1.0	1.0
1940	0.2	4.5	4.7
1945	0.4	20.1	20.5
1950	6.6	34.6	41.2
1955	26.3	57.6	83.9
1960	49.7	99.4	149.1
1965	122.8	190.1	312.9
1970	241.1	336.9	578.0
1971	266.6	360.5	627.1
1972	310.5	401.7	712.2
1973	354.3	447.5	801.8
1974	377.6	473.6	851.2
1975	322.5	419.7	742.2
1976	349.9	449.8	799.7
1977	330.7	424.4	755.1

Source : MCA and E.I. du Pont de Nemours & Co. (See References 2.2 and 2.3).

Note : These figures include returns from the twenty companies who report under the MCA scheme, together with estimates or returns from companies in India and Argentina, and Communist countries.

Table 2.2 shows the distribution by end-use of the total sales of F-11 and F-12 in 1977 by the twenty companies reporting under the MCA scheme. The combined totals of these sales, 698.2 thousand metric tons of F-11/12, is equivalent to 92.5% of the estimated total world production in 1977 of 755.1 thousand tons F-11/12.

The distribution shows that aerosol propellants were the dominant application for both compounds, accounting for 48.6% of the total. For F-11 the second major application was in blowing plastic foams (33.9%), while for F-12 it was refrigeration (40.3%).

The MCA data is invaluable for global considerations of fluorocarbon usage and release, including scientific research relating to the ozone depletion theory. It also enables data for the EEC to be viewed against the world perspective, and a presentation of this comparison is given later in Section 2.3.4 (Table 2.9).

TABLE 2.2 : TOTAL F-11 AND F-12 SALES BY CATEGORY FOR YEAR 1977

(From Companies Reporting under MCA Scheme)

	F-11	F-12	Total F-11 & F-12
Sales			
- thousands of tons	315.3	382.8	698.2
Distribution of Sales			
Aerosol Propellant	52.2	45.6	48.6
Refrigeration			
- hermetically sealed	1.6	17.1	10.1
- non-hermetically sealed	6.3	23.2	15.6
- total	7.9	40.3	25.7
Blowing Agent			
- closed cell foam	19.0	2.3	9.9
- open cell foam	14.9	3.1	8.4
- total	33.9	5.4	18.3
All Other Uses	6.1	8.7	7.5
	100.0	100.0	100.0

Source : MCA (Based on data from 20 reporting companies). Reference 2.2.

TABLE 2.3 : 1974 OECD PRODUCTION AND CONSUMPTION OF F-11 AND F-12

Country	Production	Net Export(-) or Import (+)	Domestic Consumption		Share of OECD Consumption
	'000 tons	'000 tons	'000 tons	% of EEC total	%
Belgium	-	+ 3.2	3.2	1.4	0.5
Denmark	-	+ 4.2	4.2	1.9	0.6
France	72.0	- 27.0	45.0	20.2	6.4
Germany	88.3	- 27.6	60.7	27.2	8.7
Ireland	-	+ 2.9	2.9	1.3	0.4
Italy	38.0	+ 7.0	45.0	20.2	6.4
Luxembourg	-	+ 0.3	0.3	0.1	0.04
Netherlands	29.0	- 15.0	14.0	6.3	2.0
United Kingdom	72.0	- 24.0	48.0	21.5	6.8
Total: EEC Countries	299.3	- 76.0	223.3	100.0	31.9
Austria	-	+ 5.0	5.0		0.7
Finland	-	+ 4.8	4.8		0.7
Greece	-	+ 3.0	3.0		0.4
Iceland	-	+ 0.2	0.2		0.03
Norway	-	+ 2.9	2.9		0.4
Portugal	-	+ 3.4	3.4		0.5
Spain	8.7	- 1.5	7.2		1.0
Sweden	-	+ 5.6	5.6		0.8
Switzerland	-	+ 8.4	8.4		1.2
Turkey	-	+ 1.4	1.4		0.2
Yugoslavia	-	+ 0.7	0.7		0.1
Total: Europe exc.EEC	8.7	+ 33.9	42.6		6.0
Total: Europe inc.EEC	308.0	- 42.1	265.9		37.9
Australia	14.0	+ 0.8	14.8		2.1
Canada	23.5	- 1.4	22.1		3.2
Japan	34.2	- 2.2	32.0		4.6
New Zealand	-	+ 5.0	5.0		0.7
U.S.A.	376.0	- 14.8	361.2		51.5
Total: OECD exc.Eur.	447.7	- 12.6	435.1		62.1
TOTAL: OECD	755.7	- 54.8	700.9		100.0

Source: OECD. (Reference 2.4)

For the present study the main limitations of the MCA statistics are

a) A breakdown for individual countries or the EEC as a whole is not available.

b) The data covers F-11, F-12, (and also F-22), but not F-113 and F-114.

c) The accuracy of the end-use distribution is open to question. Producers may know their home markets well enough, but export sales end-use distribution is not always known with the same precision.

2.2.2 OECD Data

On behalf of the Chemicals Group of the OECD Environment Committee the OECD Environment Directorate Secretariat carried out a study in 1976/77 on the economic impact of restrictions on the use of fluorocarbons, and their final report was issued in October, 1977. (Reference 2.4). During this study a survey was made of 1974 F-11 and F-12 production, consumption and usage in 25 countries.

The production and domestic consumption figures returned (or estimated) for each country are reproduced in Table 2.3, and have been re-grouped to highlight the contributions made by EEC countries, which together accounted for 39.6% of the OECD production total, and 31.9% of consumption. The USA was the dominant contributor accounting for nearly half of OECD production and 51.5% of consumption.

TABLE 2.4 : 1974 OECD END USE DISTRIBUTION OF F-11 AND F-12 CONSUMPTION.

	EEC	USA	Other OECD	Total OECD
Thousands of metric tons				
Aerosols:				
Personal	122.1	180.0	49.8	351.9
Domestic	32.0	20.6	13.3	65.9
Industrial	11.0	12.3	4.7	28.0
Medical	2.8	10.6	2.7	16.1
	167.9	223.5	70.5	461.9
Refrigeration	17.7	84.2	25.0	126.9
Plastic Foams	35.5	31.3	18.0	84.8
Other Uses	2.2	22.2	2.9	27.3
	55.4	137.7	45.9	239.0
Total: All Uses	223.1	361.2	116.4	700.9
Percentage Distribution	%	%	%	%
Aerosols:				
Personal	54.7	49.8	42.8	50.2
Domestic	14.3	5.7	11.4	9.4
Industrial	4.9	3.4	4.0	4.0
Medical	1.3	2.9	2.3	2.3
	75.2	61.9	60.5	65.9
Refrigeration	7.9	23.3	21.5	18.1
Plastic Foams	15.9	8.7	15.5	12.1
Other Uses	1.0	6.1	2.5	3.9
	24.8	38.1	39.4	34.1
Total	100.0	100.0	100.0	100.0

Source : OECD (Reference 2.4)

Table 2.4 presents the results of the OECD Secretariat's analysis of domestic consumption and use distribution, based on returns submitted by 13 countries. These indicate that for the overall consumption of F-11/12 in 1974 the use in aerosols (65.9%) was nearly twice that of the total of non-aerosol uses. Another feature is that whereas refrigeration accounted for 23.3% of USA domestic consumption, the corresponding figure for the EEC is only 7.9%. (More recent data for the EEC appears in Section 2.3.)

The OECD data is of particular interest because it is the only recent survey which provides information on individual countries, including the EEC member states. For the following reasons, however, we were not content to rely on it for application in the present study:

a) In accordance with procedural rules, the OECD data was supplied by the governments of the countries concerned and not directly by industry, (as is the MCA data), and the way in which each government assembled the information it transmitted to the OECD Secretariat is not generally known. The EEC fluorocarbon producers have advised against relying on the accuracy of the data, and since there are no more than two primary fluorocarbon producer-marketers in any EEC country, it is understandable that for commercial reasons companies are reluctant to reveal exact production and sales figures.

b) The data is now over three years old.

c) The usage in plastic foams is not split between closed and open cell foams.

d) The survey did not cover F-113 and F-114.

2.3 Statistics Provided by EEC Fluorocarbon Producers.

2.3.1 Data Collection Procedure

In seeking recent and reliable information on CFC production and consumption in the EEC, Metra approached the EFCTC, the European Fluorocarbon Technical Committee of CEFIC, the European Federation of National Chemical Associations. The outcome of this approach was that all the nine EEC fluorocarbon producer-marketers, including the du Pont company which is not a member of EFCTC, agreed to submit production and sales figures for 1976 and 1977 to a firm of independent accountants, Peat Marwick Mitchell and Company, for aggregation. While it would have been of interest to obtain data for each EEC country, this was not practicable for reasons of commercial security as explained above in Section 2.2.2.

The reason for this general procedure being valid is that there is negligible intermediate commodity trading in CFCs although there is considerable trading between the producers themselves. There are middlemen between producers and some of the end users: for example, material may be purchased in bulk and broken down for sale in small containers for refrigerator servicing, or in mixtures of chemicals for plastic foam production, but within the EEC the producers are able to determine the main application sectors of the majority of their sales, especially in their home markets.

The information which producers were asked to supply to the accountants, for the calendar years 1976 and 1977, and for each of the four chlorofluorocarbons F-11, F-12, F-113 and F-114, was as follows and was designed to avoid the possibility of double counting or omission:

1) Production - together with purchases and imports.

2) Sales to each of the other EEC co-producers.

3) Sales in the home market for
   a) Aerosols
   b) Refrigeration
   c) Foam plastics - polyurethane flexible
      - polyurethane rigid
      - other
   d) Solvent and other uses.

4) Sales to each other EEC country (excluding co-producers) for:
   a) Aerosols
   b) Refrigeration
   c) Foam plastics
   d) Other uses.

5) Total exports to countries outside the EEC.

6) Estimated distribution of F-11/12 home market sales between the main aerosol product groups.

7) Estimated employment in CFC manufacture, including dependent processes but excluding marketing, distribution, etc.

The difference between the sales breakdowns in 3) and 4) reflects the better information which producers have on home market sales for plastic foam blowing agents.

TABLE 2.5 : EEC CHLOROFLUOROCARBON PRODUCTION AND USE: 1976 AND 1977

CHLOROFLUOROCARBONS		11	12	Total: 11+12	113	114	Total: 113+114	Total: 11,12 113,114	Total Change '76 to '77
1. PRODUCTION (incl. imports from outside the EEC)	1976	169,724	156,709	326,433	16,697	6,827	23,524	349,957	
	1977	163,263	155,844	319,107	16,463	7,416	23,879	342,986	- 6,971
2. SALES IN HOME MARKETS (exc. sales to co-producers)									
a) Aerosols	1976	64,489	69,921	134,410	48	3,690	3,738	138,148	
	1977	58,178	65,191	123,369	108	3,945	4,053	127,422	- 10,726
b) Refrigeration and Air Conditioning	1976	1,761	13,558	15,319	24	27	51	15,370	
	1977	1,854	12,684	14,538	67	38	105	14,643	- 727
c_1) Foam - flexible polyurethane	1976	12,413	143	12,556	293	-	293	12,849	
	1977	12,775	117	12,892	419	-	419	13,311	+ 462
c_2) Foam - rigid polyurethane	1976	13,770	360	14,130	7	-	7	14,137	
	1977	14,790	291	15,081	-	-	-	15,081	+ 944
c_3) Foam - other	1976	1,254	1,375	2,629	-	-	-	2,629	
	1977	1,128	1,750	2,878	192	-	192	3,070	+ 441
c_4) Total Foam	1976	27,437	1,878	29,315	300	-	300	29,615	
	1977	28,693	2,158	30,851	611	-	611	31,462	+ 1,847
d) Solvents and other uses	1976	3,909	85	3,994	5,783	-	5,783	9,777	
	1977	4,589	6	4,595	6,519	-	6,519	11,114	+ 1,337
e) Total Home Sales	1976	97,596	85,442	183,038	6,155	3,717	9,872	192,910	
	1977	93,314	80,039	173,353	7,305	3,983	11,288	184,641	- 8,269
3. SALES TO OTHER EEC MARKETS (exc. sales to co-producers)									
a) Aerosols	1976	20,494	22,010	42,504	56	1,404	1,460	43,964	
	1977	18,589	20,610	39,199	12	1,196	1,208	40,407	- 3,557
b) Refrigeration and Air Conditioning	1976	446	5,008	5,454	21	63	84	5,538	
	1977	629	5,126	5,755	65	53	118	5,873	+ 335
c) Foams - all types	1976	12,692	147	12,839	34	39	73	12,912	
	1977	12,952	1,451	14,403	44	337	381	14,784	+ 1,872
d) Solvents and other uses	1976	174	10	184	5,876	202	6,078	6,262	
	1977	276	-	276	6,312	-	6,588	6,588	+ 326
e) Total Other EEC Markets	1976	33,806	27,175	60,981	5,987	1,708	7,695	68,676	
	1977	32,446	27,187	59,633	6,433	1,586	8,019	67,652	- 1,024
4. TOTAL HOME AND OTHER EEC SALES	1976	131,402	112,617	244,019	12,142	5,425	17,567	261,586	
	1977	125,760	107,226	232,986	13,738	5,569	19,307	252,293	- 9,293
5. TOTAL EXPORTS TO COUNTRIES OUTSIDE THE EEC	1976	39,098	44,480	83,578	3,802	1,381	5,183	88,761	
	1977	36,464	44,723	81,187	4,100	1,556	5,656	86,843	- 1,918
6. TOTAL SALES : HOME/OTHER EEC/EXPORT	1976	170,500	157,097	327,597	15,944	6,806	22,750	350,347	
	1977	162,224	151,949	314,173	17,838	7,125	24,963	339,136	- 11,211
7. Production less Sales	1976	- 776	- 388	- 1,164	+ 753	+ 21	+ 774	- 390	
	1977	+ 1,039	+ 3,895	+ 4,934	- 1,375	+ 291	- 1,084	+ 3,850	+ 4,240

Source: Report to CEFIC/EFCTC by Peat Marwick Mitchell & Co. on collation of data supplied to them by EEC fluorocarbon producers.

2.3.2 Data Aggregation

From the information provided by the producers the accountants were asked to derive the following:

1) Total production within the EEC, including imports from outside the EEC, of each of the four CFCs. (This combination was necessary because only one producer is a significant importer).

2) Total exports of each CFC outside the EEC.

3) Total usage of each CFC within home markets and other EEC markets for each industry category as given in 2.3.1. 3) and 2.3.1. 4) above.

4) Estimated distribution of F-11/12 usage in the main aerosol product categories by country.

5) Total employment in CFC manufacture in the EEC.

Table 2.5 gives the aggregated figures for each chlorofluorocarbon as provided by the accountants, together with summations for F-11/12, F-113/114 and F-11/12/113/114, and the change in the combined totals from 1976 to 1977.

All producers reported, but certain of the smaller producers could not supply a full sales analysis by use and the accountants allocated these sales in the same proportions as those of the other producers. No other adjustments had to be made.

TABLE 2.6 : EEC CHLOROFLUOROCARBON SALES 1976/77 - DISTRIBUTION BY END-USE

Chlorofluorocarbon :		F-11		F-12		Total F-11 + F-12		F-113		F-114		Total F-113 + F-114		Total F-11,12, 113,114.	
Sales in EEC		tons	%	tons	%	tons	%	tons	%	tons	%	tons	%	tons	%
Aerosols	'76	84,983	64.7	91,931	81.6	176,914	72.5	104	0.86	5,094	93.9	5,198	29.6	182,112	69.6
	'77	76,767	61.0	85,801	80.0	162,568	69.8	120	0.87	5,141	92.3	5,261	27.2	167,829	66.5
Refrigeration and Air Conditioning	'76	2,207	1.7	18,566	16.5	20,773	8.5	45	0.37	90	1.7	135	0.8	20,908	8.0
	'77	2,483	2.0	17,810	16.6	20,293	8.7	132	1.00	91	1.6	223	1.2	20,516	8.1
Foam Plastics: - flexible polyurethane	'76	18,155	13.8	154	0.14	18,309	7.5	326	2.7	(Distribution of use of F-114 in foam plastics not available)					
	'77	18,541	14.7	196	0.18	18,737	8.0	449	3.3						
- rigid polyurethane	'76	20,140	15.3	388	0.34	20,528	8.4	8	0.07						
	'77	21,467	17.1	487	0.45	21,954	9.4	-	-						
- other	'76	1,834	1.4	1.483	1.3	3,317	1.4	-	-						
	'77	1,637	1.3	2,926	2.7	4,563	2.0	206	1.5						
Total foams	'76	40,129	30.5	2,025	1.8	42,154	17.3	334	2.8	39	0.72	373	2.1	42,527	16.3
	'77	41,645	33.1	3,609	3.4	45,254	19.4	655	4.8	337	6.1	992	5.1	46,246	18.3
Solvent and other uses	'76	4,083	3.1	95	0.08	4,178	1.7	11,659	96.0	202	3.7	11,861	67.5	16,039	6.1
	'77	4,865	3.9	6	0.01	4,871	2.1	12,831	93.4	-	-	12,831	66.5	17,702	7.0
Total Sales in EEC	'76	131,402	100.0	112,617	100.0	244,019	100.0	12,142	100.0	5,425	100.0	17,567	100.0	261,586	100.0
	'77	125,760	100.0	107,226	100.0	232,986	100.0	13,738	100.0	5,569	100.0	19,307	100.0	252,293	100.0
Export Sales - to countries outside EEC	'76	39,098		44,480		83,578		3,802		1,381		5,183		88,761	
	'77	36,464		44,723		81,187		4,100		1,556		5,656		86,843	
TOTAL EEC AND EXPORT SALES	'76	170,500		157,097		327,597		15,944		6,806		22,750		350,347	
	'77	162,224		151,949		314,173		17,838		7,125		24,963		339,136	
Export Sales as % of Total Sales	'76	22.9		28.3		25.5		23.8		20.3		22.8		25.3	
	'77	22.5		29.4		25.8		23.0		21.8		22.7		25.6	

Source: CEFIC/EFCTC/Peat Marwick Mitchell data collation (1978)
Further analysis by Metra.

Discrepancies between production/import and sales totals are attributable to stock changes and reporting errors, the latter being liable to occur in end-of-year movements.

The aggregate employment figures were:

1976	1977
2079	2091

No report was made on estimated F-11/12 distribution between aerosol product sectors because insufficient information was available.

The overall exercise is considered to have been very successful, and the collaboration of the companies concerned is gratefully acknowledged.

2.3.3 Analysis of Results

Table 2.5 gives a rather complex picture of sales distribution by application because of the separation of home and other EEC sales. In Table 2.6 the two sets have been amalgamated, allocating the 'other EEC' data for F-11, F-12 and F-113 usage in plastic foams in the same proportions as the more detailed breakdown available for home sales. It is not considered justifiable, however, to make assumptions on the end-use distribution of exports outside the EEC.

Table 2.7 shows the distribution of EEC, export and total sales of each of the four CFCs.

TABLE 2.7 : EEC SALES OF CHLOROFLUOROCARBONS BY COMPOUND : 1976/77.

CFC	Year	Sales in EEC		Exports to Countries Outside EEC		Total Sales	
		Tons '000	%	Tons '000	%	Tons '000	%
11	1976	131.4	50.2	39.1	44.0	170.5	48.7
	1977	125.8	49.8	36.5	42.0	162.2	47.8
12	1976	112.6	43.1	44.5	50.1	157.1	44.8
	1977	107.2	42.5	44.7	51.5	151.9	44.8
Total 11+12	1976	244.0	93.3	83.6	94.2	327.6	93.5
	1977	233.0	92.3	81.2	93.5	314.2	92.6
113	1976	12.1	4.6	3.8	4.3	15.9	4.6
	1977	13.7	5.4	4.1	4.7	17.8	5.3
114	1976	5.4	2.1	1.4	1.6	6.8	1.9
	1977	5.6	2.2	1.6	1.8	7.1	2.1
Total 113+114	1976	17.6	6.7	5.2	5.8	22.8	6.5
	1977	19.3	7.6	5.7	6.5	25.0	7.4
Total 11,12, 113,114	1976	261.6	100.0	88.8	100.0	350.3	100.0
	1977	252.3	100.0	86.8	100.0	339.1	100.0

Source : CEFIC/EFCTC/Peat Marwick Mitchell data collation. Further analysis by Metra.

TABLE 2.8 : F-11/12 PRODUCTION AND USE IN THE EEC
Comparison of OECD (1974) and CEFIC/EFCTC (1976/77) Data

Thousands of Metric Tons

All EEC Countries	OECD Data 1974 Tons '000	OECD Data 1974 %	CEFIC/EFCTC Data 1976 Tons '000	1976 %	1977 Tons '000	1977 %
Production	299.3		326.4		319.1	
Imports	Data incomplete					
Exports			83.6		81.2	
Net exp.(-)/imp(+)	- 76.0		n.a.		n.a.	
Domestic Consumption	223.3	100.0	244.0	100.0	233.0	100.0
Of Which:						
Aerosols - personal	122.1	54.7	n.a.		n.a.	
- domestic	32.0	14.3				
- industrial	11.0	4.9				
- medical	2.8	1.3				
	167.9	75.2	176.9	72.5	162.6	69.8
Refrigeration	17.7	7.9	20.8	8.5	20.3	8.7
Foam Plastics	35.5	15.9	42.2	17.3	45.3	19.4
Other Uses	2.2	1.0	4.2	1.7	4.9	2.1

Notes: 1) Imports and exports relate to trade between EEC and non-EEC countries.

2) For CEFIC/EFCTC data, domestic consumption is equated with Sales in the EEC.

Sources: Metra summation of data taken from

a) OECD 'The Economic Impact of Restrictions on the Use of Fluorocarbons'. ENV/Chem./77.2 Appendix 1. (Oct. 1977)

b) CEFIC/EFCTC/Peat Marwick data collation.

2.3.4 Comparison with OECD and MCA Data

In Table 2.8 the EEC production and sales distribution figures for F-11 and F-12 in 1976 and 1977 are compared with the corresponding OECD data for 1974.

In Table 2.9 the EEC sales distribution for F-11 and F-12 in 1977 is compared with that of all the companies reporting in the MCA scheme, and the non-EEC distribution is shown by difference.

TABLE 2.9 : 1977 TOTAL F-11 AND F-12 SALES BY CATEGORY FOR EEC AND ALL REPORTING COUNTRIES.

Thousand of metric tons of F-11/12

Data Source (see footnotes):	(1)	(2)	(3)
Sales Category	EEC	Non-EEC	All MCA Reporting Companies
Aerosols	162.6 (69.8%)	176.5 (37.9%)	339.1 (48.6%)
Refrigeration & Air Conditioning	20.3 (8.7%)	158.7 (34.1%)	179.0 (25.6%)
Foam Plastics	45.3 (19.4%)	82.2 (17.7%)	127.5 (18.3%)
Other Uses	4.9 (2.1%)	47.7 (10.3%)	52.6 (7.5%)
Totals:	233.0 (100.0%)	465.1 (100.0%)	698.2 (100.0%)

Sources : Column (1) CEFIC/EFCTC Data from 9 companies
Column (2) Difference between Col (3) and Col (1)
Column (3) MCA Data from 20 reporting companies.

2.3.5 Comments on the 1976/77 EEC Statistics

The composite data displays in some of the preceding tables are not easy to assimilate at a glance and the summary of 1977 data in Table 2.10 below may be helpful.

TABLE 2.10 : SUMMARY OF EEC FLUOROCARBON PRODUCERS SALES STATISTICS FOR 1977.

	Total F-11, F-12.	Total F-113, F-114.	Total F-11, 12, 113, 114.
Sales - thousands of tons.			
Sales in the EEC	233.0	19.3	252.3
Exports outside the EEC	81.2	5.7	86.8
Total Sales	314.2	25.0	339.1
Percentage of Total Sales	92.6	7.4	100.0
Export Sales as % of Total	25.8	22.8	25.6
Distribution of EEC Sales Tonnages by Use Category.	%	%	%
Aerosols	69.8	27.2	66.5
Refrigeration and Air Conditioning	8.7	1.2	8.1
Foam Plastics	19.4	5.1	18.3
Solvent and Other Uses	2.1	66.5	7.0
	100.0	100.0	100.0

Source: CEFIC/EFCTC (Abstract of Table 2.6)

Reviewing all the data, the following features are noteworthy:

1) The tonnages of F-11 and F-12 greatly exceed those of F-113 and F-114, and together accounted for 92.6% of the total sales of the four CFCs by EEC producers in 1977.

2) Aerosols accounted for two thirds of CFC sales in the EEC in 1977, but at 167.8 thousand tons this represented a drop of 7.8% from the total of 182.1 thousand tons used in aerosols in 1976. In the other use categories refrigeration remained little changed in 1977 at less than 2% below 1976 consumption, and there were significant rises in consumption in foam plastic and solvent/other use applications of 8.7% and 10.4% respectively.

3) Exports outside the EEC are substantial fractions of the sales of each of the four CFCs and represented 25.6% of total sales in 1977.

4) Taking known trends into account, such as rising usage in foam plastics manufacture, the OECD data for overall EEC consumption in 1974 appears reasonably consistent with the 1976/77 data.

5) In a global context, EEC consumption of F-11 and F-12 in 1977 amounted to one third of world sales by the 20 producers reporting in the MCA scheme. The principal difference in distribution was in the refrigeration and air conditioning sector which took 25.6% of world sales but only 8.7% of sales in the EEC, the margin being largely taken up by higher EEC usage in aerosols.

6) The most striking contrast is between the EEC sales distribution of F-11 and F-12 in 1977 and that for sales by reporting countries outside the EEC in that year. (Table 2.9).

The proportion of sales for aerosol propellants in the EEC (69.8%) was substantially higher than in non-EEC sales (37.9%), and while the proportions for foam plastics were much the same, refrigeration and air conditioning accounted for 34.1% of non-EEC sales in 1977, but only 8.7% of the EEC total. 'Other uses', which include solvent cleaning applications, were also proportionately much greater in non-EEC sales.

Reasons for these major differences include:

a) the slump in USA aerosol sales after 1973, partly due to the ozone depletion controversy. USA aerosol fillings fell from a peak of 2902 million in 1973 to 2150 million in 1977; in the same years EEC fillings were 1644 and 1862 million respectively. The USA fallback was mainly in the personal products sector in which chlorofluorocarbon propellants predominated.

b) In 1977 a significant move away from CFC propellants was already evident on account of the ozone depletion issue and the prospect of legislation against CFCs in aerosols.

c) The much more extensive use of refrigeration and air conditioning, including automotive air conditioning, in developed countries outside the EEC especially in the USA.

2.4 Release of Chlorofluorocarbons to the Atmosphere

A rough estimate of CFC releases to the atmosphere associated with CFC sales in the EEC may be made using the following assumptions:

a) That all CFC sales for aerosols, plastic foams other than rigid polyurethane, and solvent and miscellaneous uses are released within a year of sale.

b) Of the CFCs used for rigid polyurethane there is an initial loss in manufacturing of 10%, followed by slow release at a uniform rate of 4.5% per year. (McCarthy et al. Reference 2.1).

c) That at least two thirds of sales to the refrigeration and air conditioning industry are for replacement and testing purposes and that under the prevailing fairly steady rate of sales an equivalent tonnage is released to atmosphere over the same period equal to 66.6% of sales per year.

On this basis it is estimated that of the sales of F-11, 12, 113 and 114 in the EEC in 1977 of 252.3 thousand tons, there will have been an actual or equivalent release of about 226 thousand tons (89.6% of the sales total) within a year of consumption.

There is, of course, an additional release of CFCs from closed cell foam manufactured in previous years, and also from discarded refrigeration equipment, but in the absence of a data base for earlier production and use this additional component cannot be assessed.

2.5 Need for Monitoring Future CFC Production and Use in the EEC.

For so long as the release of CFCs into the atmosphere is a matter of general concern, and irrespective of regulation, we consider that the production and use of CFCs in the EEC should be monitored on a systematic basis.

The MCA now performs a global monitoring function on CFC release by collecting annual production and use data for F-11, F-12 and F-22 from producers representing over 95% of world production, but the data is aggregated and not available for particular countries or regions.

The 1974 OECD statistics provided data for individual countries,but that was an isolated exercise and there is no announced intention of repeating it.

Currently there is no regular collection of CFC statistics in the EEC, and the producers regard their company figures as commercially sensitive material which they would not be happy to divulge, even on a national basis, because there are no more than two suppliers in any one country. They have cooperated in providing aggregate EEC data for the purpose of this study, but that again is in the nature of a once-off exercise.

Monitoring is necessary, we believe, because the volumes and patterns of usage are changing significantly from year to year. Over the past two years CFC sales to the aerosol industry in the EEC decreased, but demand rose in the plastic foam and solvent cleaning sectors, in which there are distinct prospects for further sustained growth, and major new uses could develop in the future - such as for working fluids in low-grade heat recovery systems. If regulation is deemed to be necessary, then up-to-date information on fluorocarbon usage trends should be available when the decisions to implement control measures are made, and thereafter so that the nature and extent of regulation can be varied in the light of current circumstances.

We recommend, therefore, that a regular monitoring procedure should be instituted in the EEC along the lines adopted for the present study, but covering all fluorocarbons produced in quantities of more than, say, 500 tons per annum by any one manufacturer, and with the independent accountants reporting on individual fluorocarbons only when total production exceeds some selected level, say 5000 tons p.a. Possibly the EEC fluorocarbon producer-marketers would be prepared to do this on a voluntary basis, as they already do for the MCA scheme, but sooner or later obligatory reporting would probably become necessary because of the possibilities attaching to importation. At present virtually all CFC trading is between CFC producers (and their agents) and the actual users or distributors to well defined industry sectors, but this might not always apply in the future.

This study has demonstrated the need for reliable data in connection with regulatory consideration, and we believe that CFC production and sales should be monitored as long as possibility of regulation exists, as well as in the event of regulation being enacted.

2.6 Conclusions

2.6.1 Collated statistics provided by independent accountants to whom all CFC manufacturers submitted returns show that EEC production and imports of F-11, 12, 113 and 114 in year 1977 totalled 343 thousand tons, a reduction of 7 thousand tons on the 1976 total. Imports probably did not exceed 10 thousand tons in either year.

2.6.2 Sales of the four CFCs in 1977 amounted 339 thousand tons, of which 87 thousand (25.6%) were exported outside the EEC, and F-11/12 sales accounted for 92.6% of the total.

2.6.3 Distribution of EEC sales by end use in 1977 was as follows:

	F-11/12	F-113/114
Sales in EEC - thousands of tons	233.0	19.3
Distribution	%	%
Aerosol propellants	69.8	27.2
Refrigeration and air-conditioning	8.7	1.2
Foam plastics	19.4	5.1
Solvent and other uses	2.1	66.5
	100.0	100.0

2.6.4 Sales for aerosols in the EEC fell from 182.1 thousand tons in 1976 to 167.8 thousand tons in 1977, a drop of 7.8%. Refrigeration sales showed little change at 20.9 and 20.5 thousand tons respectively in 1976 and 1977, but sales for foam plastics rose from 42.5 to 46.2 thousand tons, an increase of 8.7%. Significant growth also occurred in the solvent and other uses category, from 16.0 to 17.7 thousand tons, a rise of 10.4%.

2.6.5 Sales of F-11/12 in the EEC in 1977 were 10 thousand tons above the consumption reported by OECD for 1974; in that year EEC consumption accounted for 31.8% of that of the OECD countries total, and the USA for 51.5%.

2.6.6 The 1977 EEC sales of F-11 and F-12 represented one third of the world sales of 698 thousand tons by the 20 CFC manufacturing companies reporting under a scheme administered by the MCA (U.S. Manufacturing Chemists Association), and whose sales amounted to 92.5% of the estimated world production in 1977 of 755 thousand tons of F-11/12.

2.6.7 A comparison of the 1977 sales category patterns within and outside the EEC reveals substantial differences: aerosol propellants accounted for 70% of F-11/12 sales in the EEC but only 38% of non-EEC sales. The proportions for foam plastics were similar at around 18%, but while refrigeration and air conditioning accounted for 8.7% of EEC sales, they made up 34% of the non-EEC total. Reasons for these disparities include the slump in USA aerosol sales due to the ozone depletion issue which has not been parallelled in the EEC, and to the greater use of refrigeration and air conditioning in certain countries outside the EEC, especially in the USA where automotive air conditioning is a significant CFC consumer.

The effectiveness of any regulatory action designed to reduce CFC release to the atmosphere could be affected by changes in the CFC consumption pattern, because reductions secured by restrictions on particular compounds and uses could be nullified by growth in other CFC production and application sectors. Although the MCA monitoring system is invaluable in a global context, the analysis in this study shows that CFC usage can vary considerably from one region to another. It is believed, therefore, that EEC production, use, imports and exports of CFCs should be monitored for as long as the possibility of regulation exists, and also during the time during which any enacted regulation remains in force.

References in Section 2

2.1 McCarthy R.L., Bower F.A. and Jesson J.P. World Production and Release of Fluorocarbons 11 and 12. Atmospheric Environment 11, 491, (1977)

2.2 1977 World Production and Sales of Fluorocarbons FC-11 and FC-12. Manufacturing Chemists Association. June 26, 1978. (Includes report by Alexander Grant and Co.)

2.3 World Production and Release of Chlorofluorocarbons 11 and 12 Through 1977. Manufacturing Chemists Association Fluorocarbons Technical Panel. July 17, 1978. (Calculation by E.I. du Pont de Nemours & Co. from data published in Alexander Grant and Co. report '1977 World Production and Sales of Fluorocarbons FC-11 and FC-12 of June 26, 1978.)

2.4 OECD. The Economic Impact of Restrictions on the Use of Fluorocarbons. Final Report, ENV/Chem./77.2, October 1977.

3. THE FLUOROCARBON MANUFACTURING INDUSTRY

3.1 General

The chlorofluorocarbons to which this study relates are all made by reacting hydrogen fluoride (anhydrous hydrofluoric acid) with a chlorinated hydrocarbon corresponding to the generic type of CFC required. By far the largest tonnages produced are the chlorofluoromethanes F-11 and F-12, for which the required chlorocarbon is carbon tetrachloride, and they are produced together in one reaction system and then separated. By an analagous process the chlorofluoroethanes F-113 and F-114 are co-produced from perchloroethylene.

Of the primary raw materials, hydrofluoric acid is made from mineral fluorspar and sulphuric acid, and the chlorocarbons by treating hydrocarbons with elementary chlorine.

A by-product of CFC manufacture is hydrogen chloride, which arises both from hydrocarbon chlorination and chlorocarbon fluorination, and this is usually either sold as aqueous hydrochloric acid or utilised on site in other processes.

Thus, although the chlorofluorocarbons themselves are relatively safe chemicals which can be used with simple precautions in the smallest of firms, their production in the quantities now demanded entails the handling of large tonnages of highly toxic and corrosive substances, and can only be undertaken by organisations with substantial technological and other support facilities.

Some CFC producers also make one or more of the precursor or intermediate raw materials, but there is considerable variation in the nature and extent of backward integration.

In assessing the impact of any restrictive regulation on the use of CFCs it is necessary to examine the technical and economic problems presented by having to make a major turn-down in production or wide variations from the normal output ratios of co-produced compounds. It is also necessary to consider the effects on the ancillary sectors of the industry which supply the raw materials or utilise the by-products.

3.2 Industry Structure

Fluorocarbons are manufactured in five countries of the EEC by the ten companies listed in Table 3.1. Nine of them are producer-marketers, but the output of one of the West German producers, von Heyden, is marketed by another: Hoechst.

All the producers are major companies or members of major groups in the chemical and allied industries, with multi-national interests. As ranked by total sales, seven of them are among the twenty leading chemical corporations in the world.

Some of the producers own or have holdings in European fluorocarbon operations in countries outside the EEC, including Greece and Spain which have applied for membership of the Community.

