Journal of Fluorine Chemistry, 18 (1981) 1–24

Received: November 26, 1980

TRENDS AND PERSPECTIVES FOR THE TECHNOLOGICAL AND COMMERCIAL DEVELOPMENT OF FLUORINE CHEMICALS

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Plenary lecture given at the opening of the 7th European Symposium on Fluorine Chemistry (Venice - September 1980)

1 INTRODUCTORY REMARKS

The generation of post-war fluorine chemists has created an industrial chemical activity which has withstood the oil crisis, inflation, and the chemical industry's loss of leadership in industrial development at large. Few fluorine products have been in decline during the last five years.

A review of the paths on which the industrial fluorine chemistry has been moving in the past decade may be of interest for :

a) extrapolation of future research activity;
b) decisions on investment in the field of fluorine chemicals.

This will be done in this report, by examining the principal classes of fluorine compounds. I shall consider, specifically, chlorofluorocarbons, fluorinated polymers, industrial gases such as uranium and sulphur hexafluorides and other presently less widely used fluorine derivatives. I shall consider the historical cause of their development and the reasons which justify their future evolution.

2 THE FLUORINE DERIVATIVES

About half of the hydrogen fluoride produced in the world is now used directly in the processes of gasoline alkylation and steel pickling, and in the aluminium and glass industries.

The other half of the hydrogen fluoride constitutes an intermediate for recently developed products which have shown remarkable growth potential: we refer to them more specifically here as "fluorine chemistry."

Fluorine chemistry found its guidelines thanks to the capacity of the element to impart to its derivatives two contrasting types of behaviour, both novel, depending on :

a) fluorine forming compounds in the highest oxidation states for particular elements (for example, carbon in linear or cyclic derivatives such as the perfluoroalkanes and fluorinated polymers, or of sulphur in sulphur hexafluoride).
To this class belong all those compounds in which the high degree of substitution by fluorine causes physical and chemical inertness by comparison with the original hydrocarbon derivatives; peculiar interfacial properties are also imparted in compounds such as the perfluorinated surfactants and the chlorofluorocarbons, which have spread into the aerosol, foam and solvent sectors of industry:

b) fluorine, through a precise partial substitution, causing an isogeometrical transformation (P. Goldman, 1969) which combines a maximum effect on the molecule's electronic configuration with a minimum steric distortion as compared to the original hydrogenated molecule. From such a substitution, special chemical properties or biological activities follow. These cannot be predicted from first principles but have found application in particular sectors (such as anaesthetics, drugs, agrochemicals, and antibacterials).

These are the characteristics which have contributed to the success of fluorine chemistry, and which continue to suggest new results from current research.

3 HISTORY AND PRESENT STATE

The industrial development of fluorine organic chemistry started because of the prospects of applications which could be foreseen in derivatives of two classes of compounds, chlorofluorocarbons and fluorinated polymers, which had been first prepared shortly before the second world war.

In the history of the development of fluorine chemistry, the different sectors have been developed along the same lines and in parallel with the great expansion of the rest of the chemical industry (petrochemistry and polymers, aerosols and refrigerants, surfactants, etc.).

In the decade 1970-1980 the growth of the chemical industry has lost momentum as has industrial development in general (Table 1).

During this same period, research has been substantially re-directed away from total innovation (new products), and towards:

improvement of processes (or development of new processes);
adaptation of existing products to unusual applications;
and, finding new applications.

This new trend has been enhanced by multidisciplinary approaches to the problems, and the main guiding factors have been :

improvement of performance quality,
cost reduction, and
bio-ecological considerations.

In this overall picture, fluorine chemicals have met a mixed fate. Table 2 shows the overall trend of hydrogen fluoride consumption and use in USA.

There has been a decline in the use of fluorine chemicals in aluminium production, aluminium fluoride and synthetic cryolite. This corresponds to a temporary slow-down of industrial activity and to technical improvements in the area. There has also been a decline in aerosol propellants particularly chlorofluorocarbons because of cost and for ecological reasons, and there has been a major decline in the use of consumer products.

