Kent and Riegel's

HANDBOOK OF INDUSTRIAL CHEMISTRY AND BIOTECHNOLOGY

ELEVENTH EDITION

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HANDBOOK OF INDUSTRIAL CHEMISTRY AND BIOTECHNOLOGY

Volume I

ELEVENTH EDITION

Edited by

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To my Wife
ANITA

Preface

The central aim of this book is to present an up-to-date account of the science and engineering and industrial practice which underlie major areas of the chemical process industry. It attempts to do so in the context of priorities and concerns which characterize the still early days of the new millennium and, perhaps more important, it provides various tools for dealing with those factors through, for example, an extensive discussion of green engineering and chemistry and related topics. The heart of the book is contained in twenty eight chapters covering various areas of the chemical process industry. It is to be noted that the products and processes associated with a particular area are discussed in the context of the corresponding chapter rather than in the isolated manner characteristic of an encyclopedia.

This work, Kent and Riegel's Handbook of Industrial Chemistry and Biotechnology, is an outgrowth of the well known Riegel's Handbook of Industrial Chemistry, the last edition of which, the tenth, was published in 2003. It follows the essential arrangement of earlier versions, i.e., several chapters devoted to general or "infrastructure" topics, with most of the book being given over to the various areas of the chemical process industry. However, this version introduces a wealth of new, timely, and very useful "infrastructure" material, and greatly enhances the process industry content. (The latter is most noticeable in this book by increased emphasis on biotechnology, although all of the chapters have been reviewed and updated as necessary by their respective authors.) In keeping with past practice, all of the new chapters have been written by individuals having demonstrated expertise in their respective fields. All told, the work may in many respects be regarded as a sourcebook for practice in the chemical process industries.

Concerning the infrastructure or contextual material mentioned above, the Handbook contains three new chapters which lie in the area often referred to as "green chemistry". The first and most comprehensive of these is titled Green Engineering: Integration of Green Chemistry, Pollution Prevention and Risk Based Considerations. It provides an excellent guide for applying the methods of green chemistry and engineering to process and product development activities, whether for new products and processes, or for upgrading older ones. Written by a team of experts in the field, the chapter can be of enormous help to all practicing chemists and chemical engineers, as well as to students studying in either discipline. Another new chapter, Industrial Catalysis; A Practical Guide, is a valuable adjunct to the "Green" chapter since catalysis is an important aid in the practice of Green Chemistry. The third new chapter in what might be termed the "green" group is Environmental Chemical Determinations.

Succinctly put, *green chemistry,* also termed *sustainable* chemistry, is described by that chapter's authors, as "the use of chemistry to reduce pollution at the source, through the design of chemical products and processes that reduce or eliminate the use or generation of unwanted or hazardous substances." *Green engineering* is defined as "the design, commercialization, and use of processes and products that are feasible and economical, yet at the same time minimize 1) generation of pollution at the source, and 2) risk to human health and the environment." Risk assessment methods used in pollution prevention can help quantify the degree of impact for individual chemicals and thus is a valuable tool for intelligent design of products and processes by focusing on the most beneficial methods to minimize risk.

Even a superficial look at the literature on green chemistry shows that catalysis is regarded as a very important tool. After all, if in the idealized case one can produce desired product B from A, with no unwanted side reactions or by-products, by choosing appropriate reaction conditions and a suitable catalyst, one will have done a great deal to promote efficiency and prevent pollution. Therefore, another of the new chapters, Industrial Catalysis, a Practical Guide, is of special relevance. Finally, this particular portion of the new material is rounded off with the chapter Environmental Chemical Determinations, which discusses the many complex factors involved in detecting, tracking, and measuring chemical species which have found their way into the environment.

Additional chapters in the grouping broadly referred to as infrastructure include the new Recent History of the Chemical Industry: 1973 to the Millennium: and an update of the chapter titled Economic Aspects of the Chemical Industry, in which some of the material extends information provided in the former. Rounding out the infrastructure group are yet another new chapter Nanotechnology: Principles and Applications, together with the earlier ones which cover such diverse and fundamental topics as process safety, emergency preparedness, and applied statistical methods.

Biotechnology first appeared in the Riegel's Handbook some time ago as a chapter titled Industrial Fermentation. It has since been updated several times and more recently was joined by a chapter on Industrial Cell Culture. For this Handbook, the biotechnology content, rather than being updated, has undergone a major reorganization, including revision of content and emphasis. The former fermentation chapter has become two which are titled, respectively, Industrial Biotechnology: Discovery to Delivery, and Industrial Enzymes and Biocatalysis. This revision was accomplished by two teams from a major biotech company and thus reflects that background. It is informative to interpose at this point a statement (edited) by the authors of the first of these two chapters. They describe it thus: *"The chapter uses an approach to integrate gene discovery, functional genomics, molecular evolution and design, metabolic pathway engineering, and production processes including formulation of delivery systems. The chapter walks the reader through biomolecule discovery, development and delivery, by starting from screening millions of natural and designed gene variants in the mountains of DNA sequences available today. Also included are several state-of-the-art examples of purposeful modifications of cellular metabolism, and descriptions of unit operations and unit processes which link the upstream and downstream technologies to manufacture biochemicals, enzymes, peptides, and other products on an industrial scale. "Commercializing new bioproducts is a complex, time consuming process, and therefore an integrated biotechnology approach is necessary. It is the authors' hope that the chapter will help readers learn how to design and produce biotechnology products rapidly and successfully."* Revision of the cell culture chapter was accomplished by a team from another biotech company. The new title, Industrial Production of Therapeutic Proteins: Cell Lines, Cell Culture and Purification, reflects its new content and orientation. Also, as might be expected by persons knowledgeable in the field, the chapter Animal and Vegetable Oils, Fats and Waxes is rich in related biotechnical content, as is effectively described in the chapter's early pages.

Finally, addressing an area of great interest in connection with world energy needs, we have added a chapter in a related area, Biomass Conversion. Written by a team whose primary work lies in that area, it provides comprehensive coverage of the subject from biomass structure and composition to thermochemical and biological routes for conversion to energy and a host of chemicals and products including liquid transportation fuels. This chapter defines the opportunity for using sustainable sources of biomass as feedstock for new refineries that will produce fermentable sugars and chemical intermediates from which much needed forms of fuels can be made.

As mentioned earlier, the crux of the Handbook comprises twenty eight chapters which are devoted to various areas of the chemical process industry. This information, together with supporting "infrastructure" material described above, viz., process safety, emergency preparedness, statistical methods, green engineering and chemistry, provides *in toto* many sophisticated and useful tools to aid in the design of new products and processes and for study and evaluation of older ones. The handbook should prove useful also to individuals who possess a background in chemistry or chemical engineering and work in related areas such as regulatory agencies and environmental organizations. Among other benefits, it will help ensure that the work of such individuals reflects knowledge of relevant contemporary science and engineering and industry practices. Reflecting new realities in the world energy situation, this edition also includes a chapter titled The Nuclear Industry.

Individuals who have responsibilities in the chemical process industries are usually engaged, consciously or otherwise, in continually reviewing their operations to ensure that they are safe, efficient, and in compliance with current environmental regulations. They are also, or should be, anticipating future needs. It is hoped that the information contained herein will provide the wherewithal by which chemists, chemical engineers, and others who have a peripheral interest in the process industries, for whatever reason, can ensure that they have touched every base, dotted every *i*, and crossed every *t* in their quest to make the processes and products for which they are responsible as environmentally sound, safe, and efficient as possible.

Because of the scope of the book and the large number of products and processes it covers, some redundancy is inevitable. For example, more than one chapter includes discussions of gasification and hydrogen production. However, there are significant differences in emphasis in the various discussions. Thus, rather than distract readers by referring them to information in locations other than the one of their primary interest, such topics have been left intact in the context in which they are discussed.

As in all the earlier versions of this work for which I have been privileged to serve as designer and editor, I am happy to acknowledge again the unselfish and enthusiastic manner in which the contributing authors have shared their knowledge and insights so that many others may learn and still others may benefit. The picture of a bit of knowledge, acting like a stone tossed into a quiet pond, spreading the result of the impact ever more widely, is, I think, apt. There is a saying that knowledge is power, and the authors who have contributed their knowledge and expertise to this work are pleased to have had the opportunity to empower others. All have been unstinting in their efforts to make their contributions as complete and informative as possible, within the space available, and I am indeed humbled and honored to have had a part in bringing it about. Needless to state, errors of omission and shortcomings in organization are mine.

Grateful acknowledgement is made to the publishing houses and technical/scientific organizations for permission to reproduce copyrighted illustrations, tables, and other materials, and to the many industrial concerns which contributed drawings, photographs, and text material. And finally, I wish to express my thanks to Springer editor, Dr. Kenneth Howell, for his many helpful suggestions and support along the way, and for leveling several bumps on the road to publication.

James A. Kent
Morgantown, West Virginia USA

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Volume II

1

Recent History of the Chemical Industry* 1973 to the Millenium: The New Facts of World Chemicals Since 1973

Fred Aftalion

I. OVERCAPACITIES AND THE SEARCH FOR REMEDIES

The first oil shock that occurred at the end of 1973 with the Yom Kippur war served to pinpoint the crisis which world chemicals were already undergoing.

The chemical industry's soaring development after the war was due to the extraordinary burst of innovations occurring between 1935 and 1955 and coinciding with an explosion of world demand in a variety of sectors served by chemicals. Production units multiplied in Europe as well as in the United States and Japan.