TABLE 3.1 : FLUOROCARBON MANUFACTURERS AND PLANTS IN THE EEC

EEC Member State	Company/ (Parent Company)	CFC Plant Location	Estimated CFC Production Capacity		
			Plant '000 tons/year	Member State '000 tons/year	% of EEC Total
France	Pechiney Ugine Kuhlmann S.A.	Pierre Benite, nr. Lyon	80	105	24.9
	Rhone-Poulenc S.A.	Salindres, nr. Nimes	25		
Germany	Hoechst A.G.	Hoechst, Frankfurt (am Main)	) 100	125	29.6
	Chemische Fabrik von Heyden (Squibb Corp. U.S.A.)	Regensburg	)		
	Kali-Chemie A.G. (Solvay et Cie, Belgium)	Bad Wimpsen, nr.	25		
Italy	Montedison S.p.A.	Spinetta Marengo, nr Milan Porto Marghera, nr Venice	) 60)	60	14.2
Netherlands	Akzo Chemie Nederland B.V. (Akzo B.V.)	Budel, nr. Eindhoven	20	32	7.6
	Du Pont de Nemours Nederland B.V. (E.I. du Pont de Nemours & Co., U.S.A.)	Dordrecht, nr. Rotterdam	12		
United Kingdom	Imperial Chemical Industries Ltd.	Runcorn, Cheshire, England	80	100	23.7
	I.S.C. Chemicals Ltd (Rio Tinto-Zinc Corporation, UK)	Avonmouth, nr. Bristol England	20		
		Total	422	422	100.0

Source : Metra, from trade publications and industry sources.

Estimates of the production capacities of the CFC plants in the EEC are included in Table 3.1 but it must be stressed that these are only approximate indications and that CFC plants cannot be considered as having a fixed capacity. Some plants are operated on a campaign basis to produce a range of fluorocarbons and output rate varies with the product mix, and with continuous process plants making F-11 and F-12 the capacity varies with the F-11/12 ratio.

In 1977, EEC production and imports of F-11, 12, 113 and 114 totalled 343 thousand tons. If imports from outside the EEC did not exceed 10,000 tons, then the estimated total production capacity of about 422 thousand annual tons suggests an overall utilisation of less than 80% in that year.

The CFC producers were not prepared to provide employment data on a plant basis, and it must be appreciated that employment in any individual plant will vary not only with overall capacity but with the extent of backward integration in making precursor materials, the degree of automation, multiplicity of units and other factors. In Table 3.2 we provide our surmise of the distribution of the 1977 total of approximately 2100 personnel

The EEC producer-marketers other than du Pont maintain formal contact for discussion of technical matters through the European Fluorocarbon Producers Technical Committee (EFCTC) under the aegis of the European Council of Chemical Manufacturers Federations (CEFIC) and

TABLE 3.2 : ESTIMATED EMPLOYMENT DISTRIBUTION IN CFC MANUFACTURE IN THE EEC IN 1977.

Country	Employment in CFC Manufacture (see footnotes)
France	500
West Germany	540
Italy	380
Netherlands	180
United Kingdom (England)	500
	2,100

Source : Metra estimates

Notes : 1) Estimates relate to the distribution of the estimated total employment in 1977 of 2091, provided by CEFIC/EFCTC in conjunction with CFC production and sales statistics.

2) Employment relates to personnel engaged in CFC manufacture in CFC producers' own plants, including dependent processes but excluding marketing, distribution, etc.

all of them support the extensive Fluorocarbon Research Program administered by the MCA, which is concerned with the influence of fluorocarbons on the environment, particularly the halocarbon-ozone problem.

Since sales of F-11/12 in 1977 were 11,000 tons below the 1976 total of 244 thousand tons, there is unlikely to be any immediate problem in complying with the EC Council's Resolution to the effect that F-11/12 production capacity in the Community should not be increased.

3.3 Production Processes

3.3.1 F-11 and F-12

The chlorofluoromethanes F-11 and F-12 are co-produced by the interaction of hydrogen fluoride (HF) with carbon tetrachloride (CCl_4) in the presence of a catalyst. The reaction may be carried out in the liquid phase using an antimony chloride catalyst, or by passing the vaporised reactants through a bed of solid catalyst granules. The output from the reaction system consists of a mixture of fluorocarbons, by-product hydrogen chloride and some unconverted raw materials, and it is taken through a series of separation and purification stages to obtain the individual products. To explain some limitations of the process it is necessary to discuss it in a little more detail.

The catalytic fluorination of chlorocarbons can be regarded as a sequence of steps in which the chlorine atoms of the chlorocarbon molecules are progressively replaced with fluorine atoms, a molecule of hydrogen chloride being generated for each fluorine atom introduced.

Starting with carbon tetrachloride and hydrogen fluoride it is possible to produce four different fluorocarbons and the reaction sequence can be represented as follows, although the actual chemistry of the system is more complicated.

$$\underset{}{CCl_4} \xrightarrow{HF} \underset{\substack{+\\HCl}}{\overset{(F\text{-}11)}{CCl_3F}} \xrightarrow{HF} \underset{\substack{+\\HCl}}{\overset{(F\text{-}12)}{CCl_2F_2}} \xrightarrow{HF} \underset{\substack{+\\HCl}}{\overset{(F\text{-}13)}{CClF_3}} \xrightarrow{HF} \underset{\substack{+\\HCl}}{\overset{(F\text{-}14)}{CF_4}}$$

In the reactor all these steps are occurring simultaneously but at different rates governed by temperature and other factors. By controlling the process conditions it is possible to obtain a final product mix consisting very largely of F-11 and F-12 in equal proportions. However, some co-production of the more highly fluorinated compounds is inevitable, and as there is a relatively small market for F-13 and F-14 the process is usually operated so that they arise in minimal quantities. Although under-fluorinated material including unconverted carbon tetrachloride can be re-cycled, over-fluorinated products for which there is no adequate sale may have to be discarded, and then represent a waste of raw materials.

Although it is possible to vary the F-11/F-12 production ratio between fairly wide limits, it is not possible to obtain a 100% yield of either compound.

3.3.2 F-113, F-114, and F-115.

The process is analagous to that used for F-11 and F-12, and for this series of fluorocarbons the parent chlorocarbon is hexachloroethane (C_2Cl_6), although in practice it is convenient to provide a feed of perchloroethylene (C_2Cl_4) and chlorine (Cl_2). Treatment with hydrogen fluoride in the presence of a catalyst results in progressive fluorination accompanied by elimination of by-product hydrogen chloride, and the reactor output mixture is subjected to fractional distillation and other processing to obtain pure products.

As with F-11/12 production, it is not practicable to obtain 100% yields of one chlorofluorocarbon, and the process is normally operated so as to produce a pair of CFCs, either F-113 with F-114, or F-114 with F-115. Although we are mainly concerned with F-113 and F-114, the use of F-115 as a component of the azeotrope with F-22 - Refrigerant 502 - appears to be increasing.

3.3.3 F-21, F-22 and F-23

For this series the chlorinated hydrocarbon starting point is chloroform, ($CHCl_3$), and progressive fluorination yields F-21 ($CHCl_2F$), F-22 ($CHClF_2$) and F-23 (CHF_3). All these compounds find application in refrigeration and air conditioning but the principal demand is for F-22 both as a refrigerant and as the precursor for tetrafluoroethylene monomer, which is used for making the plastic 'PTFE' - polytetrafluoroethylene.

F-22 is relevant to this study as a potential substitute for F-12 and other perhalogenated refrigerants, and if adequately cleared in respect of toxicity it might be used as an aerosol propellant.

3.3.4 Plant Operation

Because of the similarities in the catalytic fluorination processes used for making a wide range of CFCs, it is possible to have multi-purpose production plants and to operate them in campaigns to produce batches of different compounds.

In practice, because the demand for F-11/12 is so much greater than for all the other CFCs together, most F-11/12 production and that of the intermediate raw materials is carried out in specialised units designed to operate continuously, 24 hours a day, with only occasional stoppages for maintenance, breakdown or emergency. A plant may have one or more of these units, possibly as a result of installing additional units over the years as the CFC market has expanded.

Various combinations of facilities exist and a typical situation would be for a plant to be equipped with two or more continuous process units for F-11/12, and other smaller units for making the rest of the product range. Depending on sales levels, these smaller units might be operated continuously or in campaigns. Producers do not necessarily make the full range of CFCs which they market, but operate their production facilities to the best economic effect and purchase the balance of their requirements from other producers. For a small producer, especially one with little or no backward integration in raw materials, the best option may be to concentrate on making the higher value CFCs and leave F-11/12 production to the large integrated manufacturers.

Special process problems could arise in the event of regulation entailing a major cut-back in CFC production, since for continuous process plants there are technical limitations to the extent to which throughput can be reduced aside from the economic penalty of the fixed cost element which increases the total unit cost of production. Multi-unit plants have an extra dimension of flexibility in that one or more units can be shut down in order to maintain operation of the others at technically satisfactory levels.

3.4 Raw Materials

3.4.1 Requirements for F-11 and F-12 Production

Of the immediate precursors for F-11 and F-12, hydrofluoric acid is made by reacting 'Acid Grade' mineral fluorspar with concentrated sulphuric acid (100% H_2SO_4). Acid grade fluorspar, also known as 'acidspar', and containing not less than 97% calcium fluoride (CaF_2), is prepared by the beneficiation of fluorspar ores, principally by flotation, while sulphuric acid is made from a variety of sulphur bearing materials including natural elementary sulphur, anhydrite, pyrites and other sulphide ores including zinc sulphide concentrates, and from by-product sources such as the desulphurisation of natural gas and oil.

The other precursor, carbon tetrachloride, is made in the EEC by three routes:

a) together with perchloroethylene by the chlorination of propylene derived from the cracking of naphtha

b) by the chlorination of methane, available from natural gas

c) by the chlorination of residues and co-products arising from the production of other chlorocarbons, principally vinyl chloride

The chlorine required for all three methods is obtained by the electrolysis of brine, together with caustic soda.

Thus the basic raw materials are

Fluorspar ore
Sulphur - natural and by-product sources
Rock salt
Naphtha (from crude oil), or methane (from natural gas).

All these raw materials are now available in the EEC from indigenous sources, although there is also importation.

There is also a requirement for large amounts of electric power for the electrolysis of salt.

The overall materials flow scheme is represented by Figure 1.

Figure 1 - Materials Flow Diagram for F-11/12 Production.

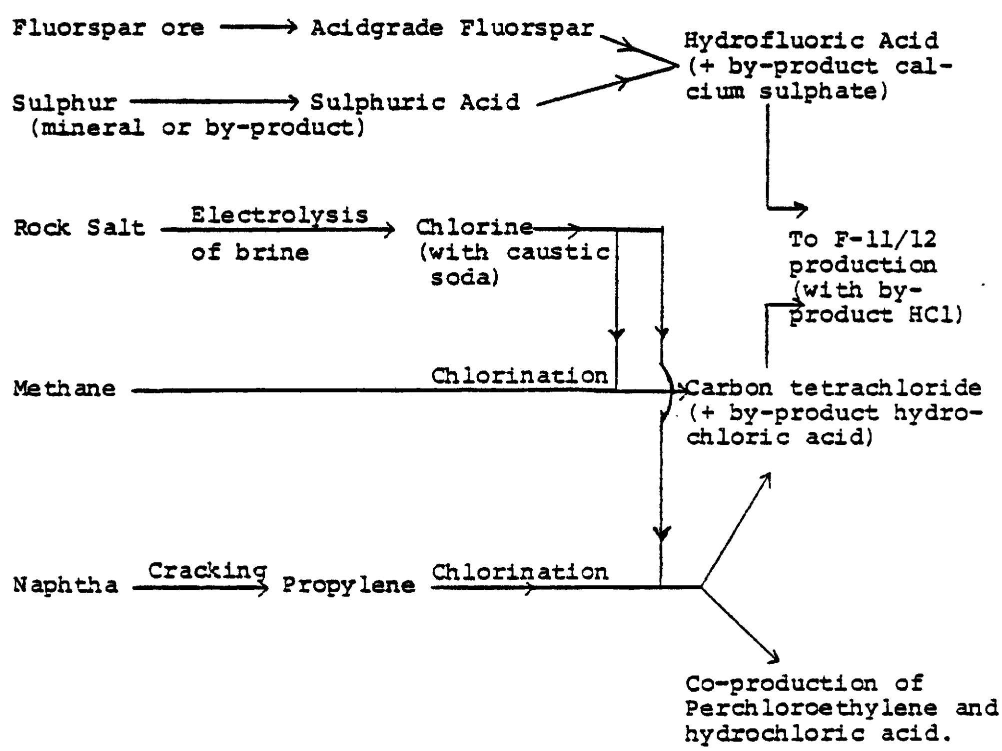

TABLE 3.3 : RAW MATERIALS AND PRODUCT QUANTITIES IN F-11/12 MANUFACTURE

Metric Tons

Raw Material or Product	Quantities for Production of 1000 metric tons of 50:50 F-11/12 Mixture		Metra Comments
	Source A	Source B	
Primary Raw Materials			
Fluorspar	480	600	Fluorspar: 90% yield on CaF_2 content of acidspar corresponds to 560 tons spar for 250 tons HF.
Sulphur	(Not stated)		Sulphur: 236 tons natural elementary sulphur are required for 700 tons of 100% sulphuric acid.
Salt	3900	3100	
Methane	120	-	
Naphtha	-	100	
Intermediates			
Sulphuric Acid	600	700	Sulphuric Acid: 700 tons is thought to be the more typical figure.
Chlorine	2300	1800	
Propylene	-	100	
Precursors			
Hydrofluoric Acid (HF)	240	250	HF: 240 tons implies 99% yield, 250 tons implies 95% yield.
Carbon tetrachloride (CCl_4)	1200	1200	CCl_4: 1200 tons implies over 99% yield.
Co-products			
Calcium sulphate	800	1000	
Caustic soda (as NaOH)	2600	2000	
Hydrochloric acid (as HCl)	1400	1100	
Electric power	8500 MWh	(6650 MWh)	Power for Source B calculated pro rata to requirement for chlorine in Source A.

Sources: A) EFCTC member company using methane route to carbon tetrachloride.
B) EFCTC member company using propylene route to carbon tetrachloride.

Two of the CFC producers represented on the EFCTC, one making carbon tetrachloride from methane and the other from propylene, provided details of the raw materials of F-11 and F-12 in a 50:50 ratio. The figures are given in Table 3.3 together with some comments. Companies tend to be reluctant to reveal precise quantity data because this discloses plant conversion efficiencies.

Since EEC production of F-11/12 was of the order of 300,000 tons in 1977, an indication of some of the overall raw materials tonnages involved can be obtained by multiplying the appropriate figures in Table 3.3 by 300. The split of carbon tetrachloride production from methane and propylene, and hence the actual usage of salt and chlorine is not known however.

3.4.2 Requirements for F-22, F-113 and F-114

The inorganic requirements, chlorine and hydrofluoric acid, and the basic raw materials for these are the same as for F-11 and F-12.

Similar organic starting materials can also be used, since the precursor for F-22 is chloroform, $CHCl_3$, which can be made from the chlorination of methane. The perchloroethylene needed for F-113 and F-114 can be made together with carbon tetrachloride by chlorinating propylene, although it can also be derived from ethylene dichloride.

The production tonnages of these CFCs are so much smaller than those of F-11 and F-12 that it seems unnecessary to detail the variations in raw materials/product ratios.

TABLE 3.4 : GEOGRAPHICAL DISTRIBUTION OF CFC SALES IN 1977 BY EEC PRODUCERS

Chlorofluorocarbon	F-11	F-12	Total F-11/12	F-113	F-114	Total F-11/12 113 & 114
Total Sales :						
thousand of tons	162.2	151.9	314.2	17.8	7.1	339.1
Distribution of Sales :	%	%	%	%	%	%
Producers' Home Markets	57.5	52.7	55.2	41.0	55.9	54.4
Other EEC Markets	20.0	17.9	19.0	36.1	22.3	20.0
Exports outside EEC	22.5	29.4	25.8	23.0	21.8	25.6
	100.0	100.0	100.0	100.0	100.0	100.0

Source : CEFIC/EFCTC Data.

3.5 Marketing of Chlorofluorocarbons

In the EEC the primary marketing of CFCs is virtually all conducted by the nine producer-marketers named in Section 3.2 and this also applies to any significant volumes of imports. In general, each company offers the full range of CFCs for which there is any substantial demand but may only make some of them, and there is a good deal of trading among producers to cover production gaps and shortfalls.

Because of over-capacity and the possibility of regulatory action there is strong competition in the home, EEC export and non-EEC export markets, and the distribution of 1977 sales between these three segments is shown in Table 3.4. On average a little over half the sales were in producers' home markets, and more than half of the balance was exported outside the EEC. Competition is not only between the CFC producers but also with respect to alternative materials. The prospect of legislation has stimulated competition in the non-aerosol sectors, such as refrigeration, where it is surmised that no restrictive measures are likely to be introduced in the short or medium term.

For the principal CFCs the producers prefer to trade in bulk and much of the refrigeration grade material is sold through specialist suppliers to the contract and servicing business. For example, although Du Pont have a United Kingdom subsidiary, they supply the UK refrigeration business through British Oxygen, which has an extensive depot network with cylinder handling and distribution facilities. A proportion of CFC sales for plastic foam production is marketed through suppliers of the chemical reactants and may be incorporated in 'ready-to-mix' systems.

Technical service and application research have always been strong features of the fluorocarbon industry and these functions have undoubtedly made big contributions to the growth of established markets and to the development of new ones.

With the growth of world sales from a few thousand tons a year in the early 1940s to over 800,000 tons in 1974, CFCs F-11 and F-12 have changed from being low volume specialities to bulk chemicals with correspondingly lower profit margins.

Major investment in the products and their pre-cursors, and the complex interdependence of co-products in the heavy chemical industry give the larger producers a particularly strong economic incentive to continue in business. But there is a very noticeable shift of marketing interest to the lower volume higher value products, and to new applications for which producers can develop technical know-how and patent situations and sell on this basis and not largely on price.

3.6 Value of Chlorofluorocarbon Sales

Prices of CFCs to individual customers vary with a number of factors including the grade and specification of the compound or mixture supplied, location, annual off-take and delivery quantity, aside from any special discount arrangements that may apply.

From the industry it has been suggested that average prices can be taken for EEC sales, including exports, and the levels proposed (in June 1978) are UCE 520 per ton for F-11, and UCE 610 per ton for F-12, with a 50:50 mixture of F-11/12 being sold at the average of the single compound prices, i.e. UCE 565 per ton.

On this basis the values of 1977 sales volumes at current average prices would be as shown in Table 3.5.

TABLE 3.5 : VALUE OF 1977 SALES OF F-11 AND F-12 AT MID-1978 AVERAGE PRICES.

CFC	Average Mid-1978 Price UCE/ton	Total 1977 Sales tons '000	Value of Sales UCE million
F-11	520	162.2	84.3
F-12	610	151.9	92.7
		314.1	177.0

Source: Metra, from EFCTC and other industry sources.

No average prices have so far been proposed in respect of F-113 and F-114 which certainly command very much higher prices than F-11/12. We estimate the average selling price of these CFCs to be not less than UCE 1250 per ton, and hence assess the value of the 1977 sales volume of 25,000 tons F-113/114 at not less than UCE 31 million. Adding this to the F-11/12 sales value, we arrive at a total of UCE 208 million for the total value of 1977 sales of F-11, 12, 113 and 114 at current average prices, of which the export component (to countries outside the EEC) is approximately UCE 53 million.

Although we think it important to make an assessment of the value of CFC sales at the interface between the producer-marketers and their customers, there is an arbitrary element in assigning values to goods which do not represent the final stage of a sales chain. Nearly the whole volume of CFC sales is for the production of other goods and services, and further value is added at every step. When sold through intermediary suppliers in small quantities very much higher prices may apply than those quoted above. Refrigerant grade F-12, for example, might cost the equivalent of three times the overall average price per ton when supplied in cylinders of 13 kg net weight for refrigerator servicing purposes. But at this stage the material can be considered as having already entered another industry sector, and the differential partly reflects the costs of handling and distribution including the very considerable costs of maintaining cylinder stocks.

There are also difficulties in trying to assess the added value of CFCs because they are made from raw materials which are indigenous to the EEC, but which are also imported. It is not possible to say that the first effect of reducing CFC production would be an equivalent reduction in the imported raw materials because so much depends on the local circumstances obtaining at the time. For example, if hydrofluoric acid is being made for CFC manufacture using sulphuric acid derived from anhydrite it does not follow that reducing the production rate will lead to a lower level of imported sulphur consumption at some other location where sulphuric acid is manufactured, because economic and other considerations may not permit such flexibility. At current prices we estimate the cost of imported sulphur and naphtha (or crude oil) requirements equivalent to 1 ton of 50:50 F-11/12 mixture to be less than UCE 28. This is less than 5% of the average sales value of UCE 565 per ton, and since only a fraction of the EEC production of CFCs is made from imported materials the added value in respect of the materials employed must be over 95%. Similar considerations apply to the electric power requirement for chlorine production, much of which is generated from indigenous fuels.

There is some importation of CFCs into the EEC, often to cover special circumstances such as a plant breakdown. It is generally more economic to purchase from other EEC producers and the volume in 1977 is believed to have been less than 10,000 tons of F-11, 12, 113 and 114, which is less than 3% of total sales tonnages, compared with exports of over 25%.

3.7 Contribution to Added Value in the EEC Economy

Since CFCs are used as intermediates or ancillaries in the production of other goods and services, their added value when used within the economy in which they are produced is incorporated in the added value of the end products and cannot be considered as a separate contribution. In other words, if CFCs were to be replaced as aerosol propellants, blowing agents, etc. by other materials or methods which resulted in no alteration in the added value of the end products, the net direct effect on the added value of the economy would be nil.

The specific contribution of the CFC industry to added value in the EEC is the net added value of exports outside the EEC, viz. value of export sales less cost of imports used in their production.

Although we have data on recent export tonnages, accurate figures on export prices and costs of specifically related imports are not available.

The estimates of added value of exports given below in Table 3.6 are based on 1977 export tonnages, the mid-1978 average selling prices used in Section 3.6 for assessing gross sales values, and a nominal deduction of 10% to cover related imports of raw materials and fuel, and the possibility that export selling prices are somewhat lower than the overall average. It is also assumed that the export tonnages do not include any re-export of imported CFCs.

TABLE 3.6 : ESTIMATE OF ADDED VALUE TO EEC OF 1977 CFC EXPORTS AT MID-1978 PRICES

	(A)	(B)	(C)
CFC	Average Mid-1978 Selling Price for Home and Export Sales UCE/ton	1977 Exports outside EEC tons '000	Estimate of Added Value = 0.9 (AxB) UCE million
F-11	520	36.5	17.1
F-12	610	44.7	24.5
F-113 & 114	1250	5.7	6.4
	Totals:	86.9	48.0

Source : Metra

3.8 Social and Economic Implications of Regulation

3.8.1 Effects on Sales Tonnages and Product Mix

The three scenarios to be examined involve restrictive measures on aerosol applications of CFCs as follows:

Scenario (1) - A ban on CFCs in 'non-essential' aerosols 3 years from the end of 1978, i.e. 1982 would be the first full year of the ban.

Scenario (2) - A similar ban coming into effect after 5 years, i.e. 1984 would be the first full year of the ban.

Scenario (3) - A reduction of 50% in the quantities of CFCs used in aerosols over a 3 year period, i.e. by the end of 1981, followed by maintenance of this maximum permitted use for two more years, after which a ban on all non-essential uses would apply as in the other scenarios, becoming effective in 1984 as in Scenario (2).

To make sales volume forecasts related to these scenarios a number of assumptions have to be made, and views have to be taken on the average growth rates for the non-aerosol applications of CFCs, since these would partly off-set the fall in sales in the aerosol category.

The principal explicit and implicit assumptions made in constructing sales volume forecasts are that:

(a) Export sales outside the EEC in 1977 can be allocated to application categories in the same proportions as those for sales within the EEC, and similar growth patterns for the non-aerosol categories will apply for internal and export sales.

(b) The scenarios applying to the use of CFCs in aerosols within the EEC would also apply to export sales. (In practice the regulations in the export markets might be more or less severe than the EEC restrictions, but there is little doubt that a number of countries now importing CFCs from the EEC would follow any EEC lead on regulation and in some instances might anticipate it. It would also be open to the Commission to take measures to prevent export for use in aerosols. For estimation purposes it has been assumed that the 1977 ratios of EEC and export sales will remain the same for each CFC over the projection period.)

(c) CFC sales to the exempt aerosol product sectors in 1982 and 1984 would be equivalent respectively to 5.0% and 5.5% of the total 1977 sales volume for all aerosols.

(d) The base year for Scenario (3) would be 1976, and in 1982 the permitted maximum of 50% of the 1976 CFC sales for aerosols would be fully utilised.

(e) Sales volumes for 1982 and 1984 for the non-aerosol application categories can be estimated by applying the average annual growth rates proposed in Table 3.7 to the total 1977 sales volumes in each category estimated as indicated in (a). Also that these volumes would be achieved despite price increases which the producers might have to make for any reason including rises in raw materials prices and the dis-economies of reduced production rates.

TABLE 3.7 : ESTIMATED AVERAGE ANNUAL GROWTH RATES FOR CFC SALES BY EEC PRODUCERS IN NON-AEROSOL APPLICATION CATEGORIES : 1978 - 1984.

Growth of Sales Tonnage : % p.a.

	Refrigeration and A/C	Foam Plastics	Solvent/Other
F-11	10	8	10
F-12	2	8	-
F-113	-	-	10
F-114	-	8	-

Source : Metra.

The growth rates in Table 3.7 represent our view that there will be strong and sustained expansion in the foam plastic and solvent cleaning sectors over the next six years and that F-11 sales for air conditioning and miscellaneous uses will also show a high growth rate in this period. A low rate for F-12 in refrigeration is forecast because we believe there is a trend towards greater use of F-22 and F-502, and because we think the industry will take steps to reduce refrigerant losses due to leakages and wasteful filling and maintenance practices.

On the basis outlined above forecasts have been made of sales tonnages of F-11, 12, 113 and 114 in the years 1982 and 1984 under the three regulatory scenarios, and these are given in Table 3.8 together with the figures for actual sales and assessed end-use distribution in 1977.

TABLE 3.8 : EEC CHLOROFLUOROCARBON SALES PROJECTIONS FOR 1982 and 1984 UNDER REGULATORY SCENARIOS

Thousands of metric tons.

Year	1977			1982	1982	1984
Regulatory Scenario:	(No regulation)			Scenario(1) Ban on CFCs in 'non-essential' aerosols.	Scenario(3) CFC usage in aerosols reduced to 50% of 1976 quantities.	Scenario(2) Ban on CFCs in 'non-essential' aerosols (Scens.(1) & (3) also apply)
Chlorofluorocarbon and Application Category.	Total Sales tons '000	Distrib. %	Forecast Growth Rate % p.a.	Total Sales tons '000	Total Sales tons '000	Total Sales tons '000
F-11						
Aerosols	99.0	61.0	-	5.0	42.5	5.5
Refrigeration	3.2	2.0	10	5.2	5.2	6.3
Foam Plastics	53.7	33.1	8	78.8	78.8	91.7
Other	6.3	3.9	10	10.1	10.1	12.3
	162.2	100.0		99.1	136.6	115.8
(Export content at 22.5%)	(36.5)			(22.3)	(30.7)	(26.0)
F-12						
Aerosols	121.6	80.0	-	6.1	60.8	6.7
Refrigeration	25.2	16.6	2	27.8	27.8	29.0
Foam Plastics	5.1	3.4	8	7.5	8.8	8.8
	151.9	100.0		31.4	97.4	44.5
(Export content at 29.4%)	(44.7)			(9.2)	(28.6)	(13.1)
F-113						
Aerosols	0.16	0.8	-	)	)	)
Refrigeration	0.17	1.0	-	) 1.7	) 1.7	) 2.0
Foam Plastics	0.85	4.8	-	)	)	)
Solvent & Other	16.66	93.4	10	26.8	26.8	32.5
	17.84	100.0		28.5	28.5	34.5
(Export content at 23%)	(4.1)			(6.5)	(6.5)	(7.9)
F-114						
Aerosols	6.58	92.3	-	0.3	3.3	0.4
Refrigeration	0.12	1.6	-	0.2	0.2	0.3
Foam Plastics	0.43	6.1	8	0.6	0.6	0.7
	7.13	100.0		1.1	4.1	1.4
(Export content at 21.8%)	1.6			(0.2)	(0.9)	(0.3)

Note : Total Sales = Sales in EEC + exports to non-EEC countries. Export sales have been allocated to application categories in same proportions as EEC market distribution.

Source: Metra.

TABLE 3.9 : COMPARISON OF 1977 CFC SALES MIX WITH PROJECTIONS FOR 1982/84 UNDER REGULATION

Year and Scenario	1977		1982		1982		1984	
	(No regulation)		Scenario (1)		Scenario (3)		Scenario (2)	
Chlorofluorocarbon	Sales tons '000	% of total	Sales tons '000	% of total	Sales tons '000	% of total	Sales tons '000	% of total
F-11	162.2	47.8	99.1	61.9	136.6	51.2	115.8	59.0
F-12	151.9	44.8	31.4	19.6	97.4	36.5	44.5	22.7
Total F-11 + F-12	314.2	92.6	130.5	81.5	234.0	87.7	160.3	81.7
(Total as % of 1977 total)	(100.0)		(41.5)		(74.5)		(51.0)	
(Ratio F-11/F-12)	(52/48)		(76/24)		(58/42)		(72/28)	
F-113	17.8	5.3	28.5	17.8	28.5	10.7	34.5	17.6
F-114	7.1	2.1	1.1	0.7	4.1	1.5	1.4	0.7
Total F-113+F-114	25.0	7.4	29.6	18.5	32.6	12.2	35.9	18.3
(Total as % of 1977 total)	(100.0)		(118.4)		(130.4)		(143.6)	
(Ratio F-113/F-114)	(71/29)		(96/4)		(87/13)		(96/4)	
TOTAL F-11,12,113, 114	339.1	100.0	160.1	100.0	266.6	100.0	196.2	100.0
(Total as % of 1977 total)	(100.0)		(47.2)		(78.6)		(57.8)	

Source : Metra.

No forecasts are made for the intermediate years because we think too high an element of speculation is attached to estimating the rate of run-down in consumption of CFC propellants by the aerosol industry in the intervals between the announcement of a proposal to regulate, enactment of legislation and subsequent implementation.

It is also thought unwise to speculate on what the sales of CFC aerosol propellants would be over the next few years in the absence of restrictions because the ozone controversy and the possibility of regulation are already influencing aerosol sales and the choice of propellants. Trends will vary according to what may be termed the regulatory climate, and it is unlikely that propellant usage will ever return to the pre-1975 pattern.

In Table 3.9 a comparison is shown of the 1977 sales mix and product pair ratios with those projected for 1982 and 1984 under the regulatory scenarios. The extent of the production cut-back and the changes in the demand ratios for the co-produced products have major operational and economic implications and these are discussed in the following sections.

3.8.2 Effects on Industry Structure and Operations

The projections made in Section 3.8.1 for F-11/12 sales show that a ban on the use of CFCs in most aerosols in 1982 or 1984 would reduce sales of these CFCs to 41.5% or 51.0% respectively of the 1977 sales volumes. Since the total EEC production capacity utilisation in 1977 was less than 80%, the bans could reduce average plant utilisation to 30 to 40%.

Most F-11/12 is made in high capacity continuous process plants and it is unlikely that these are capable of stable operation at loadings of less than 50%, apart from the economic penalty associated with the higher ratio of fixed to variable costs.

Faced with the problem of demand falling below the level at which continuous operation is practicable, a producer may have several alternatives:

a) To move out of the CFC business altogether.

b) To continue as a marketer (and possibly as a producer of the lower volume CFCs which can be made campaign-wise in small plants suitable for discontinuous operation). In this case the requirements of F-11 and F-12 would have to be brought in from other sources and the plant either scrapped or 'moth-balled' against the possibility that circumstances might eventually justify re-commissioning.

c) To operate the plant intermittently.

   This is usually a very unsatisfactory procedure for plants designed to operate continuously. The shut-down and start-up procedures are expensive, maintenance requirements tend to increase, there are problems with labour deployment, and material conversion efficiencies suffer. It can also entail an increase in storage capacity and hence require capital investment in a facility which is not currently an attractive economic proposition.

d) With a multi-unit plant, to close down one or more sections and maintain the load on the others at technically satisfactory levels.

e) To try to secure a larger share of the remaining market by holding down prices at levels which will persuade some other producers to abandon the business.

Similar problems arise in respect of the production of some of the raw materials and intermediates, including carbon tetrachloride - which is used almost exclusively for CFC production, and hydrofluoric acid - for which CFCs are now the major outlet.

In the USA the overcapacity situation arising from the restrictions being placed on CFC aerosol propellants has already resulted in a number of CFC plant closures, and certain companies have in effect adopted variants of option (b) above by continuing in the fluorocarbon business but arranging for certain of their requirements, especially of F-11/12, to be supplied by other companies.

Since they do not acknowledge that a case for restricting CFC usage has yet been made out and as no formal proposals for regulation in the Community have yet been put forward, the EEC producers were disinclined to discuss with us in detail how they might cope with a major reduction in demand, although they agreed that changes in the structure of the industry would be a real possibility.

Our view is that in the context of our scenarios substantial reductions in operating capacity would be inevitable and that these should be brought about in a rational way so that production and distribution costs for supplying the available market are minimised by enabling a number of appropriately located units to continue to operate at high capacity utilisation. This implies some collaborative action, and there are precedents in the European chemical industry for dealing with the problems of over-capacity.

The foregoing discussion applies mainly to F-11/12. For F-113/114, if our forecast of a strong growth rate in solvent uses for F-113 proves correct, the total demand in 1982 and 1984 will be higher than in 1977 despite the loss of most of the F-114 market for aerosols. The problem here will be the technical one of making F-113 together with the F-115 requirement for refrigeration without over-production of F-114, but we believe there is enough flexibility in the process to achieve this, and also to cope with the imbalance in the F-11/F-12 demand ratio which, according to the estimates in Table 3.9, could move from 52:48 in 1977 to 76:24 in 1982 under Scenario (1), or 72:28 in 1984 under any of the scenarios.

3.8.3 Effects on Prices and Sales Values

3.8.3.1 Reference basis: value of sales at present prices

To isolate the impact of the regulatory scenarios on CFC prices and sales from the movements in the prices of all goods and services over the period concerned, and which it is beyond our brief to attempt to predict, the following discussion relates to the present, mid-1978, economic context.

TABLE 3.10 : VALUES OF FORECAST CFC SALES IN 1982 AND 1984 UNDER REGULATION AND AT 1978 AVERAGE PRICES

Values in UCE millions

Year & Scenario		1977/1978 (No Regulation)		1982 Scenario (1)		1982 Scenario (3)		1984 Scenario (2)	
CFC	Assumed Mid-1978 Price UCE/Ton	Actual 1977 Sales Ton'000	Estd.1978 Value UCE mn	Forecast Sales Ton'000	Value at Mid-1978 Prices UCE mn	Forecast Sales Ton'000	Value at Mid-1978 Prices UCE mn	Forecast Sales Ton'000	Value at Mid-1978 Prices UCE mn
F-11	520	162.2	84.3	99.1	51.5	136.6	71.0	115.8	60.2
F-12	610	151.9	92.7	31.4	19.2	97.4	59.4	44.5	27.1
Total F-11/12		314.2	177.0	130.5	70.7	234.0	130.4	160.3	87.3
(Total as % of 1977/78 total)		(100.0)	(100.0)	(41.5)	(39.9)	(74.5)	(73.7)	(51.0)	(49.3)
Total F-113 and F-114	1250	25.0	31.3	29.6	37.0	32.6	40.8	35.9	44.9
(% of 1977/78 total		(100.0)	(100.0)	(118.4)	(118.4)	(130.4)	(130.4)	(143.6)	(143.6)
Total F-11,12, 113 & 114		339.1	208.3	160.1	107.7	266.6	171.2	196.2	132.2
(% of 1977/78 total)		(100.0)	(100.0)	(47.2)	(51.7)	(78.6)	(82.2)	(57.8)	(63.5)

Source : Metra, using sales tonnage forecasts from Section 3.8.1 (Table 3.8) and prices assumed in Section 3.6.

As a reference basis, Table 3.10 shows the sales tonnage projections for 1982/84 made in Section 3.8.1 (Table 3.8) evaluated in terms of the current price structure used in Section 3.6 for assessing the present value of CFC sales. It will be seen that in 1982 under Scenario (1) the sales value of F-11/12 falls to 40% of that of the 1977 tonnage and is still under 50% in 1984, and these falls are only moderately off-set - to 51.7% and 53.5% respectively - by the projected rises in F-113 sales. A more gradual fall to the 1984 situation might occur under Scenario (2), providing aerosol propellant sales in 1982 approached the allowed maximum of 50% of 1976 sales, and dropped progressively over the following two years.