TABLE 1

Indices of production for the OECD European member countries, the United States and Japan

		AVERAGE ANNUAL GROWTH RATE %	
		TOTAL INDUSTRIAL PRODUCTION	CHEMICAL PRODUCTION
1965-1970	Europe	6.0	10.5
	USA	3.5	8.0
	Japan	15.5	16.0
1970-1974	Europe	4.0	8.0
	USA	5.0	6.5
	Japan	5.0	6.0
1974-1978	Europe	1.0	2.5
	USA	3.0	5.5
	Japan	3.0	2.5

TABLE 2

HF consumption by end use in USA

	1965		1970		1974		1978		1979	
End use	10^3T	%	10^3T	%	10^3T	%	10^3T	%	10^3T	%
aluminium production	89	43.4	121	40.9	139	37.1	110	34.5	108	34.2
chlorofluorocarbons (1)	90	43.9	124	41.9	164	43.7	120	37.7	117	37.0
gasoline alkylation	6	2.9	11	3.7	15	4.0	18	5.6	18	5.7
steel	9	4.4	8	2.7	13	3.5	11	3.4	11	3.5
others	11	5.4	32	10.8	44	11.7	60	18.8	62	19.6
Total	205		296		375		319		316	

(1) including intermediates for fluoropolymers.

On the other hand the great majority of what we have previously defined as fluorine chemistry has been, and still is, in a growth situation.

This arises because it is essentially a chemistry for new technologies and its chemicals are speciality products which are not replaceable by other materials.

Let us examine in some detail the record of the most important products.

3.1 Chlorofluorocarbons

Chlorofluorocarbons are the products which practically started off organic fluorine chemistry. The first mass application was the use of dichlorofluoromethane (CFC 12) in 1939. The application of the same compound in a mixture with type 11 followed in aerosols.

Figure 1 shows the trend of world-wide production of chlorofluorocarbons 11 and 12, which are the most used compounds of this type.

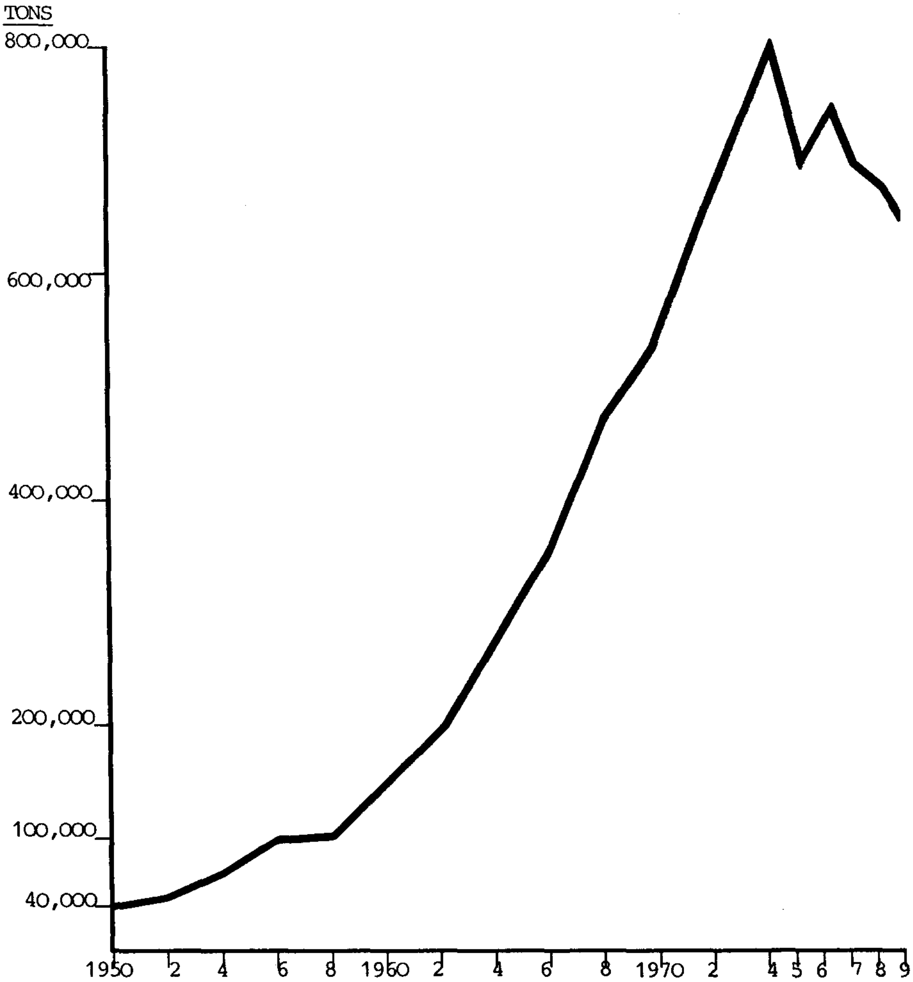

Fig. 1. World production of CFC 11 and 12 (excluding communist countries).

There are to-day fewer than 20 producers in the world and their total capacity is about one million tons, more or less stable since 1973.