Two other factors contributed to this rapid growth. The use of oil as a substitute for coal provided the chemical industry with abundant, cheap raw material that was easy to transport. With interest rates lagging behind the rate of monetary erosion over a number of years, industry leaders were tempted to carry out investments that they would not have made had currencies remained stable and interest rates higher. The fear of these leaders that competition would get the better of them if they slowed down their investments, the race for market shares advocated by a number of consultant firms like the *Boston Consulting Group*, the belief—quite widespread among world chemicals leaders—that they had to keep building new units to keep up with forecast needs, all had a share in building up production overcapacities which were already becoming apparent before 1973 in certain sectors of heavy chemicals (petrochemicals, synthetic fibers, thermoplastics, and fertilizers).

The establishment of an OPEC cartel that led to a rise in the price of a barrel of crude oil from $3 to $12, then the 1979 Iranian

*This chapter consists of two chapters taken from a book by Dr. Fred Aftalion. *A History of the International Chemical Industry*, Second Edition, translation by Otto Theodor Benfy, Copyright © the Chemical Heritage Foundation, Philadelphia, PA (2001). This material is reprinted by permission of the copyright owner and Fred Aftalion. All rights reserved. The book traces the development of the Industry from its earliest days, describing the activities of the pioneers of chemical science and the entrepreneurs who built on their work to create the chemical industry as we know it. Space limitations permit the inclusion of only Chapter 6. "World Chemicals Since 1973," and Chapter 7, "The Period of the 1990s." Noteworthy changes that have occurred in the industry since 2000 are mentioned in the following chapter, "Economic Aspects of the Chemical Industry."

Revolution which made it soar to $40, and finally the publication of the gloomy forecasts of the Club of Rome experts which mistakenly saw oil shortages ahead when, in fact, these had been artificially engineered by the Cartel members—all these facts upset chemical leaders in industrialized countries. And yet some of them still continued to invest in new plants during the stock-building lulls that occurred in 1974 and 1979 through consumers' speculating on new price rises.

This only made the necessary adjustments much harder when they had to be carried out at the beginning of the 1980s. Companies were to suffer greatly from an error of judgment, building new plants at great expense at the same time that economic growth rates tumbled from over 10 percent to a mere 2 to 3 percent. Caught between the increasing cost of their hydrocarbon raw materials and the ever-lower prices they had to use to sell their products in markets where offer exceeded demand, leading chemical companies in industrialized countries were forced to go through agonizing reappraisals.

This led them to act in a number of different directions. First and foremost, they had to lower their operating costs by cutting down on excess personnel and taking the measures needed to increase the productivity of each company. At the same time, they had to reduce, in a concerted way if possible, the overcapacities affecting the hardest-hit sectors. Finally, it seemed advisable to redirect production into areas that were less sensitive to economic change. This meant increasing the share of specialties in relation to commodities in overall turnover.

A new generation of leaders was called upon to carry out the socially painful and politically delicate job of rationalizing and restructuring the chemical industry through layoffs and plant closures. These same leaders were also given the more exalting, but just as difficult, task of defining the redeployment strategy that needed to be followed and of determining on a case-by-case basis the sectors that should be abandoned and those that, on the contrary, had to be invested in force.

By 1973, it was obvious that the chemical industry had reached a degree of maturity to the extent that all the companies involved in that area in industrialized countries were long established and that no discovery likely to affect its development had been made over the last two decades. While new areas of research like composite materials and biotechnologies had emerged, no immediate fallout was expected for a number of years. Thus failing any rapid internal growth brought about by major scientific breakthrough, the strategy of leaders anxious to refocus or diversify their portfolio of activities very often consisted of a kind of Monopoly game, as a range of production was shifted from one enterprise to another without anything new being created.

THE RESTRUCTURING OF SECTORS IN DISTRESS

Priority action was required in petrochemicals, in the large thermoplastics, in fertilizers, and in synthetic fibers where the most serious investment mistakes had been made. The hardest cases were those of *petrochemicals* and *thermoplastics*. For one thing, a steam cracker cannot technically operate under 60 percent of its capacity. For another, the products that emerge are linked to one another in almost invariable proportions. Finally, a polymerization unit cannot have its pace slowed down without this affecting the upstream monomer unit to the same extent.

In addition to such rigidities, there was the need to reduce not only the quantities produced but also the number of production units. The problem then arose of sharing the sacrifices among the different producers within an economic area.

The problem was most easily solved in Japan because of the discipline which MITI managed to establish within the country's petrochemical industry. Making the most of a new law that allowed competing producers to act in concert, a cartel was set up with the object of cutting down ethylene production. Four groups of petrochemical producers were formed within which the necessary arbitrations took place. This led Sumitomo to close its Niihama units, Mitsubishi a number of its

Mizushima plants, and Showa Denko two of its Ohita installations.

At the same time, producers reached agreements on cutting down competing PVC and polyolefin sales networks, while MITI authorized the import of naphtha through an organization consisting of Japan's petrochemical producers. Its price served as a marker for naphtha produced in Japan.

In Europe, of course, it was difficult to show such disregard for market laws. The views of the European Economic Community Commission in Brussels had to be taken into account, and they upheld the principle of free competition as set down in article 85 of the Rome Treaty. Moreover, in Western Europe there were a number of petrochemical industries that operated according to the rules of private capitalism while there were others, as in France, Italy, Austria, Norway, and Finland, that were state-controlled and more concerned about retaining market share than ensuring profitability.

Despite such obstacles, unilateral decisions were taken and bilateral arrangements carried out among firms, leading to some measure of production rationalization. Between 1980 and 1984, twenty-five ethylene and eight polyethylene units were scrapped in Western Europe while ethylene oxide capacities were reduced by 10 percent.

The 1983 agreement between ENI and Montedison put some order in Italy's chemical industry, as ENI took over the PVC and polyethylene operations of Montedison. Previously in France, Rhône-Poulenc had sold its petrochemicals division and its thermoplastics to the Elf Aquitaine group. At the same time, steam crackers were being shut down in Feyzin and Lavera, and a vinyl chloride unit in Jarrie. The association between BP Chimie and Atochem in polypropylene and the exchange of Atochem's Chocques unit for ICI's Rozenburg polyethylene unit were other instances of rationalization.

The Brussels Commission also gave its approval to three large-scale operations: the ICI and BP Chemicals exchange of polyethylene/PVC, the vertical integration of vinyl chloride involving AKZO and Shell Chemicals, and the recent Enichem and ICI association, which produced European Vinyls Corporation and was intended to lead to major capacity cuts in PVC.

In West Germany, rationalization measures were less spectacular because the heads of Germany's leading chemical companies had not waited for the crisis to delineate their respective fields of operation and to establish close links with international oil companies, either through long-term supply contracts or through parity associations.

A number of American companies became involved in restructuring. Union Carbide sold its Antwerp site to BP Chemicals; Monsanto, its Seal Sands acrylonitrile unit to BASF; Esso, its Stenungsund steam cracker to Statoil; while Hercules joined up with Montedison to set up the Himont company, which accounted for 20 percent of the world polypropylene market.

In the *United States* the petrochemical industry set its house in order along purely capitalistic lines. Each company involved acted alone for fear of infringing antitrust legislation and the main concern was to restore profitability. Unlike Du Pont, which acquired Conoco, other chemical companies tried to get rid of their petrochemicals. Hercules sold its DMT units to Petrofina, and subsequently its 40 percent stake in Himont to Montedison, while Monsanto was shedding its Texas City petrochemical site.

Major divestments took place, particularly in the major thermoplastics, which were taken over by individual entrepreneurs who bought up the units the chemical giants wished to get rid of. As Hoechst, Union Carbide, Du Pont, Monsanto, ICI, and USS Chemicals withdrew from a number of the major oilbased intermediates as well as from polystyrene, polyethylene, and PVC, a number of large, hitherto unknown companies emerged: Huntsman Chemical, El Paso Products, Aristech, Vista Chemical, Sterling Chemicals, and Cain Chemical.

At the same time, oil companies were integrating downstream petrochemicals and polymers. Such was the case of Occidental Petroleum, which through its chemical subsidiary Hooker (later Oxychem) bought up

Tenneco and Diamond Shamrock's PVC in 1986, becoming the largest American producer in this area. Likewise, BP Chemicals fully acquired its subsidiary Sohio. The long-standing petrochemical divisions of the large oil groups returned to profits in 1986 after some painful tidying up but no agonizing reappraisal, helped along by falling oil prices and dollar rates.

Most of them had cut down on operating costs and diversified to the point at which they were able to face up to the economic ups and downs without too much apprehension. Productivity improvements and a better utilization of existing capacities because of higher demand put Exxon, Mobil, and Texaco on the way to prosperity in petrochemicals in 1986.

Standard Oil of California added the petrochemicals of Gulf Oil, purchased in 1984, to its subsidiary Chevron Chemical. Other United States petrochemical producers took advantage of special circumstances. Amoco was served by a strong terephthalic (TPA) base and its good performance in polypropylene; Arco, by its Lyondell subsidiary in Channelview, Texas, and by its development of the Oxirane process through which propylene oxide could be produced by direct oxidation with styrene as a coproduct. The process also led to MTBE (methyl tertiary-butyl ether), the antiknock agent used as a substitute for tetraethyl lead.

Even Phillips Petroleum, badly affected by Boone Pickens' takeover attempt, managed to make substantial profits from its petrochemicals because of drastic restructuring. New prospects were also opening up for the United States chemicals industry as needs grew for butene and hexene comonomers used to produce linear low-density polyethylene (LLDPE), also as consumption of higher olefins to prepare detergent alcohols increased and as demand for MTBE used as a gasoline additive soared.

The problem of overcapacities in *chemical fibers* in each economic region was both easier to overcome because of the small number of producers and more complicated because of outside factors. In *Europe*, producers suffered heavy losses from 1973 onward. For one thing, the Europeans were not particularly suited to manufacture chemical fibers at satisfactory cost, a fact that was proved by growing imports from Southeast Asia. For another, the capacity increases decided upon did not tally with any comparable increase in demand in the foreseeable future.