3.8.3.2 Price-demand relationships

For the sales volume projections in Section 3.8.1, one of the assumptions was that for non-aerosol applications price-demand elasticity would be very low. We believe this to be broadly true in the short and medium term, especially for the refrigerant sector, since all vapour-compression refrigeration and air-conditioning equipment is designed to operate with one specific refrigerant. To change it to a different refrigerant means either an expensive conversion or replacement for existing equipment, or a radical re-design for new models, and for most applications the only practicable alternatives today would be a different CFC refrigerant. F-12 accounts for the majority of present refrigerant sales and, as explained in Section 5. , the main potential alternatives are F-22 and F-502, for which the current prices are respectively around two and three times the price of F-12. Another factor is that the cost of the refrigerant charge is a relatively small fraction of the cost of the whole unit. In fact, in this sector the only defence against refrigerant price increase would be measures to reduce wastage of material in filling and maintenance procedures and due to leakage : this is also reviewed in detail in Section 5

For the other main non-aerosol application, foam plastics, a greater price-demand elasticity might be evident. Although there are no satisfactory prospective alternatives to F-11 as a blowing agent for flexible and rigid polyurethane foams, major increases in foam prices caused by higher CFC costs would ultimately be reflected in the demand for the final product or substitution by other materials and designs. Nevertheless, in the medium term a relatively low degree of elasticity is to be expected in this sector, and similar considerations would apply to the solvent cleaning application.

3.8.3.3 Probable outcome of regulation

Four possibilities can be considered : no change in price levels in the present economic context; a moderate price increase; a very large price increase; a reduction in prices.

a) No price change or moderate increase.

If operating capacity were to shrink until it bore the same relation to actual demand as at present, and with several producer-marketers in competition, there might be no need for prices to rise except in response to external economic factors. In practice such a simple outcome is unlikely, and we think that the disturbance involved and the commercial accommodations associated with re-balancing production and demand would entail some increase in price which could be maintained against competition and which would not affect demand.

b) High price increase.

For a plant with a variable/fixed production cost ratio of 80/20, not thought to be untypical for CFC manufacture, an output reduction of 60% would double the unit cost of production. If the major producer-marketers continued to manufacture F-11/12 under conditions of a ban on CFC aerosol propellants, and attempted to obtain the same return on investment while neutralising production cost increases (including those of the precursor materials), then prices could rise to two or three times present levels and possibly more. We do not think such levels could be maintained because:

- with capacity greatly in excess of demand they would represent a highly artificial situation which could only be continued by agreements unlikely to be acceptable in the EEC.

- the CFC industry is unlikely to adopt pricing policies which in the long term are likely to depress growth of demand for non-aerosol applications and stimulate the search for alternatives.

- direct or indirect competition could develop from CFCs made outside the EEC. (By indirect competition is meant that products requiring the use of CFCs in manufacture could be more cheaply made outside the EEC). Such competition would raise pressure from imports and reduce or even eliminate the ability to export, since export prices could not be maintained too far out of line with home prices for CFCs.

c) Lower prices

In theory, a gross excess of capacity could lead to intensive competition for the available market, causing prices to fall - at least until some producers dropped out, when a normal equilibrium, with economic prices, would be re-established. This would simply be an intermediate stage on the road to course (a) during which heavy losses might be sustained, and we think the industry would succeed in by-passing such an unnecessarily costly exercise.

Our assessment, therefore, is that there would be a rational re-balancing of operating capacity with demand, as suggested in Section 3.8.2, resulting in a moderate price increase geared to the world price situation and which would not retard the natural growth of demand from the non-aerosol outlets.

In the F-113/114 product sector, manufacturing costs could rise due to the problem of making F-113 (and F-115) with very little F-114, and with any precursor material price rises - especially for hydrofluoric acid - which might be linked with the demand cutback for F-11/12. With rising overall demand for F-113/114/115 however, there would be no necessity for 'ration-

TABLE 3.11 : ADDED VALUE OF PROJECTED CFC EXPORT SALES UNDER REGULATION AND AT MID-1978 PRICES

Year and Scenario		1977/78 (No Regulation)		1982 Scenario (1)		1982 Scenario (3)		1984 Scenario (2)	
CFC	Mid-1978 Added Value for Exports UCE/Ton	Actual Export Sales Ton'000	Added Value UCE mn	Forecast Export Sales Ton'000	Added Value UCE mn	Forecast Export Sales Ton'000	Added Value UCE mn	Forecast Export Sales Ton'000	Added Value UCE mn
F-11	468	36.5	17.1	22.3	10.4	30.7	14.4	26.0	12.2
F-12	549	44.7	24.5	9.2	5.1	28.6	15.7	13.1	7.2
TOTAL F-11/12		81.2	41.6	41.5	15.5	59.3	30.1	39.1	19.4
F-113 & F-114	1125	5.7	6.4	6.7	7.5	7.4	8.3	8.2	9.2
TOTAL F-11,12,113,114		86.9	48.0	38.2	23.0	66.7	38.4	47.3	28.6
<u>Total Loss</u> of Added Value relative to 1977/78									
- UCE mn			-		25.0		9.6		19.4
Loss if Added Value per ton could be raised by:									
10%			-		22.7		5.8		16.7
20%			-		20.4		1.9		13.9
30%			-		18.1		(Gain) 1.9		11.0

SOURCE: Metra, based on data and projections in Sections 3.6, 3.7 and 3.8.1

alisation' of production facilities, and we see no reason to expect major price increases in the present economic context.

3.8.4 Loss of Added Value to the EEC Due to Fall in CFC Export Sales

Export sales to non-EEC countries could fall due to:

- Non-EEC countries also restricting the use of CFCs

- Deterioration in price-competitiveness.

In the forecasts made in Section 3.8.1 it was assumed that the end-use pattern of exports was the same as for sales within the EEC and would remain so under regulation, and that the ratio of export to EEC sales would remain constant.

Extracting the export components of the projections in Table 3.8 and applying the prices used in Sections 3.6 and 3.7, less 10% to cover cost of imports and a lower than average export sales price, the added values of exports are as shown in Table 3.11.

The worst case is that of Scenario (1) in 1982 when the added value of exports is UCE 23mn a fall of 25mn from the 1977/78 figure of UCE 48mn.

TABLE 3.12 RAW MATERIALS REQUIREMENTS FOR F-11/12 COMPARED WITH TOTAL EEC PRODUCTION

Material	Order of Annual Production in EEC Tons '000	Requirement for 300,000 tons 50:50 F-11/12 Tons '000	CFC Requirement as Percentage of EEC Production %
Naphtha	30,000	22.5 (For 225,000 Tons)	0.08
Propylene	4,000	22.5 (For 225,000 Tons)	0.6
Methane	n.a.	9.0 (For 75,000 Tons)	-
Sulphuric Acid	19,000	210	1.1
Salt	35,000	990	2.8
Chlorine	5,800	578	10.0
Acid Grade Fluorspar (see footnote)	400 (?)	168	40(?)

Sources: 1) EEC Production data from varous statistical sources including United Nations Yearbook of Industrial Statistics, Vol. II. Commodity Production Data 1966-75.

2) CFC Requirements - calculated from data in Table 3.3

Note : Data on acid grade fluorspar production capacity and output for the EEC and Spain appears in Table 3.14 and is discussed in Section 3.8.5.3. Actual current output in the EEC is uncertain.

3.8.5 Impact on Raw Material and Co-Product Industry Sectors

3.8.5.1 Identification of significantly affected sectors

From the data presented in Section 3.4 (Table 3.3) it will be evident that CFC production in the EEC on the present scale of over 330,000 tons p.a., consumes very large quantities of several basic raw materials and intermediates, and is also associated with large tonnages of co-products.

In assessing the impact on these ancillary product sectors of a major CFC production cutback, amounting under Scenario (1) to as much as 60% of the 1977 sales of 314,000 tons of F-11/12, it is important to distinguish between effects which are essentially local because an ancillary operation is part of a CFC production complex - and effects which involve what is virtually a separate industry.

In Table 3.12 below are listed the raw material requirements for 300,000 tons of 50:50 F-11/12, assuming that 75% is made using the naphtha/propylene route to carbon tetrachloride and 25% using methane, and the approximate total annual production of these materials in the EEC. The production of basic raw materials is subject to wide fluctuations with the level of industrial activity and the figures quoted are order of magnitude indications.

It is clear from Table 3.12 that the naphtha/propylene requirements are negligible in relation to total production and this also applies to the methane demand.

The sulphuric acid requirement, although a substantial tonnage, represents less than 1.2% of EEC production and makes concomitantly small demands on sulphur sources. However, there will be some individual plants linked to the production of hydrofluoric acid for CFC manufacture, and while it would be open to the operators to seek alternative markets, it is likely that some of the older and less economic units would have to cease production if the on-site demand were to dail or be drastically curtailed.

Of the other primary raw materials, although salt mining and extraction operations would not be materially affected, there could be a significant impact on chlorine demand, for which CFC production now accounts for about 10%, and a major effect on the fluorspar industry. These sectors are discussed in the following subsections: 3.8.5.2 and 3.8.5.3.

Turning to the two precursors of F-11/12, the production of anhydrous hydrofluoric acid ('AHF') can be considered an integral part of the CFC industry which provides the main outlet, much being made for a captive use with a proportion being supplied to CFC producers who do not have an AHF production facility. There is some demand for AHF for other purposes and also for the aqueous acid, largely for inorganic fluoride manufacture, but we do not think it necessary to discuss hydrofluoric acid as a separate industry sector. Carbon tetrachloride is in a different category, however, because although used almost entirely for making F-11/12, much of it is co-produced with chlorocarbons having important applications independent of CFC production, and this aspect is considered in Section 3.8.5.4.

Of the other co-products, caustic soda and hydrochloric acid are considered in Section 3.8.5.2 in conjunction with chlorine.

The only other significant by-product tonnage is that of the calcium sulphate residues from the reaction of fluorspar with sulphuric acid. There is a limited outlet for these residues in building materials, but they tend to constitute a disposal problem.

The material sectors requiring further discussion, therefore, are:

- Chlorine/caustic soda and hydrochloric acid;

- Fluorspar;

- Carbon tetrachloride and associated chlorocarbons.

3.8.5.2 Chlorine, Caustic Soda and Hydrochloric Acid

In the long term, chlorine production is an expanding industry and although a 60% cutback in F-11/12 manufacture in the EEC could reduce the demand for chlorine by perhaps 6% in the short term, this would eventually be taken up by increases in demand for other chlorine derivatives and applications, and fluctuations of this order have been encountered in trade cycles in the past and would not cause a fundamental disturbance in the industry. However, the production of 1 ton of chlorine by the electrolysis of brine is accompanied by the simultaneous production of 1.13 tons of caustic soda and a cutback in chlorine demand can unbalance the off-take. The impact of this could range from a welcome relief if caustic soda supply were already surplus to demand, to a serious shortfall if supply was in balance or already short, and we would not care to predict the situation in 1982/84 or thereafter.

The production of carbon tetrachloride and its conversion to CFCs both involve the co-production of hydrochloric acid - HCl, in amounts related to the hydrogen content of the hydrocarbon starting material and the extent of the subsequent fluorination.

Starting with naphtha the production of 1 ton of 50:50 F-11/12 mixture requires 1.8 tons of elementary chlorine and yields 1.1 tons of by-product HCl, a net chlorine requirement of 0.7 tons, representing the actual chlorine content of the product. The co-product HCl can be absorbed in water to make aqueous hydrochloric acid, for which there is a certain demand, or used in place of chlorine as a raw material in other chemical processes, the latter course only being practicable on an integrated chemical complex. It is also possible to convert HCl back to elementary chlorine but this is expensive and usually avoided if there is an economic outlet for the HCl itself. When CFC production and co-product HCl utilisation are in reasonable balance, a major downturn in CFC production could lead to a shortfall of HCl which would have to be made up from other sources - at worst by burning chlorine with hydrogen, which is an expensive alternative, (although it might be a means of compensating for an imbalance in chlorine/caustic soda demand). It must be remembered that there are other processes besides CFC production which also yield large quantities of co-product HCl, and there have been circumstances where the economic utilisation of this HCl has been a problem for the chemical industry. As with the chlorine/caustic soda balance, it is difficult to predict whether a downturn in CFC production in a few years time would actually present any serious problems.

3.8.5.3 The acid grade fluorspar industry

The production of acid grade fluorspar by mining ores, followed by flotation of the crushed mineral to obtain a concentrate, is a distinct industry in the EEC and one which would be very seriously affected by a substantial cut-back in fluorocarbon manufacture. Indeed, it has already suffered the loss of much of its export market in the USA due to the impending restrictions on CFC aerosol propellants.

Although the industry is not a large employer of labour, probably less than 5000 for all grades of fluorspar production in the EEC, most mines and flotation plants are situated in rural areas offering little alternative employment opportunities.

There are two main grades of fluorspar: the metallurgical grade or 'metspar' containing a minimum of 70% CaF_2 and mainly used in the iron and steel industry; and the acid grade, or 'acidspar', containing over 97% CaF_2, which is mainly used for the manufacture of hydrofluoric acid, the principal precursor of organic and inorganic fluorine chemicals.

According to a report prepared by the Commodities Research Unit Limited and quoted in "Industrial Minerals" (Reference 3.1), the end use distribution of Western World acidspar consumption in 1976 was as shown in Table 3.13.

TABLE 3.13 WESTERN WORLD ACIDSPAR END-USE DISTRIBUTION - 1976

End Use	Thousands of Metric Tons	% of Total
Fluorocarbon chemicals	600.0	37.4
Non-fluorocarbon chemical uses	193.2	12.1
Aluminium industry	407.0	25.4
Flotation concentrates for briquetting	310.0	19.4
Inventory re-building	91.7	5.7
	1601.9	100.0

Source : Commodities Research Unit (Reference 3.1).

Note : The term 'inventory re-building' is taken to mean increases in the acidspar stocks held by producers.

Production of metspar and acidspar are tending to converge as the availability of the natural mineral grade of metspar declines and the steel industry comes to accept the briquetted or pelletised concentrates which can be made from low grade ores. The only major potential growth area is the steel industry,because the use for fluorocarbons is already declining due to regulation in the USA,and the demand from the aluminium industry is unlikely to grow with metal output because of the trend to re-cycle fluorine so as to reduce atmospheric pollution.

The present world situation is one of oversupply because optimistic demand forecasts in the early 1970s led to the development of new deposits in Africa and the Far East, resulting in some disruption of the price structure. We understand that the world trade situation tends to be dominated by the interaction of the USA demand and Mexican production situation, and in the past the USA has used European acidspar sources as a second string to the government controlled Mexican source.

To obtain information about the industry in West Europe we approached the Bureau International Technique du Spathfluor in Brussels, of which the main Continental suppliers are members, and the principal acidspar producer in the UK, Laporte Industries Limited. We also consulted the EEC export statistics published by Nimexe, which showed that in 1976, 91920 tons of acidspar, average value UCE 75/Ton, were exported to countries outside the EEC, including 65,000 tons to the USA and Canada. The origins of these exports were France (627 tons), Germany (2814 tons), Italy (72315 tons) and the UK (16164 tons).

TABLE 3.14 : STRUCTURE OF EEC AND SPANISH ACID GRADE FLUORSPAR INDUSTRY - DETAILS FROM REPORTING COMPANIES

Country and Company	Locations of Mines (M) Flotation Plants (FP)	Nature of Area	No. of Employees	Acid Grade Fluorspar Production Annual Output Tons (C=Capacity)	Acid Grade Fluorspar Production End-Use Distribution
FRANCE					
S.E.C.M.E.	Fontsante (M/FP)	Near large tourist resort	150	45,000(C)	100% to aluminium industry
S.E.C.M.E.	Langeac (M/FP)	Rural-small town	100	25,000(C)	95% aluminium 5% ceramic etc.
SOGEREM	Montroc (M/FP)	Rural	70	40,000(C)	5% aluminium 90% fluorocarbon 5% other
COMIFLUOR	Olette/La Bastide (FP)	Rural	50	60,000(C)	35% aluminium 60% fluorocarbon 5% other
Soc. Miniere de Trebas	Trebas (M/FP)	Rural	70	20,000(C)	50% fluorocarbons 50% ceramic etc.
GERMANY					
Fluss u. Schwer-spatwerke Pforzheim	Black Forest (M) Karlsruhe (FP)	Rural	85	50,000(C)	15% aluminium 60% fluorocarbons 25% other
ITALY					
Fluormine S.p.A.	Brescia (FP)	Near town	25	-	Home Consumption
	Torgola (M/FP)	Rural	125	11,500	Aerosol FCs 24,000 Other FCs 9,000 Non-FC Chemicals - Aluminium -
	Presolana (M/FP) Camerata (Bergamo)	Rural	80	4,300	Other uses 6,500 39,500
	Prestavel (M/FP)	Rural	90	13,500	Exports EEC 300 Other 1,500
	Vallarsa-Mezzolombardo (Bolzano-Trento) (M/FP)	Rural	115	12,000	
				41,300	41,300
SPAIN					Home / Other EEC / Outside EEC
Fluoruros S.A.	Caravia and Colleda (in Asturias) (M) Pinzales (Gigon) (FP)	Rural	276	Aerosols Other FC Non-FC Chems. TOTAL =	8,000 / 50,000 / 14,000 - / 40,000 / - - / 10,000 / - 108,000 Tons
Minerales y Productos Derivados S.A.	Osor (M/FP)	Rural	125	25,000	(1977) Home / (1977) Other EEC / Outside EEC
	Ribadesella (Asturias) (M) Llanera (M) Torre (FP)	Rural	103	45,000 FCs Non-FC Chems Aluminium Other	16,000 / 11,000 / 21,000 3,500 / 4,000 / 9,000 15,000 / 19,000 / 5,000 1,500 / - / - 36,000 / 34,000 / 35,000
	Berja (M/FP)	Rural	36	30,000	
			264	100,000	
		Other Personnel	135		
		TOTAL	399		
UNITED KINGDOM					
Laporte Industries (Main Acidspar Pro'r) Alusuisse British Steel Corp. (Mainly produces metallurgical grade spar	Derbyshire England	Rural	ca. 400	117,000	Fluorocarbons (UK Production) 70,000 Other Chemicals 30,000 Spar Exports 17,000 117,000

SOURCE: Continental Companies : B.I.T. Spathfluor, from details provided by individual companies
UK - Producing Companies

Details furnished by producers on mine and plant locations, employment, production and end-use are given in Table 3.14, but it must be noted that one of the two main Italian producers, Mineraria Silius S.p.A. which has substantial capacity in Sardinia, has not reported. Except where stated otherwise the data in Table 3.14 applies to the situation obtaining in the first half of 1978.

It is difficult to make a sensible analysis of the production and end-use data because it appears that some relates to capacity and some to actual output. Taking the figures as they are, the acidspar said to be related to fluorocarbon production in the EEC amounts to 316,000 tons, including exports by Spain to the EEC of 101,000 tons. But the total fluorspar requirements for fluorocarbons in the EEC, including the fluorocarbons not covered in this study, is unlikely to be much more than 200,000 tons p.a. The total capacity/output amounts to 600,000 tons p.a. so the fluorocarbon off-take probably represents more than a third of actual total production.

Continuity of operation at any of the mines from which over 50% of the output end-use is for fluorocarbons could be at risk in the event of a major cutback in CFC production, and the total personnel recorded for these is 1785, of which 1110 are in the EEC and 675 in Spain, spread over 20 or so rural locations. Bearing in mind that one Italian producer has not yet reported, the total number of jobs at risk could exceed 2000.

3.8.5.4 Carbon tetrachloride and allied chlorocarbon product sectors

Practically all of the carbon tetrachloride ('CTC') produced is used in the manufacture of F-11 and F-12, and we believe that the great majority of the EEC requirement of CTC is produced by the CFC manufacturing companies or their parent or associated organisations. These companies also supply CTC to CFC producers who do not make their own CTC, although there are alternative sources.

The difficulties associated with cutting back CTC production in line with a fall in CFC demand depend on how the CTC is made. When it is the sole product of methane chlorination the problems of cutback are typical of those encountered in reducing the utilisation of most continuous process chemical plants, and can be considered in the same context as the problems of CFC production cutback which were discussed in Section 3.8.2.

A high proportion of CTC is co-produced with perchloroethylene by the chlorination of propylene. Some perchloroethylene is used for making F-113 and F-114 but the main application is as a cleaning solvent and a problem arises if the co-product demand ratio falls outside the limits of process flexibility. A possible answer might be an arrangement whereby the CTC/perchloroethylene producers supply the residual CTC requirements of CFC manufacturers currently using the methane route to CTC.

Substantial amounts of CTC and perchloroethylene are also co-produced by the chlorination of the waste chlorohydrocarbons arising from the manufacture of vinyl chloride monomer. This process could also fail if CTC demand drops below a certain level, and a waste product disposal problem would then arise which could be very expensive to solve. Here again, a possible solution might be to arrange for this process to continue and restore the balance by reducing production from methane.

In our view these potential problems provide further examples of the need that would arise for collaborative action in the EEC chemical industry in the event of CFC regulation.

3.8.6 Social Implications

3.8.6.1 Employment in the CFC manufacturing and associated chemical industry sectors

According to the estimates submitted by the nine EEC producer-marketers (Section 2.3), employment in CFC manufacture including dependent processes but excluding marketing, distribution etc., totalled 2079 in 1976 and 2091 in 1977. It is impossible to arrive at a precise figure because CFCs are produced in chemical plant complexes where there are shared services such as engineering maintenance, utilities and laboratory and technical support facilities. The associated administrative and commercial activities are also spread over a number of products, and in some cases intermediates such as carbon tetrachloride and hydrofluoric acid are supplied from a separate plant within or outside the CFC producer's organisations. It is certain, however, that the employment quoted above does not represent the total number of job opportunities that would be lost in the industry if manufacture of the four CFCs on which this study concentrates were to cease, and we think the figure should be increased by at least 10%, i.e. to about 2300.

The effect on employment of a cutback in the production of CFCs and associated intermediate materials of the order implied by the regulatory scenarios, would depend very much on the extent to which operating capacity was reduced in line with demand. The number of employees needed to operate a continuous process plant is largely independent of throughput, so that if all the existing CFC plants continued in operation under regulation there would only be a small reduction in the labour requirements, principally related to the transport and handling of materials. In Section 3.8.2., however, we advanced the view that a degree of rationalisation involving plant closures would be inevitable, and in that event significant reduction in employment would certainly occur.

The maximum output reduction occurs under Scenario (1), in which the use of CFCs in non-essential aerosols would cease at the end of 1981, resulting in the 1982 sales of F-11/12 falling to little more than 40% of those in 1977. The other scenarios would permit a more gradual run-down,with F-11/12 sales in 1984 projected to be 51% of the 1977 datum.

Given that growth prospects exist for the non-aerosol applications of CFCs, it is likely that the reduction in operating capacity would lag behind the initial sales reduction,and that the fall in employment would be less than pro rata to the drop in sales. It is not practicable to calculate a figure but in our opinion employment is unlikely to fall by much more than a third, i.e. from around 2300 down to about 1500. The main proviso to this view is that regulatory action is restricted to the aerosol field; if it were to be extended to other uses, causing a greater drop in sales than we have forecast, a more radical re-organisation of the industry could occur, with a greater loss of jobs.

It is also necessary to distinguish between loss of jobs and actual redundancies. In the EEC most CFC manufacture is carried out in parallel with other chemical process operations, and efforts would be made to minimise redundancy by transferring labour either to new activities or to fill vacancies caused by natural wastage. In social terms, however, the loss of job opportunity may be equally or even more serious than premature retirement.

3.8.6.2 Social consequences relating to the fluorspar industry

In social terms we believe that a reduction in CFC usage could have more adverse effects in relation to the fluorspar industry than to the chemical industry. The latter has scope to neutralise the effects of job loss in a particular product sector, and chemical complexes are adjacent to relatively large communities, but fluorspar mining and processing are carried out almost exclusively in rural areas with little alternative employment to offer, and closure of a mine could result in other job losses in the vicinity and virtually extinguish a small community.

In Section 3.8.5.3 we showed that employment linked with acidspar production in the EEC and Spain probably exceeds 2000, and we think that this could fall by at least a third if spar demand were to fall in line with the projected CFC cutback. The industry has already lost much of its export market to North America, and it is known that a number of mines would be vulnerable to any further reduction in demand.

3.9 Conclusions

3.9.1 Chlorofluorocarbons are manufactured in the EEC by ten companies in five countries: France (2), West Germany (3), Italy (1), Netherlands (2) and the UK (2). All the producers are members of major multi-national groups and the output of one of the West German producers is marketed by another. Because there are no more than two producer-marketers in any one country there is a reluctance to disclose production and sales data except for aggregation on an EEC basis as was done for this study.

3.9.2 Total CFC production capacity in the EEC is estimated at about 422,000 tons per year and output in 1977 is thought to represent less than 80% of capacity.

3.9.3 CFCs are produced by the catalytic fluorination of chlorocarbons with hydrogen fluoride made from sulphuric acid and acid grade fluorspar. The principal chlorocarbon precursor is carbon tetrachloride, mostly made by chlorinating either methane, or propylene derived from naphtha cracking. By-product hydrochloric acid arises from the chlorination and fluorination processes.

3.9.4 Over half the 1977 CFC sales were in producers' home markets and over half the balance was exported outside the EEC. The total value of 1977 sales volumes of F-11, 12, 113 and 114 at mid-1978 prices is assessed at UCE 177 million, and the added value of the export sales is estimated at about UCE 48 million.

3.9.5 Sales projections based on a number of assumptions as to growth rate and exportation indicate that bans on the use of CFCs in most aerosols in 1982 or 1984 would reduce sales of F-11/12 to 41.5% and 51.0% respectively of the 1977 sales volume. This would reduce average plant utilisation to less than 40%, which is below viable levels for continuous process CFC plants. In the context of the regulatory scenarios it is concluded that reduction in operating capacity would be inevitable, and that collaborative action would be desirable to rationalise manufacture so as to minimise production and distribution costs.

3.9.6 The forecast of strong growth in F-113 sales for solvent applications could lead to demand for F-113/114 being higher from 1982 onwards under regulation than in 1977 despite the loss of the F-114 aerosol market.

3.9.7 The regulatory scenarios would cause major imbalances in demand for the two pairs of compounds, and the F-11/F-12 sales ratio could move from 52 : 48 in 1977 to 76 : 24 under Scenario (1) in 1982, or 72 : 28 under Scenarios (2) and (3) in 1984. It is believed, however, that there is sufficient process flexibility to cope with such variations.

3.9.8 From considerations of price-demand elasticity, alternative marketing policies and possible competition from outside the EEC, it is believed that relatively moderate price increases would ensue specifically from regulation. It is projected that the added value of CFC exports could fall from the estimated 1977/78 level of UCE 48 million to UCE 23 million and 28.6 million respectively under the 1982 and 1984 ban scenarios, and to UCE 31.4 million in 1982 under the 50% reduction scenario.

3.9.9 Direct employment in CFC manufacture and dependent processes in the EEC, excluding marketing, distribution and ancillary services is estimated to be about 2300. It is thought unlikely that this figure would fall below 1500 in the event of restrictions on the use of CFCs in aerosols.

3.9.10 Other sectors of the chemical industry would be affected by a major cutback in CFC production. In particular, the chlorine-caustic soda and related sectors could be disturbed by reductions of the order of 5% in the demand for chlorine, and in the availability of hydrochloric acid; and reduced consumption of carbon tetrachloride would cause problems with processes in which it is co-produced with perchloroethylene, including the utilisation of vinyl chloride monomer production by-products. Outside the CFC production complexes, however, the effects of regulation would be disturbance rather than disruption.

3.9.11 The fluorspar mining and processing industry has already lost much of its acid grade spar export market due to CFC regulation in the USA, and regulation in Europe would almost certainly result in mine and plant closures since CFCs typically account for more than 60% of the acid spar output of at least 14 mines and works in France, Germany, Italy, Spain and the UK. The number of jobs at risk may not exceed 2000, but nearly all the mines are in rural areas with little alternative employment opportunity.

4. AEROSOLS

4.1 The Aerosol Industry in the EEC : A Perspective

With an annual output approaching 2000 million units, the manufacture of aerosols in the EEC, together with the ancillary supply of materials, components, equipment and services, has become a substantial industry employing over 40,000 people and having a distinct identity.

As demonstrated by the data presented in Table 2.6, aerosol production is by far the largest end-use for CFCs in the EEC, accounting for 182.1 thousand tons of EEC sales of F-11, 12, 113 and 114 in 1976 (69.6% of total sales of these CFCs in the EEC) and 167.8 thousand tons (66.5%) in 1977.

A brief statistical presentation will indicate the prominence of the EEC aerosol industry in a world context, and the distribution of the filling sector among the member states.

Table 4.1 provides world production and growth rate data for 1970 to 1977, and includes comparative figures for the EEC, the rest of Western Europe, the USA and the rest of the world. It will be seen that 1867 million aerosols were filled in EEC countries in 1977, equivalent to 33% of the world total. EEC fillings rose progressively at an average rate of about 9% per annum between 1970 and 1974. There was a fall in 1975 followed by a recovery in 1976 to the highest level yet recorded, of 1874 million units. The 1977 total is only slightly lower, with a sharp fall in the Italian total being compensated by rises in fillings in France and the U.K. USA production slumped from a peak of 2092 million units in 1973 to 2295 m. in 1976.

TABLE 4.1 : WORLD AEROSOL PRODUCTION 1970 - 1977

Millions of units

	1970	1971	1972	1973	1974	1975	1976	1977
EEC Countrs.	1247	1412	1474	1644	1779	1633	1874	1867
Other W.Eur.	181	217	246	286	299	277	300	338
Total W.Eur.	1428	1629	1720	1930	2078	1910	2174	2205
USA	2623	2554	2823	2902	2722	2354	2295	2150
Rest of Wrld.	724	830	922	1078	1209	1213	1335	1303
World Total	4775	5013	5465	5910	6009	5477	5804	5658

TABLE 4.2 : AEROSOL PRODUCTION IN EEC COUNTRIES 1970 - 1977

Millions of units

	1970	1971	1972	1973	1974	1975	1976	1977
U.K.	304	349	361	438	478	440	495	533
W. Germany	401	412	389	397	418	425	457	454
France	254	304	359	394	450	383	455	476
Italy	138	158	173	194	203	173	253	188
Netherlands	90	119	120	136	155	147	145	143
Belgium	39	45	45	49	46	46	51	54
Denmark	13	13	14	14	14	14	13	13
Ireland	8	12	13	22	15	5	5	6
Luxembourg	-	-	-	-	-	-	-	-
Total EEC	1247	1412	1474	1644	1779	1633	1874	1867
% Increase (Decrease)	-	13.2	4.4	11.5	8.2	(8.2)	14.8	(0.4)

Sources : Principally Metal Box and national trade association data (1977 data is provisional)

There has been a further fall, to 2149 mn. units in 1977, but there are indications of some recovery in 1978. Part of the decline since 1974 is attributable to adverse publicity based on the CFC-ozone depletion theory.

Corresponding production data for individual EEC countries are given in Table 4.2.

The UK, Germany and France are the three largest producers, each contributing approximately 25% of the EEC total. Italy, Netherlands and Belgium are fourth, fifth and sixth respectively; Denmark and Ireland have only very small aerosol industries; and Luxembourg does not appear to have any aerosol fillers.

Production and consumption patterns and volumes vary widely from country to country, and the Netherlands for example is a major exporter to the rest of Continental Europe. There are big differences in per capita consumption, ranging from 2.6 in Denmark to more than 8 in France and the UK, and major variations between product groups. Examples of the latter are the importance of deoderants and anti-perspirants in Germany; household products in the UK; perfumes and colognes in France; and insecticides in Italy. In all countries, however, the personal products category is predominant. In 1977 production distribution patterns for all the producing countries in the EEC except Ireland is shown in Table 4.3, and it will be seen that the personal products categories account for 1058 million units, 56.8% of the total.

TABLE 4.3 : 1977 EEC AEROSOL PRODUCTION BY PRINCIPAL PRODUCT CATEGORIES

	Belg.	Denm.	France	West Germ.	Italy	Neths.	U.K.	E E C	
No. of units - millions	54	13	476	454	188	143	533	No. of Units	Distrib.
Product Category	%	%	%	%	%	%	%	millions	%
Hairsprays	31.2	23.1	20.7	28.6	29.9	11.8	23.2	445	23.9
Anti-perspirants and De-oderants	10.7	23.1	7.1	28.6	12.8	3.1	12.9	270	14.5
Other personal	3.9	7.7	37.9	7.0	12.8	3.8	18.3	343	18.4
Household	19.7	7.7	11.5	13.4	7.1	48.3	18.3	308	16.5
Insecticides	25.1	3.8	7.2	5.3	20.2	22.4	12.8	210	11.3
Paints	1.1	3.8	0.9	5.9	1.4	-	4.0	56	3.0
Others	8.3	30.8	14.8	11.0	15.9	10.6	10.5	230	12.4
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1862	100.0

Sources : Metal Box / Metra

Notes : (1) Luxembourg - no production
(2) Ireland - production ca. 6m. units but no analysis available
(3) Netherlands - Paints included in 'Others'

Six main sectors can be discerned in the industry:

a) Bulk raw materials production and supply, for example of tinplate, aluminium, CFC and hydrocarbon propellants, plastics and solvents such as alcohols and methylene chloride. These materials are not basically specific to the aerosol industry although special grades are often necessary.

b) Manufacture of components such as metal and glass containers, valves and valve components, gaskets, plastic caps, etc.

c) Production of active ingredients for aerosol formulations, such as resins for hair sprays, perfume concentrates, insecticides, etc.

d) Manufacture and installation of machinery and plant, especially aerosol filling equipment.

e) Aerosol filling: fillers may be filler-marketers ('self fillers'), contract loaders or both.

f) Marketing and distribution, through wholesale and retail outlets.

Many other sectors supply goods and services to the aerosol industry but it is the six mentioned above that are most closely concerned with the fortunes of the industry and from which most of the aerosol trade association membership is drawn.

As readers of this report will be aware, a high proportion of substances that need to be dispensed from a container in relatively small amounts at a time, mainly in the range of a fraction of a gram to tens or hundreds of grams per application or treatment, are now available in aerosol dispensers. In the UK, for example, over 2500 different aerosol products are on sale covering 200 different functions. Most manufacturers of substances ranging from personal care and medical preparations to insecticides and car maintenance materials now provide at least part of their sales range in aerosol packs, and it follows that most major national and multi-national companies in these fields are also major primary marketers of aerosols.

There are seven national aerosol trade associations in the EEC (all countries except Ireland and Luxembourg), and the majority of EEC aerosol fillers and marketers and of the suppliers of specialised equipment and materials to the industry belong to one of them or to the International Aerosol Association. All these associations are members of the Federation of European Aerosol Associations (the FEA) whose Coordination Centre is based in Brussels.

The national associations and the FEA are concerned with every aspect of aerosol manufacture and marketing of common concern with an emphasis on regulatory, safety and technological aspects rather than essentially commercial and economic issues. Many of the member companies also belong to trade associations representing their overall product sectors such as chemicals, toiletries and pharmaceuticals.

There are companies in all sectors of the industry in the EEC with USA parents who are already experiencing at first hand the technical and marketing problems in adjusting to a ban on CFC propellants, and who can transmit this experience to their European subsidiaries.

4.2 Factors Responsible for Growth

The rapid growth of aerosol production from a world total of under 200 million units in 1954 to a peak over 6000 million in 1974 can be ascribed to five main factors:

a) Sustained attractiveness of pressurised packaging to the general public in respect of a wide range of products. The growth and repeat purchase performance of aerosol sales in many major market sectors must be associated with the appeal of perceived qualities of convenience, effectiveness, and acceptable value for money. At the same time, it is apparent that the level and pattern of aerosol sales reflects prevailing social habits and attitudes, and is also linked with environmental and economic situations. The high volume of hair spray and de-oderant sales, for example, relates to standards of personal grooming and also to climate, and appreciation of the labour-saving feature of many aerosol products indicates the value placed on this factor in developed countries in which a high proportion of housewives also have jobs. Correspondingly, some of the recent criticism directed at aerosols derives not only from environmental pollution and similar practical considerations, but contains an element of disapproval of some of the social attitudes and values which contribute to the popularity of aerosol products.

b) The development of reliable and inexpensive valves and containers,and of machinery permitting high volume low cost production.

c) The availability of technically satisfactory, safe and economic propellants - principally the chlorofluorocarbons.

d) The technical service available to fillers and marketers from the propellant, component and other suppliers.

e) Early recognition by the industry of the importance of establishing and maintaining a good reputation for reliability and safety, and the consequent extensive voluntary adoption of codes of practice.