From the graph, the following trends can be deducted, average annual growth rate (AAG)

World-wide production 1954-1974	AAG %	13%
World-wide production 1974-1979	AAG %	-3%

3.2 Fluoropolymers

Under this heading we refer to two classes of products with different characteristics: plastics, of which the most important is polytetrafluoroethylene (PTFE), and elastomers, of which the most important is derived by copolymerisation of vinylidene fluoride and perfluoropropene.

3.2.1 Fluoroplastics

PTFE is the most utilised product of its class. In Europe, PTFE constitutes 90% of the fluorinated plastomers market. The remaining 10% is made up by a certain number of truly plastomeric products including :

PFA	tetrafluoroethylene-perfluoro (alkylvinyl ether) copolymer,
FEP	fluorinated ethylene-propylene copolymer,
PVDF	polyvinylidene fluoride,
ECTFE	ethylene-chlorotrifluoroethylene copolymer.

Development of fluorinated polymers arose for those applications in which PTFE could not be employed because of difficulty in its processing or in those applications for which more conventional processing methods (extrusion and injection moulding) give lower costs which counterbalance, at least partially, the higher price of the raw material used. Often these polymers are used to fabricate objects with better thermo-mechanical properties than would be possible with more conventional materials.

The development of use of PTFE can be seen in Table 3, showing data from 1963 to 1979.

From 1963 till 1972 the average yearly growth rate was 19% in West Europe and 24% in Japan.

TABLE 3

PTFE world consumption (tons)

	1963	1972	1976	1978	1979	AAG % 1963-72	AAG % 1972-79
W.Europe	750	3650	5300	5800	6200	19	8
USA	3500	6300	7250	7800	8100	7	4
Japan	240	1635	2100	2600	2800	24	8
others	200	1400	2200	2600	2800	24	9
World total	4690	12985	16850	18800	19900	12	6

The growth rate in the USA market was much lower in the same period and equal to 7%. PTFE consumption in the USA had started to develop at an annual growth rate of 12% but it remained substantially constant from 1968 up to 1972 because of a slow-down in military and aerospace programmes during that time.

After 1972, growth restarted in the USA but at a slower rate than in other industrialised contries as can be clearly seen in Table 3.

The world-wide capacity is presently about 25000 tons per annum, and its distribution can be seen in Table 4.

TABLE 4

PTFE world consumption, prduction capacity and commercial balance in 1979 (tons)

	CONSUMPTION	PRODUCTION CAPACITY	COMMERCIAL BALANCE
West Europe	6200 = 31 %	10500 = 42 %	Exporters
USA	8100 = 41 %	10000 = 40 %	Export = Import
Japan	2800 = 14 %	3500 = 14 %	Export = Import
others	2800 = 14 %	1000 = 4 %	Importers
World total	19900 = 100%	25000 = 100%	

Examining further Table 4, and assuming that plant is working to total capacity, Europe shows as a strong exporter of PTFE, Japan and USA have a balance of exports and imports, and the other areas are nett importers.

The consumption of the other polymers has increased with a trend similar to that of PTFE; their consumption has remained at about 10% of the total over the last five years.

3.2.2 Fluoroelastomers

Among the different compounds in this category, those which have been obtained by polymerisation of vinylidene fluoride and hexafluoropropene make up 85% of world-wide production. A limited number of products accounts for the remaining 15%. The most important among them are : -

Fluorosilicon rubbers;
Perfluoromethylvinylether-tetrafluoroethylene copolymers;
Propylene-tetrafluoroethylene copolymers.

These fluorinated products are used on account of their performance in highly specialised sectors, e.g. for military and aerospace requirements under exptremely severe operating conditions. Fluorosilicone rubbers, for example, are utilised at very low temperatures, while perfluoroalkylvinylether copolymers have superior chemical and mechanical properties in comparison with the more generally used fluoroelastomers based on vinylidene fluoride.

The considerable increase in the use of fluoroelastomers is mainly due to their excellent heat stability, their good compression set and their ease of processing.

The trends in consumption of fluoroelastomers is shown in Table 5.

TABLE 5
Fluoroelastomer world consumption (tons)

	1970	1974	1976	1978	1979	AAG % 1970-79
W. Europe	365	575	650	750	830	9.5
USA	850	1300	1450	1800	2000	10.0
others	100	250	350	470	550	21.0
World total	1315	2125	2450	3020	3380	11

Annual average increases in fluoroelastomers consumption, over the period 1970-1979, are :

USA	10.0 %
West Europe	9.5 %

World production is restricted to four producers with an overall capacity of about 4000 tons per year. Montedison is the sole European producer.

