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Chemical Research in Germany State of the Art and Perspectives for the Nineties *

Chemical Industry as a Part of National Economy

The last months have seen dramatic political, economic, and social changes in Europe and, especially in Germany. These will be recognized by future historians as being just as "revolutionary" as the technological upheavals in the last century that we now call the First Industrial Revolution. Most of today's industries came into being at that time, among them the chemical industry. In the following decades the chemical industry increasingly evolved into the main driving force behind further developments.

In the middle of the last century in Germany as in the whole of Europe a rash of new dye factories sprang up, thereby giving birth to the chemical industry. Many of these ventures proved short-lived. In fact, the best-known chemical companies in Germany today were all latecomers on the scene. Bayer and Hoechst were founded in 1863, BASF followed in 1865. The key for the success of these companies, compared to their contemporary competitors, was the insight that corporate research was needed to increase scientific knowledge. This led to an early acceptance of the crucial role of research in ensuring a company's long-term success. From the very beginning there was an awareness of the close interaction of basic and applied research as well. So the chemical industry was not a product of the traditional crafts, but arose through the deliberate application of scientific research results for industrial purposes. This is one of the reasons why chemical industry has played and still plays an important role in our society.

In 1989 the chemical industry in the Federal Republic of Germany contributed 11 per cent to the total turnover of the manufacturing industry. This means position four behind the automotive industry, mechanical engineering industry, and electrical engineering industry. In 1989 the West German chemical industry concluded a very successful decade. After weathering the recession of the early 1980s, we have experienced almost continuous growth.

The turnover in 1989 rose by 6.4 per cent over 1988 to 160 bn DM *(Table I)*. As the chemical industry performed very well in 1988, too, the increase on a high basis was somewhat lower than that of manufacturing industry as a whole, which grew by 8.2 per cent. In 1990 the growth declined to 1.4 per cent. The political turbulences and the currency relations affected the results as well. In 1989 exports accounted for 54 % of total chemical turnover (1990 : 52 %). With 86 bn DM the German chemical industry is the world's leading exporter as well as the leading importer with 51 bn DM.

TABLE I. - *Figures for German industry (1989).*

	Chemical industry		Industry	
	Billion DM	% Change (1988)	Billion DM	% Change (1988)
Turnover	160.2	+ 6.4	1,453.4	+ 8.2
Exports	86.0	+ 7.6	641.3	+ 13.0
Export ratio	53.8 %		44.1 %	
Imports	51.2	+ 13.8	506.6	+ 15.2
Employees (1 000)	581	+ 0.9	6,951	+ 1.6

Source : VCI.

With reference to the share of the world's chemical turnover *(Fig. 1)* the chemical industry of the Federal Republic of Germany is in fourth position behind the USA, Japan and USSR. Three German companies rank amongst the ten leading chemical companies of the world.

These figures give an impression of the importance of the German chemical industry for our national economy. However, this strength is contrasted by a lack of natural resources in our country. Of the most important raw materials for chemical production - oil, natural gas, and rock salt - Germany only has an adequate supply of the latter. Beside this drawback chemical companies in Germany face higher cost of energy than most of their European competitors.

For example the electricity prices for industrial users in Germany *(Fig. 2)* are higher than in the EC. The same is true for the prices of natural gas *(Fig. 3)*.

It is for these reasons that the chemical industry in Germany is obliged to keep a high standard in research, to develop superior technologies and exploit synergies within an established integrated system of production.

Research and Development in Germany

On account of these disadvantages research and development (R & D) traditionally rank high in Germany. German export goods

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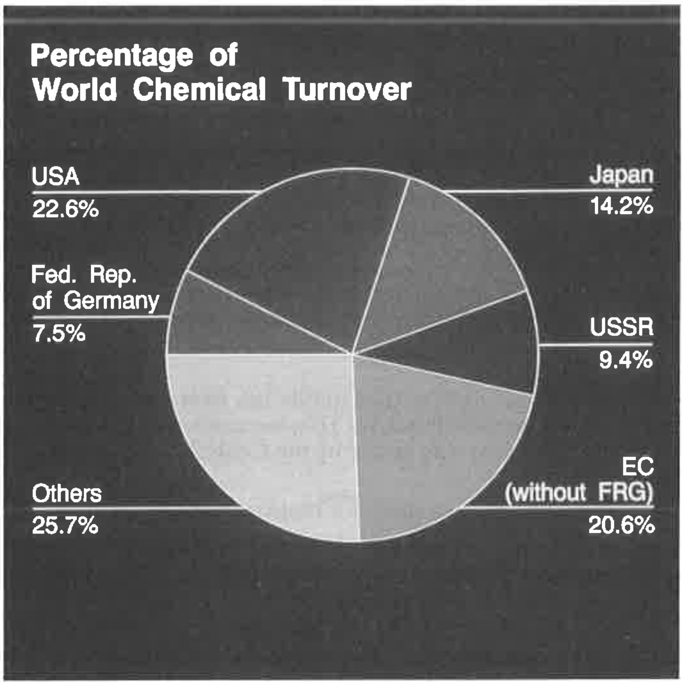