In view of such imbalance, one might have thought that a number of producers would withdraw from the market. But this did not happen because some of them had to heed government instructions to maintain employment. Also textiles accounted for only a share of the business of the companies involved and could be kept up through the profits generated in other areas. From 1978 to 1985 two agreements were implemented with the blessing of the European Economic Community Commission. The first aimed for a linear reduction of existing capacities; the second and more important one allowed each producer to specialize in those areas where it held the best cards, giving up what amounted to marginal productions.

Thus Courtaulds withdrew from polyester and from Nylon to concentrate on its acrylics and cellulose fibers; ICI focused on Nylon and Bayer on acrylics; Rhône-Poulenc withdrew from acrylics but revamped its Nylon and polyester units well-integrated in upstream intermediates; Montedison decided in favor of polyester and acrylics; AKZO focused on polyesters and on aramide fibers while keeping up its profitable rayon sector. Such efforts, which aimed to reduce European chemical fiber capacities by 900,000 tons and to increase productivity through specialization, undoubtedly corrected the situation.

Nonetheless, European producers are still faced with two kinds of competition: first imports of synthetic fibers from Turkey, Taiwan, South Korea, and Mexico, against which it is hopeless to expect that the multifibers agreements —which contravene GATT rules—will constitute a permanent obstacle; and second, imports of natural fibers such as cotton, for which prices have fallen spectacularly in recent times.

The Japanese solution to chemical fiber overcapacities naturally involved MITI which pushed through a 17% cut in existing polyester, Nylon filament, and acrylic fiber capacities between 1978 and 1982. These were linear cuts, however, and did not restrict the range of synthetic fibers developed by each producer, contrary to the specializations that marked the second stage of Europe's approach.

The United States was faced with an additional problem because its market remained wide open to textile imports from developing countries. These imports constituted an indirect threat to American producers of chemical fibers. Their first reaction was to reduce their bases in Europe. Du Pont closed its acrylic units in Holland in 1978 and in Northern Ireland in 1980; the following year it ceased production of polyester thread in its Uentrop unit in Germany. Monsanto did likewise in 1979, shutting down its Nylon units in Luxembourg and Scotland and selling its acrylic fiber installations in Germany and Ireland to Montedison.

In the United States itself, capacity cuts were not so substantial and the 1983 upturn boosted utilization of remaining units to 80 percent of their capacities. Major American producers such as Du Pont, Celanese, and Monsanto returned to satisfactory profit margins. Other companies for which fibers were not an essential sector withdrew from this area. Chevron Chemical, for instance, shut down its Puerto Rico Nylon and polypropylene fiber units between 1980 and 1982 as well as the polypropylene fiber unit in Maryland.

The *fertilizer* market was in no better shape than the petrochemicals and chemical fibers markets, for world producers had largely allowed supply to exceed demand.

The situation in this area was further complicated by the unequal distribution worldwide of the raw materials required to produce fertilizers and the special attention which governments bestowed on agriculture. Such attention had led to a surfeit of production units and their increasing control by governments, either directly through taking a stake in the companies concerned, or indirectly through establishing ceiling prices for home sales or export subsidies. The emergence of new producers in Eastern countries and in developing areas increased the share of state-controlled companies in world production from 30 to 64 percent for ammonia, from 40 to 65 percent for potash, and from 10 to 46 percent for phosphoric acid between 1967 and 1986.

In Western Europe, nitrate fertilizer producers had deemed it expedient to set up a cartel arrangement for exporters called Nitrex. But the collapse of demand in countries outside its area had prevented it from functioning properly, sparking a fight for market shares even within the community.

As a country like Morocco switched from its long-established role as phosphate exporter to downstream ammonium phosphate and superphosphate integration, traditional fertilizer producers were forced to reappraise their strategy and take severe rationalization measures.

Japan which had none of the required raw materials and, accordingly, had high production costs, began, as early as the 1970s, gradually to cut down capacities along the lines jointly agreed upon by the authorities and the five main Japanese producers of nitrate and phosphate fertilizers.

In *Europe*, the pressure of events disrupted the whole market as the number of producers was drastically reduced. Because of market proximity, production both from Eastern Europe of nitrates and from Africa of superphosphates were becoming dangerously competitive. Supply conditions for natural gas varied according to each country's policies. France, for instance, agreed to pay extra for Algeria's gas, while Holland's Groningen gas, which Dutch ammonia producers were getting at a very favorable price, was linked to the price of petroleum products. On the other hand, a number of Scandinavian state-controlled companies like Norsk Hydro and Kemira, were pushing ahead with ambitious fertilizer programs, taking advantage of their interests in North Sea oil or of the conditions under which they were being supplied with oil and gas from the Soviet Union.

Between mergers and acquisitions, the structure of the fertilizer industry in Western Europe was spectacularly pared down. A few giants emerged to dominate the market. In France, there was CdF Chimie, later to be known as ORKEM, which had just taken a 70 percent stake in Air Liquide's subsidiary La Grande Paroisse, and Cofaz, which was taken over by Norsk Hydro; in Western Germany, there was BASF and Ruhr Stickstoff; in Britain, ICI and Norsk Hydro, which bought up Fisons; in Italy, ANIC and Montedison's subsidiary Fertimont; in Holland, DSM's UKF and Norsk Hydro NSM; in Finland, Kemira, which took over both Britain's Lindsay and its Kesteven facilities.

But the scene has not yet become sufficiently clear, since the competing companies do not all enjoy, within the community, the same raw materials supply conditions, and Europe is still open to imports from other countries that do not apply the rules of market economy.

In the *United States*, the situation was in many ways different. With its large sulfur, natural gas, phosphate, and even potash resources, America's fertilizer industry rested on a sound base. It was an exporter of minerals and fertilizers, and did not have to worry to the same extent as Europe's industry about competing imports from Socialist countries. But reserves of sulfur extracted by the Frasch process have been depleted in Louisiana and Texas, and President Ronald Reagan's "payment in kind" (PIK) farm-acreage cuts reduced the fertilizer requirement of American farmers. These farmers are also much in debt and are having trouble selling their products on saturated markets.

Consequently, very little money has been sunk into extracting phosphate rock in Florida or in increasing nitrogen fertilizer capacities, for a new ammonia and urea unit can cost as much as $250 to $500 million to build in the U.S., depending on the state of the existing infrastructure.

With such dim market prospects, it is understandable that W. R. Grace has decided to shut down its Trinidad ammonia unit, or that a company as large as International Mineral Chemicals has tried to diversify through purchase of Mallinckrodt and has put half its fertilizer assets up for sale.

THE NATIONALIZATION OF FRANCE'S CHEMICAL INDUSTRY

When a left-wing government came to power in 1981, France's chemical industry was in dire straits judging from the losses of the major groups: CdF Chimie was losing 1,200 million francs; Péchiney Ugine Kuhlmann 800 million francs; Rhône-Poulenc 330 million francs; Chloé Chimie 370 million francs; Atochimie 130 million francs; and EMC 100 million francs. Admittedly world chemicals were in poor shape. But while French leaders were posting losses amounting to 7 to 10 percent of their turnover, Hoechst and BASF were still making consolidated profits that year of 426 million DM and 1,290 million DM, respectively, even though they had noticeably slumped.

There were many reasons, some of them old, for the difficulties of France's chemical industry as illustrated by losses of 7 billion francs in seven years—4 billion francs in 1981 alone. Caught between increasingly heavy charges and price controls on the home market, France's chemical entrepreneurs never managed after the war to achieve sufficiently profitable margins. They ran up high debts to make up for their lack of funds, building up ever heavier financial costs.

A further disadvantage of France's chemical industry was its scattered production sites, originally due to the need during the two World Wars to keep plants far from the battlefields. For both social and political reasons, it was inconceivable in France to have a site like BASF's Ludwigshafen where 52,000 people are concentrated on six square kilometers with three thermal power plants and countless production sites. The first concentrations which President Georges Pompidou sought to carry out had not changed things much, neither had they cut down increased operating costs. Indeed, the leaders of merged companies had not cared at the time to close sites down and reduce personnel, two moves that might have improved the performance of the new groups.

Although the state spent considerable sums for chemical research, particularly through CNRS and the universities, the fallout for industry was scarce because of the persistent lack of communication between industry and those doing research.

The research and development sectors of the companies themselves made few breakthroughs, so that the chemical industry had to rely for a large part on foreign technologies, a fact that left little room for maneuver.

In addition to the difficulties inherent in their environment, France's companies also suffered the effects of bad management decisions in specific areas. Rhône-Poulenc had been badly prepared for the chemical fibers slump and had sunk too much money in heavy chemicals. These did not fit in with the group's original calling, as its leaders demonstrated when they withdrew, at the height of the crisis, from petrochemicals and the base thermoplastics, concentrating on specialties. The purchase of GESA from PUK in 1978, of Sopag the following year from the Gardinier brothers, and the sale of Lautier were hardly fortunate decisions for a group that could draw no advantage from getting further into fertilizers and that could have diversified to good purpose on perfumes through Lautier.

PCUK had never managed to strengthen Francolor's international base to good purpose and had finally sold it to ICI. Also, it wasted a lot of money in belatedly trying to develop a PVC chain. In 1981, PCUK was negotiating with Occidental Petroleum the sale of its chemical division, which had long since ceased to be of interest to the group's leaders.

At no time since it was set up was CdF Chimie master of its destiny, subject as it was to political pressures rather than economic rationality. Constantly in the red despite a number of worthwhile activities, it received the final blow when the untoward decision was taken in 1978 to build, on borrowed money, a one-billion-franc petrochemical site in Dunkirk in the framework of Société Copenor set up in joint venture with the Emirate of Qatar.