3.3. Uranium and sulphur hexafluorides

These products, which have completely different applications are related because of dependence on availability of elemental fluorine; elemental fluorine is basic to sulphur hexafluoride (SF_6) production and essential in the last step of processing uranium ores to uranium hexafluoride (UF_6).

The electrolytic production of elemental fluorine is a very critical process, requiring an electrolytic cell of special design and a remarkable electrochemical and technical expertise. It is an advanced technology and few producers possess it. The production unit of elemental fluorine is generally integrated with SF_6 or UF_6 units.

Uranium hexafluoride production is a necessary step during uranium enrichment.

Outside communist-bloc countries, UF_6 production is concentrated with five producers with a total production capacity of 30000 tons per year.

Historic trends of the world-wide production capacity and consumption of uranium hexafluoride are shown in Fig. 2.

In the past, the UF_6 production was higher than consumption resulting in a build up of stockpiles, while the present demand exceeds the installed capacity and stockpiles are being depleted.

Sulphur hexafluoride is utilised in electrochemical equipment (HV breakers, substations, cables), in nuclear particle accelerators, in X-ray, welding control and radar equipment, for thermoacoustic insulation in window-panes and for magnesium melting.

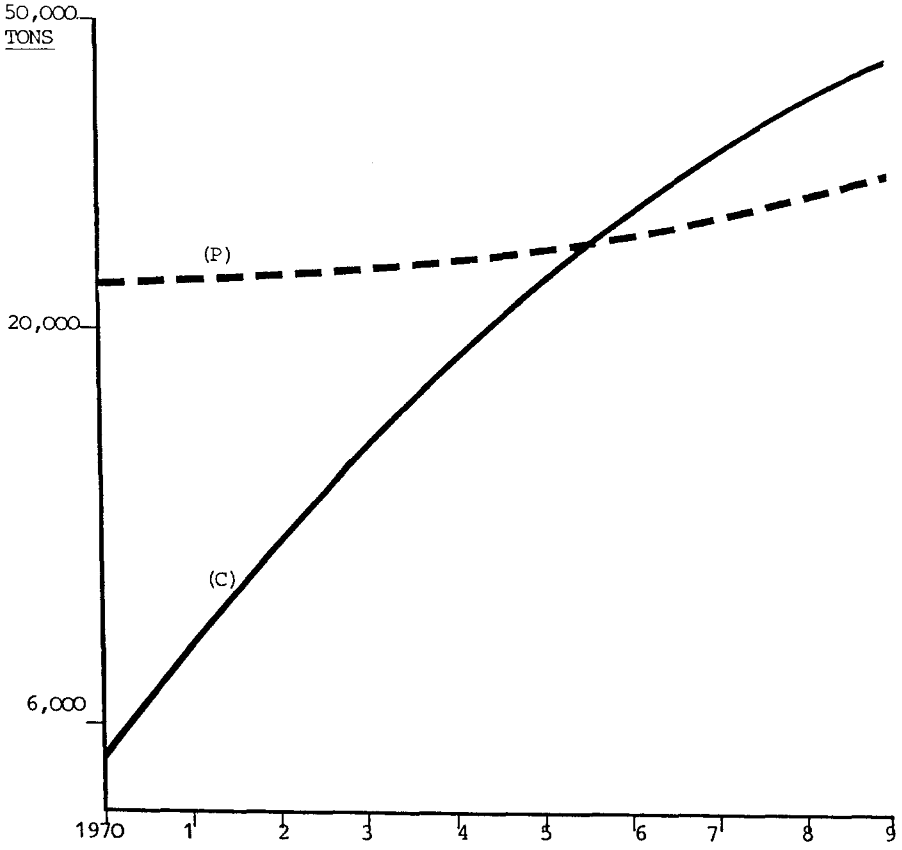

Fig. 2. Trends of UF_6 world capacity (P) and consumption (C)

There are seven SF_6 producers in the world, with a total overall annual capacity of rather less than 4000 tons, in comparison with a consumption of 2700 tons in 1979.

Western Europe has been the area with the highest development of SF_6 production. In the last eight years the demand has increased at an annual average rate of 15%. In the United States a growth rate of less than 10% per annum has been recorded. In Europe the major application has been in the electromechanical industries, which have developed very advanced technologies, even by comparison with the USA. These industries have kept exports of products at high levels. It is estimated that more than 50% of the sulphur hexafluoride used in this sector has its final destination outside Western Europe.

European supremacy has also been enhanced by the installation of electrostatic accelerators in nuclear physics research centres, magnesium production and, recently, the production of double-glazed window systems which offer a high degree of acoustic and thermal insulation.