There is no doubt that the propellant, component and equipment suppliers have played a crucial role in the development of the industry, and they are particularly active in trade association activities. Research, development and technical service by the supply sectors will also be a major factor if the industry in the EEC has to move away from CFC propellants.

4.3 Dominance of Chlorofluorocarbon Propellants

Although more expensive than the available alternatives, chlorofluorocarbons rapidly became the most extensively used propellants - more so in Europe than in the USA - and until the advent of the ozone depletion theory they maintained this position for three reasons:

a) CFCs score highly in every category of application property necessary or desirable in an aerosol propellant, whereas all the alternatives have substantial drawbacks in one or more respects.

b) This comprehensive suitability is particularly desirable in the formulation of toiletries, which are the largest market sector and which often employ high liquid propellant concentrations.

TABLE 4.4 : 1976 AEROSOL PRODUCTION IN EEC COUNTRIES, ANALYSED BY PRODUCT SECTOR AND PROPORTION OF UNITS PROPELLED BY CFCs.

Millions of aerosol units

Product Sector	Belgium		Denmark		France		Germany		Ireland	
	No.	%CFC	No.	%CFC	No.	%CFC	No.	%CFC	No.	%CFC
Insecticides	10.8	42	1.3	65	26.3		27	90	1	50
Paints & Lacquers	0.3	All	0.3	44	3.5		23	90	-	-
Household Products	9.5	56	1.1	33	54.3	Data not available	54	60	2	50
Hairsprays	17.6	94	2.8	99½	105.7		133	90		
Deods/Antiperspirants	6.6	All	4.6	All	46.3		140	99	1	All
Colognes/Perfumes	1.5	All	0.4	All	120.4		15	100		
Other Personal	0.8	68	1.0	31	35.6		19	90		
Med/Pharm/Vet.	not known		0.2	99	37.0		1	100	-	-
Automotive	2.6	52	1.5	21	4.7		12	40	-	-
Industrial	0.9	80	0.5	56	10.5		13	70	1	All
Food/Miscellaneous	0.8	32	0.0	-	11.4		3	70	-	-
Total	51.3	73	13.5	76	455.5		457	84	5	70

Product Sector	Italy		Netherlands		U.K.		Total EEC
	No.	%CFC	No.	%CFC	No.	%CFC	Approx. No.
Insecticides	54.9	20	24.8	40	47.5	50	194
Paints & Lacquers	3.4	10	(A)	100	16.5	All	47
Household Products	31.6	20	69.0	14	96.5	6	318
Hairsprays	56.4	80	17.8	100	139.0	97	473
Deods/Antiperspirants	52.5	100	11.9	100	66.5	97	329
Colognes/Perfumes	1.9	100	4.6	100	63.5	All	207
Other Personal	14.1	10	1.1	100	17.5	50	89
Med/Pharm/Vet	7.3	100	1.0	100	22.0	All	69
Automotive	) 29.4	100	3.5	50	10.0	80	49
Industrial	)		(A) 4.2	70	9.5	85	54
Food/Miscellaneous	1.5	5	(B) 7.5	25	6.5	40	31
Total	253.0	61	145.4	61	495.0	72	1875

(A) "Paints/Lacquers" are included in "Industrial".

(B) Includes 3.6 lighter refills.

Source : Ireland - estimate by Metra, based on data collected in Ireland; Other countries - data supplied to Metra by national aerosol associations through FEA.

c) The marketing efforts of the chlorofluorocarbon manufacturers, who have generally provided a much higher level of technical service than the alternative propellant suppliers,particularly in Europe, and have been helped in this by the higher value of CFCs.

To gauge the extent to which the EEC aerosol industry has been reliant on CFC propellants, Metra enlisted the help of the FEA and the national aerosol associations in obtaining for each member country a breakdown of 1976 aerosol fillings by product group, and an estimate of the proportion of units in each group filled with CFC propellants. Table 4.4 summarises the information provided, from which it is apparent that the product sectors can be divided into two categories:

Category A

Products in which a consistently high (80 - 100%) proportion of all the units made in 1976 employed CFC propellants, viz.

Hairsprays	(80 - 100%)
De-oderants/Antiperspirants	(97 - 100%)
Colognes/Perfumes	(100%)
Medicinal/Pharmaceutical and Veterinary products	(100%)

These sectors accounted for about 57% of total fillings. Data on the actual CFC content of hairsprays and antiperspirants/de-oderants obtained by the research department of a major filler-marketer appears in Table 4.5.

TABLE 4.5 : CFC CONTENT OF PERSONAL CARE PRODUCTS BY COUNTRY

Average CFC Content
weight %

	Hairsprays	Antiperspirants & Deoderants	Weighted average for Hairsprays plus AP/DO products (Note 2)
Belgium	73	79	74
France	85	66	86
Germany	50	85	58
Italy	57	72	61
Netherlands	73	82	75
U.K.	54	89 (Note 1)	73
Overall weighted average for the six countries :			68%

Source : Communication to Metra from major aerosol filler-marketer.

Notes 1) UK production is mainly anti-perspirants, other production is mainly de-oderants.

2) Weighted averages calculated from average CFC contents (as found by analysis) and estimated product tonnages for each country.

Category B

Products in which the propellant selection is less well-defined. Examples are household products (6% CFC in UK, 56% CFC in Belgium), and automotive products (21% CFC in Denmark, 80% CFC in UK).

This category accounted for about 43% of units produced.

Assuming France to be in line with the average CFC usages in the other countries, 73% of the units made in 1976 were based on CFC propellants. It is known that in some instances a combination of CFC and another propellant was used, and this particularly applied to insecticides and hairsprays in Germany.

The general inferences to be drawn from the data in Table 4.4 are that CFCs are the preferred propellants in the toiletry and in the medical and allied sectors; that problems are likely in switching to alternatives; and that in most other sectors a high degree of substitution is evidently practicable.

The characteristic features of CFC propellants (mainly F-11, F-12 and F-114) which account for their excellence in this function are as follows:

Purity

CFCs are produced to very high purity specifications, hence their physico-chemical properties are constant from batch to batch, and there are none of the problems and hazards which may exist when products are subject to contamination and variable composition.

Vapour Pressure/Temperature Characteristics

CFC propellants are liquefied gases, and by adjusting the proportions of the individual CFC components a range of convenient vapour pressure/temperature curves is obtainable. Although some differential evaporation and hence some change in vapour pressure may occur as the aerosol is used, an adequate and substantially constant pressure characteristic can be maintained throughout its life, and practically all the contents are available for discharge.

Solvent and Diluent Functions

As well as being propellants, CFCs serve as solvents for active ingredients, and also as volatile diluents. In some products, especially toiletries and some insecticides, CFCs are used in high concentrations in the formulations because of these ancillary properties. If smaller propellant concentrations were used the CFCs would have to be replaced with other solvent-diluents.

In this connection it may be noted that F-11 (CCl_3F), which is widely used in 50/50 and other mixtures with F-12 (CCl_2F_2), is not itself a propellant because its boiling point (23.8^{o}C) is too high. The functions of F-11 are to modify the vapour pressure characteristics of F-12 and to act as a solvent and diluent, and this point needs to be borne in mind when framing any regulations applying to propellants.

Chemical Stability and Compatability

Although F-11 is susceptible to hydrolysis in the presence of water, CFC combinations can be selected having a very high degree of chemical inertness and compatibility towards most formulation ingredients and materials of construction of cans and valves.

Non-flammability

The existing CFC propellants are non-flammable and tend to reduce the flammability of mixtures containing flammable ingredients.

Biological Safety

Tests and usage over many years have established that the CFC propellants in current use are non-injurious to life in the range of concentrations normally encountered in the manufacture and use of aerosols. They cannot be regarded as being innocuous, however, and if inhaled in sufficient concentration can produce cardiac arrhythmia - the usual cause of death due to aerosol 'sniffing'.

Odour

The odour of CFC propellants is faint enough for them to be suitable for use in high grade perfumery products.

Other Properties

According to the nature of the application, other properties such as high density, low viscosity, high dielectric strength, low latent heat of vaporisation etc. may contribut to the usefulness of CFCs as propellants.

4.4 Basic Questions on CFC Propellant Substitution

The possibility that the use of the existing CFC propellants may be restricted or prohibited raises the following fundamental questions:

(i) Are alternative substances or systems available which are technically satisfactory, economically viable, and which satisfy all reasonable safety requirements.

(ii) Is it feasible for industry to adapt to any of the available alternatives and produce commercially acceptable products substantially equivalent to those now made using CFCs?

(iii)Having answered (i) and (ii), what would be the socio-economic implications of applying the three regulatory scenarios given in Section 1?

(iv) Since the regulatory scenarios allow for a small exempt category in which the manufacture of aerosols with CFC propellants would be permitted on socio-economic grounds, what criteria should be applied in adjudicating on applications for exemption?

4.5 Alternatives to CFC Propellants

4.5.1 General

Alternatives to CFC propellants, mainly compressed and dissolved gases, hydrocarbons and mechanically actuated systems, have always been available and, since CFCs are relatively costly and not the answer for every application, some of these alternatives have always commanded a share of the market and the industry has maintained a watch for others.

The possibility of a ban on the established CFC propellants, soon to be a reality in the USA and Sweden, engendered an intensive search for new substitutes and for means of ameliorating the disadvantages of the known alternatives.

Rather than review all the conceivable possibilities that have been considered and why most of them have been ruled out for technical, safety and economic reasons, we think it will be more helpful to summarise the present position on alternatives and potentialities, and minimise detailed discussion of the numerous and often complex technological considerations involved.

4.5.2 Compressed Gases

Permanent gases such as compressed air or nitrogen have little application in the main aerosol product sectors because it is impracticable to introduce enough gas into the head space of a container of the dimensions and construction needed for most everyday uses to provide a satisfactory pressure range during discharge. Compressed gases appear to have no potentiality as substitutes for CFCs, but a recent press report claims otherwise (See Section 4.13).

4.5.3 Dissolved Gases

4.5.3.1 Possibilities

The only practicable possibilities are carbon dioxide and nitrous oxide, and both are already in use in the EEC although only one company - L'Air Liquide of France - makes any serious attempt to promote the use of nitrous oxide, under the trade name 'Protoxal'.

The main problems attaching to the use of these dissolved gases are:

a) the difficulty of introducing enough propellant into the system to maintain good discharge characteristics when a forceful well atomised spray is needed throughout the life of the pack. To approach this requirement it is necessary to use above average initial internal pressures, and this causes problems with container design and leakage.

b) because a relatively small amount of propellant is present in the system in comparison with the situation when using a liquefied gas, even a small leak rate causes rapid loss of internal pressure.

c) the use of a dissolved gas requires a liquid in which the gas has a high solubility and which is also suitable as a vehicle for the active ingredients of the formulation, and the two requirements are not always compatible. One of the most useful solvents from both standpoints is ethanol, but this immediately raises an economic problem in high alcohol duty countries. (See Table 4.7)

4.5.3.2 Carbon Dioxide (CO_2)

Carbon dioxide has attractions as a propellant because of its manifest safety and low cost - the bulk price is typically about 20% of that for CFC propellants, and the amount needed per can may be only 10% of the CFC requirement. The latter saving may be offset, however, by the need to replace the liquid CFC with another solvent/diluent such as alcohol or methylene chloride.

At present, the main application of CO_2 in the EEC is in windscreen de-icers, where a jet of liquid rather than a

TABLE 4.7 : ALCOHOL REGULATIONS AND DUTIES : EXAMPLES OF DIFFERENCES BETWEEN EEC COUNTRIES

	Belg.	Denm.	France	W.Ger.	Italy	Neths.	U.K.
1. Permissibility for use in cosmetic products:							
a) Ethyl alcohol of agricultural origin	Yes	Yes	Yes	Yes	Yes	Yes	Yes
b) Ethyl alcohol of industrial origin	Yes	Yes	No	No (Note 1)	Yes	No	Yes
c) Isopropyl alcohol	No	Yes	No	Yes	No	Yes	Yes
d) Alcohols for export products not allowed for internal market	Yes	Does not apply	Yes for (c)	No	Yes	No	Does not apply
2. Taxation on alcohols mentioned in 1(a), (b) and (c)	Yes (a), (b)	No	Yes (a)	Yes (a)	Yes (a), (b)	Yes (a), (b) & (c)	Yes but only on undenatured ethyl alco.
3. Amount of tax per litre of 100% alcoh.	100 B.fr	-	4.5 F.F.	6 DM	varies w. origin (Note 2)	6.88 fl.	£9.49
4. Tax recovery for export	Yes	-	Yes	Yes	Manuf.tax only	Yes	Yes
5. Tax on alcohols in imported products	Yes	-	As interior & surtax	Yes (for ethyl alc.)	Yes	Yes	Yes if not denatured

Source : COLIPA - Analysis of Questionnaire Returns, November 1976.

Note 1. In Germany all ethyl alcohol must be purchased from the 'Bundesmunopolverwaltung'

Note 2. Italy applies manufacturing tax plus excise duty depending on origin of the alcohol.

spray is needed and the relatively small fall in pressure with temperature is an advantage over liquefied gas propellants. It is also used in some floor polishes and other household products, automotive de-greasers, and in at least one surface coating preparation.

In personal products CO_2 has the advantage of not producing the chilling effect which may occur with liquefied gases.

Ample supplies of CO_2 are available, but on account of the low price and the small market potential in comparison with outlets such as beverage handling and carbonation it does not pay the suppliers to provide aerosol fillers with much technical service beyond the point of delivery to the filling machine.

Drawbacks to using CO_2 in applications where liquefied gases are the normal propellants include:

- the need to use initial internal container pressures well above average to leave enough pressure available when the contents are almost fully discharged. This requires a stronger can and aggravates leakage problems.

- as pressure falls during the life of the aerosol the discharge rate also falls and the spray quality may deteriorate. To compensate for the lower discharge rate the active ingredient concentration may have to be increased and this increases the possibility of valve blockage.

- in high alcohol duty countries, the choice of suitable solvents for the CO_2 and active ingredients is restricted.

- CO_2 forms a weak acid solution in water, and extra precautions are needed to prevent corrosion of metal containers.

CO_2 is finding new applications in combination with other propellants, however, and in Germany it has been found practicable to reduce the CFC content of hair sprays and other products by 50% by adding CO_2.

4.5.3.3 Nitrous Oxide

Most of the technical limitations mentioned in relation to CO_2 also apply to nitrous oxide, except that nitrous oxide does not form an acid solution with water and is therefore more acceptable for aerosol food products. It is more expensive than CO_2 and although the amount in a single aerosol would be far too small for the gas to exercise its anaesthetic effects, this property of nitrous oxide may have some marketing disadvantages and reduce its acceptability to fillers.

4.5.3.4 Future Potential

It is concluded that the potentialities of carbon dioxide and nitrous oxide as propellants have not been fully exploited or explored, partly because of lack of vigorous promotion. At present they cannot be regarded as satisfactory substitutes for liquefied gas propellants in the major product sectors, although they do have some potential in combination with them.

4.5.4 Liquefied Hydrocarbon Gases

Certain liquefied hydrocarbon gases, viz. propane and the normal and iso-butanes, are realistic alternatives to CFC propellants for the majority of aerosol products. They are already extensively used in the EEC, mainly for products other than toiletries, while in the USA, where they have been used to a greater extent than in Europe for many years, the imminent ban on CFCs has resulted in a substantial switch to hydrocarbons for a wide range of products including toiletries.

Suitable vapour pressure characteristics for most purposes can be obtained by blending, with the outstanding advantage of liquefied gas propellants that satisfactory pressurisation can be maintained throughout the life of the pack.

Hydrocarbon ('HC') propellants are superior to CFCs in respect of chemical stability and compatibility with other materials. Propane-butane propellants are considered to have a lower inhalation toxicity than CFC propellants, and we are not aware of any adverse biological or environmental effects being attributed to the use of these compounds in aerosols.

HC propellants are cheaper weight for weight than their CFC equivalents, and being less than half the density are cheaper still on a volumetric basis. They are already available in Europe from indigenous sources, and production could readily be stepped up to cope with any foreseeable demand for many years ahead.

On the negative side, HC propellants are markedly inferior to CFCs in their solvent properties and this poses some formulation difficulties. For the higher grades of toiletries using quality perfumes there can be an odour problem with the normal propellant grades of HCs, because it is difficult to remove the last traces of the sulphur and olefinic compounds present before purification. For most practical purposes this can be dealt with by using masking agents or an additional purification process.

The outstanding drawback to hydrocarbon propellants is their very high flammability: they have low flashpoints (propane: - 104°C) and low flammable limits in air, those for n-butane being 1.9 to 8.5% by volume. Whereas CFCs can be handled with few special safety measures, elaborate precautions must be rigidly observed with HCs, and these are governed by statutory regulation and local authority control, often augmented by voluntary codes of practice.

In addition to hazards attaching to HCs in the manufacture of aerosols, the substitution of CFCs by hydrocarbons obviously raises the flammability of formulations and so increases the fire and explosion risks in the transportation of aerosol packs, in storage at wholesale and retail premises, and at the ultimate point of use. Under EEC regulations aerosols with flammable contents over 45% must be labelled as flammable, and packages must bear a warning symbol. Believing this to be a major sales disadvantage, marketers are reluctant to exceed the 45% limit, but this presents near insuperable formulation problems in personal product sectors because the most suitable non-flammable substance which can be used instead of CFCs as a bulk ingredient is methylene chloride, and in the EEC this is subject to a 35% limit in toiletries. If the active ingredients make up 5% of the contents, the formulator is left with a 15% gap which is difficult to bridge.

However, despite these and other difficulties it is the case that hydrocarbon propellants have been used for many years and on a large scale in most non-toiletry aerosol product sectors, and that in the USA a wide range of HC propelled personal products are now being marketed. Hydrocarbon propellants must, therefore, be regarded as practical though in some important respects unattractive alternatives to CFCs.

4.5.5 Dimethylether ($CH_3.O.CH_3$)

This compound, a liquefied gas with a boiling point of -24.5^{o}C, is strongly advocated by the sole suppliers in the EEC, Aerofako bv, as an alternative propellant to CFCs and hydrocarbons. It has been used by Aerofako and other companies in Continental Europe since about 1963, and is marketed by Aerofako under the trade-name 'Aeropur' at prices about 50% higher than those of hydrocarbon propellants but around half the price of F-11/12.

The suppliers claim that dimethylether ('DME') has the following attributes and advantages:

- Lower flammability than hydrocarbons
- Low toxicity, as demonstrated by extensive inhalation, mutagenicity and other biological tests
- Environmental safety
- Suitable vapour pressure/temperature characteristics (similar to F-12)
- Miscibility with water over a wide concentration range
- Good polar solvent characteristics, e.g. for resins, making it a cheaper alternative to ethyl alcohol when the latter is subject to excise duty, and a superior solvent to hydrocarbons
- Compatibility with perfumes
- Usable as a propellant for most applications other than for foam products.

Formulations for hairsprays, de-oderants, perfume sprays, air freshners and insecticides are quoted in the technical literature, and apart from flammability the only significant disadvantages acknowledged are incompability with rubber and gasket materials such as neoprene, and a tendency for higher leak rates through container gaskets.

Under present EEC directive, formulations containing DME are subject to the same 45% limit for classification as 'flammable' as are hydrocarbons, and Aerofako are suggesting that a limit of 65% should apply to DME because of its lower flammability as demonstrated by closed drum and flame extension tests.

In reporting our interim findings to the Environment and Consumer Protection Service we felt unable to state that DME could be regarded as an alternative to hydrocarbons for replacing CFC propellants for the following reasons:

i) Although available for more than a decade DME has not found general acceptance and is hardly used at all in the USA and the UK. (The suppliers estimate a total of only 60 million units filled with DME since 1963.)

ii) Aerofako are the sole supplier in Western Europe of DME propellant, which is manufactured by Union Kraftstoff of West Germany, and this raised the question of adequate availability of supplies.

iii) Dubiety about the safety of DME was expressed to us from a number of sources, mainly on the grounds that ethers are subject to the hazards of peroxide formation, and that in the presence of organic chlorine compounds DME might form a very toxic compound: bis (chloromethyl) ether, ('BCME').

We have had assurances from Aerofako that 50,000 tons per year of DME could be made available, equivalent in volume to more than 100,000 tons F-11/12, and have been given evidence of a test in which no BCME formation was detected in DME/F-12 mixtures stored in aerosol cans at 50°C for 3 weeks.

Major filler-marketers in the toiletry field have recently indicated to us that they are re-considering the potentialities of DME but will wish to conduct their own tests as to its suitability and safety.

The evidence in favour of DME is impressive and we think that a prima facie case has been made for further evaluation of its potentialities by the aerosol industry. It would be premature to affirm, however, that DME can be regarded as an established alternative to CFCs and hydrocarbons.

4.5.6. "New" Fluorocarbon Propellants

The fluorocarbon industry has been actively pursuing the attractive prospect of developing fluorine compounds with the virtues of the present CFC propellants but innocuous to the ozone layer. Such compounds would either have to contain no other halogen but fluorine, or have short tropospheric lifetimes.

All the conceivable alternatives have been synthesized and their physico-chemical properties established, and likely candidates have been given initial screening tests for biological safety. Among the few that are still in the running are:

F-22, $CHClF_2$, b.pt - 40.8°C

This is widely used in refrigeration and might be used as a propellant in conjunction with vapour pressure depressants such as ethanol. Early toxicity tests gave a positive indication of mutagenicity; further test programmes are in progress but results may not be available for another year or so. Probably no fluorocarbon producer would advocate the use of F-22 as a propellant until this doubt has been resolved, but one company is promoting it to aerosol manufacturers for technical evaluation.

F-133A $CH_2Cl.CF_3$ b.pt +6.1^{o}C
and
F-142B $CH_3.CClF_2$ b.pt -9.2^{o}C

These CFCs are being made in pilot plant quantities for technical evaluation but have not yet been fully screened for toxicity. They are likely to be expensive to manufacture in quantity.

F-152A $CH_3.CHF_2$ b.pt -24.7^{o}C.

This is already used in refrigerant 500 and as an intermediate in making certain plastics. It is inflammable and expensive, and not yet available in quantity.

There are others such as F-123, F-124, F-125 and F-143A which are still under consideration as long term possibilities, but which do not seem to have reached the serious evaluation stage.

Thus the present situation is that there are no fully proven fluorocarbon alternatives to the existing CFC propellants, and if some of the prospects under consideration eventually prove technically, biologically and environmentally acceptable they would be significantly more expensive, and substantial capital investment would be entailed in adapting existing plant or providing new plant for their manufacture. A time scale of up to six years could be involved and there must be some doubt as to whether the fluorocarbon manufacturers would commit themselves to the capital investment, especially if any residual doubt were to exist on any environmental or toxicity aspect. In the meantime, any ban on CFCs will have driven aerosol manufacturers to hydrocarbon and other non-CFC propellants (as it has in the USA), and they may not be interested in returning to CFCs except perhaps on a partial basis to reduce flammability and improve technical properties in hydrocarbon or other systems.

With these very uncertain prospects for fluorocarbon propellants other than those in current use, we were unable to recommend the evaluation of scenarios based on such alternatives.

We are aware that the International Research and Technology Corporation of Virginia, USA, evaluated some scenarios based on F-22/F-142b propellants in its report for the EPA entitled "The Economic Impact of Potential Regulation of Chlorofluorocarbon-Propelled Aerosols" IRT-462-R, April 1977. These scenarios assumed substantial usage of F-22/F-142b propellants by 1978, whereas experience in the USA has been a major switch to hydrocarbons, with F-22/F-142b being still in the experimental stage.

4.5.7 Mechanical Systems

A great many of the products available as aerosols are also obtainable in non-aerosol packs and dispensers, although the latter may not always be as effective or convenient. We are concerned here, however, with alternatives to aerosol propellants, that is with devices designed to produce the same effect as an aerosol dispenser using a propellant gas in the formulation.

Mechanical alternatives fall broadly into two classes:

i) Devices which embody pre-stored pressure and hence are still aerosols in the terms of the definition employed in this report.

These include packs incorporating a spring-loaded piston, and various systems in which the product is contained in an internal flexible and impermeable bag on which pressure is exerted by a compressed gas enclosed between the bag and the external rigid container.

ii) Devices which are operated by externally applied force, such as rubber bulb actuated perfume and hair sprays and the piston operated insecticidal sprays.

Many of the pre-stored pressure devices are only suitable for dispensing liquids and pastes, while the older type of manually operated bulb and piston sprays were relatively clumsy - often needing two hands for operation - and gave poor atomisation. Because of their limitations and drawbacks these systems have, in general, either been superseded by the propellant actuated aerosol or have failed to capture a significant share of the market.

With the prospect of a CFC ban, however, the mechanical principle has been revived, and attention has been concentrated on the development of the so-called 'finger pump', with the aim of providing a pack which can be held and operated in one hand, and which is also capable of providing a well atomised spray.

The initial introduction of the modern type of finger pump into the USA and Europe met with a poor market response, despite heavy promotion. Some headway has been made, however, and pump quality has been further improved and may not have reached optimum development. The pump has found more acceptance on the Continent than in the UK, and a major UK filler-marketer recently decided to launch a new perfume spray as an aerosol in the UK, and in finger pumps elsewhere in Europe.

Finger pumps have some inherent limitations which cannot be overcome by design improvement. The amount of energy which can reasonably be provided by repeated digital pressure does not match that obtainable from a reservoir of liquefied gas propellant and imposes restrictions on spray characteristics, and there are obvious difficulties in using a finger pump hair spray at the back of the head. With some products the pump also poses the problem of what solvent to employ in place of the propellant, especially where high taxes on alcohol apply.

Our conclusion is that in the event of a CFC ban in the EEC pumps will obtain a significant market share, but that it will be a relatively small one so long as propellant based aerosols are available in which the public has confidence.

4.5.8 Conclusions on Alternatives to CFC Propellants

To summarise our findings on the available alternatives to existing CFC propellants:

a) Compressed gases appear to have little potential, although as this report was being finalised a press report appeared claiming otherwise. (Section 4.13).

TABLE 4.6 : PROPELLANT USAGE BY FILLERS IN EEC COUNTRIES

Country and Filler Capacity Classes (See Note A)	Belgium	Denmark	West Germany			Netherlands			United Kingdom		
	(1)	(1)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Propellant Usage:											
CFCs only	10	18	80	9	1	2	0	0	80	11	3
Hydrocarbons only	0	0	0	0	0	0	0	1	1	0	1
CFCs and hydrocarbons	2	3	13	12	0	7	3	0	20	5	4
Compressed gases only	0	0	1	0	0	0	0	0	0	0	0

Source : Metra, from questionnaire returns supplied by national aerosol associations.

Note (A) Filler Capacity Classes : (1) Up to 10 million units p.a.
(2) 10 to 30 million units p.a.
(3) Over 30 million units p.a.

b) Dissolved gases, carbon dioxide and nitrous oxide, are safe propellants, but have some insuperable technical limitations.

c) Hydrocarbons have been established as alternatives for a wide range of aerosol products in spite of the drawbacks of flammability and poor solvent characteristics.

d) Dimethylether is an attractive alternative to hydrocarbons because of its lower flammability, better solvent powers and miscibility with water, but the majority of the industry still has doubts about possible safety and technical snags and will not accept DME without further trials.

e) No other fluorocarbon propellants are yet available which have been fully cleared in toxicity trials, and some years could elapse before safe alternatives to the existing propellants could be supplied in quantity at acceptable prices.

f) Mechanical dispensing systems which simulate aerosols have inherent limitations likely to restrict them to a minority market share in competition with acceptable propellant based aerosols.

The overall conclusion is that in the present state of knowledge, the majority of the industry would opt for conversion to hydrocarbons if faced with having to adjust to a ban on CFCs. Although not every country provided returns to a questionnaire on propellant usage, the replies listed in Table 4.6 indicate that a large percentage of fillers in the EEC, probably more than 75%, are not currently using CFCs.

4.6 General Implications of Conversion to Hydrocarbon Propellants

For the reasons given in Section 4.5, the only feasible course presently available to the aerosol industry if it is to continue to make and market pressurised aerosol packs without CFC propellants is to convert the majority of its manufacture - probably at least 80% - to liquefied hydrocarbon gas propellants. It is important to appreciate the implications of this scale of conversion, both to the industry and to the public at large, and the bearing on regulatory provisions.

4.6.1 Rationalisation in the Filling and Marketing Sectors

This phrase is a euphemism for changes whereby some firms would cease to make and sell aerosols, while others would expand their operations.

Because of the safety precautions essential with HC propellants, such as the siting of storage tanks to meet minimum distance and separation requirements from buildings, some companies could no longer make aerosols on existing sites. Relocation will not always be possible or acceptable, and the alternatives for self-fillers are either to stop filling and marketing their own products, or to transfer manufacture to a contract filler.

Some firms may stop making particular product lines because they are unable or do not believe it to be possible to develop satisfactory re-formulations based on HC propellants, and this will leave opportunities for other marketers.

4.6.2 Changes in Other Industry Sectors

Providing the conversion is not accompanied by a major decline in the aerosol market, we would not expect structural changes in the container, valve and other components sectors, although they will have to modify their manufacture to match changed design and construction requirements. There are opportunities for technical innovation, which might result in some companies growing at the expense of others. The Precision Valve organisation, for example, appears to have made an important advance with its "Aquasol" valve, which enables two phase water-hydrocarbon systems to be used for toiletry products for which water was previously thought to be an unacceptable component.

The filling machinery and ancillary plant manufacturers are already capable of supplying equipment for hydrocarbon propellants. A rush to convert to HCs could result in a temporary boom for this sector and stretch its resources.

European hydrocarbon propellant suppliers would certainly have to expand their production and transportation facilities, and competition in service, quality and price could develop. The number of suppliers could increase, and we are aware that certain major suppliers of HC propellants in the USA, who claim to be able to supply products of higher purity and more consistent composition than are generally available in the EEC, may consider entering the European market.

The manufacturers of chlorofluorocarbons and the precursor intermediates and raw materials would certainly have to cut their output, and this may well result in some plant and mine closures as discussed in Section 3.

Other basic material industries such as tin-plate and aluminium could be affected by variations in aerosol sales, but it is most unlikely that the tonnages involved would be large enough to cause structural changes.

4.6.3 Fire and Explosion Risks

Due to observance of legal and self-imposed rules and standards, the industry has a remarkably good record which it is anxious to maintain. Nevertheless, there are mishaps from time to time, and even if regulations are further tightened, the multiplication of HC propellant filling lines and of the numbers of HC filled aerosol units being transported, stored and used is almost bound to result in greater numbers of accidents. One of the consequences of banning CFC propellants, therefore, is to replace the somewhat problematical long term dangers of stratospheric modification with the certainty of an immediate increase in hazards at ground level.

Insurance premiums in respect of all the manufacturing and other facilities involved will increase; retailers may have to comply with awkward storage and shelving restrictions; and any accidents which even indirectly involve aerosols may arouse the antipathy of the fire services and the responsible authorities, and attract general disfavour.

There are organised bodies of opinion which consider aerosol packaging to be a wasteful use of resources and a source of unnecessary environmental pollution. Any known or potential risk is used as a means of attacking this form of packaging, and is liable to exploitation for political purposes.

The industry is concerned, therefore, about the possibility that extensive replacement of CFC by HC propellants might lead eventually to the discrediting of aerosols, further prohibitions, and a catastrophic market decline.

4.6.4 Product Characteristics and Quality Changes

A change of propellant is not simply a matter of replacing one ingredient in a mixture by another. Not only may the whole formulation have to be changed but the spray discharge characteristics may also have to be modified, including the volumetric rate and velocity, and this means altering the valve and nozzle designs.

It is unnecessary to embark on an extensive review of the technological considerations involved, but one example will be cited of the problems encountered in converting a toiletry product such as a hair spray to hydrocarbon propellants.

One of the procedures established in the USA to measure flammability risks is the so-called flame extension test in which flame elongation is measured when an aerosol spray is directed across an ignition source such as a candle flame. Although there is no regulation governing flame extension in the EEC, aerosol manufacturers do pay attention to this characteristic. Substitution of CFCs by HCs tends to increase flame extension, and to counteract this the manufacturer can reduce the aerosol discharge rate, i.e. the amount of material expelled in unit time. Since users tend to actuate a spray for a fairly constant number of seconds, it then becomes necessary to raise the active ingredient concentration to ensure that the user still receives the same 'dosage' at the lower discharge rate, and in a hair spray this can cause solubility problems. Assuming these to be overcome, the net result is that the user can get more dosages from a given can size and fill, and this will reduce unit sales. Furthermore, users may perceive the difference in spray characteristics and find them less satisfactory.

A number of aerosol toiletry marketers told us that while they have developed HC formulated products as an insurance against a possible CFC ban they are not fully satisfied with the quality, and would not wish to market these products in competition with others based on CFC propellants.

The aerosol industry would prefer any CFC regulations in the EEC to be implemented simultaneously throughout the Community, to avoid a situation in which manufacturers in some member states might be able to continue making higher quality products than could be produced in others, leading to inequity in the export trade.

Another factor which would assist in maintaining fair competition would be harmonisation of regulations which affect the other major components of aerosol formulations - in particular the alcohol use regulations and duty structure.

4.7 Crucial Importance of Regulatory Timescale

From the information gleaned in Europe, and in the USA where over 80% of aerosol filling has already been converted to non-CFC propellants and systems, we have no doubt that this vigorous and inventive industry could successfully adapt the great majority of the existing product range to alternative propellants - mainly hydrocarbons, and a fundamental assumption in this conclusion is that the use of hydrocarbons would not be subject to unduly onerous restrictions.

The main requirement for the industry to make a successful adaptation is <u>time</u>: time to design, procure and install new filling plant; time to develop and test new formulations; time for the ancillary sectors to supply new equipment, components and materials in adequate quantities; and time to complete the investigation of possibilities such as DME and the Aquasol valve which could make important contributions to product quality and safety.

4.8 Regulatory Scenarios for CFC Propellants

We see four possible basic approaches to reducing CFC usage in the aerosol industry which could be applied singly or in conjunction and on different timescales:

a) Complete prohibition, except for a few categories exempted on special social and other grounds. This would have the biggest impact on CFC release.

b) Selective product bans - prohibiting CFC usage in particular product categories.

This is the approach being considered in Canada but it is open to a number of objections in an EEC context.

To obtain a worthwhile reduction in CFC release it would be necessary to ban CFCs in major product sectors, mainly toiletries (as in Canada), but these are the areas in which conversion is most difficult. Exempting the other sectors would not be a great help to the industry as a whole and, it could be argued, would allow the continuation of unnecessary CFC release from aerosols which could easily be manufactured with alternative propellants. Also, there could be problems in defining the banned and exempt categories, and in relation to exports and imports.

c) Chlorofluorocarbon Usage Quotas.

The essence of this concept is that the aerosol industry would be 'rationed' to a fraction of its current CFC consumption and that fillers would use this ration to overcome the quality and safety problems of formulations based on hydrocarbons alone.

Total CFC consumption could fairly readily be monitored, but administration of the system by regulation could be complicated. We are of the view that it would be difficult to operate other than on a voluntary basis, and it is only suggested as an intermediate or holding position pending resolution of the CFC-ozone issue.

d) Price Control

If the prices of CFC propellants rise substantially, this will undoubtedly provide a strong incentive to switch to alternative propellants. Aside from any administrative problems in imposing duties, it may be objected that this is not a suitable approach in an industry which accounts for such a large percentage of present CFC release. If it is really important to reduce CFC emission from aerosols it hardly seems appropriate simply to provide a financial incentive and then leave the outcome to the interplay of economic forces, and we suggest that more positive controls are required whose effects can be quantified.

In our interim presentation to the Environment and Consumer Protection Service we provided a short list of scenarios based on approaches a) and c), and as recorded in detail in Section 1.7.2, it was decided that three scenarios should be considered, two envisaging bans except for exempt categories after 3 and 5 years respectively from the end of 1978, and one involving a reduction in CFC usage by 50% over 3 years, to be followed by a full ban after a further two years if justified by the scientific evidence on the ozone depletion issue.

4.9 Exempt Category Determination

The U.S. Environmental Protection Agency adopted the following criteria for determining 'essentiality' in adjudicating on requests for exemption from the CFC propellant ban:

a) Non-availability of alternative propellant or product

b) Economic significance of the product, including the economic effects of removing the product from the market

c) Environmental and health significance of the product

d) Effects on the 'quality of life' resulting from no longer having the product available or using alternative products.