Elf Aquitaine had established under Sanofi a small conglomerate with profit-making subsidiaries involved in pharmaceuticals and perfumes. But Atochem, set up on a joint basis by Total and Elf, was a loss-making concern, as was Chloé Chimie, a cast-off of Rhône-Poulenc, which retained only 19.50 percent of its capital, while Elf and Total each acquired a 40.25 percent stake in the new chemical entity.

EMC was more a mining than a chemical company. It focused on potash, having restricted its diversification to the purchase of the animal food company Sanders and to a subsidiary in Tessenderloo, Belgium.

It was in this environment that the nationalization measures decided upon by the new Socialist government took place. The state took control of 40 percent in value of production of commodity chemicals and 70 percent of petrochemicals in France, an event that had no precedent in the free world's industrial countries.

Société L'Air Liquide, which figured as one of the companies to be nationalized on the initial Socialist list, escaped this fate, no doubt because the disadvantages of taking over this star multinational had been pointed out to the President of the Republic by one of his brothers, who was adviser to the group. On the other hand, Roussel-Uclaf, which had never needed state funds, found the government partly in control of its capital in addition to the main shareholder Hoechst.

Short of the extreme solutions advocated by some Socialists in favor of a single French chemical entity, the nationalized part was cut up along the lines announced by the Ministry of Industry on November 8, 1982. The restructuring signaled the death of PCUK as an industrial enterprise. Its various sectors were shared out among the other state-controlled groups. Most favored was Rhône-Poulenc, which received the agrochemicals and pharmaceuticals sectors with Sedagri and Pharmuka as well as the Wattrelos and La Madeleine sites in the north of France, together with a plant in Rieme, Belgium. At the same time, its fluorine division was boosted. The lion's share went to Elf Aquitaine with what amounted to two-thirds of PCUK's turnover, including, in particular, the halogen and peroxide products.

Complex negotiations with Total (Compagnie Française des Pétroles) ended with the group's withdrawing from Atochimie and Chloé Chimie, after which Elf Aquitaine set up its Atochem subsidiary to encompass all its chemical activities. After a long and brilliant independent career, Rousselot was split between Atochem and Sanofi.

Already sorely tried, CdF Chimie came out the worst from the restructuring. It inherited the Oxo alcohols and organic acids of the Harnes unit and had to call upon Esso Chimie to ensure their survival; it also got an ABS unit that was too small, which it exchanged with Borg Warner for a 30 percent share in their European subsidiary company—the Villers Saint-Paul site, which could become profitable only with the help of the industries to be set up there; the polyester resins division of the Chauny unit, and the downstream activities of the Stratinor subsidiary, both open to stiff competition. Among the lot there were some profitable sectors, however, such as Norsolor's acrylics, well integrated on the Carling site, and Société Lorilleux, a small ink multinational of PCUK's. But CdF Chimie was left to manage the difficult fertilizer sector swollen by Rhône-Poulenc's and EMC's divestments (GESA and APC), as well as a petrochemical branch set off balance by the unfinished Dunkirk site. As for EMC, all it got from PCUK was the historic site of Loos, which nevertheless served to boost its chlorine and potash divisions.

This enormous restructuring job, no doubt, did produce chemical groups with sounder bases and a more promising future. But the financial cost to the country was considerable, for not only were the shareholders refunded with public money to compensate for nationalization, but the companies that were now state-controlled had to be bailed out: their losses in 1982 were even higher than those registered the previous year. Just as high was the social cost. Manpower cuts which the former company leaders had been loath to carry out had become not only absolutely necessary but also easier to implement by a leftwing administration.

RESTRUCTURING IN ITALY AND SPAIN

As was to be expected, the path to overcapacities aided by state subsidies had brought *Italy's chemical industry* to the edge of the precipice. In 1981, SIR and Liquichima, on the brink of bankruptcy, had been taken over by ENI, the state-controlled oil group whose own chemical subsidiary ANIC was also losing considerable sums of money. Montedison had been able to show balanced books only once in ten years, in 1979. Its debts had soared to $2 billion in 1984.

The rather belated restructuring measures consisted, in their first stage, in the sale of the state's 17 percent share in Montedison to private interests. Then Italy's petrochemicals and plastics companies were shared out between Montedison and ENI's chemical subsidiary Enichem.

These two groups then set out to concentrate their efforts on polyesters and acrylics in the fibers area. At the same time, Montedison gave up control of SNIA Viscosa, specializing in polyamides, to Bombrini-Parodi-Delfino (BPD). The restructuring, carried out together with manpower cuts and unit shutdowns, made it possible for Montedison in 1985 and Enichem in 1986 to post operating profits after long years in the red. Enichem received a further boost from association with ICI in PVC and with BP and Hoechst in polyethylene, for it had emerged from the restructuring in a less favorable position than Montedison because it was still saddled with commodity chemicals.

Montedison, now 45 percent owned by the Ferruzzi sugar group, reinforced its strategic sectors by purchasing Allied-Signal's fluorine polymers through its stake in Ausimont, by fully acquiring the Farmitalia and Carlo Erba pharmaceutical subsidiaries, and by buying from Hercules its 50 percent share in Himont, the joint subsidiary set up in 1983 in polypropylene.

The two Italian giants were still very much in debt, a fact that could lead to further divestments. But their leaders could nevertheless contemplate the future with some equanimity. Their heavy chemical sectors were finally merged under Enimont in 1988.

The *Spanish chemical industry* was also faced with considerable difficulties. Short of innovations, it had developed through foreign technologies and had lived a sheltered life behind customs barriers and import licenses not conducive to cost cuts. Neither Spain's petrochemicals industry, which was in the hands of the Enpetrol state group and the private company CEPSA, nor the main national companies Explosivos de Rio Tinto (ERT) and Cros, were in a position to face without transition the pressure of competition felt when Spain joined the Common Market. This was particularly true of ERT, which had missed bankruptcy by a hair, and Cros, which had remained in the red for a long time. Neither would be able to avoid severe restructuring.

Their total merger project failed through lack of financial means, and it was Kuwait in the end which, through the Kuwait Investment Office, took a 47 percent share in ERT and 24 percent in Cros in 1987 and promised to provide the necessary cash for the two groups to form a joint fertilizer subsidiary.

ARAB COUNTRIES GAIN A FOOTHOLD

As soon as OPEC was set up, Middle Eastern countries had sought to find ways to invest their oil revenues in downstream industries. *Kuwait*'s approach was, preferably, to acquire shares in existing companies. It thus bought up Gulf Oil's interests in Europe, took a share in Germany's Hoechst, and injected considerable capital into ERT and Cros in Spain.

Qatar had chosen to associate with CdF Chimie to set up a petrochemical base in the Emirate and to build the Dunkirk site through Copenor.

Saudi Arabia's policy has been to develop a national petrochemical industry that would sell its products worldwide. More than Qatar and Kuwait, it had abundant supplies of ethane and methane extracted from gases that were being flared. The ethane separation capacities of its refineries alone accounted for a potential of 3.5 million tons a year of ethylene.

Sabic, the body in charge of the project, had cleverly involved itself with major international groups such as Mobil, Exxon, Shell, and Mitsubishi. Production would then be easier to place in Europe, North America, and Southeast Asia without wounding national feelings. The first giant methanol unit came on stream in 1983, while the other Saudi productions located in Al Jubail and Yanbu have gradually begun supplying low- and high-density polyethylene, ethylene glycol, ethanol, dichloroethane, vinyl chloride (monomer and PVC), and styrene as the relevant units came on stream.

Since 1970, Saudi Arabian Fertilizer has been producing urea and melamine in Dammam, in association with Sabic; the two companies have scheduled construction of a 1,500-tons-a-day ammonia unit in Al Jubail.

Because of the obviously low cost of the principal local methane and ethane raw materials, and because the fixed costs of the installations are high with regard to variable costs, European petrochemical producers were afraid that Saudi Arabia with its low home consumption, would flood outside markets with its ethylene derivatives and methanol at cut prices. So far, however, Saudi exports have not shaken up the market because they have been carefully channeled through the distribution networks of Sabic's international partners.

Taking a different course than Algeria with its liquefied natural gas, the Gulf States have thus upgraded their natural resources and already account for 10 percent, 5 percent, and 4 percent of world production of methanol, ethylene, and polyethylene respectively.

THE AMERICAN CHEMICAL INDUSTRY CAUGHT OFF BALANCE

The difficulties resulting from world overcapacities were enhanced in the United States by the behavior of financial circles and the reaction to this behavior of the U.S. chemical industry leaders. America's chemical giants had reached their advanced stage of development because of the long patience of their shareholders and the acumen of their leaders based on thirty years of product and process innovation. Just like their German and Swiss counterparts, U.S. chemical industry leaders had upheld the notion of long-term interest over the more immediate concern of the various types of shareholders.

The shock waves sent out by the two oil crises, which had not spared the United States, the growing influence of financial analysts on the behavior of shares quoted on the Stock Exchange, and the arrival at the head of the large industrial groups of graduates from glamorous business schools trained more in finance than in technology gave the scene a new twist. Shareholders were more interested in the instant profits they could draw from breaking up a group than with the added value that could be patiently built up through its development.

Drawn along by their own convictions or under pressure from bankers and "raiders," U.S. chemical leaders were constantly redeploying their activities. The *leveraged buyout* (LBO) system had already been applied by the leaders of FMC's American Viscose division when they sought to buy, with the help of the banking world in the early 1970s, the Avtex rayon and polyester producer, which thereby became a successful company. Despite the risk to buyers in borrowing from financial organizations as much as 90 percent of the amounts needed for the purchase, the system was eagerly seized upon by individuals wishing to set up their own business and taking advantage of the disenchanted mood of potential sellers. This is how *Huntsman* became the world's leading producer of styrene and polystyrene after buying up the relevant sectors from companies like Shell and Hoechst, which wanted to pull out of them.