4. THE FUTURE

What are the perspectives?

The trends in the commercial fluorine-chemical industry will, of course, be affected by increased energy costs, by the general and apparently irreversible slow-down of industrial development in technologically advanced countries, and by high inflation rates which will lower consumer buying power.

Gross generalisation would, however, be misleading: it is better to examine analytically the different categories of products, keeping in mind their specific properties, the reasons for their initial development, their actual possibilities in connection with the needs of industry and society, and the requirements and the economic and technological challenges that the future of our industrial civilization implies.

The traditional applications of hydrogen fluoride are in the aluminium industry, gasoline alkylation and steel pickling. Overall, these account for about 45-50% of total consumption. In absolute value, the quantities used in these applications will expand at a rate comparable with the overall expansion of industry.

Other outlets for HF are, however, of particular interest and we must consider separately chlorofluorocarbons, fluorinated polymers, industrial gases such as UF_6 and SF_6, and other products.

4.1 Chlorofluorocarbons, CFC

It is not possible to make reasonable projections in this area without forecasting first the final solution of the ozone depletion controversy which originated from the Rowland and Molina hypothesis. It is a matter of opinion but I think that, on the basis of data acquired in the course of the experimentation programme (the chlorofluorocarbon industry world-wide is spending an average of 1.8 million US dollars per year on a concerted research programme on this vital topic), it is possible to make a reasonably educated guess as to the outcome of the research.

Presently, I am convinced, and this is the opinion of a man of the industry, that the latest experimental results demonstrate that alarm over the effect of chlorofluorocarbons on the ozone layer is not justified to the extent to which public and government concern has been expressed (a similar alarm was raised for ozone when the US civil supersonic aircraft was being designed; because of this alarm the aircraft was cancelled): certainly, there seems no need for an immediate reduction in the use of these compounds because of the possibility that delay could have fatal results.

Results of surveys carried out to now certainly do not point to any ozone depletion in the stratosphere but, indeed, to the opposite, that is to an increase in ozone. These surveys prove beyond any doubt that the many assumptions and simplifications adopted for simulating the behaviour of chlorofluorocarbons in the stratosphere turned out to be inconsistent and unjustified, and to this date no evidence of damage to ozone by chlorofluorocarbons has been produced.

On the other hand, it seems that limitation of CFC use as propellants adopted by the industry, either voluntarily or by law, may prove irreversible. Consequently, the future use of CFC may be restricted to cases in which their solvent properties, chemical inertness, and non-flammability will make them indispensable.

What about other applications? At present there are no legal limitations on their use. Voluntary limitations to the uses of chlorofluorocarbons 11 and 12 would be promoted only if substitutes were available with similar properties.

Let us examine the possible implications of their replacement.

4.1.1 Air conditioning and refrigeration

In this context we mean applications in the industrial, commercial and civil sectors, for transportation and household use, as shown in Table 6.

TABLE 6
Refrigeration and air conditioning applications

APPLICATION	REFRIGERATION	AIR CONDITIONING
INDUSTRIAL	1) FOOD CHAIN - COLD STORAGE WAREHOUSES - FOOD FREEZING PLANTS - FOOD PROCESSING PLANTS 2) CHEMICAL/PHARMACEUTICAL INDUSTRY PROCESSING & STORAGE OF CHEMICALS 3) ICE FACTORIES	METALLURGICAL, CHEMICAL AND OTHER INDUSTRIES WITH WORKPLACES EXPOSED TO HIGH TEMPERATURES
COMMERCIAL	- RETAIL FOOD DISPLAY CASES - ICE MACHINES - VENDING MACHINES - DRINKING WATER COOLERS	- CHILLERS FOR OFFICES, AIRPORTS, CINEMAS, SUPERMARKETS, Etc. - UNITARY AIR CONDITIONING
TRANSPORTATION	- REFRIGERATED TRANSPORT IN GENERAL - FISHING VESSELS	ALL PASSENGER TRANSPORT SYSTEMS
DOMESTIC	- REFRIGERATORS - FREEZERS - DEHUMIDIFIERS	UNITARY AND ROOM AIR CONDITIONERS

In 1978 the chlorofluorocarbon consumption for these applications was about 42000 tons in Europe and 160000 tons in USA: the consumption has been mainly of CFC 12, with some use of CFC 22.

In a consideration of possible substitutes for chlorofluorocarbons for use in air conditioning and refrigeration, after a preliminary screening of about 20 compounds research is now restricted to very few products on which tests of long term biological activity are in progress. There is no industrial process available as yet for any of these products.