FIGURE 1. - *Percentage of world chemical turnover.*

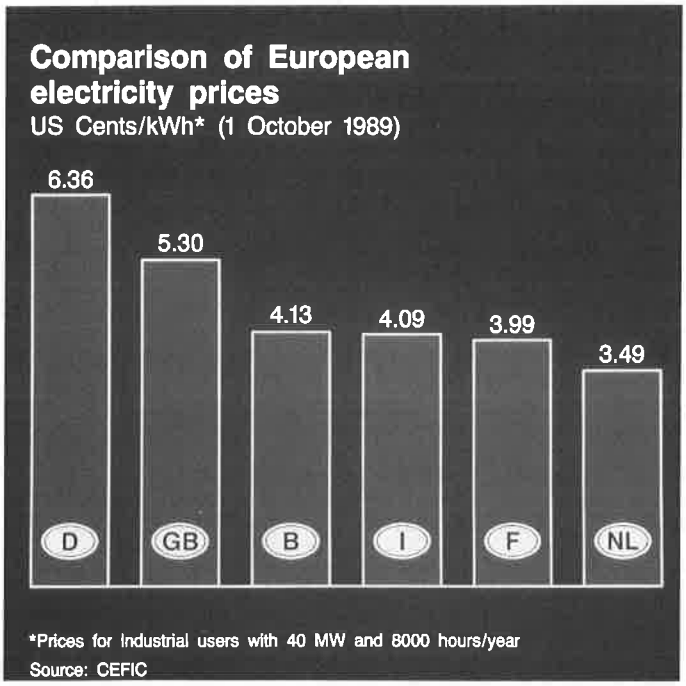

FIGURE 2. - *Comparison of European electricity prices, US cents/ kWh (1 October 1989).*

can only meet international competition by high quality standards. So 54 per cent of total German exports are goods that require intense research efforts.

In 1989 total expenditures on R & D amounted to 67 bn DM and for the year 1990 the sum reached 70 bn DM. In the period from 1981 to 1989 expenditure increased by 67 per cent. In 1989 64 per cent of the national R & D budget were contributed by industry, 34 per cent by the Central and the Länder Governments *(Fig. 4)*. Only a minor amount (< 2 %) was financed by private institutions or from foreign countries.

A look at the sectors that do R & D in Germany shows a share of industry of 71 per cent ; 12 per cent of the total funds go into

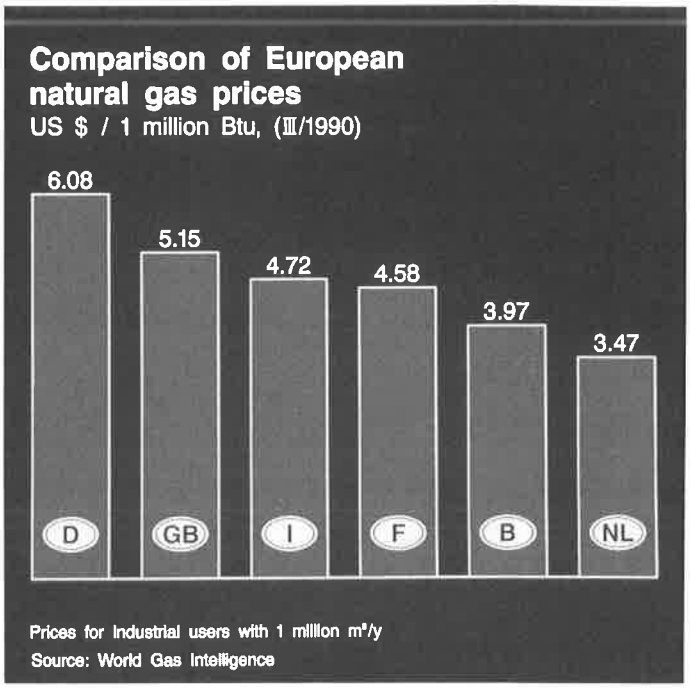

FIGURE 3. - *Comparison of European natural gas prices, US $/ 1 million Btu (III/1990).*

national institutes and 14 per cent into universities. A little less than 3 per cent or - in terms of money - 1.9 bn DM of German R & D expenditures are spent in other countries *(Fig. 5)*.