Likewise, it is because Du Pont, having spent $7.4 billion to acquire Conoco, sought to reduce its debts by selling part of Conoco's chemicals and also because Monsanto, ICI, and PPG were withdrawing from petrochemicals, that firms like *Sterling Chemicals, Vista Chemical*, and *Cain Chemical* have emerged since 1984. Cain Chemicals was itself to be taken over by Oxychem (Occidental Petroleum) in 1988. Various acquisitions made at the right moment turned Vista within three years into one of the leading PVC and detergent alcohol producers in the United States. Through purchases made in its behalf by Sterling Chemicals, Cain Chemicals became a major petrochemical company with assets worth $1 billion in 1987, including ethylene, ethylene oxide, glycol, and polyethylene units, all strategically located in the Gulf of Mexico area. A further newcomer on the American scene was *Aristech*, which emerged through the takeover by its management of the heavy chemicals division of USX (U.S. Steel).

All these companies were acquired under very favorable conditions, as more often than not they were sold by the large groups at 25 percent of their replacement value. Contrary to assumed notions, individual entrepreneurs were thus able to acquire installations which until then only the most powerful groups could afford to run. These groups gave up whole sections of their traditional chemicals to redeploy in specialties for which they had no particular disposition and, at times, in areas even further removed from their original areas of competence. Thus *Diamond Shamrock* gave up its chemicals to Occidental Petroleum at the worst possible time, to devote itself exclusively to the energy sector, which in fact failed to live up to expectations.

One of the most powerful of America's chemical companies, *Allied Chemical*, became a high-technology conglomerate under the leadership of Edward L. Hennessy, Jr., who was formerly with United Technology. After acquiring Bendix and Signal, it took on the name of *Allied-Signal* and is now focusing on electronics and space, having entrusted a large part of its chemicals to the portfolio subsidiary Henley, which will sell them to the highest bidder. As for *Monsanto*, it shed a number of fibers, plastics, and petrochemical units both in Europe and in the United States and decided to hinge its further development on biotechnologies, a new area for the group. It bought up in particular the aspartame producer *Searle* for $2.6 billion.

At the same time as these changes were being wrought by the protagonist themselves, other major changes were taking place under outside pressure. Wily businessmen acting as "raiders," with the help of financial concerns that issued high-risk and high-interest "junk bonds" to finance a large share of the targeted acquisitions, set their sights on large companies quoted on the Stock Exchange: they acted in the belief that the company's parts would be worth more sold separately than as a whole.

The raiders' takeover bids had instant attraction for shareholders, and their criticism of the way the firms they were after were being managed was often not without truth. But it stood to reason that once the raiders had bought the company, they would break it up to reduce financial charges and to refund the money borrowed for the raid. The more interesting assets were often the first to be sold off, for they found ready buyers. To counter the raiders, the managers of the targeted firms were likely to raise the ante. But this only aggravated the financial problem, and the group's dismantling was unavoidable.

The instant advantage which both shareholders and raiders drew from these operations was obvious. But their consequence was, sooner or later, to destabilize the enterprises concerned, when these did not disappear altogether. The most spectacular case was *Union Carbide*, coveted in 1985 by the real estate developer S. Hayman, who had already taken over GAF Corporation.

To fight off the raid, Union Carbide had to borrow $3 billion. To reduce such an unbearable debt, the group's management was forced to sell its best sectors (batteries, consumer products, engineering plastics, agrochemicals) and even its headquarters in Danbury, Connecticut. This was how one of the best chemical concerns in the United States, with sales amounting to $10 billion, was left with only three areas of business after divesting to the tune of $5.3 billion. Even these areas—industrial gases, petrochemicals and plastics, and graphite electrodes—were faced with stiff competition. And with debts that still remain three times as high as the industry's average, Union Carbide is in no position to invest in the short term in anything likely to push it back to its former major rank in chemicals.

Other U.S. companies involved in chemicals were also the victims of raiders in 1985. To fight off C. Icahn, *UniRoyal* was taken over by its management and was forced to sell off its chemicals to Avery, which in turn placed them on the block, before accepting a leveraged buyout by the management. *Phillips Petroleum* had to buy back its shares from C. Icahn and B. Pickens and was forced to sell $2 billion worth of assets to refund part of its debt. And what about *Gulf Oil*, which sold itself to Standard Oil of California to escape the clutches of Boone Pickens, or *Stauffer Chemical*, which changed hands three times within a single year from Cheeseborough Pond to Unilever and finally to ICI, when it was broken up among ICI, AKZO, and Rhône-Poulenc?

Attracted to the U.S. market, European investors had also joined the raiders' ranks. This is how the Britain-based Hanson Trust managed to acquire *SCM*. This was a company that had just completed its restructuring; but after Sylvachem was sold off by the new owners, it retained only chemical production of titanium dioxide.

Anglo-French tycoon J. Goldsmith, unable to take control of Goodyear, nevertheless made substantial profits from his raid on the company. Goodyear was left with the sole alternative of withdrawing from all the sectors except chemicals in which it had diversified outside of tires.

In a number of cases, transactions led to an agreement between the heads of companies that had stock options and were eager to make a profit, and the potential buyers. This was how *Celanese*, an able and well-diversified company that had the means to retain its independence and competitiveness with regard to any major company, was acquired by Hoechst following a transaction that was satisfactory both to the German buyer and to the shareholders of the American group, at least for the time being.

The fear that their company might be the target of an "unfriendly" takeover bid induced the boards of directors of some of the well-managed chemical companies to guard against such attacks either through deceptively appealing offers—"poison pills"—or through purchase of their own shares. This was certainly not the best for industrial firms to make use of their funds.

COPING WITH SAFETY AND ENVIRONMENTAL PROBLEMS

Handling chemicals has never been without danger, if only because of the unstable and harmful nature of a number of substances when they are placed in certain conditions of temperature, pressure, or concentration.

Chemists have always been haunted by the risks of explosion. The explosion which occurred on September 3, 1864, in the Heleneborg laboratory near Stockholm, where Alfred Nobel was handling nitroglycerin, caused the death of five persons, including Emile Nobel, his younger brother. The ammonia synthesis unit set up by BASF within the Oppau plant was totally destroyed in 1921 by an explosion causing the death of over 600 people. In 1946, the French cargo ship *Le Grand Camp*, carrying 2,500 tons of ammonia nitrate, exploded in Texas City, killing 512 people. Other disasters, such as that of Flixborough in England, which took place through rupture of a Nypro caprolactam pipe within the plant in 1974, or again the one caused in a holiday camp in Los Alfraques in Spain when a tank-wagon carrying propylene exploded in 1978, are reminders of the explosive nature of certain chemical products and of the need to handle them strictly according to the prescribed security rules.

A number of chemicals, fortunately a limited number, become dangerous either when they are used wrongly, or when they are accidentally set free. *Thalidomide*, put on the market in 1957 by the German company Chemie Gruenenthal, was indeed a powerful sedative. But it took three years to perceive that when prescribed to pregnant women, it dramatically crippled the newborn children. The synthetic intermediate for insecticides, *methyl isocyanate*, which Union Carbide has used for years without incident in its West Virginia Institute plant, caused over 2,000 deaths when it escaped in 1984 from a storage tank in Union Carbide's Bhopal plant in India.

Other products act insidiously, so that it is harder to establish their effects on human and animal health and more generally on the environment. Indeed, progress in understanding the safe dosage of minute quantities of impurities has enabled governments to fix with greater care the maximum allowed content of *vinyl chloride monomer, formaldehyde,* and *benzene* beyond which these products could become dangerous for workers to handle.

Lessons have been drawn from accidents caused by faulty handling of certain substances. Through the work carried on by Alfred Nobel, we know how to stabilize nitroglycerin in the form of dynamite, and since 1946 methods have been devised to avoid the spontaneous explosion of ammonium nitrate. Ammonia units with capacities of 1,500 tons a day have been operating for decades without incident.

Because of the painful thalidomide episode, long and costly tests are now carried out to study the possible secondary effects of pharmaceutically active substances. A great number of drugs that today save many lives would not have been available had they needed to go through the long periods of tests that are now required by legislation.

Likewise, in industrial countries, increasingly stringent regulations limit noxious vapor discharge from chemical plants, which are required to treat their effluents effectively. The transport of dangerous substances is also closely monitored by the authorities. Such precautions stem not only from the publicity which the media now gives to any catastrophe worldwide, but also from the public's instinctive distrust of chemistry, which it still regards as a mysterious science.

But just as an air crash does not mean the end of commerical aviation, neither does the damage caused by improper use of certain substances mean the end of the chemical industry. The image of chemicals is tarnished, however. Citizens who deliberately risk their own death, when they are not actually killing others, because of speeding on the roads or because they are addicted to alcohol, tobacco, or drugs, are less and less inclined, for all that, to accept accidental security breaches when these are not caused by themselves.

Politicians in our parliamentary democracies who wish to please public opinion feel the urge to take into account demands that are more emotional than scientific, and advocate restrictions even when these go against the best interests of the citizens. The *Three Mile Island* nuclear power plant accident in the United States which resulted in no fatalities, the more recent *Chernobyl* explosion which, as of 1988 had directly caused two deaths, have, with no good reason, prevented any resumption of the U.S. nuclear program and have aroused fears in European countries in people least likely to give way to mass hysteria.

The *Seveso* leak, which occurred in Italy on July 10, 1976, in the trichlorophenol unit belonging to Hoffmann-La Roche's subsidiary Givaudan, did have an impact on the immediate environment and a number of people were temporarily affected by the dioxin vapors. But the accident caused no lasting harm. It was the publicity which the media gave to it that forced Hoffmann-La Roche to close down the unit, turning Seveso into a dead city.