After chlorofluorocarbons the most commonly used fluid is at present ammonia which was once considered the best refrigerant.

Ammonia was generally substituted in refrigeration because of its toxicity, because of contamination of products after leaks, and because of the possibility of formation of explosive mixtures with air. To these well known facts must be added that use of CFC rather than ammonia generally means a lower consumption of energy per unit of refrigeration as has been shown in a study carried out by the Battelle Institute examining the possible energy consequences of a complete fluorocarbon ban in the USA. The final report quantifies, in terms of additional fuel oil consumption, the extra energy required by the best available substitute of CFC 12 and 22 in refrigeration and air conditioning as shown in Table 7.

TABLE 7
Global energy penalties using next best alternatives to chlorofluorocarbons in refrigeration, air conditioning and insulating foams (10^3 tons of fuel equivalent)

	1981	1990	DECADE
REFRIGERATION/AIR CONDITIONING	2130	22240	120500
INSULATING FOAMS	830	11400	55000
TOTAL	~ 3000	~34000	~175000

4.1.2 Foaming agents

We mean here the use of CFC in polyurethane, polystyrene and polyolefine foams, to improve insulation and lagging properties. In 1978, CFC consumption for these applications was 64000 tons in Europe and 60000 in USA; the foaming agents employed in these applications are CFC 11, CFC 12 and CO_2.

CFC expansion in this sector is because of their very low thermal transmission coefficients and also the desirable mechanical properties imparted to the final product. Foams obtained with CFC have insulating properties which are about double those induced by CO_2. The substitution of CFC in this field would involve major consequences in energy consumption as can also be seen in Table 7.

Therefore, in the refrigeration, air conditioning and insulation sectors the use of CFC effects a considerable energy saving. Table 7 shows the consolidated data of the Battelle Institute report.

Penalties estimated in terms of equivalent fuel oil consumption are relevant to USA only. In order to emphasise the practical meaning of the figures for the higher consumption calculated for 1990 assuming replacement of chlorofluorocarbons, it can be said that the 34 million tons extra of fuel oil are the equivalent of 9.5% of USA oil imports in 1978.

I must, however, emphasise that these penalties in terms of fuel oil relate only to operation of the equipment, i.e. the running costs and do not take into consideration the very high costs which would result from replacement of equipment presently operating with CFC or the modifications which would have to be introduced in the design of new equipment making it more expensive.

The need for the use of CFC in refrigeration, air conditioning and insulation, therefore, not only follows from considerations of safety but also from energy saving and rational utilisation both at present and in the foreseeable future. It would seem unthinkable to decrease applications which contribute to optimisation in the use of raw materials, energy and labour.

In conclusion, therefore, we can say that all factors relating to the use of CFC in these sectors make self restriction by industry very unlikely and possible restriction by law unreasonable.

To the contrary, we think it reasonable to believe that these products will develop more and more in the future, and this development seems very likely in view of the most recent studies of the effects (or rather non-effects) of CFC on the stratosphere.

4.1.3 Solvents

Chlorofluorocarbons employed in the solvent and industrial cleaning sectors belong basically to the 100 series.

The use is linked to developments of advanced technologies such as electronics, aeronautics and space research, and their growth rate could be substantial, of the order of 6% per year.

4.1.4 Fire extinguishers

On the market there are to-day three products which, complementing one another, cover together all sectors. Their growth rate is estimated at about 10% per annum.

4.1.5 New applications

There are forthcoming interesting applications for use in power generation for A22 and A114, in heat pump systems and in gas turbines.

4.1.6 Chlorofluorocarbons: conclusion

Summing up, we forecast a rather static situation, or a very slow increase in the market as shown in Table 8. This does not include CFC produced for fluoropolymer production, with which we shall deal later.

4.2 Fluoropolymers and other products

I have considered chlorofluorocarbons in detail because it is a critical subject, still under debate, mainly because of its ecological implications. I shall be less detailed in dealing with the other product-classes because here we are concerned with typical speciality products whose development is tied to the development of the relevant applications.

The present and future use of fluorinated compounds allows improvements of performance, safety, conservation, life-time service, and ecology. They also extend opportunities in the power, semiconductor and computer industries, and in biomedicine and agriculture.