What do these figures mean in an international context ?

A comparison with the major industrial countries shows that the USA and Japan spend most on R & D in absolute amounts. The percentage of gross domestic product, however, is the same as in West Germany (figures based on the year 1987). The share of R & D expenditure in Germany increased from 2.6 per cent in 1981 to 2.9 per cent in 1987 *(Table II)* and has been constant since then.

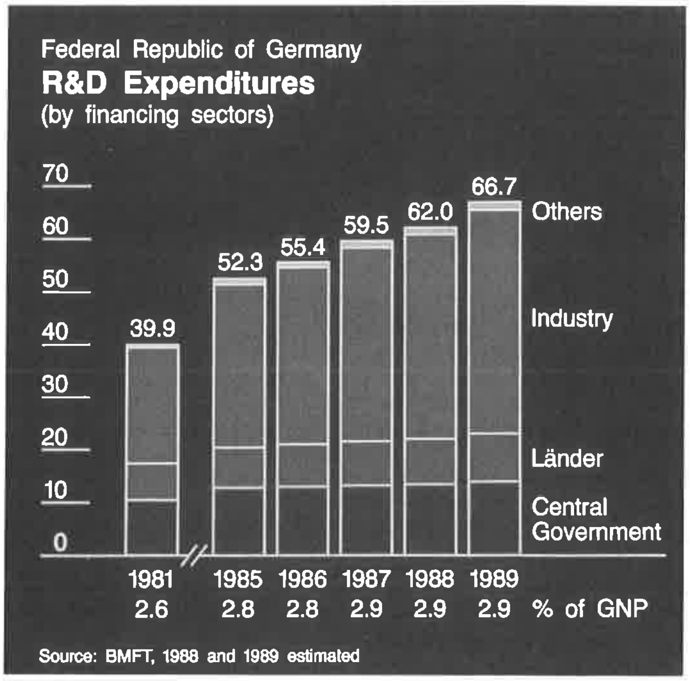

FIGURE 4. - *R & D expenditures of Federal Republic of Germany (by financing sectors).*

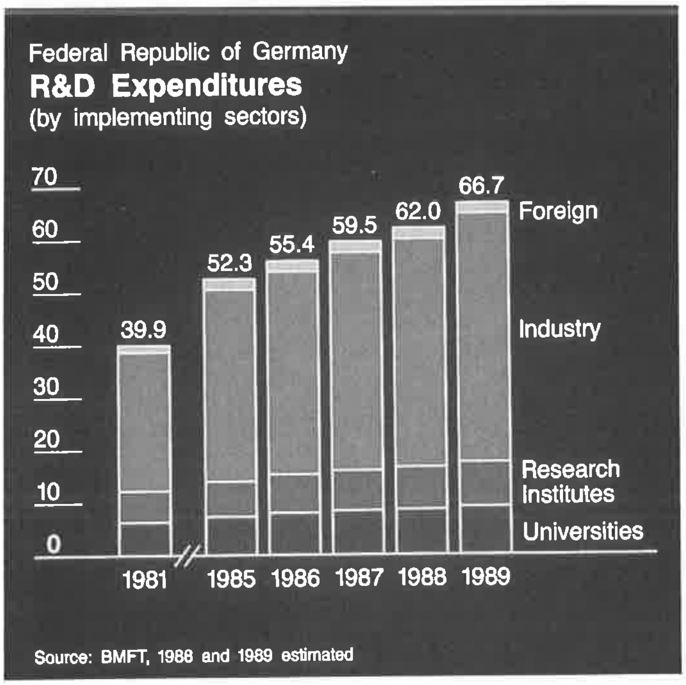

FIGURE 5. - *R & D expenditures of Federal Republic of Germany (by implementing sectors).*

TABLE II. - *R & D expenditures of major industrial countries (1987).*

	Billion US $	% of GNP
Fed. Rep. of Germany	23.2	2.9
France	16.3	2.3
United Kingdom	16.2	2.3
Italy	8.3	1.2
Netherlands	4.2	2.3
Japan	46.1	2.9
USA	130.0	2.9

Source : OECD.