The litigation over residues left in the ground by Occidental Petroleum's affiliate Hooker, in *Love Canal*, in the state of New York, led to the evacuation of all the area's residents, beginning in 1978. But no clear explanation has yet been given of the ailments some of the inhabitants have been complaining about.

The lack of universally accepted scientific explanations for certain phenomena has often meant that the precautionary measures taken by one country do not necessarily apply in another. Where sweeteners are concerned, for instance, some governments have banned *saccharin* and other governments allow its use. The same is true of *cyclamates* and *aspartame*.

DDT was banned as an insecticide as early as 1974 by most industrial nations. But it is still widely used in many developing countries. The risks of *eutrophication* are perceived differently by governments, so that legislation applying to products for the production of detergents, like *alkylbenzene sulfonate, tripolyphosphate*, or *nitriloacetic acid* (NTA) differs from country to country.

The agreement which a number of nations reached in 1987 to ban the use of *chlorofluorocarbons* in aerosols is so far the only instance of harmonized legislation, even though no one has so far managed to prove scientifically that the chlorofluorocarbons really destroy the atmosphere's ozone layer.

Thus while it is understandable that authorities must be careful to soothe the fears of a public that is insufficiently informed of the dangers that threaten it, it must also be aware of the economic and social costs of refusing to accept the risks inherent in any human activity, and also conscious of the uncertainties surrounding the rules and regulations taken to satisfy its demands.

Some companies are turning the necessity of cleaning up the environment into new opportunities to improve their profitability. Thus Du Pont has found a useful application as a building material for the calcium sulfate that was piling up as a by-product in one of its Texas plants.

SCIENTIFIC AND TECHNOLOGICAL BREAKTHROUGHS

Short of fundamental discoveries over the past fifteen years, the chemical industry has gone forward by systematically developing its store of knowledge in processes and products.

Process Improvement

Higher crude oil prices had revived studies in the use of coal as a chemical feedstock. But while the Fischer-Tropsch synthesis was still used in South Africa by Sasol, the only other industrial gasification unit was the one Eastman Kodak brought on stream in Kingsport, Tennessee, in 1983, to produce *coalbased acetic anhydride*. The coal came from the Appalachian mountains and was cheap enough relative to oil prices at the time to warrant such an installation, and the plant is now to be expanded.

Together with these studies on synthetic gas, some progress has been achieved in the use of a group of alumino-silicates, the *zeolites*, as selective catalysts to boost certain reactions. Half the world production of *p*-xylene and a quarter of the production of ethylbenzene, an intermediate required to prepare styrene, are carried out using the zeolite-based ZSM-5 catalysts developed by Mobil Oil, which played a pioneer role in this area.

Applications of the olefin *metathesis* reversible chemical reaction, discovered by Phillips Petroleum in the 1960s, were also developed in the subsequent years. By this reaction, Arco produces propylene from ethylene and butene-2; Hercules prepares its plastic, Metton, from dicyclopentadiene; and Shell synthesizes its C_{12}-C_{14} SHOP (Shell Higher Olefin Process) alcohols used for detergents.

The application of *electrochemistry in organic synthesis* had already served to bring on stream in the United States in 1965 Monsanto's first industrial adiponitrile process from acrylonitrile. This was followed in 1977 by a similar installation in Seal Sands, England, which was later bought up by BASF.

The former *Reppe chemistry*, still practiced in Germany by BASF and in the United States by GAF, also led to new developments as demand for certain intermediates such as the 1,4-butanediol increased. This diol, now also obtained from maleic anhydride, is used to produce PBT polyesters through reaction with terephthalic acid and leads to other major derivates (tetrahydrofuran, butyrolactone, N-vinylpyrrolidone).

New synthetic processes for the preparation of established products were also industrially developed: in Japan the manufacture of methyl methacrylate from C_4 olefins, by Sumitomo and Nippon Shokubai; in France, the simultaneous production of hydroquinone and pyrocatechin through hydrogen peroxide oxidation of phenol by Rhône-Poulenc; in the United States the production of propylene oxide through direct oxidation of propylene operating jointly with styrene production, developed by Ralph Landau and used in the Oxirane subsidiary with Arco, which the latter fully took over in 1980; in Germany and Switzerland, the synthesis of vitamin A from terpenes, used by BASF and Hoffmann-La Roche.

Processes apparently well established were still further improved, such as the *electrolysis of sodium chloride*, dating back to the last century: diaphragm and then membrane cells were substituted for mercury cells, which were a possible source of pollution.

Important progress was also made in *chemical engineering*, such as use of rotary compressors in ammonia synthesis or ICI's fermentation reactors in Billingham to produce the Pruteen protein from methanol reactors, having no mobile parts.

Product Development

Although research was not as fruitful after 1960, new materials put on the market in the 1970s were the outcome of research in high polymers essentially conducted within industry.

It was through such research that ICI's PEEK (polyether ether ketone), one of the first high-performance aromatic polymers, was put on sale, as well as Du Pont's aramide fibers Nomex and Kevlar, more resistant than steel in like volume.

To the range of engineering plastics were added polyethylene and polybutylene terephthalates (PET and PBT), as well as General Electric's polyethers, the PPO (polyphenylene oxide) produced through polymerization of 2,6-xylenol and the Noryl plastic produced by blending PPO with polystyrene. Other special polymers, derived like the polycarbonates from bisphenol A, were added to this range: polyarylates, polysulfones, polyetherimides.

A major step forward was taken in the area of base thermoplastics with the application of Union Carbide's Unipol process. Variations of this were subsequently offered by other low-density polyethylene (LDPE) producers such as Dow and CdF Chimie (now ORKEM).

Under a process that consisted in copolymerizing in the existing highpressure installation ethylene with 5 to 10 percent of an *α-olefin* (butene-1, hexene-1), a stronger linear low-density polyethylene (LLDPE) was produced with a higher melting point than LDPE. Thinner films could thus be produced that were just as strong but required less material.

The new polymers opened up an unexpected market for producers of C_4, C_6 and C_8 α-olefins like Shell, Ethyl, and Chevron. Their higher linear α-olefins were also used either for polyalphaolefins (PAO) intended for synthetic lubricants or to prepare detergent alcohols.

While no great new plastic has emerged over the last fifteen years, researchers in major chemical companies did their utmost to improve both the features and the performance of known polymers.

As we have just seen, they improved LLDPE by adding comonomers in the carbon chain. But also through additives they managed to render polymers more resistant to fire, to oxidation, and to alteration through ultraviolet rays.

This slowly gave rise to a new industry that consisted in supplying polymer producers and plastic processors, not only pigments and charges, but also antioxidants, light stabilizers, and fireproofing agents. Added in small doses to the polymer, they added to its value by extending its life span. Such an activity, in which the Swiss firm Ciba-Geigy plays a noteworthy role, was boosted by the spectacular development of polypropylene, a particularly sensitive polymer that has to be stabilized with appropriate additives.

Another way of improving the performance of polymers consisted in blending them either with other polymers, or with inert materials such as glass fibers, carbon fibers, or various mineral fillers. Thus were produced a series of *alloys and composite* materials. Glass fiber-reinforced polyester has long been in common use. But the possibility of introducing carbon fiber obtained through pyrolysis of polyacrylonitrile (PAN) fibers already developed in aeronautics, opened up fresh prospects, particularly in the area of sports articles. The need, in turn, to link organic polymers and mineral fillers led to coupling agents such as the silanes which Union Carbide and Dynamit Nobel have put on the market.

This is how, little by little, spurred on by the demands of the processing industries which are also under pressure from major clients like the automobile industry, a number of companies have brought a large number of improvements to plastics. While not very spectacular, these improvements have appreciably added value to existing materials.

More generally, the requirements of many downstream industrial sectors have hastened the development of derivatives that otherwise might have remained laboratory curiosities. Discoveries of new molecules have been particularly inspired by the needs of plant protection. This was because agriculture, before it became a crisis sector, offered worldwide markets for crop protection agents, and also because product approval was easier to obtain, and therefore less costly, than in the case of pharmaceuticals. The success of glyphosate, which Monsanto put on the market in 1971 under the trade name Round Up, has made it the world's leading selective herbicide, for it can be used throughout the year and becomes harmless when absorbed into the ground. A new range of synthetic pyrethroids, developed in the United Kingdom by Elliott of the National Research and Development Corporation, (NRDC), a government agency, was marketed from 1972 onward under the trademarks of Permethrin, Cypermethrin, and Decis. These wide-spectrum insecticides owe their success to the fact that they are exceptionally active in small doses and are not toxic to humans. With increasingly strict legislation and stiff competition among pesticide producers at a time of slumping agricultural markets, the golden days could well be over for crop protection products, so that the years ahead are likely to be more favorable for restructuring than for new discoveries.

Over the last fifteen years, the *pharmaceutical sector* also made great demands on the ingenuity of chemists. But from the time of the thalidomide drama, the testing times required by health authorities have increased, to the point that since 1980 ten to twelve years are needed instead of the three to four previously required to bring a drug on the market from the time of its discovery. Research and development costs, accordingly, have grown fourfold over the last ten years, dangerously reducing the number of new specialties provided for patients each year. Because of such delays, a patent protecting a new substance may be left with but a few years of validity when final approval is granted to the laboratory that made the discovery.

Such difficulties have apparently not affected the zeal of researchers. Nor have they diminished the sums devoted each year to research and development, which on the contrary have been constantly on the increase. This is because any major discovery may have worldwide portent. And in most developed countries there is a system of refunding to patients the cost of ethical drugs, so that a new active principle may provide the laboratory that has exclusive rights over it with a considerable source of profits even if such refunds are coupled with tight price controls.