Decisions are normally based on consideration of all these factors, although if a suitable alternative product or propellant is available it is not necessary to make judgements concerning the other criteria.

Although we cannot suggest a better set of criteria we think they are very difficult to apply fairly and logically in practice, because all except perhaps the first must frequently involve subjective opinions and values. It would, therefore, be particularly awkward to obtain a consistent approach to decision making on exemptions in the EEC since differing values on the issues raised are likely to prevail in different member states.

If exemption decisions are made on a national basis it can be expected that the outcome on a particular application will vary from country to country, with consequent confusion and inequity, but it is dubious whether any supranational approach is practicable.

4.10 Implications of the Regulatory Scenarios

4.10.1 General Effect on Activity

Because we believe that the EEC aerosol industry could successfully adapt to using alternatives to CFC propellants given reasonable time, and would be assisted by the experience and know-how already gained in the USA in effecting conversion and re-formulation, we think that the loss of unit sales volume related to the imposition of regulation need be only fractional, and less than the 21% decline in the USA between 1974 and 1977 - there being evidence of an arrest of the decline in the USA in 1978.

The three year notice prohibition scenario is we think, somewhat inadequate for a smooth changeover, whereas five years' notice or the intermediate case of a 50% reduction in the first three years should be ample.

There could be an immediate drop in sales due to public reaction if a ban were to be announced, but given that the industry would undertake appropriate public relations exercises as has been done in the United States, we see no reason why the maximum drop in annual sales should exceed 10% of the 1977 level in the case of the three year notice ban, and believe the penalty should be less than 5% in the other cases.

In consequence, no substantial structural changes in the supply sectors of the industry are anticipated other than in the CFC and associated sectors of the chemical and fluorspar mining industries.

In the filling and marketing sectors there would inevitably be some disturbance of employment due to some smaller fillers ceasing operations, and some of the larger fillers handing over their operations at least temporarily to contract fillers who could expect to expand their output and, we understand, are making provisional plans to do so. The net effect on employment, therefore, is likely to be some re-distribution of job opportunities rather than job loss on any scale.

4.10.2 Employment

Because of the ramifications of the industry in which many operatives may be employed flexibly between aerosol production and other manufacturing activities it is difficult to obtain reliable figures. Excluding the CFC and allied sectors the total employment is assessed at approximately 43,000. Net job loss due to regulatory action on CFCs is unlikely to exceed 3000, but job disturbance might well affect more than twice this number.

4.10.3 Effect on Prices

Because the cost of hydrocarbon propellants is typically less than one third of that of CFCs, conversion to hydrocarbons is an economic proposition and often an attractive one except where major re-location problems are involved. Producers, however, will not only need to recover their capital investment but will need to offset the additional research and development expenditure attaching to adaptation. Where a self-filler decides not to convert his own plant but to employ a contract filler, some part of the benefit of using a lower cost propellant will be offset by the contractor's margin. There are many plus and minus considerations at the manufacturing stage, but total added value relates to the final selling price to the consumer and not to intermediate stages, and although this may seem a simplistic view it appears unlikely that in terms of current price levels the change in manufacture would lead to any substantial alterations in price structure.

4.10.4 Potential Losses of Added Value

The cost of imported raw materials used in making aerosols in the EEC is a small fraction of the total added value since it principally relates to items such as tin, iron ore and alumina for making tinplate and aluminium cans. For practical purposes retail and export sales values are only slightly greater than actual added value.

It has proved difficult to obtain satisfactory detailed figures of the value of retail and export sales on a country by country basis in the EEC, but our assessment of the magnitude of the total is approximately UCE 2100 million for the value of 1977 sales at mid-1978 prices.

As explained in Section 4.10.1, we think it unlikely that the maximum sales volume losses would amount to more than 10% in any one year under the three year notice ban scenario, and 5% in the other cases. It is possible, of course, that the losses in each product sector will be different and they could be greater in the higher priced product sectors but there is also the compensatory effect, in terms of the economy as a whole, of some increase in sales of non-aerosol packaged products. (For the purpose of this discussion finger-pump toiletries are equated with the aerosol products they are designed to simulate.

For the EEC as a whole it is unlikely that a closer approximation can be obtained than taking the percentage reduction in added value as corresponding to the percentage reduction in unit sales volume. Taking the 1977 price and volume base-line, this means that the maximum annual loss of added value would be UCE 210 million under the three year notice ban scenario, and UCE 105 million under the five year scenarios, including the scenario in which CFC usage in aerosols would be reduced by 50% over the first three years, (Scenario 3).

In making projections it is now hardly possible to make forecasts as to what the sales growth rate would be in the absence of regulation. The ozone issue has already made some impact on sales, and the controversy is likely to continue for a number of years whether regulation is introduced or not.

4.11 Implementation of the 50% Reduction Scenario

4.11.1 Alternatives

If it were to be desired to adopt Scenario 3, it would become necessary to determine the way in which the partial restriction would be secured and monitored. Possible approaches include the following:

a) To allow the reduction to be made by voluntary action on the part of the aerosol filling and marketing sectors of the industry, and to monitor progress by requiring producers, marketers and users, including importers, to submit statistical returns.

This method would give maximum flexibility to the industry but does not provide a positive control, and there can be no guarantee of an adequate degree of cooperation.

b) To limit the maximum concentration of CFCs in specified products to levels estimated to provide the desired degree of reduction in CFC consumption.

If the restriction were to be applied only to hairsprays and de-oderants it is likely that this maximum would need to be about 30%. This would provide a positive control and avoid complications such as 'essential use' determination. It would also help fillers to avoid formulations categorised as 'flammable'. Monitoring of production and use would still be advisable to ensure that the required reduction was being achieved.

(We have been assured that analytical methods are available whereby the CFC content of aerosols is readily ascertainable.)

c) To impose restrictions on CFC production and importation.

Although this would achieve the required reduction it would entail a complicated and almost certainly inequitable system of rationing and allocation which would be difficult to devise and enforce, and unwieldy and expensive to operate.

We believe that (c) would not be a practicable proposition, and that the choice must lie between (a) and (b). Although another possibility is to ban the use of CFCs altogether in specified products, it would be difficult to make a selection on rational grounds that would yield the appropriate percentage reduction.

4.11.2 Differences in Alcohol Regulations and Duties

The ameliorating effects of Scenario 3 would apply unevenly in the EEC because of the differences in the regulations and duties attaching to the use of alcohols, especially ethyl alcohol and iso-propyl alcohol.

Since reductions in the volume of the CFC propellant generally need to be compensated by incorporating some other solvent or diluent in the formulation, the ameliorating effects of Scenario 3 would apply unevenly in the EEC because of the variations in alcohol duty and regulations, of which only a selection is presented in Table 4.7 on page 134.

The question of harmonisation is beyond the scope of this study and the economic problems involved are appreciated, but we suggest that the issue merits attention in the context of CFC regulation.

4.12 Conclusions

4.12.1 The aerosol industry is the largest consumer of CFCs in the EEC, and accounted for 167.8 thousand tons of F-11, 12, 113 and 114 in 1977, - 66.5% of the total sales of these compounds in the Community. Production in 1977 was 1867 million units, and only slightly lower than the 1976 total of 1874 million despite the impact of the ozone controversy.

4.12.2 The personal products sectors - mainly hairsprays, anti-perspirants, de-oderants, colognes and perfumes - represented 56.8% of fillings in 1977. These sectors(together with the medicinal, pharmaceutical and veterinary product)are currently the most heavily dependent on CFC propellants, which are used in 80 to 100% of all the units in these categories in all EEC countries.

4.12.3 Although there is scope for greater use of the dissolved gas propellants, carbon dioxide and nitrous oxide, the most realistic alternatives to CFC propellants for the majority of aerosols and particularly in the personal product categories, are liquefied hydrocarbon gases - mainly propane and butane. The main drawbacks to hydrocarbons are their high flammability and relatively inferior solvent properties, and there are difficulties in re-formulating personal products with hydrocarbons so as to achieve equivalent product quality while keeping the content of flammable material below the 45% limit, above which the packs must be labelled as flammable and then incur marketing disadvantages.

4.12.4 Experience in the USA, where most production is already converted to non-CFC propellants - mainly hydrocarbons - coupled with the advent of developments such as valves which permit the use of hydrocarbon-water mixtures in personal products and others in which water was once considered unacceptable suggest that the industry can successfully adapt to non-CFC propellants, providing it is given enough time for research and conversion, for the great majority of products. If dimethylether satisfies tests currently being conducted by the industry this could be a useful alternative to hydrocarbons because of its better solvent properties, miscibility with water and lower flammability.

4.12.5 The regulatory time-scale would be crucial to successful adaptation. Three years notice of prohibition is thought somewhat too short a period for a smooth changeover, whereas five years notice including the intermediate case of a 50% reduction in CFC usage should be adequate.

4.12.6 Excluding the CFC and allied sectors, employment in the industry is approximately 43,000. Net job loss due to regulatory action on CFCs is unlikely to exceed 3000. Job disturbance might affect more than twice this number because some fillers would not be able to convert to inflammable propellants or would have to relocate their plants. The overall result would be that contract fillers and large filler-marketers would expand their businesses at the expense of some of the smaller concerns.

4.12.7 The total value of retail and export sales for the EEC is assessed at approximately UCE 2100 million for the 1977 sales volume, and this figure is only slightly higher than the actual added value. It is believe that the maximum annual loss of added value would not exceed 10% of this figure, or UCE 210 million, under the 3-year ban scenario, or 5% - UCE 105 million under either of the 5 year scenarios.

4.13 Addendum : Possible Use of Compressed Air as a Propellant.

From physico-chemical considerations it appeared to us and to many experts who advised us in the course of this study that compressed air has little potential as a substitute for CFC and other liquefied gas propellants. However, according to a recent press report a method has been developed for using air as a propellant for the full market range of aerosols. Relevant quotations are as follows:

"From Belgium comes an idea to use compressed air as the propellant and the interesting thing about this development and the can that it requires is that conventional aerosol filling units can be used. Furthermore, all the active material in the container can be used up, following which pressure inside the aerosol unit can be reduced to atmospheric, thus avoiding any risk of explosion should the can be burned. No pumping action is involved.

The developers say that their patented unit will contain more active product, size for size, and that the sprays obtained are as finely divided as with conventional propellant-driven aerosols. It is also applicable to the full range of products already packaged and offered for sale in this form, including hair lacquers.

It is understood that discussions on the system have already been held with Reckitt-Colman and Foseco Minsep."

Source : Financial Times, 1st November 1978.

This could be a most important advance, but pending varification of the report we remain sceptical.

5. REFRIGERATION AND AIR CONDITIONING

5.1 The Role of Fluorocarbons as Refrigerants

A number of systems is available for refrigeration and air conditioning but the great majority of installed capacity and new manufacture is based on the closed cycle vapour-compression principle, in which a working fluid termed the refrigerant is alternately liquefied and evaporated. In its most basic form the cycle is as follows:

1. Compression of the refrigerant vapour, causing its temperature to rise

2. Condensation of the compressed gas to a liquid, by indirect cooling with air or water

3. Evaporation of the liquid: a process which absorbs heat from the immediate surroundings and thus produces the desired cooling effect

4. Re-compression of the vapour and repetition of the cycle.

Chlorofluorocarbons have long been the most widely used refrigerants in vapour-compression systems. Prior to 1930, however, CFCs were not generally available and substances such as ammonia, sulphur dioxide, methyl chloride and butane were employed. All of them, however, had some disadvantageous property such as toxicity, inflammability, poor thermodynamic characteristics, or tendencies to corrode metals, which limited their suitability and reliability for general use. US refrigerant technologists concluded that these substances could not provide the basis on which the refrigeration industry could expand in the future, and that a new refrigerant was needed. This perceived need led directly to the synthesis of F-12 in 1928.

The development of F-12, and later also of F-22, was the main factor enabling the rapid growth of the refrigeration industry from the 1930s onwards. Since the development of F-12 and F-22, no new refrigerants apart from other CFCs have been found that can be considered at all competitive. Consequently CFCs now account for all but a small proportion of the world-wide use of refrigerants. The only non-CFC refrigerant of any consequence for vapour compression systems is ammonia, which is used in some large scale industrial refrigeration systems.

The main fluorocarbons in use as refrigerants are as follows, arranged in decreasing order of atmospheric boiling point (Reference 5.1).

Refrigerant	Formula	BP °C
F-113	CCl_2FCClF_2	47.6
F-11	CCl_3F	23.8
F-114	$CClF_2CClF_2$	3.8
F-12	CCl_2F_2	-29.8
F-500	CCl_2F_2/$\underline{CH_3CHF_2}$ (73.8%/26.2%)	-33.5
F-22	$\underline{CHClF_2}$	-40.8
F-502	$\underline{CHClF_2}$/$CClF_2CF_3$ (48.8%/51.2%)	-45.6
F-13B1	$CBrF_3$	-57.8
F-13	$CClF_3$	-81.4
F-503	$\underline{CHF_3}$/$CClF_3$ (40.1%/59.9%)	-88.7

NB: The fluorocarbons that are not fully halogenated are underlined

These refrigerants, with different physical and thermodynamic properties, have been developed to meet the varied requirements of the many different applications of refrigeration and air-conditioning. In general, however, it can be stated that the most important refrigerants are those with boiling points in the range -20°C to -50°C, e.g. F-12, F-22 and F-502.

Among the fluorocarbons under consideration in this study (F-11/F-12/F-113/F-114), only F-12 is used on a significant scale as a refrigerant, although F-11 is increasing in importance. The data supplied by CEFIC/EFCTC provides evidence for this, and indicates that 20,500 tons of these four refrigerants were sold within the EEC in 1977, including 17,800 tons F-12, 2,500 tons F-11 and 200 tons F-113/114 (Source: Table 2.6).

Comparable data does not exist for the usage of other fluorocarbon refrigerants in the EEC countries. However, using UK market data to which we have been given access, and making the assumption that the breakdown by refrigerant type is similar for the EEC as a whole, we have produced estimates of the 1977 refrigerant market in EEC countries. (See Table 5.1, on the following page.)

The table shows that certain fluorocarbons, for which regulation is not currently contemplated, are responsible for approximately 38% of fluorocarbon refrigerant usage. The most important of these is F-22 (28%), which is not fully halogenated. Also of importance is F-502 (9%), an azeotrope of F-22 and F-115.

TABLE 5.1 : ESTIMATE OF THE 1977 FLUOROCARBON REFRIGERANT MARKET IN EEC COUNTRIES.

Refrigerant	Sales (000 tons)	% of total
F-11	2.5	8%
F-113/F-114	0.2	0-1%
F-12	17.8	54%
Subtotal	20.5	62%
F-22	9.3	28%
F-502 (Azeotrope of F-22 & F-115)	3.0	9%
Others	0.5	1-2%
Subtotal	12.8	38%
Total Refrigerants	33.3	100%

Source : First three items abstracted from Table 2.6
: Other items based on the assumption that the total EEC market is similar to the UK market.

Although the volume of fluorocarbon refrigerant usage in the EEC is on a somewhat smaller scale than in USA (per capita refrigerant consumption in USA is approximately five times higher than in EEC countries), the percentages by refrigerant type are quite similar. For example, in 1973 F-12 accounted for 56% of total fluorocarbon refrigerant usage in USA and F-22 for 30% (Reference 5.2).

The main trends in the choice of refrigerant are as follows:

a) During the '70s there has been some shift from F-12 to F-22; and from F-12 and F-22 to F-502. The growth of F-22 is largely associated with the increased use of packaged air-conditioning while the growth in use of F-502 is almost entirely due to the increased use of refrigerated food display cases in supermarkets, retail stores, etc.

b) Although still relatively small, the use of F-11 is increasing, largely due to the growth in the number of large central air-conditioning installations using centrifugal compressors.

5.2 The Main Applications of Refrigeration and Air Conditioning.

There are many different refrigeration applications and the refrigerant requirements can consequently vary considerably in terms of the refrigerant chosen and the amount used (the "charge"). It can be assumed that virtually all the refrigerant charge will eventually be

TABLE 5.2 : MAIN CHARACTERISTICS OF REFRIGERATION AND AIR CONDITIONING APPLICATIONS.

Application	Refrigerant Commonly Used				Typical Fluorocarbon Charge (Kgs)					Hermetic	Semi Hermetic	Non Hermetic
	F-11	F-12	F-22	F-502	< 1	1-10	10 - 100	100 - 1000	> 1000			
Domestic												
Refrigerators		x			x					x		
Freezers		x			x					x		
Small Appliances												
Drinking Water Coolers		x			x					x		
Dehumidifiers		x			x					x		
Ice Machines		x			x	x				x		
Air Conditioning												
Automotive		x				x						x
Home			x		x	x				x		
Commercial/Industrial	x	x	x				x	x		x		x
Food Processing & Handling												
Vending machines		x			x					x		
Retail display cases		x	x	x		x	x				x	
Cold storage warehouses		x	x	x			x	x				x
Refrigerated transport		x		x		x						x
Industrial Process Refrigeration		x	x				x	x	x			x
Miscellaneous												
Air Curtains, Solar Collectors, etc.		x				x				x		x
Heat Pumps			x			x				x		

Source : Metra

released to the atmosphere, although there may be significant time delays involved.

Table 5.2 identifies the main characteristics of refrigeration and air-conditioning applications in terms of the refrigerant commonly used, the typical fluorocarbon charge and an indication of whether or not the system is likely to be hermetic.

Unfortunately, European data does not exist that would help us to identify those applications that are of the greatest importance in terms of refrigerant usage or emission. However, two American studies are of interest in this context - one commissioned by the US Environmental Protection Agency (see Reference 5.3) and some work recently published by one of the refrigerant manufacturers, Du Pont (see Reference 5.4). Rather than present both sets of data, which might confuse the reader because of the different categories used, we have chosen to concentrate on the more recently published Du Pont data. Early in 1978, this company produced its own estimates of the US use of fluorocarbons in refrigeration and air-conditioning applications (See Reference 5.4). These are summarised in Table 5.3 where the 1976 usage associated with each application is expressed as a percentage of the total CFC refrigerant usage in that year. (For example automotive a/c accounted for 29% of total CFC refrigerant usage in 1976).

Usage is conveniently categorised under two headings:

i) the initial charge for new equipment, and

ii) refrigerant used to re-charge equipment, i.e. to make up for losses owing to leakage, breakdowns, servicing, etc.

TABLE 5.3 : ESTIMATED US USE OF FLUOROCARBONS IN VARIOUS REFRIGERATION AND AIR CONDITIONING APPLICATIONS, 1976 (expressed as a percentage of total CFC refrigerant usage).

Application	Initial Charge	Recharge	Total
Automotive A/C	10%	19%	29%
Home A/C	6%	6%	12%
Commercial & Industrial A/C	8%	17%	25%
Retail Display Cases	2%	14%	16%
Cold Storage Warehouses	2%	3%	5%
Refrigerated Transport	1%	4%	4%
Other Uses (See Note 1)	4%	4%	8%
Total R & A/C Applications	32%	68%	100%

Source : Du Pont (see Reference 5.4). Further analysis by Metra.

Note 1 : Includes all items in Table 5.2 not listed above.

The Du Pont data indicates that as much as 70% of fluorocarbon refrigerant usage in USA is for re-charging. This is an important statistic because it demonstrates that there are substantial emissions during the lifetime of refrigeration and air-conditioning equipment.

The analysis by application shows that four main applications are responsible for over 80% of refrigerant usage:

a) Automotive A/C. This is the most important refrigerant end use in USA. Included within the term "automotive", are cars, trucks, buses, trains, planes, etc. Cars are likely to be the main component (nearly 80% of the US cars built in 1977 for the US market had factory installed air-conditioning).

In Europe, automotive air-conditioning is far less common than in USA but this end-use is showing definite signs of growth. Car A/C is no longer a luxury and is becoming available on an increasing proportion of models in the medium price range.

b) Home A/C. This category is almost entirely based on F-22, which is not fully halogenated and for which regulation is not contemplated.

c) Commercial and Industrial A/C. This category accounts for 25% of fluorocarbon refrigerant usage in USA. Several different types of system are included under this heading. At the smaller end of the scale, some small commercial systems are comparable with home air-conditioning in that they usually employ F-22.

Most of the systems under this heading, however, are "chiller systems" in which the CFC refrigerant is used to cool a second refrigerant (usually brine or water) which in turn is used to cool the building or enclosure. The advantage of such systems, over a single refrigerant system, is that it is easier and more efficient to pump a cool liquid long distances than it is cold air. There is an important distinction between those chiller systems that are based on reciprocating compressors and those that are based on centrifugal compressors, because they differ in size and in the refrigerant commonly used.

d) Retail Display Cases. Approximately 60% of refrigerant usage in USA is allocated to this heading, with a very high proportion being allocated to re-charging, which suggests that there are substantial losses from this category of equipment. Under this heading are included the various types of display cases that are used in retail outlets such as supermarkets. Several different types of systems are available, ranging from the small self contained cabinet to large systems involving several display cases served by one remotely located unit.

It is interesting to note that, despite the large numbers of refrigerators and freezers in domestic use, they account for only 2% of CFC refrigerant use in USA.

In attempting to interpret these results in a European context, it is necessary to exercise caution because insufficient is known about the numbers of units that are in service in each of the equipment categories. However, from the evidence available, we would expect that both chiller systems and retail display cabinets would be among the most important uses of fluorocarbon refrigerants in EEC countries. Therefore, in discussing refrigeration and air-conditioning in the context of the ozone depletion hypothesis, these two equipment categories in particular need to be borne in mind.

5.3 Problems of Limiting the Use of CFC Refrigerants

5.3.1 Importance of Refrigeration and Air Conditioning

Of the various uses of fluorocarbons, refrigeration is arguably the most important. To a large extent it has become an integral and essential part of the mode and organisation of life in the developed world, where any curtailment of the availability of refrigeration is most unlikely to be acceptable, and the same observation is becoming increasingly applicable everywhere.

Refrigeration is used in many of the operations involved in bringing food to the consumer: in processing, bulk storage, transportation, marketing and, finally, in home storage. It is possible to do without foodstuff refrigeration in self-contained communities and where simple diets prevail. In the EEC, however, where most people are accustomed to a varied diet and live in towns and cities, refrigeration provides essential links in the chains from production to consumption.

There are, of course, many other important uses of refrigeration, in industrial processes and medicine for example, but the food chain accounts for the major proportion.

The importance of air conditioning is a more debatable question. In the USA it has become part of the way of life and restrictions would be most unwelcome; by comparison, relatively little capacity has been installed in the EEC where there are large areas of relatively temperate climate. The availability of air conditioning is being increasingly appreciated in the EEC, however, especially in the warmer regions; and if Greece, Portugal and Spain join the Community the proportion of territory consistently subject to high temperature will considerably increase. Air conditioning equipment is also a significant export item for which there are good growth prospects.

These considerations, coupled with the fact that refrigeration and air conditioning are responsible for only 8% of the end use of F-11, 12, 113 and 114 in the EEC (a much smaller proportion than in the USA), suggest that these applications of CFCs should be afforded some measure of protection in any regulation that may eventually prove necessary.

Accepting that refrigeration is essential in our society, the next question is whether perhalogenated CFCs are essential for refrigeration.

5.3.2 Scope for Alternatives to Perhalogenated CFC Refrigerants

The alternative refrigerants to be considered are:
a) Other CFCs already commercially available
b) New CFC refrigerants that might be developed
c) Non-CFC refrigerants (e.g. ammonia).
Each possibility is discussed separately below.

An important consideration in transferring to other refrigerants is that refrigeration and air conditioning equipment has a long lifetime, perhaps twenty years or more. Since, in most cases, equipment is designed for use for a particular refrigerant, operators of existing equipment would need to adapt or re-design their equipment, if that particular refrigerant were abandoned. If this were too expensive, some equipment would inevitably be written off.

<u>Existing CFCs</u>. The most likely substitute CFC is F-22 ($CHClF_2$) which is already widely used in some refrigeration applications. F-502 (the F-22/F-115 azeotrope) would also be a possible substitute in some applications, but this assumes that the F-115 component of the azeotrope is exempted from controls, which may not be the case because F-115 (C_2ClF_5) is fully halogenated.

We have discussed substitution with a leading expert on refrigeration technology (Reference 5.12) and have concluded that, for most refrigeration and air-conditioning applications, new equipment could be designed to work with F-22 or F-502. However, although for some applications this would be comparatively straightforward, there are some categories of equipment (e.g. centrifugal chillers) where a major redesign would be necessary, involving substantial delays (perhaps ten years) and substantial economic penalties.

It is necessary to record, however, that there are unresolved toxicological questions concerning F-22. Biological testing has indicated weak teratogenic and mutagenic effects, and two major CFC producers (Du Pont and ICI) who have carried out tests advise that the use of F-22 be restricted to applications where it is confined, as in closed circuit refrigeration and air conditioning applications, and that exposure should be minimised until the results of longer term studies are available in another year or so.

<u>New Fluorocarbons</u>. In addition to the established fluorocarbons, the possibility exists that new fluorocarbon refrigerants will be developed that could also be permitted in the context of the ozone depletion hypothesis. However, it is likely to be a minimum of five years before such fluorocarbon could become available on a commercial scale.

<u>Non-CFC Refrigerants</u>. In the event that no CFCs were permitted or that F-22 etc. proved unsuitable, the refrigeration industry

would have no short or medium term alternative but to return to refrigerants such as ammonia and methyl chloride. This would be a most unsatisfactory situation for all producers and users of refrigeration equipment, since these refrigerants had earlier been rejected because of the disadvantages associated with them.

5.3.3 Prospects for Alternatives to Vapour-Compression Refrigeration Systems

The current fluorocarbon-based equipment and systems have been developed over many years and represent the most economical solutions to today's refrigeration/air conditioning requirements.

Any substitution of fluorocarbon-based systems would involve substantial re-design, with associated delays and costs.

The most frequently suggested alternatives to fluorocarbon-based refrigeration systems are discussed briefly below.

Absorption Systems. In principle these are thermodynamically analagous to vapour compression systems, having in common the evaporation and condensation of a refrigerant fluid at two pressure levels within the unit. The essential differences are that absorption systems are driven by the application of heat instead of by mechanical power, and the pressure differential is produced by a physico-chemical process in which the refrigerant vapour alternately dissolves in, and evaporates from an absorbent liquid.

Of the many combinations that have been tried, only the lithium bromide-water and the ammonia-water cycles remain in common use. In the former the refrigerant is water; in the latter it is ammonia.

These systems are less efficient than vapour compression systems, typically by a factor of 0.5, and are generally used under special circumstances where waste-heat is available or where electrical supply is limited.

Thermoelectric Refrigeration. This is based on the Peltier effect where a direct electric current in a circuit comprising two dissimilar metals causes heat to be absorbed at one junction and liberated at the other - the converse of the Seebeck effect. With elementary metal combinations the effect is too small to be useful but with modern semi-conductors it is large enough to provide the basis of practical refrigeration systems.

Advantages of thermoelectric cooling include the absence of moving parts and working fluids, silent operation, and capability of functioning at high ambient temperatures in any position and in the absence of gravity. The energy utilisation efficiency is only a fraction of that obtainable with vapour compression however, (typically about 10%) and while there is certainly scope for development thermoelectric refrigeration is limited at present to applications where the efficiency factor is not a primary consideration, for example in submarines and in scientific instruments.

Air cycle refrigeration. Air has the advantages over other refrigerants in being completely safe and freely available. However, as in the previous two examples, the efficiency is low and air cycle refrigeration is therefore at present only used in circumstances where efficiency is of secondary importance, e.g. in aircraft air conditioning.

5.3.4 Preferred Approaches : Emission Reduction and Moves towards Non-Perhalogenated CFCs

In view of the essential nature of refrigeration, the comparatively small contribution that it makes to total CFC emission in the EEC and the impracticability of making any rapid switch from the perhalogenated CFCsin especially F-12, it is assumed that the existing CFCs will continue to be used for the time being but that emphasis in future will need to be placed on a) the elimination of preventable emissions from existing and new equipment, and b) the encouragement of the use of permitted fluorocarbon refrigerants, such as F-22 and perhaps F-502, or alternative refrigeration systems.

In the absence of reliable data, it is difficult to evaluate the likely impact that such an approach would have on CFC emissions. We have therefore restricted ourselves to the following two objectives.

a) to provide a general appreciation of how emissions occur, and how they might be reduced, and

b) to identify those areas where further research will be needed in order fully to understand the likely impact on CFC emissions of such an approach being adopted by EEC countries.

5.4 The Potential for Reducing Fluorocarbon Emissions

Unlike most of the other fluorocarbon applications such as aerosols, there are many different sources of fluorocarbon emission in refrigeration and air-conditioning applications.

Emissions can occur during manufacture or installation; during the lifetime of the product owing to leakage, repair or servicing; or on final disposal of the product.

The relative importance of these sources of emission can vary from one equipment category to another. For example leakage is probably the most important source for some products such as mobile air-conditioning, whereas final disposal may be the main source for many of the hermetically sealed units such as refrigerators and freezers. Unfortunately,once again we are faced with the data availability problem. Although new data has recently become available in USA and the problem has been discussed in Public Meetings before the Environmental Protection Agency, it appears that no clear concensus of opinion is emerging on how emissions might be eliminated. Research programmes currently sponsored by EPA, such as that being undertaken by the Rand Corporation, should shed some more light on this difficult subject during 1979 and 1980.

In this section our main objective is to discuss the main sources of emission and to indicate where there are likely to be opportunities for emission prevention. At this stage discussion will focus on the technical aspects. The question of how refrigeration and air-conditioning is approached in EEC countries, in order to ensure that preventable emissions are eliminated wherever possible, will be discussed at a later stage (Section 5.5).

5.4.1 Emissions during manufacture.

In an increasing proportion of refrigeration and air-conditioning equipment, the refrigerant is charged and the unit is hermetically sealed before it leaves the manufacturing plant (see Table 5.2, which identifies those applications in which the equipment is hermetic). Emissions can therefore be expected at manufacturing plants where units are charged.

Du Pont (see Reference 5.4) has identified the following sources of emission at manufacturing plants:

1. Leaks from storage tanks and distribution piping.
2. Failures of seals, relief devices, etc.
3. Quality control analyses of refrigerant.
4. Laboratory testing of equipment.
5. Testing of refrigerant charging unit accuracy.
6. Refrigerant vented from equipment requiring rework.
7. Refrigerant used for leak testing and not recovered.

Du Pont comments that they know of no previous attempt by anyone to determine the magnitude of these emissions but, based on their own experience at manufacturers' plants, they believe that the greatest losses result from venting refrigerant from units to be repaired and from leak testing. They suggest that these could be reduced as follows:

Use of refrigerant recovery equipment. Items 4,5 and 6 above can be considered together from the standpoint of emission control. Recovery equipment is already available that can transfer refrigerant to facilities that remove contaminants and then transfer the cleaned-up refrigerant to storage.

Use of leak test gas recycle equipment. Fluorocarbon/air mixtures are used for leak testing in manufacturing plants.

Leak test gas recycle equipment is available that enables this mixture to be re-used. In USA small producers have been reluctant to invest in such equipment.

Information submitted at one of the EPA Public Meetings (see Reference 5.5), indicates that the installed cost of such a system is in the range of $30-100,000 (UCE 25-80,000) and that the main purpose in installing such equipment has been cost savings by reducing fluorocarbon usage.

Achievable reductions. Du Pont state that widespread use of the recovery equipment by manufacturers could be expected to reduce the first category of emissions above by 75% and that a 50% reduction in emissions during leak testing might be achievable by further installation of recycling equipment. They also present their estimates of the main emissions in manufacturing plants in USA, from which we have calculated that the annual emissions are equivalent to about 5-7% of the amount of refrigerant used each year in charging new equipment and that this could be reduced to 2-3%.

5.4.2 Emissions during installation.

Whereas for equipment that is precharged fluorocarbon emissions can occur at the manufacturing plant, for field-charged systems emissions are likely to occur during installation. Although to a certain extent the problems that are faced are similar to those in the manufacturing plant, they are more difficult to solve.

The main sources of emissions during installation are:

a) Refrigerant released after leak testing. The small amount of refrigerant used to leak test during installation is usually released to the atmosphere when the test is complete. For manufacturing plants it was suggested that this problem could be reduced if leak test gas recycle equipment were more widely used. On purely economic grounds, such a solution is unlikely to be worthwhile for on-site installation in view of the high capital cost and the likely low utilisation.

b) Release of refrigerant used during evacuation. After leak testing has been completed and before the system is charged, it is necessary to rid the system of air and of any moisture or other contaminants. This becomes particularly difficult with units of the remote type, split into two or more parts and connected with piping. One of the methods commonly used is to purge these connecting lines with refrigerant and then to evacuate, pulling out both the refrigerant and the contaminants. Triple evacuation is usually recommended. At present there is no incentive to retain this refrigerant and in most cases it is released to the atmosphere.

At one of the EPA Public Meetings (Reference 5.6) it was suggested that the most sensible solution would be to adopt "deep evacuation", an alternative procedure that relies on the principle that when a deep vacuum is established in a closed system, any moisture will evaporate and can be extracted by pump. In order to use this procedure, installation personnel need to be equipped with a high vacuum pump, which is likely to increase installation costs.

Another solution, albeit a partial one, is the increased use of connecting devices, usually called "couplings". These are pre-charged with refrigerant by the manufacturer. This passes the problem back to the manufacturing plant where it is more likely to be solved at an acceptable cost.

c) Release of Refrigerant, if over-charged. Where a system has been over-charged, the excess refrigerant is usually removed by venting to atmosphere. We do not believe this to be a major emission source. As in a) above, the possibility of recycling exists but on purely economic grounds it is currently not worthwhile.

5.4.3 Leakages caused by equipment malfunctions.

The extent to which leakage is a major source of emission varies considerably from one category of equipment to another. Generally speaking, the less the hermeticity of the system, the more vulnerable it is to leakage. The size of the system is also important, since the larger systems usually require more joints and there are therefore more potential leakage points. A third factor is the exposure of the system to vibration.

Leakage rates for hermetic units, particularly the smaller ones such as domestic refrigerators and freezers, can be very low. At the recent EPA Public Meetings, leakage rates of 1% in five years and less than 2% in fifteen years were quoted for domestic equipment (References 5.7, 5.8). For other hermetic systems and for non-hermetic systems, the leakage rate data that does exist at present is, in our opinion, not sufficiently reliable to quote at this stage, but it is believed that annual rates in excess of 25% may occur in equipment such as automotive air-conditioning.

The most exhaustive explanation that we have identified, of the causes of leakage and how they might be eliminated, is a study undertaken by the Midwest Research Institute on behalf of the EPA (Reference 5.9). Among the equipment categories that they examined are chiller systems and the retail display cases used in commercial food and beverage refrigeration, i.e. the two equipment categories that we identified in Section 5.2 as probably being the two most important applications of CFC refrigerants in EEC countries.

For example, for chiller systems they identify the following major sources of leakage:

a) Pressure relief valves, of which there are basically two types: mechanical valves and rupture discs. Both are capable of leaking and, when a rupture disc bursts, the entire refrigerant charge can be lost.

b) Purge systems, which are installed on low pressure (F-11) centrifugal units in order to remove air which leaks into the system. They are not very efficient in separating the air from the refrigerant, and can consequently eject refrigerant and air simultaneously.

c) Compressor shaft seals. Seal leakage causes a gradual loss of refrigerant in chiller systems that are not hermetically sealed, which includes many of the older reciprocating chillers and some centrifugal units.

d) Gaskets and O-rings, which can cause leakage if the materials are allowed to deteriorate for reasons such as temperature variations in the system.

For other equipment categories, the causes of leakage are likely to be different from those cited above for chiller systems, although some are the same, (e.g. compressor shaft seals which are a common cause of leakage in non-hermetic systems).

Leakage Reduction. Reductions in emissions caused by leakage could be achieved in the following ways:

a) Leak detection. There are many different methods of leak detection available, e.g. electronic detectors, the halide torch, the bubble method and the "Dytel" leak detecting agent developed by Du Pont. Although we understand there may be scope for improving leak detection methods, the main problem lies in the extent to which leak detection is practised. We believe that there is scope for a more widespread use of leak detection systems fitted with alarm devices.

b) Design improvements. For some equipment categories such as domestic refrigerators, improvements over the years in both the design and the materials used have almost eliminated leakage. For non-hermetic systems, we understand further improvements could still be made although these are likely to be associated with increases in cost.