Chemical Research and Development

The West German chemical industry spent 11 bn DM on R & D in 1989 *(Table III)*. This compares to the 67 bn DM of total R & D spending and to the 42 bn DM of spending by industry as a whole. With a share of 17 per cent of the total and 26 per cent of industrial R & D funding the chemical industry ranks highest in research efforts among all industries. The fact that chemical companies finance 98 per cent of their own R & D is a convincing argument for the industry's productive capability. Technological innovation is possible only if free enterprise if allowed. Too much bureaucratic interference hinders the development. The consequences of the latter we now see drastically in the eastern parts of our unified country. The prerequisites for keeping the capability for innovation are formulated by the German Association of the Chemical Industry (VCI) as follows :

- Suitable general conditions for research, development and innovation on a national and European level. In this respect, practicable laws can be of more value than a state funding scheme.

TABLE III. - *Federal Republic of Germany : Chemical R & D of total R & D (1989).*

Expenditures	Billion DM	%
Total	66.7	100
Industry	42.4	64
Chemical Industry (self-financed 98 %)	11	17

- An educational system that fulfills the demands of a highly technological industrial society. This necessitates better financial support of the university sector by the Central Government and by the Länder.
- Support and added strength for basic research in chemistry.

I would now like to elucidate these fundamentals and give you some examples of the state of the art and future developments.

1. Legal Framework for Chemical R & D

The industrial researcher in Germany is confronted by a rising tide of laws, ordinances, and regulations. The last 20 years in particular have witnessed a breathtaking escalation *(Fig. 6)*. Each dot in the graph represents another law or ordinance passed. In some of these cases, a justified questioning has developed more and more into a bureaucratic obstacle race which ties up substantial personnel resources both in industry and government bodies. One dubious effect of the numerous statutory requirements is a shift in the emphasis of research activity. The innovative content of research - the pursuit of new discoveries - is becoming ever smaller relative to the effort to demonstrate that a problem has been solved responsibly, testing for potential side effects or confirming environmental compatibility. Undoubtedly, the environmental discussion will greatly influence the future lines of development in all our countries. In Germany this discussion is quite ahead of the other European countries. We must therefore take care to make proper use of our advantages in this

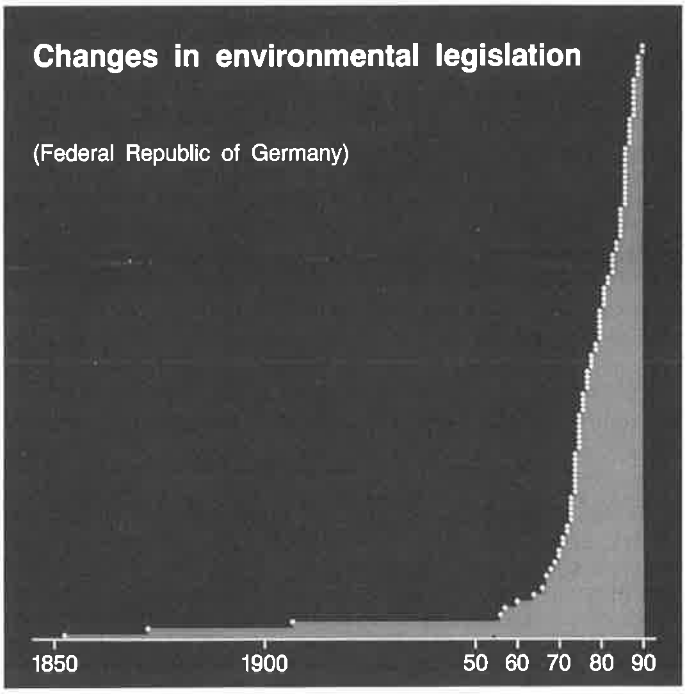

FIGURE 6. - *Changes in environmental legislation for Federal Republic of Germany.*

field up to now and stop merely national actions in favor of international harmonisation.

2. Scientific Education

Another determining factor for chemical R & D beside legislation is the state of scientific education. The completion of the single European market will also have consequences for the labor market for chemists. As German chemistry students stay longer at university than students in other countries, the Chemical Industry Fund has urged that the length of study in chemistry at German universities be shortened. In contrast to the basic education a continuing education gains more and more importance. Many firms and professional societies have begun to sponsor a wide variety of exemplary programs for postgraduate and professional education in recent years.