And while it is also true that thirty pharmaceutical companies alone account for 60 percent of worldwide ethical drug sales, the sums of money invested in research do not always get their full return. Thus it is that a small company like Janssen's laboratory, Janssen Pharmaceuticals, in Belgium, which was acquired in 1979 by Johnson and Johnson and which has among its discoveries diphenoxylate (1963) and loperamide (1975), has proved more innovative over the last fifteen years than the Rhône-Poulenc group, which has produced no major new molecule during the same time, although it devotes far more money to its research.

Indeed, success depends at least as much on chance, the ability of researchers, and the strategy of management in that area as on the sums expended. Valium and Librium, which have been providing Hoffmann-La Roche with its largest profits since the end of the 1960s, were the outcome of Leo Sternbach's acumen. Instead of merely modifying the meprobamate molecule as management had requested, he began studying the sedative properties of benzodiazepines used as dyestuff intermediates and on which he had worked for twenty years previously at Cracow University.

One of the most prolific inventors of the 1960s was most certainly Sir James Black, a Nobel laureate in 1988. While working for ICI, he discovered the first β-blocking agent Propranolol in the early 1960s. He also discovered Cimetidine, sold under the trade name of Tagamet as an anti-ulcer agent by SmithKline & French from 1974 onward, and which has become the world's largest-selling specialty. After working successively for ICI, SmithKline & French, and for Wellcome in Britain, Sir James now has his own business, and he is convinced that small competent teams are, by nature, more innovative than the large armies of researchers which many of the big companies have set up.

Likewise, the successful ventures of Merck Sharp & Dohme cannot be dissociated from the work of its president, Roy Vagelos. This biochemist, a latecomer to research, supervised the whole process of work to bring Mevacor, the new cholesterol miracle drug, onto the market. It has just been approved by the U.S. Food and Drug Administration. Mevacor was but the crowning touch to Merck's scientific tradition with its long series of discoveries: α-methyldopa against hypertension, indomethacin and sulindac to fight arthritis, and cefoxitine, an antibiotic.

At a time when pharmaceutical research is becoming increasingly costly and the likelihood of a great discovery remains hazardous, success will come to laboratories which not only sink large sums of money into research but also rely on teams where competence does not necessarily rhyme with size, and whose management has reached a sufficient level of scientific maturity.

THE CRAZE FOR BIOTECHNOLOGY

The catalytic action of living organisms, or rather of the proteins they contain, had received the beginnings of an explanation with the experiments of Payen and Persoz on malt amylase separation in 1833 and with J. J. Berzelius's catalyst theory in 1835. In 1897 Eduard Büchner demonstrated that a yeast extract could turn sucrose into ethyl alcohol. Fermentation took place without the presence of living organisms through enzymes. In this case zymase was the catalyst.

Ethyl alcohol, already known to alchemists, was used by industry towards the middle of the last century when continuous distillation in columns was devised by Ireland's Aeneas Coffey in 1830 and when it became exempt from excise duties on alcohol if methanol was added to it.

After alcohol, *lactic acid* was the second product obtained industrially from sugar fermentation, starting in 1880. The levo-isomer is still made this way to the tune of 20,000 tons a year.

In 1890, the Japanese chemist Jokichi Takamine had introduced a fermentation process in the United States by which an enzyme blend was produced. This takadiastase catalyzed starch and protein hydrolysis. Some years later in 1913, Boidin and Effront discovered the "*bacillus subtilis*" that produced an *α-amylase* stable under heat. This enzyme was used to desize cloth and later in the sugar fermentation process.

During World War I, Chaim Weizmann had succeeded in producing for the British Admiralty acetone and butanol on a large scale through anaerobic fermentation of starch. The Germans were then producing as much as 1,000 tons a month of glycerin from sugar. These war productions proved no longer competitive in peacetime. But *citric acid*, which Pfizer began producing in 1923 from sucrose, is still biochemically made today from *Aspergillus niger*, which Currie advocated in 1917.

The discovery of *penicillin* and its industrial development during World War II have led the pharmaceuticals industry increasingly to resort to *biosynthesis* for the preparation of its active principles. Through rigorous selection of the microorganisms extracted from the soil or from various molds, the cost of an antibiotic like penicillin has been brought down to $30 per kilo, compared with $25,000 per gram initially—an impossible target if the exclusively synthetic process had been used. Moreover, it became possible to extend the range of antibiotics that could be used. The antianemia *vitamin* B_{12} and most of the amino acids were prepared in the same way through culture of microorganisms in selected environments containing precursors.

In the case of *steroids*, biosynthesis permitted reactions that could not be achieved through direct synthesis. In 1952, this was how Upjohn researchers in the United States managed to introduce on carbon atom 11 of the steroid nucleus, a hydroxyl group –OH, using the *Rhizopus arrhizus* fungus, making the switch from the pregnancy hormone progesterone to cortisone and its derivatives.

Microorganisms are also capable of separating optical isomers. In the case of sodium glutamate, where it is necessary to start from levo-glutamic acid to obtain the desired flavor, and where synthesis produces only a racemic blend, it was a particular yeast called *Micrococcus glutamicus* that led to the required isomer through carbohydrate fermentation.

Considering that sodium glutamate, like other amino acids, is contained in soy sauce, which is a traditional Japanese food, it is not surprising that Japan should have become interested very early in this type of fermentation. Firms like Ajinomoto and Kyowa Hakko dominate the world market for amino acids and particularly for *glutamic acid* and *l-lysine*. It is also through enzymes that the resolution of *dl-methionine* into its optical isomers is achieved since its laboratory synthesis yields the racemic form.

Heat-stable amylases are frequently used in both the United States and Japan to produce *syrups with a high fructose content* from corn starch.

Single-cell proteins such as ICI's Pruteen were produced through culturing microorganisms on a bed of organic material.

Interest in biosynthesis grew still further with the discovery in 1953 of the structure of DNA, then in the 1960s of the genetic code of proteins. It then became possible to clone microbe or plant cells, through *genetic engineering*, by recombination of fragments of genetic material from different species. Thus, towards the end of the 1970s, the biotechnology firm Genentech succeeded in isolating the human insulin gene and to insert it into the DNA of the *Escherichia coli* bacteria: through reproduction, these bacteria produced the *first human insulin*, which Eli Lilly and Company has been marketing since 1982.

The *human growth hormone* (HGH), which can only be extracted in minute quantities from the pituitary glands, can now be isolated in larger quantities through genetic engineering.

Monoclonal antibodies (mabs), which replicate the antibodies in the organism with the added advantage of being "immortal," were discovered in 1975 by scientists working at the Cambridge Medical Research Council in the United Kingdom. They serve more particularly as reactive agents for medical diagnostic purposes.

Through *plant genetics*, it has also been possible to render plants resistant to chemical agents (Calgene, Monsanto) as well as to improve crop yields (Pfizer) with new seeds.

With the prospects which *biogenetics* was opening up for medicine and agriculture, a number of private laboratories sprang up in the United States between 1971 and 1978—*Genentech, Cetus, Genetic Institute, Biogen, Amgen*, and *Agrigenetics* to mention but the principal ones. These laboratories managed to finance their work with the help of venture capital, research contracts with the major chemical firms like Du Pont, Monsanto, Eastman Kodak, W. R. Grace, or shares purchased on the stock exchange.

Vast sums of money have been spent over the last ten years but with small tangible results, prompting the definition of biogenetics as a business likely to bring in a small fortune as long as a large one is invested! Thus far the only commercial fallout of biogenetic research involved human insulin (Eli Lilly), the human growth hormone HGH (Genentech, KabiVitrum), the hepatitis B vaccine (Merck, Smith, Klein-RIT), interferon (Boehringer, Ingelheim), the amylase enzyme (Novo), a number of veterinary vaccines (AKZO Pharma), and monoclonal antibodies for diagnostic reactive agents. Hopes raised by interferon and interleukin-2 as cancer cures have not materialized, but the tissue plasmogen activator (TPA) as a blood clot dissolver in heart attacks was approved by the U.S. Food and Drug Administration (USFDA).

Plant genetic research is encountering opposition from the U.S. Department of Agriculture and the Environmental Protection Agency. Pressured by environmentalists, the U.S. administration is loath to approve developments which could affect the environment in unknown ways. In addition to these administrative obstacles, there is uncertainty over patent rights, for there are no legal precedents. Finally, the biocompanies recently set up will need to associate with large pharmaceutical groups to develop and market the products born of their research.

Generally speaking, although *biotechnology* has acquired credibility in many areas, its development is being slowed by scientific, economic and administrative obstacles. First and foremost, proteins are complex substances that cannot be handled as easily as the simple molecules involved in traditional organic syntheses.

It is true that Japan's Ajinomoto and Kyowa Hakko, in particular, have become masters of the art of producing amino acids. Likewise, enzymes have remained the specialty of Novo (now Novo Nordisk) in Denmark, Gist Brocades in Holland, and Bayer's subsidiary Miles in the United States, which together account for 60 percent of the world needs in the area.

Even when they are technologically sound, however, bioproducts may turn out to be economically uncompetitive. The profitability of l-lysine from one year to the next, for instance, depends on soy market prices. In the same way, the single cell proteins which BP produced in 1963 in Lavera from a petroleum base, using a process developed by France's Champagnat, never managed to compete with soy cakes for animal food. ICI has also just been forced to close down its 50,000-ton Pruteen unit in Billingham.

At current crude oil prices, the production of ethanol from biomass is not profitable, either. Whether produced from beets, sugar cane, or corn, it can become competitive only if it is subsidized. And these subsidies would only be forthcoming for political reasons: to please their farmer voters, the French, Brazilian, and United States governments would adopt such a policy to absorb excess agricultural products. From cereals, corn in particular, starch is produced and hydrolyzed to form glucose which ferments to ethanol.