Returning to the example of chiller systems, the MRI study (Reference 5.9) identifies several design improvements including:

- for the pressure relief valves, the installation of a refrigerant collecting vessel in the vent system
- for purge systems, the replacement of low-pressure (F-11) systems by high-pressure (F-12) systems
- for compressor shaft seals, the replacement of old seals by new ones.

5.4.4 Losses during repair work and servicing.

Although repair work and servicing occur under different circumstances and have different objectives, from an emission control point of view they pose similar problems.

When a system breaks down and repairs have to be made, it is usually necessary for the refrigerant charge to be removed at least from that part of the system on which the work must be done. In USA (References 5.4, 5.9) this often results in the refrigeration charge being vented to atmosphere, and we understand that this practice is also common in the EEC countries.

This situation is largely brought about by the economic and other pressures under which the service engineer is working. In deciding what to do with the refrigerant, he needs to know whether or not the refrigerant is contaminated (e.g. as a result of electric motor burn out in hermetic systems, which produces acids). If it is contaminated, it is likely to be discarded. If it is not contaminated, the service engineer has three choices:

a) He could try to isolate the refrigerant in another part of the system. Some units have liquid receivers designed for this purpose. In many systems, however, this is not possible.

b) He could temporarily transfer the refrigerant to a suitable container. However, if the equipment does not have a built-in transfer system, the service engineer would need to be equipped with a suitable pump. Even when he is supplied with this equipment, he may decide that saving the refrigerant charge is not worth while in view of the time it would take to effect the transfer and return of the refrigerant. Two important factors in this decision are likely to be the size of the refrigerant charge and the replacement cost of the refrigerant, which will depend upon the fluorocarbon that is being used.

c) His final option, and the one that is frequently arrived at, is to discard the refrigerant.

In discarding the refrigerant, it may be vented to atmosphere or disposed of in some other way that causes fluorocarbon emissions.

Emission Reduction. The following possibilities exist for reducing emissions during repair work and servicing:

a) Design improvements, whereby more systems would be equipped with liquid receivers or other means of isolating refrigerant.

b) Changes in procedures to ensure firstly that uncontaminated refrigerant that could not be isolated would be transferred temporarily to a suitable container rather than discarded; and secondly that contaminated refrigerant would be recaptured in some way rather than venting it to the atmosphere. We understand that changes of this kind would radically alter the costs of repair and servicing (for some US cost estimates, see Reference 5.10).

Refrigerant recapture and the question of what to do with recaptured refrigerant, is further discussed in Section 5.4.6.

5.4.5 Loss of Refrigerant when Equipment is Scrapped

Some systems such as domestic refrigerators and freezers are scrapped without any thought being given to what happens to the refrigerant. In these circumstances we can assume that the refrigerant eventually escapes into the atmosphere. However, in most systems with large refrigerant charges a conscious decision is made on whether or not to keep the refrigerant.

If the refrigerant is thought to be contaminated, it is likely to be discarded. If it is not contaminated, someone has to decide whether or not it would be worthwhile recapturing the refrigerant for future use elsewhere. As in the previous section, important factors affecting this decision will include the size of the charge and the type of refrigerant.

Emission Reduction. From the comments above it is clear that significant reductions in fluorocarbon emissions would be achieved if those responsible for systems with large charges could be persuaded to recapture the refrigerant charge; and if a means could be found of recovering refrigerant from the smaller systems such as domestic refrigerators and freezers that are currently overlooked.

5.4.6 Refrigerant Recapture and Re-use

In Sections 5.4.4, 5.4.5, we have seen that the opportunity exists to recapture refrigerant that is currently being vented to atmosphere during repair work and servicing, or when equipment is scrapped.

For refrigerants with low volatility (e.g. F-11, F-113), this is relatively straightforward. However, the more commonly used refrigerants (e.g. F-12) exist in refrigeration systems as pressurised liquids in equilibrium with their vapours. When the system is opened, the fluids rapidly evaporate and escape. In order to recapture the refrigerant it is therefore necessary to draw out the vapours using a compressor, liquefy them in a condenser, and then collect the liquid under pressure. Self contained units are available for this purpose.

However, Du Pont (Reference 5.4) warn .... "the removal of refrigerant from a machine and storage in a suitable container must be done by experienced and knowledgeable people. In a field as large and diverse as refrigeration service work, there are bound to be many who do not appreciate all the hazards involved. Even experienced servicemen may not fully understand the potential hazards of overfilling cylinders". They also warn of the problems caused by mixing refrigerants (for example F-12 and F-22 form an azeotrope that cannot be separated) and of the use of inappropriate containers.

In some circumstances recaptured refrigerant can be re-used in its existing state. For example, refrigerant recaptured from the production line at manufacturing plants (as discussed in 5.4.1) is suitable for re-use and, when a system is opened for repairs, the refrigerant that is temporarily removed can usually be returned to the system.

However, whenever contamination is feared, the refrigerant cannot be re-used in its current state and the question arises of what to do with it if it cannot be released to atmosphere.

<u>Reprocessing</u>. The ideal solution would be to be able to reprocess (ie.purify) the recaptured refrigerant so that it could be re-used. However, at present only the CFC manufacturers are in a position to comment on whether or not such a solution is realistic, and they do not appear to be optimistic.

For example at the recent EPA Public Meetings, one manufacturer stated (Reference 5.11):

"Widespread reprocessing of recovered refrigerant has not developed to date and seems unlikely under current circumstances. If such reprocessing is found to be essential in the future, adequate incentives will be needed to develop this service".

Among the problems that have been identified are:

a) <u>Logistics</u>. There would be organisation problems in collecting refrigerant from widely dispersed locations. (These problems might be reduced if refrigerant quantities below a certain size were excluded, e.g. refrigerators, freezers, small appliances).

b) <u>Analytical Procedures</u>. Each batch of recaptured refrigerant would need to be analysed separately to determine the nature and extent of contamination and to identify the type of reprocessing required.

c) <u>Viability</u>. A substantial capital investment would be required to cover such items as:

- storage tanks for different refrigerants
- distillation equipment
- analytical laboratory
- filtering and drying equipment
- cylinder handling facilities

It is unlikely that the value of the product would cover the reprocessing costs.

Destruction. If the refrigerant cannot be re-used without treatment and it is not worthwhile purifying it, the only other option is to try to destroy it. Although it is possible to destroy small quantities in the laboratory by decomposing the fluorocarbon in a hot gas flame, the products of decomposition are principally acids which on a large scale would pose further disposal problems.

5.5 Possible Courses of Action

This section is addressed to the courses of action that might be taken in the refrigeration and air-conditioning sector, if it were decided that it is necessary to reduce fluorocarbon emissions.

We have already discussed (in Section 5.3) the impracticability of a ban in the short or medium term on the use of F-11/F-12/F-113/F-114 as refrigerants. We are therefore assuming that these fluorocarbons will continue to be used, but that emphasis in future will need to be placed on a) the elimination of preventable emissions from existing and new equipment, and b) the encouragement of the use of other fluorocarbon refrigerants, such as F-22 and perhaps F-502, or alternative refrigeration systems.

Each of these subjects is discussed separately below (5.5.1, 5.5.2) and some possible courses of action are considered.

Since there is still no clear concensus of opinion on many of the aspects discussed, further research of a more technical nature needs to be carried out. In the USA important research programmes have been initiated by EPA (e.g. that being undertaken by the Rand Corporation) and, in order to benefit from the progress that has already been made there, we recommend that any research initiated in Europe should be co-ordinated with that sponsored by EPA.

In order to investigate the implications of different courses of action in EEC countries, the existing data base must be improved. This is discussed in Section 5.5.3.

5.5.1 The Elimination of Preventable Emissions

The methods of emission reduction identified in Section 5.4 are summarised below and comments are made on the appropriateness of regulatory legislation and of voluntary restrictions by the industry.

Manufacturing Plants

- Further investigation is necessary of the extent to which refrigerant recovery equipment and leak test gas recycle equipment is used;
- If necessary, regulatory legislation could be introduced to make such equipment compulsory in plants above a certain size.

Equipment Installation

- Voluntary restrictions by the industry should be sufficient to stop the practice of purging.

Leak Detection

- Further investigation is necessary to determine the extent to which adequate leak detection procedures are practised.
- If necessary legislation could be introduced to raise leak detection standards.

Design Improvements

- Technical evaluations are necessary to determine the extent to which leakage can be reduced for the various equipment categories.
- It is conceivable that eventually legislation could be introduced to regulate certain design features of equipment that influence leakage and the loss of refrigerant during repair work (e.g. inclusion of liquid receivers in certain categories of equipment).

Refrigerant Recapture

- Voluntary restrictions by the industry may be sufficient to stop venting to atmosphere during repair work and servicing, or when equipment is scrapped.
- An investigation of the cost implications is necessary, since economic pressures may prevent voluntary restrictions being adhered to, in which case regulatory legislation may need to be considered.

Refrigerant Reprocessing

- Technical evaluation studies (some are already being undertaken by the refrigerant manufacturers) are necessary to determine the technical feasibility of reprocessing, and the associated costs.
- Since viability is likely to be a major constraint, further studies are likely to be necessary to determine whether viability might be achievable if a selective approach were adopted (e.g. by only collecting batches of over 1000 kgs; by not reprocessing severely contaminated batches).

Refrigerant Destruction

- Technical evaluation studies need to be undertaken to confirm that, if necessary, refrigerant can be destroyed on a large scale.

In the absence of an adequate data base we have made our own very approximate estimates of the likely reductions in emissions that might be achieved. We believe that emissions could be reduced to about one third of the current level if all the possible courses of action were successfully followed, and assuming that recaptured refrigerant is either reprocessed or destroyed.

However, although it is clear that most emissions are capable of being reduced, the responsibility for effecting these reductions is so widely dispersed (manufacturers, installers, service engineers, supermarkets, householders, etc.), that it will be difficult to ensure that the necessary steps are taken.

For example, consider refrigerant recovery. If voluntary restrictions are introduced to prevent venting to atmosphere, the economic pressures may nevertheless prevent adherence to these restrictions and regulations may have to be imposed. It would however be very difficult to enforce these regulations, because it would be virtually impossible to provide evidence that refrigerant had been deliberately and unnecessarily released.

Therefore not all of the anticipated reductions in emissions will be achieved in practice, and the most promising courses of action are likely to be those that do not rely on voluntary action by any party against his own economic interests.

This suggests that priority should be given to:

- Action at Manufacturing Plants
- Leak Detection
- Design Improvements.

5.5.2 The Transfer to Permitted Refrigerants or Alternative Refrigeration Systems

On the assumption that certain fluorocarbons continue to be regarded as not constituting a danger to the ozone layer it should be possible to transfer some refrigeration and air-conditioning applications to these refrigerants (e.g. F-22 and perhaps F-502).

If these circumstances emerge, the possible courses of action include the following:

- Technical evaluation studies to determine the suitability of F-22 etc., for each of the major categories of equipment.

- Since development costs are likely to be substantial, manufacturing companies may need to be given economic incentives to develop appropriate equipment.
- Once appropriate equipment is available in a particular equipment category, legislation could be introduced to prevent the sale of equipment in that category using F-11, F-12, etc.

Since, in the long term, alternative refrigeration systems might also provide solutions to this problem, another possible course of action is:

- Technical evaluation studies to determine the suitability of alternative refrigeration systems (e.g. absorption, air cycle, thermoelectric), for certain of the major equipment categories.

5.5.3 Improvement in the Data Base

In order to investigate the implications of different courses of action, an adequate data base is needed that would give the number of units in service, the typical fluorocarbon charge and CFC release characteristics, for each major category of refrigeration and air-conditioning equipment.

Had this data been available for EEC countries during the course of our study, we would have been in a better position to identify the major sources of emission and to estimate the likely reductions that might be achieved.

We discussed these data requirements with such bodies as CECOMAF (the European Committee of Manufacturers of

Refrigeration Equipment). It was clear that these data requirements cannot be met at present.

A substantial research effort, comparable to that currently being undertaken in the USA on behalf of EPA by the Rand Corporation, will be needed if the data base is to be improved.

5.6 Socio-Economic Aspects

5.6.1 Production and Market Statistics

The lack of reliable, comprehensive and up-to-date statistics hampers discussion of the value of the refrigeration business in the EEC,but the figures quoted in Tables 5.4 and 5.5, inadequate as they are, give some idea of the magnitude.

TABLE 5.4 : REFRIGERATION AND AIR CONDITIONING EQUIPMENT: PRODUCTION IN THE EEC IN 1975.

	Air Conditioning Machines (thous. units)	Refrigerators (other than household) and Freezers (no. of units)	Refrigerators for Household use (thous. units)
Belgium	n.a.	15 (Note 1)	n.a.
Denmark	n.a.	14120	619
France	n.a.	2,032,930	n.a.
Germany (F.R.)	258 (Note 1)	244,231	2633
Italy	n.a.	n.a.	n.a.
Netherlands	n.a.	n.a.	n.a.
U.K.	21 (Note 2)	197,586	1109

Source : United Nations - Industrial Statistics

TABLE 5.5 : REFRIGERATION AND AIR CONDITIONING EQUIPMENT: MARKET SIZE AND IMPORT FORECASTS FOR THE EEC IN 1975.

Forecasts for 1975 - millions of U.S. dollars.

	Air Conditioning Equip.		Refrigeration Equipment	
	Market Size	Imports	Market Size	Imports
Belg. Neths.	41.9	23.8	65.4	65.0
France	72.0	16.0	125.0	74.0
Germany (FR)	309.6	50.6	176.4	68.6
Italy	230.5	12.5	56.4	5.7
U.K.	49.2	15.6	129.6	51.1
	703.2	118.5	552.8	264.4

Source : US Dept. of Commerce 1972 : World Market for US Exports.

Note : Market size = production plus imports less exports.

The forecasts in Table 5.5 suggest that production less exports in the six EEC countries listed would total \$584.7 million for air conditioning equipment and \$288.4 million for refrigeration equipment in 1975, in terms of the dollar values obtaining in 1972. Perhaps the most striking feature is the volume of air conditioning equipment.

5.6.2 Employment

No data for the EEC as a whole or most individual countries are available, and it would be unwise to attempt to extrapolate from USA statistics, because of the very different distribution of manufacture, for example the prominence of automotive air conditioning in the U.S.

In 1976 the British Refrigeration and Air Conditioning Association estimated employment in the industry in the UK to be approximately 40,000. Without reasonably accurate production data it is not possible to assess employment in the other EEC countries but it seems likely that the order of magnitude for the EEC as a whole could be at least 200,000.

5.6.3 Impact of Emission Reduction Measures

It is assumed that for the time being no restrictions would be placed on the use of perhalogenated CFC refrigerants for servicing existing equipment or for new manufacture but that the industry might be encouraged to reduce release to the atmosphere by adopting the type of measures discussed in Sections 5.4 and 5.5.

Although there would be some economic gains in reducing refrigerant losses it is likely that these would be outweighed by the additional costs,and these would be reflected in somewhat higher equipment prices and servicing charges. To the degree that new equipment sales are price sensitive this could slow down sales growth, and a possible counter-productive effect of higher servicing costs would be to discourage users from having equipment serviced until it became imperative: this could tend to increase CFC releases due to delays in correcting leakages and other malfunctions. There seems no reason to believe, however, that any of these measures would reduce employment though they could possibly retard the growth of new job opportunities.

5.7 Conclusions

5.7.1 The great majority of refrigeration and air conditioning equipment employs the vapour-compression system, for which fluorocarbon refrigerants are used almost exclusively except for some large industrial systems using ammonia. The only alternatives to fluorocarbon refrigerants in vapour-compression systems are substances such as ammonia, sulphur dioxide and methyl chloride which have long been discarded for general application because of toxicity, flammability or poor thermodynamic efficiency.

5.7.2 Sales of F-11, 12, 113 and 114 refrigerants in the EEC amounted to 20.5 thousand tons in 1977, representing only 8.1% of the EEC total and less than half the usage in foam plastics. The bulk of these sales were of F-12 (87%) and F-11 (12%). A small decrease on the 1976 total of 20.9 thousand tons may be due to the trend towards greater use of F-22 (which is not perhalogenated and is not considered a threat to the ozone layer), especially in packaged air conditioning units, and of F-502 (an azeotrope of F-22 and F-115) in retail food display cabinets.

5.7.3 The use of the less thermally efficient absorption type refrigeration systems employing waste heat instead of electro-mechanical energy may grow, but no serious competitor to the vapour-compression system is likely to emerge for many years.

5.7.4 It is believed that, for most applications, systems currently using perhalogenated CFC refrigerants could be re-designed to use F-22 or F-502, but, existing installations could not readily be converted and stationary refrigeration equipment normally has a long life-time.

5.7.5 Because of the importance of refrigeration in the developed world - especially in food storage and transportation, the large volume of installed capacity and the impracticability of any rapid switch to alternative manufacture, no restrictions on the use of perhalogenated CFC refrigerants have been considered. The preferred approach is to concentrate on the elimination of preventable emissions from existing and new equipment, and to encourage the use of non-perhalogenated CFC refrigerants where practicable. It is estimated that some 70% of refrigerant sales are for replacement purposes due to leakage and contamination, and that avoidable losses occur in the manufacture, testing and installation of new equipment. Technology and procedures are available for substantially reducing these emissions.

5.7.6 The cost of emission reduction measures would probably not be fully compensated by savings in refrigerant consumption and would tend to raise the cost of new equipment and servicing, with possible adverse effects on the growth rate of the industry.

5.7.7 Detailed analysis of refrigerant usage, trends and socio-economic factors in the refrigeration and air conditioning industry in the EEC is seriously hampered by the lack of adequate and up-to-date statistics.

REFERENCES

5.1 DuPont "FREON" Product Information, Technical Bulletin B-2.

5.2 "Economic Significance of Fluorocarbons", US Bureau of Domestic Commerce Staff Study, US Department of Commerce, December 1975.

5.3 "Preliminary Economic Impact Assessment of Possible Regulatory Action to Control Atmospheric Emissions of Selected Halocarbons", Arthur D. Little Inc., September 1975, for US Environmental Protection Agency.

5.4 "Non-Aerosol Propellant Uses of Fully Halogenated Halocarbons". Information submitted to the US Environmental Protection Agency by the Freon Products Division, E.I. DuPont de Nemours & Company, dated 15th March 1978.

5.5 Verbal submission from a representative of Production Control Inc., at an EPA Public Meeting, 21st February 1978

5.6 Verbal submission from a representative of Aeroquipt Corporation (and at the request of the Air Conditioning and Refrigeration Institute) at an EPA Public Meeting on 25th October 1977.

5.7 Verbal submission from a representative of AHAM at an EPA Public meeting on 25th October 1977.

5.8 Verbal submission from a representative of General Electric at an EPA Public Meeting on 25th October 1977.

5.9 "Chemical Technology and Economics in Environmental Perspectives - Task III - Chlorofluorocarbon Emission Control in Selected End-Use Applications". Prepared by the Midwest Research Institute for EPA. Report No. EPA-560/1-76-009, November 1976.

5.10 Written testimony presented by the National Environmental Systems Contractors Association at the EPA Public Meeting on 21st February 1978.

5.11 Statement of Allied Chemical Corporation presented at the EPA Public Meeting on 22nd February 1978.

5.12 Correspondence with Professor Ir. A.L. Stolk (of the Technische Hogeschool, Delft), President of Commission B2 "Refrigerating Machinery", International Institute of Refrigeration.

6. FOAM PLASTICS

6.1 Application and Consumption of CFCs in the Production of Foam Plastics

6.1.1 Extent of use of CFCs as blowing agents

The use of CFCs, especially F-11, as blowing agents for the manufacture of foamed plastics has become the second largest application of CFCs in the EEC, where it accounted for 46,246 tons, or 18.3% of the total sales of F-11, 12, 113 and 114 in 1977. This is 2.25 times the total consumption of these four CFCs in refrigeration and air conditioning in the same year, and a reversal of the ranking in the United States and world markets. An analysis of this consumption is given in Section 6.1.3.

The growth of the foamed plastic industries is linked with their penetration of a number of key structural and insulation materials markets, including building construction, furniture and automotive upholstery, packaging, and the insulation of refrigerators, bulk transport and industrial plant. In some instances foam plastics have not simply replaced older materials but have caused major changes in design and manufacturing technology which would now be difficult to reverse.

In addition to the economic importance of the industries involved there is a significant social value element, for example in relation to energy and materials conservation, and the distribution and storage of food.

For some of the largest foam plastics production sectors, particularly the rigid and lower density flexible polyurethane foams, CFC blowing agents currently have unique applications, and the growth of CFC blowing agent consumption is strongly linked to the expansion of these sectors.

6.1.2 Nature of Foam Plastics and Blowing Agents

Plastic materials may be produced in the form of a foam to provide combinations of low density with flexibility or rigidity, and with thermal or electrical insulation properties.

Foam plastics are essentially dispersions of gas bubbles or cells in a plastic matrix and there are two extreme types:

- open cell foams in which there is a high degree of interconnection between the voids, allowing free passage of gas between the foam and the environment.

- closed cell foams in which there is little interconnection and gas can only enter or leave the foam by diffusion through the cell walls, the permeability depending on the nature of the material and the gas.

To develop the cellular structure blowing agents are used which are either gases or volatile liquids, and which are either generated chemically during the formation of the plastic, or introduced into the mix or melt and expanded or volatilised by heat or pressure reduction. They are termed primary blowing agents when they are responsible for all or most of the foaming action, and secondary blowing agents when they are employed to supplement the action of the former - usually to yield a lower density foam than would otherwise be obtainable.

The plastic material itself may be formed by chemical reactions and foamed at the same time, as in polyurethane foams. With thermoplastic materials such as polystyrene and polyolefins, the plastic is pre-produced and subsequently melted and expanded. After formation the chemically produced foams must be allowed to cure and stabilise, and the thermoplastic materials to solidify.

The plastics most extensively used in foamed forms and their main application fields are:

<u>Flexible polyurethane</u>

- furniture and automotive upholstery; bedding; packaging; textiles; thermal and acoustic insulation.

<u>Rigid polyurethane</u>

- insulation applications in building construction, bulk transport, industrial plant, refrigerators and other appliances; furniture; packaging; automotive and marine.

<u>Polystyrene</u>

- packaging; insulating boards and sheets.

<u>Polyolefins</u>: polyethylene and polypropylene

- electric cable insulation; packaging; gaskets and seals; expansion joints in building construction.

Depending on the material and application, foam plastics may be produced continuously or batchwise in the form of slabs, boards, sheets and tubes which are then fabricated into the required shapes by cutting and machining, or by 'thermoforming', i.e. heating and moulding into shape. Finished or semi-finished components may be made by foaming into moulds; cavities and voids can be filled with foam by injecting a liquid mix and allowing it to foam and solidify; and tanks, pipes etc. can be insulated by spray coating.

Factors which govern the selection of the blowing agent include cost, vapour pressure - temperature characteristics, chemical stability and compatability with the plastic, solubility in the polymer, effect on the viscosity of the mix during the forming process, and thermal conductivity. In practice, relatively few substances satisfy the essential requirements for the four types of foam mentioned above, and the most widely used are:

Carbon dioxide

- mainly used as the primary blowing agent for flexible polyurethane foams, for which it is generated chemically in the mix by the interaction of water with isocyanate.

Chlorofluorocarbons

- the most widely used secondary blowing agents for low density flexible polyurethane foams.

- used almost exclusively for closed cell rigid polyurethane foams in which the low thermal conductivity of the CFC gas trapped in the cells makes an all important contribution to the thermal insulation characteristics.

- used to varying extents for polystyrene, polyolefin, phenolic and other foams.

Hydrocarbons

- hydrocarbons, mainly normal and iso-pentane, are used to a large extent for foaming polystyrene.

Methyl chloride

- used as a primary blowing agent for polystyrene board, sometimes in conjunction with CFCs.

Methylene chloride

- finds application mainly as a secondary blowing agent for flexible polyurethane but is little used in the EEC for this function.

When foam plastics are first formed the cells are occupied by the blowing agent gases or vapours. With open cell foams, given free access of air, these gases are rapidly replaced by air due to diffusion through the interconnecting network of channels, and the process may be complete in a matter of days.

With unconfined closed cell foams the rates of inward diffusion of air and outward diffusion of the blowing agent gas vary according to the nature of the system and may be very slow indeed, taking months or years to complete. With low permeability systems the blowing agent gas can be regarded as an integral component of the foam and its characteristics contribute to the insulating and other properties.

CFC blowing agents in conjunction with closed cell rigid polyurethane form a unique combination because the CFCs have much lower thermal conductivity than any other blowing agents and their rates of diffusion through the cell walls are so slow that the exceptionally good insulating characteristics may be substantially retained for many years, and almost indefinitely if the foam is enclosed between impermeable walls, as in refrigerator doors and panels.

The final point that must be brought out in this general review is that, at present, foam blowing agents are used once only and are not recovered either for re-use or for destruction prior to disposal.

The CFC used for making 'prompt emitting' foams, particularly flexible polyurethane, is mostly released into the atmosphere via the ventilation systems before the foam leaves the factory.

The ultimate destination of CFCs used in making rigid polyurethane is less certain. When the foam is exposed to the air a proportion of the CFC content will diffuse out during the working life. When the foam is finally scrapped the fate of the residual CFC content depends on the mode of disposal. If dumped,the CFC may remain trapped indefinitely; if the foam is burned some of the CFC may be decomposed, but this practice is forbidden in some areas because of the acid gases generated.

In the following sections the consumption of CFCs in foam manufacture is analysed, and the main applications - in flexible and rigid polyurethane foams - are considered in detail.

TABLE 6.1 : CHLOROFLUOROCARBON FOAMING AGENT SALES ANALYSIS 1976/1977.

Sales of CFCs for Manufacture of Foam Plastics		F-11		F-12		F-113		F-114		Total F-11,12, 113,114		%age Change in Sales '76 to '77
		tons	%	tons	%	tons	%	tons	%	tons	%	
Reported Sales in CFC Producers' Home Markets.												
Flexible polyurethane	'76	12,413	45.2	143	7.6	293	97.7	-	-	12,849	43.4	+ 3.6
	'77	12,775	44.5	117	5.4	419	68.6	-	-	13,311	42.3	
Rigid polyurethane	'76	13,770	50.2	360	19.2	7	2.3	-	-	14,137	47.7	+ 6.7
	'77	14,790	51.5	291	13.5	-	-	-	-	15,081	47.9	
Other foam plastics	'76	1,254	4.6	1,375	73.2	-	-	-	-	2,629	8.9	+ 16.8
	'77	1,128	3.9	1,750	81.1	192	31.4	-	-	3,070	9.8	
Total home sales	'76	27,437	100.0	1,878	100.0	300	100.0	-	-	29,615	100.0	+ 6.2
	'77	28,693	100.0	2,158	100.0	611	100.0	-	-	31,462	100.0	
Reported Total Sales in other EEC Markets for foam plastics	'76	12,692		147		34		39		12,912		+ 14.5
	'77	12,952		1,451		44		337		14,784		
Estimated sales distribution in EEC (based on home market distrib.)												
Flexible polyurethane	'76	18,155	13.8	154	0.14	326	2.70	n.a.		18,653	7.1	+ 2.9
	'77	18,541	14.7	196	0.18	449	3.30	n.a.		19,186	7.6	
Rigid polyurethane	'76	20,140	15.3	388	0.34	8	0.07	n.a.		20,536	7.8	+ 6.9
	'77	21,467	17.1	487	0.45	-	-			21,954	8.7	
Other foam plastics	'76	1,834	1.4	1,483	1.30	-	-	n.a.		3,317	1.3	+ 43.8
	'77	1,637	1.3	2,926	2.70	206	1.50	n.a.		4,769	1.9	
TOTAL SALES IN EEC FOR FOAM PLASTICS	'76	40,129	30.5	2,025	1.8	334	2.80	39	0.72	42,527	16.3	+ 8.7
	'77	41,645	33.1	3,609	3.4	655	4.80	337	6.10	46,246	18.3	
Total Sales in EEC for all uses	'76	131,402	100.0	112,617	100.0	12,142	100.0	5,425	100.0	261,586	100.0	— 3.6
	'77	125,760	100.0	107,226	100.0	13,738	100.0	5,569	100.0	252,293	100.0	

Source : CEFIC/EFCTC Data (abstracted from Table 2.5)
Further analysis by Metra.

6.1.3 Analysis of CFC Sales for Foam Plastics

The EEC fluorocarbon producers' data for 1976/77 home market sales of CFCs for foam plastics was allocated to three sectors: flexible polyurethane, rigid polyurethane and other foams, (Table 2.5). Sales for foams in other EEC markets could not be broken down, and in the sales distribution analysis presented in Table 2.6 the total sales for foams in the EEC were allocated in the same proportions as those of the home market sales. Relevant abstracts of the data from Tables 2.5 and 2.6 are presented in the accompanying Table 6.1.

It must be stressed that there is no direct information to support the estimated allocation of the total EEC sales, and since the non-home sales for foams represented over 30% of the total in both years, there could be a wide margin of error. Some corroboration of the estimate for rigid PU foams is provided by information from major raw materials suppliers that the total EEC production of rigid foam in 1977 was around 160,000 tons (exclusive of the CFC content). It is known that a good average figure for CFC usage is 135 tons per thousand tons of foam material, giving a total CFC requirement of 21,600 tons. This is in close agreement with the estimate of just under 22,000 tons F-11/12.

It has not yet been possible to obtain adequate supporting evidence for the estimate for flexible PU foam. Extrapolation of 1976 production data supplied by members of trade associations representing almost all the flexible PU block manufacturers in the EEC does not account for more than about 12,000 tons of our estimate of 18,000 tons. A substantial part of the gap may be attributable to in-house production, for example by car manufacturers, and to independent moulders, who are not affiliated to Europur.

Taking the CFC producer sales figures, the most notable features are:

a) the predominance of the polyurethane foams as CFC consumers, accounting for 91% of CFC foaming agent sales in home markets.

b) that F-11 is the principal CFC blowing agent, accounting for 90% of 1977 sales in this sector, which consumed 33% of all EEC sales of F-11 in that year.

c) F-12 figures mainly in the sales for non-urethane foams, and nearly 1,000 tons of F-113/114 were used as blowing agents in 1977.

d) Between 1976 and 1977 all three foam sectors showed significant growths and the overall increase was 8.7%. The CFC demand for rigid PU foams has overtaken that for flexible PU, and from this and other information it appears to be growing at a significantly faster rate.

The proportion of export sales outside the EEC associated with foam plastics is not known, but if it is the same as in EEC sales it would account for 16,200 tons of the exports in 1977.

6.2 Flexible Polyurethane Foams

6.2.1 Sources of Information

Our principal channel of general, commercial and technical information concerning the flexible polyurethane foam industry in the EEC was EUROPUR, the European Association of Flexible Polyurethane Foam Block Manufacturers, whose

Secretariat is based in Brussels: c/o Federation des Industries Chimiques de Belgique, Square Marie-Louise 49, 1040 Bruxelles.

National trade associations in seven EEC countries are affiliated to Europur, and it is claimed that the membership represents 100% of the flexible polyurethane manufacturing business in Belgium, France, West Germany, Italy, Netherlands and the United Kingdom, and a large proportion of that in Denmark.

In addition to discussions with the President and Principal Officers of Europur, the Association collected and collated economic and other data from its members on our behalf, and we gratefully acknowledge their help and cooperation.

A useful independent source of information was Rand Corporation's evaluation of data supplied by the EPA. (Reference 6.1)

6.2.2 Functions of CFCs in Flexible Polyurethane Manufacture.

Flexible polyurethanes are made by reacting polyether and polyester polyols with isocyanates, principally toluene di-isocyanate ('TDI') in the presence of water which reacts with some of the isocyanate generating carbon dioxide gas, and this acts as the primary blowing agent forming an open cell foam structure during the polymerisation process. The reaction with water is highly exothermic, and if the temperature is too high the polymer may scorch or burst into flames. Fire is a major risk in flexible foam production and on this account there is a limit to the amount of water which can be incorporated in the mix:

5 parts of water per 100 of polyol is the accepted limit, and some companies work to a maximum of 4.8%. The water reaction also promotes cross-linking of the polymer chains which hardens the foam, so the use of water alone sets limitations on density and flexibility.

Chlorofluorocarbons, mainly F-11, are used as secondary blowing agents to obtain low density foams, and to promote softness and flexibility. They are also used for safety reasons, it being normal to incorporate at least 2-3% CFC in the mix to cool and moderate the reaction.

The normal range of foam density is 14 to 52 kg/m^3. In practice the minimum density that can be made using water alone is 22 kg/m^3, and for lower densities a secondary blowing agent must be used. The principal commercial densities are 16, 22, 28 and 35 kg/m^3, and in the EEC it is likely that at least 35% of flexible foam is made using F-11 in concentrations ranging from 2 to 20%, and averaging around 8 to 9%.

A large proportion (over 70% in the USA) of flexible foam is made in the form of slab or bun stock by metering the reactants into a mixing head feeding onto a moving conveyor belt. As foaming proceeds the layer rises to a certain height and sets. It is then cut into slabs and conveyed into storage. The foaming and setting sections must be well ventilated to prevent escape of highly toxic isocyanate vapour into the working area; the limit is 0.02 parts per million. The storage region is also ventilated and foam is typically stored for at least 18,and preferably 24 hours to allow the mechanical properties to stabilise and residual toxic vapours to escape. After this the foam is ready for 'conversion', i.e. for cutting into the required shapes and incorporation into the ultimate products.

In moulded flexible foam production the reactants are dispensed into moulds and the foam allowed to rise and cure for a period. After removal from the moulds there is a further curing period, and the shape may be finished by flexing or compression to open any remaining closed cells and release residual vapours. This process must also be conducted under well ventilated conditions.

In both processes virtually all the CFC blowing agent is irreversibly released into the air within a day or so of the foam being produced. The CFC functions solely as an adjunct of the manufacturing process: it is not a component of the final product as in aerosols or rigid foams; it is not a re-circulating working fluid as in refrigeration; and it is not even partially re-cycled as in solvent cleaning.

The preference for F-11 as a secondary blowing agent for flexible foams, despite its relatively high cost, is mainly due to the following properties:

a) suitable boiling point (23.8^{o}C) and vapour pressure characteristics

b) non-inflammability: an essential property because of the exothermic process and fire risk.

c) low toxicity, with minimal danger due to release into working areas

d) chemically inert and compatible with the polymer

e) promotes good mechanical characteristics

f) relatively rapid rate of diffusion out of the foam after production.

6.2.3 Potentialities for Eliminating or Reducing CFC Emission in Flexible Foam Production.

6.2.3.1 Alternative Fluorocarbon Blowing Agents

No alternative fluorocarbon to F-11 is commercially available which combines suitable blowing agent characteristics with a relatively low tropospheric lifetime, and no prospect is seen of one emerging for some years, if at all.

6.2.3.2 Methylene Chloride

To date the only agent found to be a reasonably practicable alternative to F-11 is methylene chloride, b.pt. 41.1°C. Its main drawbacks relative to F-11 are:

a) Higher toxicity. In different countries the Threshold Limit Value varies from 100 to 500 p.p.m. and is typically 200 p.p.m., c.f. 1000 p.p.m. for F-11. Experiments have shown that in practice it is difficult to avoid developing concentrations in these ranges in the vicinity of production and storage areas. Methylene chloride has been suspected of mutagenetic activity and long term tests have recently been completed under the sponsorship of Dow and other producers. A formal report will be available shortly and it is understood that the outcome is likely to be encouraging.

b) Less suitable than F-11 for producing soft, lightweight foams.

c) Slower diffusion rate out of the foam, so that longer initial storage times are needed in conjunction with better ventilation in production and storage areas.

Methylene chloride is used to some extent in the United States and Japan, but industry representatives advised that it could prove very difficult to secure acceptance by operatives in Europe because of the odour and toxicity.

6.2.3.3 Vacuum Blowing

This is an attractive possibility because it could yield low density foams at lower materials cost since no secondary blowing agent would be needed. It has been the subject of much research, especially for moulded products, but the cost for slab production is considered prohibitive.

6.2.3.4 Re-formulation

There has already been some progress in re-formulation which may have reduced CFC usage by 5% or so, and there is a prospect of developing polyols which would produce the requisite softness and flexibility at higher densities, thus dispensing with the necessity for secondary foaming agents. The higher density would result in material cost increases of 25% or more for applications where low density foam is currently used.