TABLE 8

Estimated consumption of chlorofluorocarbons in W. Europe and USA, in 1979-87 (excluding CFC) used as intermediates for fluoropolymers

	1979 10^3T	1983 10^3T	1987 10^3T	AAG% 1979-87
W. EUROPE				
Aerosols	176	159	159	- 1
Refrigeration/air conditioning	43.5	51	60	4
Foam plastics	66.5	84	106	6
Solvent and others	27.5	36	45	6.3
Total	313.5	330	370	2
USA				
Aerosols	8	0	0	-
Refrigeration/air conditioning	175	210	245	4.3
Foam plastics	65	85	100	5.6
Solvent and others	44	55	65	5
Total	292	350	410	4.5

(The aerosol values for 1983 and 1987 were obtained by assuming: 1) for W. Europe, a maintenance of consumption levels of CFC 11 and 12 at 70% of the quantities used in 1976; 2) for USA, a reduction of consumption of all types of chlorofluorocarbons to a practically negligible level.)

Let us quickly go through the above fields and consider the applications of different classes of fluorine products (see Tables 9, 10, 11, 12 and 13: Appendix A gives a list of the abbreviations and their full-length equivalents).

TABLE 9

Fluorine chemicals and polymers for the power industry*

1	Nuclear power		F_2; ClF_3; UF_6; PTFE; PFOA (perfluoropolyethers)
2	Power distribution	- HV breakers	SF_6
		- Substations	
		- Transmission	
		- Insulation	
3	Solar energy cells	- Coating	PVDF; PVF; FEP
4	Petroleum alkylation		HF

* Does not include energy conservation (insulation, refrigeration and heat pumps), already considered in the chlorofluorocarbon section)

TABLE 10

Fluorine chemicals and polymers for the semiconductor and computer industries*

1	Ion implantation and sputtering	inorganic fluorides (PF_5, SiF_4, etc.)
2	Vacuum systems	PFOA
3	Vapour phase soldering (VPS)	perfluoroamines; PFOA
4	Magnetic disc and tape lubrication	PFOA
5	Wire coating	PVDF; FEP

* Does not include cleaning solvent, already considered in the chlorofluorocarbon section.

TABLE 11

Fluorine chemicals and polymers for biomedical applications

1	Artificial joints, arteries	PTFE; FEP
2	Synthetic blood plasma	Perfluoromethyldecaline
3	Extracorporal circulation	PFOA
4	Anaesthetics	Chlorofluorobromocarbons
5	Lubrication of oxygen systems	PFOA; PCTFE

TABLE 12

Fluorine chemicals and polymers for performance, safety, conservation, life-time service, ecology*

1	Frothing agents for chromium plating baths	Perfluoroalkane - sulphonic acids
2	Membranes for electrolytic cells	Perfluoropolymers carrying sulphonic acid groups
3	Coatings for industrial materials	PVDF; PVF
4	Longlife lubrication	PTFE; PFOA
5	Non-flammable hydraulic fluids, inert lubricants	PCTFE; PFOA
6	Leak detection, industrial X-ray instruments, atmospheric tracers for smoke plumes	SF_6
7	Anti-smog protection: stone impregnation	PFOA

* Does not include fire fighting chemicals, already considered in the chlorofluorocarbons section.

TABLE 13

Fluorine chemicals for various applications*

1	Dyes	Benzotrifluoride derivatives
2	Drugs	Inhalation anaesthetics Antineoplastic agents Steroids Anti-inflammatory agents Antibiotics CNS agents*
3	Agrochemicals	Trifluralin
4	Surface active agents	Functional fluoroderivatives Poly(fluoroacrylates)

* Central nervous system agents

Generally speaking, applications and potential developments of fluorine chemistry are well tuned to the new requirements of advanced economies and to the trends of new technologies. We have examined what I have referred to as "intrinsic reasons which justify their future evolution," and we expect, therefore, a much greater rate of growth for these products than for the general chemical industry.

In particular, Table 14 shows the projected trend of world demand for PTFE, and Table 15 the same for fluoroelastomers.

TABLE 14

Estimated PTFE consumption in the world 1979-87 (tons)

	1979	1983	1987	AAG % 1979-87
W. Europe	6200	7700	9500	5.5
USA	8100	9500	11100	4
Japan	2800	3500	4400	6
Others	2800	3800	5100	8
World total	19900	24500	30100	5

TABLE 15

Estimated fluoroelastomer consumption in the world 1979-80(tons)

	1979	1983	1987	AAG % 1979-87
USA	2000	2900	4250	10
W. Europe	830	1300	2000	12
Others	550	960	1600	15
World total	3380	5160	7850	11

5. NEW TRENDS IN RESEARCH

What should be the role of research on the future of fluorine chemistry?

I think that we can identify three main areas for intensive research:

Energy
Agriculture
Medicine.