Powerful groups like American Corn Products and France's *Roquette Frères* produce starchy matters in this way. The former is also the leading producer of *isoglucose* (a blend of glucose and fructose) in the United States, while the latter is the largest producer of *sorbitol.* Starch can, therefore, compete directly with saccharose both for foodstuffs and for industrial uses as a fermentation or enzyme-reaction base.

This gives rise to a permanent conflict in Europe between the starch manufacturers on the one hand and the sugar and beet refiners on the other, a conflict that the EEC Commission with its *Common Agricultural Policy* of quotas and subsidies has been unable to settle. The only point of agreement between the two parties is the price which they demand for their production from downstream Community industries, a price that is far higher than world rates.

Spurred on by the Italian sugar group Ferruzzi-Eridiana, Montedison's and now Enimont's main shareholder and an associate of France's Béghin-Say sugar group, there is a campaign under way to introduce ethanol into gasoline. Farmers, of course, support the move because incorporating 7 percent of ethanol in gasoline would mean for a country like France the use of two million tons of sugar or four million tons of cereals. But ethanol happens to be in competition with methanol and the new MTBE antiknock agent as a gasoline additive. More important, a tax rebate would be needed at current gasoline prices to induce the oil industry to incorporate ethanol in prime rate gasoline. So the "farm" lobby can receive satisfaction only at the expense of the taxpayer, whether American, Brazilian, or European.

The rules that have always governed the use of ethanol, government policy favoring one agricultural raw material over another, the new constraints that limit the marketing of genetically engineered products—all these factors serve to remind those interested in the development of biotechnology how narrow is their room for maneuvering.

THE FINE CHEMICALS APPROACH

In their search for products that could provide better margins than those achieved from commodity chemicals, the industry had hit upon *fine chemicals.* These typically involved derivatives from organic synthesis, obtained in multipurpose units and sold in relatively small quantities at high prices.

The German and Swiss *dye manufacturers* (Hoechst, BASF and Bayer, as well as Ciba-Geigy and Sandoz) were in the most favorable position to develop such advanced chemicals. They had a long tradition behind them of multiple-stage syntheses involving intermediate derivatives that could also serve to prepare pharmaceutically active principles or pesticides. Starting from a number of major raw materials and working according to the chemical-tree concept, these producers can work down the line to well-defined molecules which they use in their own downstream production or sell as synthetic intermediates to outside clients.

In Europe, the giant ICI group, which had retained a strong position in dyes, also became involved in this kind of chemicals.

France, with PCUK having closed down in 1980 its Société des Matières Colorantes in Mulhouse and then having sold Société Francolor to ICI, had restricted its ambitions in this area. It retained only a few products of Rhône- Poulenc and of its 51 percent subsidiary *Société Anonyme pour l'Industrie Chimique* (SAIC), located in Saint-Fons and in Mulhouse-Dornach, respectively.

As was to be expected, the U.S. chemical leaders, Du Pont, Allied Chemical, American Cyanamid, GAF, and Tenneco Chemicals, had all withdrawn between 1976 and 1979 from the dyes sector. Only three medium-sized companies were still active in this area: *Crompton & Knowles, American Color*, and *Atlantic Chemical.*

Yet at the end of World War II, America's dye production had been the leading one worldwide. For over thirty years it had enjoyed high customs tariffs protection through the American Selling Price clause. But dyes were produced by giant companies used to large-scale continuous productions. Their engineers were not trained to run month-long syntheses campaigns involving many stages. Moreover, American marketing executives were little attracted to the German methods for "motivating" their clients. There was also the fact that during the 1960s, U.S. dye manufacturers had come to rely on imported intermediates. With rising prices and the textile slump, they found themselves caught between rising purchase costs and falling selling prices. Finally, unlike their European counterparts, U.S. manufacturers had never given international scope to their dye business. It remained restricted to the home market.

For all these reasons and also because they were not tied down like the Germans by any prestigious tradition, they unhesitatingly gave up dyes, losing at the same time the know-how needed to succeed in fine chemicals.

With more modest means, other firms were more successful. They either developed their own "chemical tree," or put to good use the know-how acquired through development of certain processes.

Ethyl became a bromine and derivatives specialist and an expert in orthoalkylation (orthoalkyl phenols and anilines). Its acquisition of Dow's bromine activities has given Ethyl a leading role in this field. *DSM* developed its fine chemicals from the benzoic acid produced during manufacture of synthetic phenol by toluene oxidation. *Atochem* took advantage of the sulfur resources of its parent company Elf Aquitaine to build up successfully a thioorganic chemicals industry (thioglycol, mercaptans, DMSO). Its position will be further strengthened by the takeover of Pennwalt. *PPG* in the United States and *Société Nationale des Poudres et Explosifs (SNPE)* in France are producing a wide range of phosgene-based derivatives to be used in the most varied manner (carbonates, chloroformates). More than any other company, *Lonza* has extended its range of fine chemicals (diketenes, HCN derivatives, pyrazoles, pyrimidines). *Reilly Tar* has become a world leader in pyridine and derivatives. *Dottikon* in Switzerland and *Kema Nobel* in Sweden have put to use their nitration experience to extend their range of nitrated intermediates. Among others, *Rhône-Poulenc* and *Montedison* are involved in organic fluorine derivatives while *Hüls'* fine chemicals division has specialized in alkylation, hydrochlorination and catalytic hydrogenation.

Thus a number of firms with special know-how in a family of products or in processes that were not among the biggest have succeeded in taking a more than honorable place as suppliers of fine chemical derivatives alongside the organic synthesis specialists originating from the dye business.

THE ATTRACTION OF SPECIALTY CHEMICALS

Besides fine chemicals sold according to specifications but accounting for only a small part of the sales of major companies, *specialty chemicals* held attractions for companies wishing to diversify. These chemicals involved substances or mixtures whose composition mattered less than the function for which they were intended: the test of success lay in performance. Thus old family businesses or more recent companies born of a leader's entrepreneurial spirit had been successful in performance products, whether these were paints, inks, or glues; or in specialties, cosmetics, detergent, or electronics industries.

Indeed, not much capital is needed to manufacture specialty chemicals compared with what is required for commodity chemicals. The development of new products is both quicker and less costly than it would be to find new processes for large-volume products or to bring to the market an original active principle for an ethical drug.

This largely explains why specialty chemicals managed to remain until the early 1970s products for medium-sized private companies. In the long run, however, the internationalization of trade, the size of advertising budgets for consumer products, and the necessary adaptation to new technologies requiring highly qualified personnel all called for funds that were not always available to family businesses. Many small owners were forced to sell out, and their need coincided with the attraction they held for large chemical groups trying to diversify away from heavy chemicals. They hoped to find in specialty chemicals the profit margins which their traditional branch of chemicals no longer supplied.

Barring a few exceptions such as *Gulf Oil* or *Diamond Shamrock*, which withdrew from downstream chemicals, all the major companies, both in Europe and in the United States, decided to make specialty chemicals a priority in their development strategy. In truth, some of them had not waited for the energy crisis for them to take a firm foothold in the specialty market.

In the United States, *Du Pont* and *PPG* had a long-established reputation in industrial and consumer paints. *W. R. Grace* since buying Dewey & Almy, and *Rohm & Haas* because of its age-old tradition in acrylics, drew substantial profits from their specialties. This was also true of *American Cyanamid* (additives for plastics, cosmetics) and of *Monsanto* (products for rubber, special polymers). Since its withdrawal from the tire business, *BF Goodrich*, aside from its PVC lines, is concentrating now on specialties.

In Europe, ICI had already acquired a large paints sector (Duco, Dulux). The three major German leaders—*Bayer, BASF*, and *Hoechst*—had not yet made great inroads into the specialties market, but the Swiss *Ciba-Geigy* could be said to be particularly well established in certain areas like additives for polymers, in which it was a world leader. *Rhône-Poulenc* had assembled some of its activities within a "chemical specialties" division. But on the whole, they could be said to be offshoots of fine chemicals rather than actual specialties, with the exception of the performance products brought out by subsidiaries such as Orogil, SFOS, Soprosoie, and Vulnax. Orogil is now fully owned by Chevron, however, and Vulnax has been acquired by AKZO. Failing to develop through internal growth, *AKZO* had very early developed its specialties by buying up companies involved in peroxides, paints, oleochemicals, and now rubber additives.

To increase their specialty sectors as fast as possible, the leaders of large companies found it more expedient to do so through acquisitions. The prices paid for the most interesting purchases can be considered high because, very often, they amounted to fifteen to twenty times the profits. But the financial sacrifices made by the buyers seemed worthwhile, for they gained a foothold in the market without the long preliminary work that would otherwise have been needed.

There were, of course, many companies that were sufficiently important or prosperous to escape being bought up. Even then their independence was often at stake. Thus *Nestlé* took a share in the cosmetics group *l'Oréal*; and in the United States, the raider Perelman managed to buy *Revlon*.

Considering that the grass always looks greener on the other side of the fence, for many leaders of the chemical giants diversification into new areas might seem more attractive than mere concentration in well-known sectors; and it was in this sense that specialty chemicals seemed a good proposition. In 1983, *Olin* began to get involved in electronic chemicals by buying up 64 percent of *Philip Hunt Chemicals*, and took a firm foothold in the sector through successive acquisitions. Other groups became interested in enhanced oil recovery and exploration, for the future of oil seemed assured at the time. In both cases, however, the electronics and oil exploration slowdown did not confirm established forecasts. The investments made in these areas have yet to prove their profitability.

Moreover, many firms were unable to contribute anything except capital to the development of sectors far removed from their traditional areas of business. They became discouraged and ended by selling out, not without suffering heavy losses. *Hercules* was seen to back out of its water treatment sector and *Rhône-Poulenc* from its very recently acquired media business.