6.2.3.5 CFC Recovery or Destruction

Considerable attention has already been paid to the possibility of recovering the CFC emitted during foam production and storage by passing the ventilating air through some type of absorption or condensation system. The most favoured approach has been that of absorption by activated carbon, but formidable snags are encountered:

a) to raise the CFC concentration to levels at which recovery becomes feasible it is necessary to reduce ventilating air volumes to a fraction of the present norms, which is difficult to combine with the need to meet the maximum isocyanate level in the working area of 0.02 p.p.m. It also reduces the cooling capacity of the system.

b) unless extra stages are added to obtain a pre-separation, the carbon will absorb water, isocyanate and other vapours, and this complicates subsequent recovery of the CFC and re-activation of the carbon.

The critical review by Rand of available information (Reference 6.1) disclosed no convincing estimates or practical demonstrations of the economic viability or technical feasibility of CFC recovery processes, and indicated that much more research would be needed, especially on the distribution of fluorocarbon emission concentrations in flexible foam plants, before the possibility of recovery could be assessed. From our own reading of the information and discussions with representatives of the industry in the EEC, we are very sceptical about a successful outcome to this approach to the problem because:

(i) a major research and development project would be required, probably over a period of 3 to 5 years, to develop and prove a reliable system, and there is a distinct possibility that the effort might not be successful.

(ii) heavy capital outlay would be involved. A major foam producer in the EEC has estimated that the cost could be at least UCE 300,000 per installation.

(iii) long shut-downs would be entailed during conversion.

(iv) from technical considerations it is unlikely that a recovery process would capture more than a fraction of the CFC emitted (estimates cited by Rand range from 50 to 80%), so recovery would not provide a complete answer.

It may be that the development work entailed will be undertaken in the United States, but it seems unlikely that the industry in the EEC would be prepared to make the commitment required.

An alternative to recovery is to destroy the CFC before release into the environment, for example by some form of incineration to convert it into simple acid gases which could be absorbed in water and neutralised. As in recovery, the main problem is the low concentration of CFC in the ventilating air, and this also appears an unpromising approach.

6.2.3.6 Improved Material Utilisation

Processes which reduce the curvature and maximise the height of the slab stock reduce the material wastage on cutting into blocks and hence reduce CFC consumption for a given output. Various methods are available including the 'Draka' process which provides for the width variation needed by custom foamers, and the Swiss 'Maxfoam' process which is particularly useful where a constant width slab is satisfactory, as is often the case with in-house producers. This process is gaining ground in the U.S. where more converters are installing their own foaming plant, and materials savings of up to 10% per kilogram of finished product are claimed.

6.2.4 Industry Structure in the EEC

There are four layers of activity in the manufacture and utilisation of flexible polyurethane foam:

(1)	Raw materials production	- principally the polyols, isocyanates and CFC blowing agents
(2)	Foam production	- slab stock and mouldings
(3)	Conversion	- preparation of finished shapes by cutting and moulding
(4)	Utilisation	- incorporation of foam shapes into the final products.

Varying degrees of vertical integration obtain in foam production, conversion and utilisation. Raw materials production is a separate activity - although raw materials manufacturers may have subsidiaries engaged in foam production.

Raw Materials Manufacture

The main polyol producers are major international chemical companies, including Bayer, Dow, ICI, Kuhlmann, Lankro, Montedison and Union Carbide, and these companies together with Du Pont also make isocyanates. As in the CFC industry, the polyol and isocyanate producers are very active in research directed towards product and process improvement and new application development, and they provide extensive technical service and advice facilities.

TABLE 6.2 : NATIONAL TRADE ASSOCIATIONS REPRESENTING FLEXIBLE POLYURETHANE PRODUCERS IN THE EEC.

Country	Trade Association	No. of member companies
Belgium	Federation des Industries Chimiques de Belgique (Brussels)	3
Denmark	Sveriges Plastförbund (Stockholm)	4
France	'GIPCEL' - Groupement des Industries de Polyurethanes Cellulaires Francaises (Paris)	4
West Germany	Schaumstoffbüro (Frankfurt/Main)	15
Italy	'APPE' - Associazione Produttori Poliuretani Espansi (Milan) 'CODIMA POLIURETANI' Consorzio Divulgazione Marchio di Qualita Poliuretani Espansi (Milan)	12)) 16 4)
Netherlands	Nederlandse Vereniging van Rubberfabrikanten ('s Gravenhage)	5
United Kingdom	'BRMA' - British Rubber Manufacturers Association Limited (London)	8
	Source : Europur	55

Foam Production

There are 55 companies (including subsidiaries) affiliated through their national trade associations to Europur, and representing all custom slab stock foam production in the countries concerned but not all in-house flexible foam production. The distribution is shown in Table 6.2. It is not thought useful to list the individual companies, but it is believed that about 70% of the European market is held by three multi-national groups of companies, in order of ranking:

PRB/Recticel (Parent Company: Generale de Belgique S.A., Belgium)

Dunlop (U.K.) - including Pirelli companies.

Metzeler (Parent Company: Bayer A.G., W. Germany).

Conversion and Utilisation

Some custom foamers also have conversion and utilisation operations, for example Dunlop market slab stock foam but also convert and make a range of bedding and other flexible foam based products. There are numerous custom converters, including some very small firms, and at the other end of the scale there are large companies such as Opel and Volkswagen which carry out all the operations from primary foam production to finished product, and work entirely on an in-house basis.

After the custom foamers there cannot be said to be a coherent flexible foam industry because the primary foam becomes a raw material for a wide range of industries.

TABLE 6.3 : EEC FLEXIBLE POLYURETHANE FOAM BLOCK INDUSTRY STATISTICS

	Belgium	Denmark	France	West Germany	Italy	Nether-lands	U.K.	TOTAL (for seven countries E=estimat
Flexible PU Foam Production in 1976.								
1. Output - all grades thousand tons	25.4	15.0	36.8	81.3	34.5	27.1	51.2	271.5
2. Value in national currency. millions	1571	n.a.	345	401	n.a.	120	n.a.	
3. Value in UCE at June 1978 inter-conversion rates. millions	39	-	61	156	-	44	-	476(E)
4. Average value. UCE/ton	1530	-	1660	1920	-	1620	-	
5. Growth rates:								
a) actual 71/76. %p.a.	0.6	n.a.	2.9	2.6	n.a.	1.5	n.a.	
b) forecast 77/82.%p.a.	3	n.a.	n.a.	1 to 3	n.a.	2	5	3 (E) (weighted average)
6. Value of raw materials including CFCs used in production								
a) In national currency millions	1026	n.a.	n.a.	n.a.	n.a.	84.1	29.7	
b) In UCE at June '78 rates. millions	25.5					30.4	44.2	
c) UCE/ton. millions	1000					1120	863	
7. Proportion of quantity or value of output for which CFC blowing agents used %	57% of quantity	n.a.	75% (one company making 50% national output)	34.5% of quantity	n.a.	45% of value	30% of quantity	
8. Actual quantity of CFCs used. tons	805	350	1250 (for 50% nat. production	2440	n.a.	800	1940	12,000(E) max.
9. Average CFC usage for CFC blown foams. tons CFC per 100 tons foam	5.6	-	9.1	8.7	-	-	12.6	
10. Fraction of ex plant production cost of CFC blown foams represented by cost of CFC blowing agents.	1.70%	n.a.	n.a.	n.a.	n.a.	5.30%	2.74%	
11. Employment in foam production	1175	n.a.	n.a.	4738	n.a.	800	1981	12,800(
12. End use distribution - all grades								
a) Furniture	70%						55%	
b) Automotive	10%						30%	
c) Bedding	10%						8%	
d) Other (packaging, textiles, etc.)	10%						7%	

Source : Data supplied by EUROPUR.
Additional calculations and estimates by Metra.

6.2.5 Industry Statistics

6.2.5.1 Source and Presentation

The economic, employment and other statistics collected on our behalf by the Europur Secretariat are presented in Table 6.3. There are a number of gaps, especially in the data for Denmark and Italy, and some of the EEC totals have been obtained by extrapolation and estimation.

6.2.5.2 Production and Value

The reported foam block production in 1976 totalled 271,500 tons, representing an average output of about 4500 tons per plant. Applying June 1978 UCE conversion rates to the values quoted in national currencies gives an estimated total value for this production of UCE 476 million.

6.2.5.3 Growth

The estimates provided by producers in four countries indicate an average growth rate of 3% annually from 1977 to 1982.

6.2.5.4 Employment

Simple extrapolation from the figures from four countries indicates a total of 12,800 employees in the flexible foam production plants of the reporting companies. The figures must be treated with reserve because in some cases personnel engaged in conversion at the primary foam factories have been included, and this would account for the variations in productivity - from 30 employees per 1000 tons foam in the Netherlands to 58 in Germany. The statistics take no account of many thousands of people engaged in converting plants not owned by the foam producers, or of employees in the polyol and isocyanate raw materials sectors.

6.2.5.5 CFC usage and costs

There is a wide variation in the proportion of foam made using CFC blowing agents, from 30% for the U.K. to 75% for a company representing half the flexible foam production in France. In the four countries for which it is possible to calculate the average CFC usage per 100 tons of CFC blown foam, this varies from 5.6 t. in Belgium to 12.6 in the U.K. Because of these variations it is impracticable to estimate the total CFC consumption by extrapolation. Assuming the higher ends of the ranges for the non-reporting countries the maximum CFC consumption would be 12,000 tons p.a., and, as pointed out in Section 6.1.3, this is far short of the estimated EEC usage of 18,000 tons for all types of flexible polyurethane foam.

The figures cited for the fraction of CFC blown foam production cost represented by the cost of the CFC are 1.7% for Belgium, 2.74% for the U.K. and 5.3% in the Netherlands. If raw materials represent 70 to 80% of production costs the figures for Belgium and the UK appear rather low in relation to the price of F-11 and the amounts used, and we would have expected the fractions to be closer to 2.5% and 5% respectively.

6.2.5.6 Applications

Only two of the seven countries, Belgium and the U.K., provided end-use distribution figures, but there is no doubt that throughout the EEC the principal uses of flexible polyurethane foam are in furniture, automotive and other transport upholstery.

In the furniture industry flexible foam is now the primary upholstery material and has largely replaced traditional materials such as flock and latex. In the automotive industry flexible foam is used for seating and squabs to the extent of about 95%, with a small amount of rubber latex being used in the highest price market sector.

Bedding is the next main outlet and market penetration is more variable. In the U.K. it has not reached 50% whereas it is up to 80% in Continental Europe.

Other uses cover a wide range including clothing and footwear laminates, floor covering underlay, thermal and acoustic insulation, sponges, and packaging.

It is fair to say that the availability of flexible polyurethane foam and the ease with which it can be shaped have revolutionised manufacturing techniques in furniture and transport upholstery: it is not a case of one material superseding others by simple replacement.

6.2.6 Consequences of CFC Restrictions

6.2.6.1 Options for Foam Producers

With established technology, since vacuum blowing and CFC recovery are not yet viable propositions, flexible polyurethane foam producers would have the following options if faced with restrictions on the use or release of CFC blowing agents:

(a) to cease foam production altogether

(b) to move the operation to a non-restricted location

(c) complete or partial substitution of CFCs with a non-CFC blowing agent - methylene chloride being the only established alternative.

(d) to cease manufacture of foams with a density of less than 22 kg/m^3.

Course (a) could be dictated by the economics of the situation and does not need discussion. Course (b) might be practicable given certain conditions, but it is not normally economic to transport raw flexible foam over long distances and it would be difficult to assume that a new location would remain free from restrictions.

Course (c), the use of a non-CFC blowing agent, depends almost entirely on the acceptability of methylene chloride since this is the only known potential substitute. Though it has some technical limitations, most of the foam quality and density requirements could probably be met after a period of experimentation,and the fundamental question is whether the applicable safety standards could be met and working conditions acceptable to operatives provided. Existing ventilation facilities would generally have to be improved, and larger storage space provided because of the longer residence time of methylene chloride in the foam. Hence, operating costs would be higher, capital costs would be incurred in plant modification and there would be loss of revenue during the shutdown entailed.

The simplest option, Course (d), is to cease making the lower density foams. Pending some convincing evidence that (c) is feasible, (d) is probably the only approach that the industry in the EEC could adopt, and it would then have to face the economic consequences of any reduction in demand due to higher density foams being unacceptable as substitutes for low density grades on grounds of quality or cost.

The ultimate outcome would probably be some plant closures to restore the capacity/demand balance.

6.2.6.2 Action by Raw Materials Suppliers

The possibility of a reduction in demand for polyols has already stimulated research on formulations which would enable the desirable mechanical qualities of lightweight foams to be obtained at higher densities. Success cannot be assured and development might take some years.

Because of their large stake in the flexible foam business the chemical companies might go further and collaborate with the foamers in developing safer ways of using methylene chloride and new foaming techniques.

6.2.6.3 Implications for Flexible Foam Converters and Users.

If users of, say, 16 kg/m^3 density foam changed to 20-22 kg/m^3 density grade they would be faced with a material cost increase of perhaps 30%, and for many applications the mechanical properties of the denser foam would be unsatisfactory or even unacceptable.

Pending any solutions to the problems by the polyol suppliers and foamers, the users would have to consider:

a) absorbing the extra cost of higher density foam or raising product prices

b) 'designing out' some of the foam content of the product

c) using alternative materials

d) switching to alternative construction systems, e.g. webbing and springs for seating.

The data in Table 6.3 indicates that upwards of 40% of flexible polyurethane foam in the EEC is made with CFC blowing agents, and since 90% or so of consumption is in furniture and automotive upholstery and in bedding, the impact on these major industry sectors would be considerable.

It is not possible to predict what mix of the four approaches listed above would ensue, but an order of magnitude can be assigned to the financial penalty of using higher density foam. The value of the CFC blown foam made by Europur af affiliated producers in 1976 was approximately UCE 240 million. If this could be substituted by foam of the minimum density producible without CFCs the total cost increase to users would be of the order of UCE 80 million.

To switch to alternative materials and systems would mean radical changes in manufacturing methods and extensive redeployment of labour. The overall demand for labour would not necessarily change - it might well increase - but local unemployment would occur, in the foam conversion sector for example, where labour could not be fully redeployed to processes requiring different trades and skills.

The net result would be higher product costs and prices, and unless circumstances were such that restrictions on CFC blowing agents were introduced simultaneously throughout the EEC and in the non-EEC countries making similar products, significant inequalities in competitiveness would be generated.

6.2.7 Regulation

Should it be decided on scientific evidence that CFC regulation is necessary to the maximum practicable extent, restrictions on the use of CFC blowing agents for flexible polyurethane foams might be considered on the grounds that

- the CFC blowing agent is not a component of the final product and is all released into the atmosphere during manufacture of the foam

- over half the demand for flexible foam can be met without using CFCs as a secondary blowing agent

- to some extent higher density foams can be substituted for CFC blown foams, and the proportion can probably be somewhat increased by advances in polyol development

- notwithstanding the disadvantages and difficulties, CFC blown foams can be replaced with other materials and systems, including those used in upholstery and bedding before the advent of flexible polyurethane foam.

Given a decision in principle that reduction of CFC emission is necessary, and recognising that there is a prima facie case for considering regulation of this application of CFCs, we would advocate postponing a decision pending further study because

- this source of prompt CFC emission represents less than 8% of CFC sales in the EEC and is expected to grow relatively slowly, at a rate of about 3% annually

- early restrictions on the production of low density flexible polyurethane foam would add significantly to costs and necessitate radical changes in manufacturing methods in the furniture, automotive and bedding industries, with concomitant re-deployment of labour

- there are prospects that over the next five years technology could be developed which would solve or alleviate the problems of dispensing with the existing CFC blowing agents

- to avoid placing the industry sectors concerned in the EEC or any member states at a serious competitive disadvantage, it is desirable that any regulatory action on this application should be implemented according to a common time-scale throughout the Community, and in countries with similar industries.

6.2.8 Future Action

It was accepted that no regulatory scenarios should be examined in relation to the use of CFCs as blowing agents for flexible polyurethane foams. If it is ultimately decided that the possibilities for reducing CFC emission from this source should be further investigated we would recommend:

a) research to settle the question whether methylene chloride is a practicable alternative to CFC blowing agents for flexible foam manufacture in the EEC

b) further exploration of other possibilities, such as vacuum blowing, for making low density foam without using the existing CFC foaming agents

c) continuing the search for polyols which would improve the mechanical properties of foams made without secondary blowing agents

d) cooperative research on (a) and (b) by the chemical and flexible polyurethane foam industries

e) coordination of research in the EEC with that proceeding in the United States and elsewhere.

6.3 Rigid Polyurethane Foam

6.3.1 Sources of Information

There is no European trade federation for the rigid polyurethane foam industry corresponding to Europur for the flexible slabstock producers, and there are only three national associations catering specifically for the interests of the rigid foam sector:

BRUFMA - British Rigid Urethane Foam Manufacturers Association - Manchester, England.

GIPCEL - Groupement des Industries de Polyurethanes Cellulaires Francaises - Paris, France.

IVPU - Industrieverband Polyurethan-Hartschaum e.V. - Stuttgart, W. Germany.

Our principal sources of information on the industry in the EEC were BRUFMA and major manufacturers of the raw materials. The Rand review (Reference 6.1) and the EPA public hearings (Reference 6.3) were again useful independent sources.

6.3.2 Functions of CFCs in Rigid Polyurethane Foam Production and Applications.

Rigid polyurethane foams are also made by the exothermic reaction of polyols with organic isocyanates while simultaneously generating gas bubbles to form a foam, but the components of the system are such that the mass sets to a solid matrix of closed cells in which the foaming agent gas is entrapped. The polyols are mainly low viscosity polyethers and the principal isocyanate is diphenylmethane diisocyanate (MDI). There are two main types: PUR foam, based on polyisocyanates, and PIR foam, based on polyisocyanurates, but it is not necessary to discuss their chemistry in detail.

For many applications the foams are made by mixing two liquids: one being the isocyanate and the other a blend of polyols, blowing agents, catalysts and other special ingredients such as surfactants. 'Ready-to-use' systems are supplied to a much greater extent for rigid foams than for flexible foams, there being far more in situ applications as opposed to bulk production followed by conversion.

In contrast to flexible foam, where carbon dioxide generated by the interaction of isocyanate with water is the principal blowing agent, for most rigid foams CFCs are the main blowing agents, supplemented by minor amounts of carbon dioxide arising from residual water in the system or relatively small additions.

Rigid foams are made in a variety of forms including:

Large blocks, for cutting into shapes.

Pre-fabricated laminates and panels, where the adhesive properties of the foam during formation are used to provide a variety of integral bonded products, such as sandwich type panels with foam cores and facings of steel, asbestos, plaster board, etc.

Mouldings, especially where a combination of high flexural strength and low weight is desirable, as in furniture and automotive components.

Spray coatings, to provide insulation for tanks, pipes, roofs, etc.

Cavity injection - foam can be injected into wall cavities to provide insulation, and into spaces formed by metal skins to provide insulation and structural strength, as in refrigerator cabinets and doors.

A range of densities and hardnesses is possible, and the structural products can be given smooth skin decorative finishes.

F-11 is the principal CFC blowing agent, but a little F-12 may be added to promote rapid frothing of the mix; this can be of advantage in filling refrigerator and freezer panels with very low density fine cellular structure foam, and the higher foam viscosity minimises leakage at joints and seams.

In addition to acting as a particularly effective blowing agent for producing the required types of cell structure, F-11 has the following advantages and special features:

a) Low thermal conductivity, coupled with slow permeation through the polymer cell walls. This combination provides the excellent thermal insulation characteristics which are the most important attribute of rigid polyurethane foam.

b) Low viscosity, which facilitates flow and penetration into cavities.

c) Suitable boiling point (23.8%). F-11 is readily volatilised by the heat of the isocyanate-polyol reaction, but the boiling point is high enough to permit blends with polyols and other ingredients to be stored and transported safely in drums.

d) Safety features: non-flammable, low toxicity, non-corrosive.

e) High chemical stability and inertness towards the polymer and precursor materials. F-11 consumes no isocyanate, in contrast to water which requires approximately 14 times its weight of MDI to produce carbon dioxide.

6.3.3 Importance of F-11 as a Component of Rigid Polyurethane Foam Insulation.

CFCs have the lowest thermal conductivity of any known substances capable of being used as blowing agents for closed cell foams,and the distinctive properties of F-11 in this respect need further explanation.

The thermal conductivity or 'k' value of rigid polyurethane foams depends on a number of factors including the size distribution of the closed cells, but the most important is the composition of the gas in the cells, and some relevant k values are listed in Table 6.4.

TABLE 6.4 : THERMAL CONDUCTIVITY OF RIGID POLYURETHANE FOAMS AND CELL GASES

	Thermal Conductivity W/mK at room temperature
Air	0.024
Carbon dioxide	0.015
F-11	0.008
Rigid polyurethane foam - freshly made	0.016
Rigid polyurethane foam - aged in contact with air	0.023

When first made the cells contain F-11 gas with perhaps a small percentage of carbon dioxide. The urethane polymer is very permeable to carbon dioxide, less so to air, and almost impermeable to F-11 at low and moderate temperatures. Thus, if the foam is exposed to the atmosphere any carbon dioxide is rapidly lost and air diffuses into the cells until its partial pressure in the cells approaches atmospheric pressure. At ordinary temperatures this process may take months or years depending on the foam dimensions, and as little F-11 is lost the foam stabilises at an internal cell pressure well above atmospheric. When formed in a closed space with virtually impermeable walls, as in a refrigerator, there is little opportunity for air to enter and the initial composition of the cell gas - predominantly F-11 - remains unchanged indefinitely.

The effect on thermal conductivity is that the k value of 0.016 W/mK for freshly made foam gradually rises to an equilibrium value of 0.023 when there is ready access of air and changes very slowly thereafter, while for foams enclosed by impermeable walls the k value remains at about 0.016. If a foam is blown with carbon dioxide the initial k value is about 0.022, but exposed to the atmosphere it rises rapidly to 0.035 when all the carbon dioxide has been replaced by air.

A number of other foamed plastics have k values of 0.035 W/mK and closed cell polyurethane foams blown with F-11 are unique in having aged equilibrium k values of 0.023 or less. In consequence, at least 50% greater thickness of other expanded plastics is required to obtain the same insulating effect as aged rigid polyurethane foam, and even greater thicknesses if the comparison is under conditions where access of air to the foam is prevented. Table 6.5 shows a comparison with four insulating materials under comparable conditions.

TABLE 6.5 : EQUIVALENT MATERIAL THICKNESSES FOR SAME DEGREE OF INSULATION (DRY CONDITIONS)

Material	Thickness mm
Rigid polyurethane foam	25
Polystyrene foam	40
Mineral Wool	45
Cork	50
Fibreboard	65

Source: I.C.I. technical leaflet.

In making such comparisons it must be borne in mind that the useful working temperature range of rigid polyurethane foam is from cryogenic temperatures up to about 90°C.

6.3.4 CFC Emission from Rigid Polyurethane Foam

With open cell flexible polyurethane the CFC emission characteristics did not require special discussion in the context of regulation, because virtually all the CFC blowing agent used can be presumed to have been released into the atmosphere within days of manufacture of the foam. Entirely different considerations apply to CFC blown closed cell rigid polyurethane, where F-11 is an essential component of the foam when it is used for thermal insulation, and may remain in the cells throughout the working life of the material or even beyond that span.

During the life history of rigid foam, CFC release to the atmosphere may occur at the following steps and stages:

- Blending of ingredients; handling and storage of blends prior to use

- Initial production of foam, when the raw materials are mixed, followed by foaming and setting

- Processing of the rigid foam: CFC is lost from cells which are opened to the air when foam slabstock is converted by cutting and machining

- Diffusion through cell walls or any open cell networks during the life of the foam

- Damage to foam during life

- Final disposal.

Essentially, these emissions can be grouped into three stages:

a) Emissions during production operations
b) Emissions during the life of the product
c) Emissions associated with disposal.

The magnitude of the release at each stage depends on a number of factors including the nature of the production process, and the type of application. The loss associated with conversion of boardstock does not occur with cavity injection, and there is less opportunity for CFC release from foam enclosed between steel walls than from foam exposed to the air throughout its life - especially at elevated temperature.

Data cited and critically reviewed by Rand (Reference 6.1) suggests that losses in the manufacturing stages mostly range from 2.5 to 20% of the CFC used and that 10% may be a reasonable average, but that in respect of the 90% or so of the

CFC entrapped in the foam in the final product it is impossible to generalise about what happens and at what rate.

Quantitative information on these questions could have an important bearing on how this CFC application is ultimately regarded and treated from the standpoint of regulation. If most of the CFC so used finds its way into the atmosphere in the course of 20 years or so it may be argued that, in the long term, the magnitude of the annual emissions from the 'bank' of installed rigid foam plus scrappage will approach the annual amount being locked into new foam. On the other hand, it may be possible to show that with appropriate disposal procedures the majority of the CFC is either permanently trapped or destroyed.

It is clear that much more research is needed on the occurrence and means of reducing CFC emission from rigid polyurethane foams before a satisfactory assessment can be made as to the most appropriate mode of regulation of this source of CFC release.

6.3.5 CFC Substitution Possibilities

No alternatives to fluorocarbons are known which would yield rigid polyurethane foam of equivalent and stable insulating performance to that obtainable with F-11/12 blowing agents, and at the present time no fully proven fluorocarbon alternatives to the fully halogenated CFCs are available. Since the low 'k' value of rigid foam is one of its most valuable characteristics there is as yet no adequate substitute for CFC blowing agents where thermal insulation is the main end use. If this particular advantage is removed then rigid polyurethane foam could only compete with other insulating materials on grounds such as ease of application and mechanical properties, but in most cases the higher cost per unit

TABLE 6.6 : RIGID POLYURETHANE FOAM PRODUCTION AND APPLICATION IN EEC COUNTRIES : 1975-1977

Units: Thousands of metric tons of foam, excluding the CFC content.

	Application					Total	Total
1977 Data from Source 'A' :	Transport insulation	Building Construction	Technical insulation	Domestic appliances	Other	Source 'A'	Source 'B' (See Note 1)
Belgium/Luxembourg	0.2	7.0	0.6	0.2	0.4	8.4	9.0
Denmark	0.1	0.9	1.9	3.0	0.1	6.0	5.0
France	2.0	12.5	0.2	5.6	1.8	22.1	24.0
West Germany	2.5	20.5	1.9	12.0	2.5	39.4	54.0
Ireland	-	0.04	0.02	0.6	-	0.66	-
Italy	3.2	11.8	1.6	28.0	1.0	45.6	37.0
Netherlands	0.5	7.7	0.6	0.8	0.2	9.8	10.0
United Kingdom	2.8	8.0	0.9	7.0	1.5	20.2	21.0
Totals of above data	11.3	68.4	7.7	57.2	7.5	152.2	160.0
Distribution - %	7.4	44.9	5.1	37.6	4.9	100.0	-
1977 totals used by Source 'A' for comparison with previous years	11.0	69.0	7.7	56.0	8.0	151.7	
1976 EEC Totals	10.0	59.0	7.0	52.0	8.0	136.0	
1975 EEC Totals	6.5	42.0	5.5	43.0	8.2	105.2	

Sources: Two major EEC manufacturers of raw materials for rigid polyurethane foam.

Note (1): Source 'B' estimated the 1977 application distribution of total EEC production to be Transport 6%, Construction 44%, Refrigeration 31%, Furniture 6%, Other 13%.

insulating effect would preclude its use.

Where the application is entirely or very largely structural the use of other blowing agents is feasible in principle, but practical experience mainly relates to carbon dioxide generated by incorporating water in the polyol blend and adding extra isocyanate. In the EEC the non-insulation applications probably account for less than 10% of total production (Table 6.6).

6.3.6 Industry Structure and Statistics

The manufacturers of raw materials and the packaged systems suppliers are principally the same major chemical companies that supply polyols and isocyanates for flexible polyurethane foam (Section 6.2.4) but the production side is much more segmented. The production of slabs, boards, etc. for conversion is a much smaller sector than the equivalent slabstock production in the flexible foam industry, and there are numerous producers of various types of prefabricated panels, insulation contractors, moulders and in-house users. Consequently there is no coherent industry structure and this is reflected by the smaller number of national trade associations and the absence of a European federation. A large proportion of users belong only to trade associations relating to their main activity, such as building construction, refrigeration and furniture manufacture.

In the absence of representative trade associations it is difficult to obtain statistics on numbers of producers and users, and on employment and its geographical distribution, and Rand reports similar gaps in details of the rigid foam industry in the United States.

The principal sources of data are the raw material suppliers and Table 6.6 shows estimates from two sources of rigid polyurethane production and end-use for the individual EEC countries in 1977, with comparisons of total EEC production and application for 1975 and 1976.

One source gives a more detailed analysis of application than the other, but except for discrepancies in the production figures for Italy and West Germany the totals and overall distributions are in fair accord, and indicate total production in 1977 to have been between 152 and 160 thousand tons. Supplementary advice suggests that the higher figure is more probable.

Different end-use categories make detailed comparison difficult, but both sources indicate that building construction accounts for about 45% of consumption, and it seems likely that all types of refrigeration together account for at least 30%.

In the United Kingdom the value of the raw materials is estimated to be about UCE 1000 per ton of foam. Somewhat higher prices obtain in Continental EEC countries where the average may be in the range UCE 1100 to 1200 per ton. The total value of the raw materials used in the EEC is assessed at about UCE 182 million, of which the input CFC cost might represent about 6.5%.

It is believed that rigid foam production in the EEC represents about a third of the world total and, according to the principal source of data for Table 6.6, production in the EEC grew from 105,000 tons in 1975 to nearly 152,000 in 1977, an increase of 44%. From 1976 to 1977 the growth was 11.5% although Table 6.1 shows that CFC sales for rigid polyurethane foam in the EEC grew by less than 7% in that period. In the absence of restrictions an overall growth rate of at least 8% p.a. seems probable within the EEC over the next five years.

6.3.7 Impact of CFC Restrictions

6.3.7.1 Sensitivity of Demand to CFC Price

If a ban were to be placed on the use of CFCs in most aerosols while leaving the main non-aerosol applications unregulated the prices of CFCs would be likely to rise, as discussed in Section 3.8.3, and this would increase the cost of the raw material for making all the CFC blown rigid polyurethane foam.

Taking the average CFC prices assumed in Section 3.6 et seq. and an average CFC usage of 135 tons per 1000 tons of other raw materials, the primary input cost of the CFC blowing agent represents about 6.5% of the total raw material value, and the average cost of making CFC blown foam would therefore rise by at least this percentage if the CFC price were to double.

If calculated simply in terms of cost per unit of insulating effect the cost of rigid polyurethane foam is similar to,or even higher than that of alternative insulating materials. The economic advantage of the urethane foam is associated with the combination of insulating performance with one or more of its other characteristics and benefits such as ease of application, adhesion to surfaces and structural strength. This is particularly the case in refrigerator cabinets where the advent of urethane foam insulation has made it possible to obtain a much larger useful internal volume for given exterior dimensions because of the smaller wall thickness needed. In addition, thinner gauge steel skins can be used because of the structural strength of the steel/foam sandwich, and the injection filling technique simplifies design and manufacture. Thus these 'plus factors' on the value of rigid foam for insulation vary with the application. Where they are relatively small as in, say, moulded section insulation, a price rise of a few percent would begin to erode the market, but in applications where the urethane foam insulation is also an integral component of the structure it seems likely that a substantial rise in the cost of the CFC blowing agent would be tolerated provided that the increase applied equally throughout competitive manufacturing areas.

6.3.7.2 Effect of a Ban on CFC Blowing Agents

Since there is no alternative non-CFC blowing agent availalbe which would provide the low thermal conductivity obtainable with the CFC agents, a ban on this application of CFCs would result in discontinuation of the use of rigid polyurethane foam in all the applications where the superior insulation performance is an essential component of the overall combination of properties, and perhaps in some purely structural applications where the use of carbon dioxide or other foaming process does not yield mechanical properties equivalent to those obtained using CFCs. It is difficult to estimate exactly what this percentage would be in practice; it would certainly be a very high proportion of the insulation applications although there could be a few instances in which the other properties of rigid urethane foam would make it the preferred material despite the lower insulation performance.

The resultant consequences would include:

a) Loss of perhaps 90% of the chemical industry's present EEC sales of raw materials for rigid polyurethane foam production, currently amounting to over UCE 180 million annually. This would be likely to dictate a number of plant closures, although in the course of time the gap might be filled by growth in demand for furniture and other structural applications.

b) Loss of most of the market for slab and board stock and pre-fabricated panels, mouldings, etc.

c) Loss of an important insulating-structural material to the building industry. Since there is no equivalent this would impose design restrictions and tend to reduce energy saving performance because of the limitations attaching to other insulating materials.

d) For cavity insulation in buildings the alternative materials would have less insulation power, so in this application poorer energy saving performance would be inevitable.

e) Existing cabinet designs for refrigerators and freezers would have to be scrapped and replaced with models with lower ratios of useful to total volume and of useful volume to weight. Costs per unit of capacity would increase.

f) Loss of a high performance insulating material to the automotive and transport industries and for general purpose insulation of tanks, piping, chemical plant vessels etc. Equivalent insulation performance would entail greater thicknesses of material and consequent dimensional and weight penalties. The compromises inevitable in some applications would increase energy losses.

g) Loss of export markets, especially for refrigerators and freezers, in countries not imposing equivalent CFC regulations, or able to import from such countries.

Unless banned or inhibited by restrictions, there could also be increased importation of rigid foam containing products from those areas.

h) Increased demand for alternative insulating materials and combinations of structural and insulating materials. This would offset some of the economic losses attaching to (a) and (b), and the associated losses of jobs and job opportunities.

6.3.8 Regulation

CFC blown rigid polyurethane foam is not indispensable to our society because there are other insulating and constructional materials which can be used to similar though not always equal effect.

However, in the context of the guiding principles discussed in Section 1.5, we did not think it sensible to propose evaluation of a regulatory scenario for this CFC application at the present time because

- CFC blown rigid polyurethane foam is a valuable and unique insulating material: no other material provides the same combination of qualities, and the CFC content of the closed cells is essential to the insulation performance.

- if this type of foam insulation could not be made the refrigeration industry would suffer substantial disturbance, economic penalties and technical disadvantages, and the building construction and some other major industries would be deprived of an important material and a design dimension.

- rigid polyurethane foam plays an increasingly significant role in energy conservation which cannot be fulfilled to the same extent by other insulating materials.

- most of the CFC blowing agent used remains trapped in the foam for a long period,and CFC release from this source is unlikely to become of major significance in relation to ozone depletion for a number of years.

If it is decided to initiate the regulation of CFC usage, then action on this application is less urgent than for the 'prompt emitting' flexible polyurethane foams. Since there is no realistic prospect of CFC recovery from this source and only a distant prospect of finding a suitable alternative fluorocarbon blowing agent, the most useful line of research concerns the rate of loss of CFC from the foam under various conditions and the ultimate fate of the residual CFC content on product disposal.

6.4 Non-Urethane Foamed Plastics

6.4.1 Significance in CFC Consumption

The analysis of the CEFIC/EFCTC statistics presented in Table 6.1 indicates that CFC sales for non-urethane foam plastics in the EEC in 1977 amounted to less than 10% of the total blowing agent sales, and less than 2% of total EEC sales for all uses. For the purpose of the present study it was decided to confine detailed consideration of the application of CFCs as blowing agents to flexible and rigid polyurethane foams, since it is in these sectors that policy decisions are needed in relation to the ozone depletion. When these decisions have been taken it should be fairly straightforward to apply these policies in respect of other foamed plastics.

It will be noted from Table 6.1 that, although comprising a small fraction of the total, CFC sales for non-urethane foams showed high percentage increases from 1976 to 1977. In the CFC producers home sales areas the rise was 16.8%, and if the assumptions made in the analysis are correct the overall rise in EEC sales in this sector was 43.8%. The difference is due to the sharp rise in F-12 sales for foams in the 'other EEC' markets (i.e. markets within the EEC but outside the CFC producers home markets), and the fact that a high percentage of F-12 blowing agent sales, amounting to 81% in 1977, is in the non-urethane category.

6.4.2 Polystyrene Foams

CFC blowing agents are used to a limited extent in the production of low density extruded polystyrene foam sheet, for which the main application is the manufacture of moulded food containers such as egg boxes and meat trays.

The largest producers of such products in Western Europe - Lin-Pac - advised that all their plants use pentane as the blowing agent, and that it is cheaper than CFCs and yields equivalent technical results. The only disadvantage attaching to pentane is its flammability, necessitating special precautions against fire and explosion and entailing higher insurance premiums.