5.1 Energy

Fluorine already plays an important role in nuclear technology; in the advanced systems for molten salt reactors and in reactors with laser induced melting (in molten salt reactors, the fuel can be dispersed in molten inorganic fluorides, improving the thermal conductivity and decreasing corrosion problems; in reactors with laser induced melting, the optical systems compounded with the fluorides give better performances).

Fluorides can contribute effectively in exploitation of solar energy (fluorinated polymer films, thanks to their low refractive index and to their high weather and U.V. resistance, can be utilised for lining solar collectors and cells, thus providing the considerable advantages of low reflective loss and of minimal dissipation for periods up to 20 years).

Furthermore, inorganic fluorides guarantee an effective solution to the problems of energy storage either in a thermal form at low and high temperatures (thanks to the high values of their heats of fusion), or in electrochemical form (in batteries with a solid electrolyte and fluorinated cathode).

Fluorinated organic compounds (chlorofluorocarbons and fluorinated oils) can be utilised for solar energy conversion into mechanical energy and for regenerating low temperature thermal sources.

5.2 Agriculture

A sector in which fluorine can continue playing an important role is agriculture.

Reconversion programmes of large uncultivated or virgin lands for selective cultivation require specific agents for eliminating weeds and pests. Research in this sector must be directed towards the identification of specific products in order to eliminate the risk of interference in the natural biological cycle.

5.3 Medicine

Considerations similar to those for agriculture occur in the field of human health. In this context fluorine forms compounds specific against many diseases or against the vector insects of epidemic diseases.

Long term systematic research should produce low cost specific action compounds with limited side effects (such as have been obtained with the fluorine derivatives of benzoylphenylurea-DIMILIN, of Philips-Duphar).

5.4 Industrial research

Finally, special attention must be paid to the improvement of synthetic processes. For example, it is necessary to continue to improve the electrochemical preparation of fluorine, minimising the energy loss due to anodic processes; to improve the flexibility of CFC technologies (for example, interconversion among the series 10, 20, 100), and to improve the syntheses of the principal monomers. Great attention must be paid to processes for selective fluorinations.

In the polymer sector, further studies will be dedicated to processes capable of obtaining chemical structures where the fluorinated unit alternates with a hydrogenated unit or is implanted on a hydrogenated chain in ways such as to add to conventional structures specific surface and electronic properties typical of fluorine-containing compounds.

The application potential of the well known polymer structures has been explored only in part; applied research will possibly find new fields of application.

5.5 Organisation

Because of the great breadth of the subject, the difficult nature of the research and the high level of specialisation required, both in human and instrumental resources, a very high financial effort would be required for the realisation of these programmes.

To open up, in a reasonable time span, the unexploited potential of fluorine chemistry, generally requires efforts beyond those available to single organisations or industries.

In order to achieve the different goals which I have mentioned, the decisive condition must be the optimisation of interdisciplinary structures; this will be made possible only by means of closer co-operation between Universities and Industry in basic and applied research and technological forecasting, in addition to training of specialists. This co-operation will allow the exploitation of specific skills within the sectors of structural research, analytical research and of application and process development. The cost of this development must be counterbalanced by an effort in rationalisation to minimise waste, overlap of function and redundancies.

6. CONCLUSION

How to sum it all up?

The chemical world is facing a crisis, and the chemical industry is already paying a high penalty for over capacity. A new class of chemicals has been created which not only has withstood this crisis exceptionally well, but seems destined to play a key role in the technologies of the future. Fluorine compounds can replace traditional materials in applications which up to now have been barred to other synthetic products; they give long life and maintenance-free service, they allow use of high and sophisticated technology which would otherwise be impossible to realise; they can substitute current products improving efficiency and safety.

By their properties these new chemicals contain in themselves the reasons which justify a more and more massive development and widespread success.

You and your predecessors have created this new class of products, other chemists and technologists have used the basic inventions to enable the chemical industry to make new products available to industry at large and to the consumer.

I wish to you and to industry that this symposium will make further contributions to this exciting and successful venture.

APPENDIX A

Legend

PTFE = Polytetrafluoroethylene

PVDF = Polyvinylidene fluoride

PVF = Polyvinyl fluoride

FEP = Fluorinated ethylene-propylene copolymer

ETFE = Ethylene-tetrafluoroethylene copolymer

ECTFE = Ethylene-chlorotrifluoroethylene copolymer

PCTFE = Polychlorotrifluoroethylene

PFA = Tetrafluoroethylene-perfluoroalkylvinyl ether copolymer

Fluoroplastics processable by injection moulding, extrusion (contrast to PTFE) etc.

PFOA = Perfluoropolyethers (Fomblin)