Whereas the education of scientists as well as of technicians and workers of the chemical professions is on an encouraging level, some developments in school education in the last two decades give cause for thought. As a consequence of several school reforms the level of general scientific knowledge has decreased. This may be one of the reasons why so many people in our country feel discomfortable about technical issues.

At present the supply and demand of young chemists are fairly well-balanced. At the moment about 1 200 young chemists leave the universities every year, mostly as PhDs. About two third join the chemical industry, the rest starting their careers at the universities, in the public sector or in other industries.

3. Basic Research

On the other hand German universities are facing an increasingly serious situation : an increasing number of students combined with a growing financial deficit. In this situation it is especially important to enable basic research at the universities to be continued in the present scope. Basic research in chemistry provides a solid framework for technological progress in other industries as well as in the chemical industry. The funds for basic research come from three sources mainly : Central Government, Governments of the Länder, and industry.

The federal funds for German basic research increased by more than 50 per cent from 1981 to 1988 while the federal R & D spending as a whole only rose by 28 per cent. In 1988 a third or 3.8 bn DM of R & D expenditure went into basic research *(Table IV)*. Among the most important areas relevant to chemistry are biotechnology and materials science. Besides these two sections there is a major amount spent on specific scientific equipment which is not commonly available.

The R & D expenditures of the Länder Governments are nearly exclusively for the benefit of the universities and, thus, for basic research. The most recent figure available is for the year 1987, where it amounted to 8.6 bn DM.

For institutions of national importance there is common financing by the Central and the Länder Governments. The most important institutions in this context are Deutsche Forschungsgemeinschaft, Max-Planck-Gesellschaft, Fraunhofergesellschaft, and various "Großforschungseinrichtungen", institutions with special expensive equipment to serve as centers for special R & D tasks. For these institutions 5.1 bn DM was spent in 1988, 70 per cent of which came from the Central Government.

Among the chemistry-related projects funded by Central ministries basic research on new forms of energy rank highest with an expenditure of 170 Mio DM in 1988 *(Table V)*. Environmental research efforts were funded with 140 Mio DM. Both projects are interdisciplinary ones with chemistry playing an important part. For developing biotechnology in Germany public funding started as early as the seventies although at a low level. By 1988, however, spending in this field amounted to 100 Mio DM after all. Starting with the year 1990 the total governmental funds for biotechnology and related fields were raised to 1.5 bn DM per years. In 1985 the current program for materials science was initiated and meanwhile approved expenditures amount to nearly 1 bn DM, of which more than 100 Mio DM was spent in 1988 on basic research efforts.

The chemical industry supports basic research as a complement to the broader-based public funding schemes. In 1989 the chemical companies awarded - through the Chemical Industry Fund - 19 Mio DM in grants to scholars and institutions, the emphasis

TABLE IV. - *Public R & D expenditures on basic research.*

Central Government Expenditures (1988)	3,840 m DM
Länder R & D Expenditures (1987)	8,600 m DM
Common Central/Länder Expenditures (1988)	5,140 m DM

Source : BMFT.

TABLE V. - *Central Government R & D funding. Examples of Projects and Institutions of Basic Research.*

Projects	million DM (1988)
Energy	170
Environment	140
Biotechnology	100
Materials Science	107
Institutions	
Universities	1,275
Deutsche Forschungsgemeinschaft *	1,050
Max-Planck Society *	900

* Central Government and Länder.

Source : BMFT.