Statistics are not readily available, but it is clear that a minority of polystyrene foam sheet production is made with CFC foaming agents, using, for example, the Gloenco extrusion system.

Du Pont (Reference 6.2) claim some special advantages in addition to safety for CFCs in this application, including better process economics associated with lower resin consumption per item and higher production rates. They also state that hydrocarbon blown foams are more liable to heat distortion and that in the U.S. there is a small specialised market for CFC blown foam containers for hot food services.

It is likely, however, that the main attraction and advantage of CFC blowing agents for polystyrene foams is the absence of fire and explosion dangers, and some manufacturers may be in locations where it would be impossible to use liquid hydrocarbons because of prohibitory regulations or the impracticability of complying with the precautions required.

Both F-11 and F-12 - especially the latter - are used for foaming polystyrene. Du Pont markets a number of blends including one of F-12 with pentane, and state that none of the hydrogen containing chlorofluorocarbons they have tested has proved a suitable substitute for F-11 and F-12 in this application.

The evidence reviewed by Rand (Reference 6.1) strongly suggests that the great majority of the CFCs used in foaming polystyrene products is released into the air during the manufacturing processes or shortly afterwards, so that these foams must be classed with flexible polyurethane as 'prompt emitters'.

If the industry could not use CFC foaming agents, then in the present state of knowledge it would have to rely for the most part on hydrocarbons, especially for low density foam sheet production, as is the case for a large fraction of EEC production already.

The conclusion is, therefore, that the industry as a whole could adapt to a CFC ban but that some producers now using CFCs would be faced with capital expenditure and interruption of production in order to instal additional ventilation equipment and other precautions necessary when using hydrocarbons, and in some instances this might dictate a move to a different location.

6.4.3 Polyolefin Foams

Uses for polyethylene and polypropylene foams include electric cable insulation, acoustic insulation, packaging (as a substitute for paper), gaskets and sealing devices, and expansion joints in building construction. A developing application in the EEC is the use of polythene foam sheet as a wallpaper backing.

According to Du Pont, there are no effective substitutes for the existing CFC blowing agents for making the low density grades of polyolefin foam which account for the bulk of the market. For high density grades alternatives including chemical blowing agents may be used,but are not ideal for all applications.

No information has been collected on the size or make-up of this market in the EEC.

6.4.4 Other Non-Urethane Foams

Other foams for which CFC blowing agents are known to be used include polyvinyl chloride and phenolic resin foams, with potential applications in the building industry due to their combination of insulation properties with non-flammability. These are still considered as being in the development stage and it is not known whether CFCs are essential for their production.

The comment may be made here that it is easy to understand why CFCs are natural choices as blowing agents in the development of new types of plastic foam, and hence tend to become established as the standard agents at an early stage. The initial selection arises because CFCs are known to have a wide range of utility as blowing agents and to be free from the hazards and complications - such as chemical reactivity - which attach to so many of the alternatives. The incentive to use cheaper agents,which may present technical difficulties or safety problems, does not develop until the scale of production and the element of competition make production cost margins more critical.

6.4.5 Future Action

The non-urethane foams are not yet significant either individually or in aggregate in the context of measures to achieve material reductions in CFC emissions. If it should be decided to regulate the use of CFCs in the urethane sectors, equity would require that consideration be given to regulating the others - particularly polystyrene foam, most types of which can be made satisfactorily with hydrocarbons and other non-CFC substances.

It would be only sensible for companies engaging in the development of non-urethane foams to keep the possibility of CFC regulation in mind when they plan to expand production and it seems unnecessary to recommend any special internationally coordinated research measures in this field.

There is a dearth of reliable statistics, however, and the significant rise in CFC consumption for non-urethane foams between 1976 and 1977 demonstrates the advisability of the detailed monitoring of CFC usage in the EEC advocated in Section 2.5.

6.5 Conclusions

6.5.1 General Foam plastics manufacture has become the second largest application of CFCs in the EEC, in contrast to the rest of the world market in which it ranks below refrigeration. The major proportion is of F-11 as a blowing agent for flexible (open cell) and rigid (closed cell) polyurethane foams, which are estimated to account for 87% of the 46 thousand tons of F-11, 12, 113 and 114 in this EEC sales category in 1977, and nearly 16% of the total EEC sales.

6.5.2 Flexible polyurethane foam

6.5.2.1 Flexible polyurethane foam is now the principal material for furniture and automotive upholstery, and is also used extensively in bedding, clothing laminates, insulation and packaging. In the EEC, chlorofluorocarbons - mainly F-11 - are used exclusively as the secondary blowing agents needed to augment the action of the chemically released carbon dioxide to make the lower density grades of foam. If CFCs were not available, there would be no viable option at present but to restrict manufacture to the higher density grades (above 22 kg/m^3); these account for less than half of total production, are typically 30% more expensive to use and have unsuitable physical properties for many of the purposes for which the low density grades are employed.

6.5.2.2 All the CFC used for blowing flexible open cell foams is rapidly released into the atmosphere, so in the ozone depletion context there is a strong case for developing alternatives and, given time, this may be feasible. Methylene chloride is a potential substitute: it is being used to some extent in the USA but is unlikely to be acceptable to operatives in EEC plants unless minimal exposure to the vapour can be assured. Formulation improvement may reduce the CFC requirement. CFC recovery and vacuum blowing are possibilities but have not yet been demonstrated to be economic in practice.

6.5.2.3 Custom produced slab or block flexible foam represents about 70% of manufacture, and this sector employs some 13,000 people and produced over 272 thousand tons of foam in 1976, with a value of approximately UCE 500 million. Other production is accounted for by custom moulders and by in-house production, especially in the automotive industry. The independent conversion sector is also a substantial employer. Growth of production is assessed to be running at about 3% annually.

6.5.2.4 Without low density polyurethane foam, users would have to resort to combinations of the more costly higher density grades with alternative upholstery materials and systems demanding completely different manufacturing techniques and entailing extensive re-deployment of labour. Higher production costs and prices would ensue, and unless a common policy on CFC control were to be adopted universally, major inequalities in competitiveness would be generated.

6.5.3 Rigid polyurethane foam

6.5.3.1 CFC blown rigid polyurethane foam combines mechanical, thermal insulation and adhesive properties conferring technical and economic advantages as an energy conserving structural material in building construction, domestic appliances such as refrigerators and freezers, and for transport and industrial insulation. The majority of the CFC blowing agent is retained in the closed cells of the foam during its useful life, and the low thermal conductivity of the CFC gas makes an essential contribution to the insulation characteristics.

6.5.3.2 No alternatives to fluorocarbons are known which would provide comparable insulation value, and the only potential substitutes for the existing CFC blowing agents are other fluorocarbons not yet commercially available or fully evaluated.

6.5.3.3 If CFC blowing agents could not be employed the rigid polyurethane foam industry would be substantially extinguished and a high performance insulation material would cease to be available. Equivalent insulation using alternative materials would entail greater thicknesses with consequent dimensional and weight penalties, and the inevitable compromises in many applications would increase energy losses. Refrigerator cabinets, for example, would have to be made with much thicker and heavier panels in place of the present slim light gauge steel/foam sandwich construction, and they would cease to be competitive in export markets in which corresponding restrictions did not apply.

6.5.3.4 Rigid polyurethane foam production in the EEC exceeded 150 thousand tons in 1977, and the raw materials value was over UCE 180 million. Growth at around 8% annually is likely to continue for several years and in the absence of CFC restrictions could accelerate due to the increasing importance of energy conservation.

6.5.3.5 Custom manufacture of slab and board is a much smaller sector than in the flexible foam industry, and there are numerous insulation contractors, pre-fabricated panel makers, moulders and in-house users. Employment is not readily assessable because of the diffuse nature of the industry. If rigid foam could not be made alternative materials would have to be used, and the overall socio-economic penalties would be those attaching to higher fabrication costs for insulation generally, probable declines in some specific export markets, especially refrigeration, and poorer energy saving performance.

6.5.3.6 The problem of CFC usage for rigid polyurethane foam is less urgent in respect of the threat of ozone depletion than prompt release applications, but the amount of CFC trapped in rigid foam is accumulating. More research is needed on the rate and mechanism of CFC release during the life of rigid foam and when it is ultimately scrapped or destroyed.

References in Section 6

6.1 Rand Working Note RAND/WN-10043-1-EPA Non-aerosol Chlorofluorocarbon Emissions: Evaluation of EPA - Supplied Data. Appendix E (Flexible Foams), Appendix F (Rigid Foams), and Appendix I (Non-urethane Foams). Feb. 1978.

6.2 'Non-aerosol Propellant Uses of Fully Halogenated Halocarbon.' Information submitted to the U.S. Environmental Protection Agency by the Freon Products Division, E.I. Du Pont de Nemours & Co. March 1978.

6.3 U.S. Environmental Protection Agency: Transcript of Proceedings of Public Meeting in Non-aerosol Uses of Chlorofluorocarbons: Foam Blowing Agents. February 23, 1978.

7. SOLVENT CLEANING APPLICATIONS

7.1 Extent and Role of CFC Usage in Solvent Cleaning

Reference to Table 2.6 shows 'solvent and other uses' to be the smallest application category of the four CFCs considered, amounting to 7.0% of sales in the EEC in 1977, and ranking just below refrigeration and air-conditioning which accounted for 8.1%.

As shown by the following data extract, only F-11 and F-113 figure significantly in this category.

TABLE 7.1 : CFC SALES IN THE EEC FOR 'SOLVENT AND OTHER USES' : 1976 AND 1977.

Sales for 'solvent and other uses':	1976 (metric tons)	1977 (metric tons)
F-11	4,083	4,865
F-12	95	6
F-113	11,659	12,831
F-114	202	-
	16,039	17,702
Sales for all uses of F-11,12,113 and 114.	261,586	252,293
'Solvent and other use' sales as %age of total sales	6.1%	7.0%

Source: CEFIC/EFCTC (Data extracted from Table 2.6).

If the end-use proportions in internal and export sales were the same, exports from the EEC in this category in 1977 would account for 4904 tons of F-11 and 3829 tons of F-113, but whereas the proportion for F-11 was only 3.9%, for F-113 it was 93.4%.

Figures for earlier years are not available and while the large rise from 1976 to 1977 cannot be taken as establishing a trend, our information from the CFC producer-marketers is that CFC solvents, principally F-113, are finding increasing application in specialised industrial and technical cleaning operations, such as flux removal from printed circuit boards, and the cleaning of electronic and precision engineering components and assemblies, and also in dry cleaning - particularly of sensitive fabrics and furs.

Very large tonnages of chlorinated solvents are also used in industrial and dry cleaning operations, mainly trichloroethylene ($CHCl. CCl_2$), perchloroethylene ($CCl_2. CCl_2$), 1,1,1, - trichloroethane ($CH_3. CCl_3$) and methylene chloride ($CH_2. CCl_2$). A reliable figure for the EEC is not available, but the total consumption of these four solvents in the USA in 1975 was estimated at about 640,000 tons (Reference 7.1) and EEC consumption must be of the order of several hundred thousand tons.

Since the price of F-113 is typically 4.5 times that of tri - and perchloroethylene, 3.0 times that of trichloroethane and 2.0 times that of methylene chloride, the preference for F-113 in certain cleaning applications clearly reflects substantial advantages over chlorinated and other solvents, and in some instances no satisfactory alternatives are available.

We cannot altogether agree with Section 3.3.2.4 of the OECD Report of October 1977 (Reference 7.2) which states: 'Limitations on the use of fluorocarbons would not affect the solvent-using sectors since the dominating solvents are the chlorocarbons'. Although that statement is true in terms of tonnage, the CFCs find unique applications in some important industries.

While it is probable that over 90% of F-113 production in the EEC is used in solvent cleaning the amount of F-11 so used is uncertain, and it seems likely that a higher proportion of sales categorised as 'solvent and other uses' are in the miscellaneous use sector. According to a Midwest Research Institute report (Reference 7.1), the tonnage of F-11 used in all solvent applications in the USA is only 10% of that of F-113.

Most of the information obtained from industry on CFCs in solvent cleaning related to F-113 and attention is concentrated on this compound in the following sub-sections.

7.2 F-113 as a Cleaning Solvent

7.2.1. Mode of Action of Volatile Cleaning Solvents

Volatile liquid cleaning agents may function in four ways:

a) Mechanical cleaning action, in which particulate and other foreign matter is flushed out of crevices and away from surfaces.

b) Solvent action, whereby greases, oils, resin fluxes and other contaminants adhering to surfaces are dissolved and then washed away.

- suitable volatilisation properties, including a low boiling point but one above normal temperatures, and a low heat of vaporisation

- compatibility with other cleaning agents or promoters

- absence of residue problems

7.2.2 Key features of F-113

In relation to the ideal, all practical cleaning solvents represent a compromise but F-113 has a particularly advantageous combination of qualities:

a) Safety Characteristics

Non-flammability - an advantage over hydrocarbon solvents, alcohols and ketones.

Low level of inhalation toxicity - the TLV (Threshold Limit Value) of F-113 is 1000 ppm, which is the same as that of ethanol, and to be compared with values of 500 for methylene chloride, 350 for 1,1,1-trichloroethane, and 100 for perchloroethylene and trichloroethylene.

Low boiling point (47.6°C) - splashes with the boiling liquid will not cause scalding: cf. perchloroethylene, b.pt. 121°C and trichloroethylene, b.pt. 87°C.

b) Chemical Stability

High stability is shown in the presence of water and structural metals. Inhibitors and stabilisers are not required and F-113 can be used under conditions where corrosive acidity would rapidly develop in chlorinated solvents.

c) Low surface tension - confers high penetrating action and wetting power: F-113 will wet PTFE plastic.

d) Selective solvent power - a moderate solvent action enables F-113 to be used with a range of plastics, resins and elastomers which would be attacked by chlorinated solvents. Where appropriate, solvent power can be raised by blending, e.g. with methylene chloride for solvency towards greases and waxes, or alcohols for polar substances.

e) Volatility. The low boiling point and heat of vaporisation reduces the energy input required for re-cycling. The low boiling point also has an advantage in temperature controlled environments. (A drawback is that it reduces 'washing capacity' in vapour rinse operations, since less liquid condenses on the components.)

f) Electrical properties. Having good dielectric properties, residual solvent does not cause insulation problems.

7.2.3 Industrial Cleaning

7.2.3.1 Applications

In general, F-113 and blends of F-113 with other agents are used where cheaper solvents are unsatisfactory; with high value items, where the superior properties of F-113 justify the extra cost; and where efficiency and reliability are all important and cost is not a critical factor, as in defence equipment.

The safety features of F-113 have hitherto tended to be an added bonus to its technical properties and not the governing factor in selection. However, with increasing emphasis on safety, these features are being accorded greater weight. This particularly applies to the low toxicity of F-113,and by using it in place of a chlorinated solvent it may be possible to avoid the need to install a more elaborate and expensive ventilation system.

The principal applications of F-113 in industrial and technical cleaning are as follows:

a) <u>Electronic and electrical components</u> - especially the defluxing of printed circuit boards and the cleaning of semi-conductors. The high cleaning efficiency increases service reliability, and is of critical importance with components that are encapsulated. This application is increasing in importance with the progressive trend towards miniaturisation in electronics.

b) <u>Electronic and electrical assemblies</u> - penetrating power and compatibility with a variety of materials in one assembly are of importance here, and typical examples are relays and other switchgear, cathode ray tube assemblies and hermetically sealed electric motors.

c) <u>Precision engineering equipment</u> - removal of grease, swarf, polishing compound residue etc. from precision parts and assemblies such as ball bearings, gyroscopes, fuel pumps, hydraulic valves, scientific and surgical equipment. Wetting and penetration are key properties.

d) Optical components and plastic assemblies - the low operating temperature and selective solvent action are of importance here, and F-113 is typically employed in removing release agents from plastic mouldings and plastic/metal assemblies before metallisation and painting.

e) Service and Maintenance Cleaning - equipment can be cleaned without dismantling or resort to hand brushing, and the electrical properties enable electromechanical equipment to be operated while immersed in liquid F-113. The maintenance of reprographic equipment has become a significant application.

f) Drying - water and water soluble contamination can be removed from parts and assemblies, for example after electroplating or other aqueous solution treatments, to provide dry and stain-free surfaces.

7.2.3.2 Operating Methods

As indicated in Section 7.2.2, F-113 is used either as the pure compound or as a blend - including some azeotropic mixtures - with other substances which confer special solvent or wetting properties. Examples are blends with alcohols to promote solvency for polar materials such as flux residues, and with water and surface active agents to remove water soluble contaminants. The operating procedures range from a single treatment with one grade of F-113, to a series of treatments with different grades.

The simplest technique is cold cleaning in which the article is swirled in a bath of the cold solvent and then withdrawn and allowed to drain and dry. The cleaning action may be supplemented by ultrasonic vibration and cavitation, which is more effective in the cold, and the operation may be carried on a small 'bench top' scale with a single bath containing a litre or so of solvent, or as one of a multi-stage process in a large plant.

Other techniques such as spraying, brushing and wiping may be employed and F-113 is also available in aerosol dispensers, which provide portability useful in dealing with components in large or static installations. The low toxicity of F-113 enhances its usefulness as a cleaning agent for in situ applications.

Vapour rinsing is the most frequently employed process either as a single stage or one or more of a sequence of stages. In this the cold article is immersed in the vapour zone above a bath of boiling solvent and cleaning is effected by the pure solvent which condenses on the article and runs off and back into the bath. As the article heats up to the temperature of the vapour, condensation ceases and the solvent drains off leaving a thin film, most of which evaporates in the air space above the vapour zone as the work is lifted out of the tank. The height of the vapour zone in the tank is controlled at a well defined level by cooling coils on which vapour is continuously condensing and running back into the sump or collecting tank.

In boiling liquid cleaning the articles are immersed in a bath of the boiling fluid, drained and removed, or the process completed by vapour rinsing. The level of contamination may be minimised by allowing the liquid to overflow continuously into a second compartment, replenishment also being continuously effected by the pure solvent condensate returning from the cooling coils which limit the vapour zone height above the liquid.

In multi-stage systems with up to four treatment tanks, articles pass through a sequence of immersions in vapour and cold and hot liquids.

Depending on the size and complexity of the installation there may be provision for continuous or intermittent solvent purification and recovery by distillation, separation and filtration units.

7.2.3.3 Sources and Control of Emission Loss

A useful review of the control of emission losses is given in the Rand survey of non-aerosol CFC emissions (Reference 7.3) which is based mainly on the Midwest Research Institute report (Reference 7.1).

There are three main sources of F-113 release to atmosphere from industrial cleaning using hot immersion and vapour rinse systems:

a) Dragout

This is the loss due to solvent adhering to the surface or trapped in crevices in the part after removal from the tank, and which then evaporates into the air.

The extent naturally depends on the size and construction of the parts being cleaned, and whether they are removed from a cold or hot liquid bath, or from a vapour rinse treatment. An important factor is operator technique, since losses are increased if parts are removed too quickly, giving inadequate time for drainage or temperature equilibriation with vapour.

Correct jigging of the parts reduces trapping of solvent, and with high throughputs mechanical handling can ensure appropriate speeds of entry and withdrawal.

b) Vapour diffusion from treatment tanks

Although F-113 vapour is over six times heavier than air, some diffusion from tanks is inevitable and the main factors are:

- mode and intensity of operation, which determines the extent to which the vapour zone is disturbed as work is processed and the time the tanks must remain uncovered

- use of tank covers during idling time. This depends on whether covers are provided, the extent to which operators use them, and the design. Roll-top covers are superior to simple lids, which if used carelessly can have the effect of extracting vapour.

- system geometry, especially freeboard height. According to Reference 7.1 this should be not less than 75% of tank width but may be only 50% in older systems. Under idle conditions it was estimated that increasing the freeboard height/width ratio from 0.5 to 0.75 would reduce evaporation loss by 36%, while an increase from 0.75 to 1.0 would reduce emission by 35% and show a savings/cost ratio of 54.6.

- condensing coil temperature and design. Refluxer coils are mostly cooled with mains water of variable temperature. Refrigerated coils are claimed to show a worthwhile savings/cost ratio by reducing losses and one informant claimed that overall solvent losses were typically reduced by 40%, with the added advantage of making the unit self-contained. Opinion on this was not unanimous, however, the other view being that adequate water cooling and correct coil design were as effective as refrigeration. Another device used in the USA but not to much extent in Europe is a 'cold trap' in the freeboard region which creates a cold air blanket over the vapour zone.

c) Solvent reclaiming and disposal procedures

The larger and more elaborate systems have facilities for the continuous purification and recycling of solvent, but in simple single tank systems impurities accumulate and eventually the charge may be discarded or dealt with in a separate recovery unit. In theory, solvent should be disposed of in ways which prevent substantial evaporation into the air, but in practice a certain amount of solvent is 'dumped' without special precautions.

In some cold cleaning applications the scale is so small or the mode of use such that recovery is either impracticable or not worthwhile, but it is believed that single stage cold cleaning is used to a much smaller extent in Europe than in the USA.

Distribution of emission losses between the main sources can vary considerably with the type of plant, the work handled and the operating technique. No reliable data are available for the EEC (or the USA) and, as with the refrigeration industry, there are no statistics on the numbers of the different types of plant in service.

7.2.3.4 Nature of the Industry

Industrial solvent cleaning is not a separate service industry as is dry cleaning, but a unit operation in the manufacturing industries and in the servicing and maintenance sectors related to them.

The supply of solvents has become a distinct sector of the chemical industry which has played a major role in developing the technology of solvent cleaning, and collaborates closely with the equipment manufacturers who also constitute a distinct industry branch. In some instances formal links exist whereby manufacturers make plant according to designs developed and patented by the solvent suppliers.

The use of F-113 certainly represents the most sophisticated technology in solvent cleaning, but for the supplying industries chlorinated solvents and plant employing them account for the major part of the turnover.

7.2.3.5 Present Consumption of F-113 and Growth Rate

The proportion of the 12,831 tons of F-113 sales in the EEC for 'solvent and other uses' in 1977 which was used for industrial cleaning is not known but an estimate of current consumption is given in Table 7.2.

TABLE 7.2 : ESTIMATE OF CURRENT CONSUMPTION OF F-113 FOR INDUSTRIAL CLEANING IN THE EEC.

Country	F-113 Consumption in 1978
	tons
France	4,500
Germany	3,600
United Kingdom	1,800
Rest of EEC	1,000
	10,900

Source : Industry contacts

Growth of consumption is put at around 10% per year.

7.2.4 Dry Cleaning

Perchloroethylene is the dominant solvent in the dry cleaning industry but F-113 is being used to the extent of at least 1500 tons p.a. in the EEC, particularly for the cleaning of sensitive fabrics, leathers and furs. Du Pont have a strong patent position on this application and it is believed that the largest market is in the U.K.

The principal source of vapour release is from solvent occluded in materials on removal from the machine. All installations are equipped with distillation recovery units and there is very little discard.

For materials liable to be harmed by the chlorinated solvents, hydrocarbons are sometimes used and F-113 has the advantage over these of being non-flammable.

The low toxicity of F-113 is another point in its favour, but it seems unlikely that F-113 will readily displace the chlorinated solvents for general purpose dry cleaning on the strength of this factor, and our impression is that the dry cleaning application of F-113 is not growing as fast in Europe as the industrial uses.

7.2.5 Other Applications

7.2.5.1 Pre-surgical skin degreasing

According to a statement made at an EPA public meeting on non-aerosol uses of CFCs held in October 1977 (Reference 7.4), F-113 is now used extensively in the USA in place of ether for cleaning and degreasing the skin prior to surgery, and was selected for this application because it is non-irritant, non-inflammable and volatile as well as having appropriate solvent action. It was said that following the introduction of F-113 as a pre-surgical skin degreaser ether has now been banned altogether from most operating theatres in the United States; we have no information, however, on the extent to which this application has grown in Europe.

7.2.5.2 Tantalum wire drawing

Though not strictly a cleaning application, F-113 is used as a lubricant solvent for the drawing of tantalum and columbium wire and tubing, and according to another statement in Reference 7.4 no other solvent has been found which gives equivalent quality results. These metals are used in heat exchangers, electronics, medical applications, aerospace components, etc. on account of their special corrosion resistance properties and high temperature strength characteristics.

7.2.6 Value of F-113 Solvent Cleaning Supply Industry

This is the sum of the values of three components:

a) sales of F-113 based solvents
b) sales of new plant designed for use with F-113 solvents, plus sales of replacement parts
c) after sales service and maintenance.

In Section 7.1 it was estimated that the 1977 sales of F-113 for 'solvents and other uses' by EEC producers totalled 16,660 tons, made up of EEC sales of 12,831 tons and exports outside the EEC of 3,829 tons. Assuming 10% annual growth rate, 1978 sales may total about 18,000 tons.

A problem in estimating the value of solvent sales is that a high proportion (possibly more than 30%) is in the form of blends of F-113 with other solvents and reagents. Du Pont, for example, market at least nine grades and blends of F-113 solvents, and I.C.I. supply six. The majority contain 90 to over 99.9% F-113 but some may contain very much less. I.C.I. 'Arklone' E, for example, is a high solvent power blend containing 50.5 F-113 and 49.5% methylene chloride. Prices vary, and details of quantities are not available, but it is believed that UCE 1350 per ton of F-113, whether sold as a pure grade or a blend, represents a mean value, and on this basis the 1978 sales of F-113 solvents could amount to UCE 24.3 million.

New plant sales are believed to be running at about UCE 5.2 million and if we add 10% of this figure to cover spares and service, this gives a total value for the F-113 solvent cleaning supply industry sector of approximately UCE 30 million.

7.2.7 Price - Demand Sensitivity

Since F-113 is used where its special properties justify its preferment to much lower priced solvents, and mainly in the manufacture and maintenance of high value products, it is unlikely that the volume of demand would be very sensitive to price variation in the short term. In the longer term, an increasing differential between the prices of F-113 and conventional solvents would tend to:

a) stimulate the F-113 solvent cleaning equipment manufacturers and users to adopt solvent loss reduction measures on the lines indicated in Section 7.2.3.3.

b) retard trends towards the adoption of F-113 systems in preference to other solvent systems.

c) promote research and development to improve the cheaper solvent systems, e.g. in compatibility with sensitive materials.

d) encourage compromises between the lowest cost solvents and F-113, e.g. the adoption of 1,1,1-trichloroethane in place of trichloroethylene and perchloroethylene.

A decrease in the price differential would have the opposite effects and would certainly promote sales of F-113 systems relative to those employing flammable or more toxic solvents.

For the reasons explained in Section 3.8.3.3, the effect of regulating the use of CFCs in aerosols would increase the manufacturing cost of F-113. This might be reflected in a higher price, but as F-113 currently carries a higher profit margin than the large tonnage CFCs, producers have some flexibility in pricing, and are likely to adopt marketing strategies which will optimise the returns from the undoubted growth potential for F-113 solvent systems, where what is being sold is really a combination of material and technology.

7.2.8 Substitution Possibilities

At present there is no commercially available substance with a spectrum of properties approaching that of F-113, and no other known substance which has been adequately assessed as a potential alternative. The compounds which might be developed as substitutes are other fluorocarbons, possibly CFCs containing hydrogen and hence more susceptible than F-113 to tropospheric decomposition, and less likely to affect the ozone layer.

At an EPA public hearing in October 1977, (Reference 7.4) a spokesman for the Bell Telephone System said that Bell had used F-113 for contact cleaning since the 1930s and had not yet discovered a satisfactory alternative. They would evaluate any promising partly hydrogenated CFCs which might become commercially available, and examples cited of compounds which might be worth testing were F-131 ($CHCl_2.CHClF$) and F-132a ($CHF_2.CHCl_2$). Representatives of the fluorocarbon manufacturing industry present were not prepared to go further than saying that possibilities were being examined, and a period of seven years was likely between identifying a likely compound, proving it and establishing commercial production.

Although there is no prospective equivalent to F-113, this does not mean that it is indispensable in all its applications, or that the only approach to substitution is to develop compounds with similar properties.

The situation is that there are a number of uses in important EEC industries, electronics for instance, where at the present time it would either be impracticable to dispense with F-113, or such a retrograde step as to jeopardise the continuation of the product sector concerned. At the other end of the scale there are applications where F-113 has some valuable advantages over alternatives, for example over flammable dry cleaning solvents, but where equivalent jobs can, and in fact are being done by other means. In the middle there is a grey area where the 'essentiality' of F-113 could be debated.

Possible approaches to dispensing with F-113 in the absence of an equivalent compound include:

a) To 'design out' the need to use F-113 based cleaning solvents, for example by developing ways of making printed circuit boards without using existing type fluxes, or making components from materials which are compatible with other cleaning solvents.

b) To adapt existing solvent systems to provide substitutes for F-113 in specific applications. It is unlikely that finality has been reached in the development of non-CFC solvent technology.

c) In instances where F-113 has been selected primarily on safety and convenience grounds, to suffer the added risks and costs of using other solvents and installing the necessary safety equipment.

To some extent approaches (a) and (b) are in progress all the time as part of the normal continuing processes of new development and improvement.

7.3 Regulation

7.3.1 Cases For and Against Regulation

In the event of a decision that there are grounds for restricting the use of CFCs in the EEC, including their use as propellants in non-essential aerosols, then the pros and cons of applying restrictive regulations to the use of CFCs in solvent cleaning appear to us to be as follows:

7.3.1.1 Case for Regulation

a) Equity. Although CFC sales for solvent cleaning represent less than 7% of total sales in the EEC in

1977, it is arguably inequitable to allow the non-essential fraction of this application to escape regulation while imposing restrictions on other non-essential use sectors.

b) Growth potential. Solvent cleaning using CFCs has considerable growth potential which the CFC producers will be particularly keen to exploit in view of the threat to the aerosol propellant business. Therefore it might be better to regulate at an early stage and avoid the greater economic hardship and disturbance which would ensue from applying restrictions at a much later date.

c) Substitution potential. As indicated in Section 7.2.8, some possibilities exist for dispensing with CFC solvents, and announcement of an intention to regulate would stimulate the search for alternatives.

7.3.1.2 Case Against Regulation

a) Social and Economic Value. Although the CFC solvent cleaning supply industry is not of great magnitude, some of the applications of CFC solvents are vital to industry sectors which are of considerable social and economic value in the EEC. Also, even in sectors where CFC solvents are not indispensable, they make a significant contribution to safety.

b) Small Impact on CFC Release Reduction. It is likely that if regulation were proposed, many users of CFC solvents would make a case for exemption on essential use grounds, and that the actual reduction in CFC use achieved would be less than 5% of sales in the EEC. Taking this in conjunction with (a) and the present status of the ozone depletion theory, there are grounds for deferring action on this application until the need for regulation is more clearly established.

c) Complications of Applying and Harmonising Regulation. In relation to the extent of use, there would be a large number of applications for exemption, and because of the industrial and social implications we think there might be great difficulty in securing consistent treatment by the EEC member states.

d) Situation in Countries Outside the EEC. It seems unlikely that the United States will regulate against this application in the near future. A number of other industrially developed countries are unlikely to regulate ahead of the USA, and for the EEC to do so would put a number of high technology industries at a competitive disadvantage unless so many exemptions were granted as to make the exercise pointless.

7.3.2 Decision Not to Evaluate Regulatory Scenarios

From consideration of the above pros and cons of introducing regulation against CFC solvent applications at this juncture we advised against the evaluation of regulatory scenarios in this study, and the recommendation was accepted.

7.3.3 Non-restrictive Control Measures

7.3.3.1 Fiscal Measures

Because CFC cleaning solvents are frequently employed in making high value products, the imposition of an excise tax might be a method of discouraging their use except where no reasonable alternatives exist and where the extra cost would not be unduly burdensome. Objections to this course include the complications attaching to setting up an elaborate administrative and control system for a relatively small volume of material, and the fact that there would still be many claims for exemption on social grounds, e.g. medical uses.

7.3.3.2 Measures to Reduce Release to Atmosphere

Our preferred approach is similar to that proposed for the refrigeration industry of trying to reduce avoidable losses. Although almost all the amounts of CFCs used in solvent cleaning must eventually pass into the atmosphere,the effect of emission reduction measures would be to retard the rise in CFC consumption for this application, and enable a given rate of consumption to support a larger volume of solvent cleaning capacity.

The means available have been outlined in Section 7.2.3.3 and are of two types:

Equipment design changes, such as the provision of suitable solvent tank covers, refrigerated refluxer coils and cold traps, and adoption of minimum freeboard/tank width ratios.

Operating practice improvement, including the use of tank covers during short idling periods and shutting down altogether during long ones, adequate draining and vapour temperature equilibriation, and proper solvent disposal procedures.

To make progress on these lines it would be necessary to secure the active cooperation of the supplying and using industries, and one of the first steps would be to carry out research to establish reliable cost/benefit data on the various measures available. As with the refrigeration industry, this work should be co-ordinated with any being sponsored by the U.S. Environmental Protection Agency or elsewhere. It would also be necessary to obtain more data on the usage of CFC solvents in different industry sectors and on the numbers, types and capacities of the units in service.

After ascertaining the optimum measures the next step would be to secure their implementation. Equipment design modifications could be introduced either by regulation or the adoption of voluntary codes. Probably the only practicable way of promoting better operating practice would be a process of information and training.

Some evidence of progress in emission control would be provided by monitoring F-113 consumption in relation to new and existing installed capacity, but a complicating factor is the variation in operating intensity.

7.3.3.3 Promotion of Substitution

While the possibility of regulation exists the leading manufacturers of F-113 can be relied upon to screen alternative fluorocarbons and, in collaboration with major users, to evaluate compounds that appear promising.

As noted in 7.2.8, other methods of eliminating the use of F-113 in solvent cleaning, such as the development of ways of making printed circuit boards without fluxes or of improved non-CFC solvent systems will continue irrespective of the prospect of regulation, although that prospect certainly provides an added impetus.

For the time being, therefore, it seems doubtful whether any formal measures are needed to promote these lines of approach, and we believe that it would suffice for the EEC to keep in touch with developments.

7.4 Conclusions

7.4.1 Solvent cleaning is the principal application in the 'other use' category to which 4.9 and 12.8 thousand tons respectively of EEC sales of F-11 and F-113 were allocated in 1977; it probably accounted for at least 90% of the total F-113 sales of 16.7 thousand tons, but the proportion for F-11 was not established.

7.4.2 F-113 solvent cleaning systems find increasing application in technical, industrial and dry cleaning in preference to much cheaper chlorinated and other solvents because F-113 has a unique combination of suitable physical properties with good safety characteristics, high chemical stability and cleaning activity, and compatability towards a wide range of materials.

7.4.3 Applications fall into two broad categories : those where F-113 is advantageous in terms of safety and performance but for which reasonably effective alternatives are available, and those for which F-113 is indispensable or nearly so. The former include dry cleaning - especially of delicate fabrics and furs, the latter include the manufacture of certain types of electronic and electrical components and assemblies, (e.g. the defluxing of printed circuit boards), and of precision engineering and optical equipment.

7.4.4 Some scope exists for reducing the need for F-113 solvents, for instance by eliminating fluxes in miniature electronics. Also, the release of F-113 from the hot liquid and vapour rinse systems in which it is mostly used could be cut down by taking extra precautions to minimise drag-out losses and vapour escape.

7.4.5 Many users of CFC solvent cleaning systems would be able to make out a good case for exemption from regulation on 'essential use' grounds, and the reduction in CFC release achievably by regulation would be less than 5% of the EEC total. The value of the CFC solvent cleaning supply industry in the EEC is put at about UCE 30 million, but a much greater value lies in terms of service to the electronic and other important EEC industries.

References in Section 7.

7.1 Midwest Research Institute. Chemical Technology and Economics in Environmental Perspectives, Task 1 - Technical Alternatives to Selected Chlorofluorocarbon Uses. Feb. 1976.

7.2 OECD Report ENV/Chem./77.2 (Rev.). The Economic Impact of Restrictions on the Use of Fluorocarbons. October, 1977.

7.3 Rand Working Note RAND/WN/.10043-1-EPA. Non-aerosol Chlorofluorocarbon Emissions: Appendix G. Survey of EPA Supplied Data on the Solvent Industry. Feb. 1978.

7.4 U.S. Environmental Protection Agency. Proceedings of Public Meeting re. Fully Halogenated Halocarbons: Non-aerosol Propellant Uses. Panel on Chlorofluorocarbons Used as Solvents. Vol. II, Washington D.C. October 26, 1977.