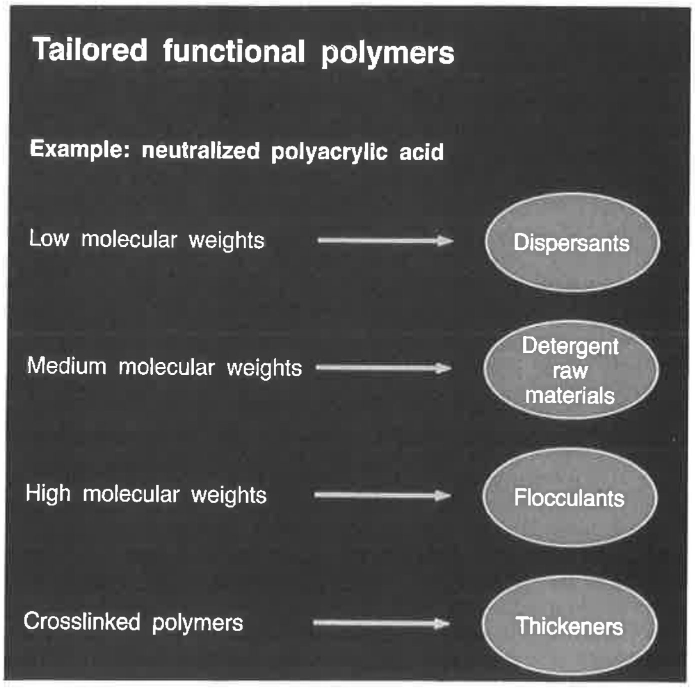

FIGURE 7. - *Tailored functional polymers.*

being on funding chemistry-related basic research. For 1990 and 1991 an additional 20 Mio DM is budgeted for research projects. Besides these funds grants are bestowed on university teachers in all fields of chemistry. Today this fast and flexible aid to chemical education is more valuable than ever.

The Fund also supports specialized areas of research which have a particular potential for the future, especially biological chemistry and materials science. For both of these disciplines the funding by the chemical industry receives an allotment of 40 per cent of the total funding from the German Ministry for Research and Technology. Thus research in biological chemistry between 1983 and 1992 will be supported with 73 Mio DM, 29 Mio DM of which is spent by the Research Ministry. For a non-industrial basic research program in materials science the chemical industry and the Research Ministry have announced the provision of 27.5 Mio DM for the coming years.

As a rule basic research for chemistry in Germany is carried out at universities and research institutes. Applied research is mostly done by the chemical industry.

This system has proven very efficient in the past. It will be successful in the next decades, too, if appropriate mechanisms ensure a frictionless transfer of demands and results in both directions. New opportunities arise from new discoveries, and these result from basic research. Applied research in turn transforms the discoveries into innovative solutions to problems on an industrial scale. At present we live in an exciting period with a lot of developments somewhere between basic discovery and industrial breakthrough. Another reason why we live in an exciting period lies in the dramatic political changes in Europe which led to German unity. This development, undreamt-of a few months back, will certainly have an important impact on the scientific landscape in Germany. Therefore it is worth while having a brief look at the situation of chemical R & D in the eastern part of our country.

4. *Impact of National Unity*

Chemical research in the former German Democratic Republic was organized in a way totally unlike that in the Federal Republic. There was not much basic research done. Most researchers at universities were more or less dependent on the chemical production collectives. These in turn expected their problems to be solved. The research work at universities generally suffered from insufficient equipment as well. Of more importance within East German research was the Academy of Science on the Soviet pattern. Within the 56 institutes of the Academy there were 9 chemical institutes with about 3,000 employees, amongst them 1,300 scientists. The Academy did hardly any basic work but performed applied research, often under a direct order from the Communist Party or the chemical firms. The latter in turn had few or no research facilities of their own. Therefore the current problem of research is that there are too many research people outside industry often specialized on obsolete technologies born out of the autarkichal efforts of the former Socialist system. On the other hand the level of basic research is rather low although scientific education is comparable to a western standard. Chemical firms will certainly have a demand for chemists in the future, but the present unsettled situation of most of the companies and their inadequate high number of personnel prevents the engagement of a large number of chemists.

Federal Government as well as the chemical industry have taken the first steps toward aiding basic research. An emergency funding was started at the end of 1989. The first steps after the unification must be to integrate the research staff, to abandon double work and to adjust the targets to the actual market requirements. The reorganisation of chemical research in the 5 new Länder of the former GDR will take place within the current national and European research programs as well as by special national measures. The transient phase requires pragmatic solutions to avoid a brain drain.

Challenges for the Chemical Industry in the Coming Decade

It is predictable, without being a prophet, that environmental aspects will essentially influence the future development of the chemical industry. Therefore we must face a gradual change in our manufacturing processes. Further savings of the conventional resources oil and gas are unavoidable : besides this there will be an enhanced utilization of renewable resources. Another aspect is to further efforts for the recycling of waste products. The Federal Government supports research for new environmental technologies with 700 Mio DM per year.

For example, basic efforts are aimed at the development of biodegradable polymers for environmental relevant uses such as detergents and cleansers.

Within applied research there is a remarkable trend from individual substances toward combinations of ingredients. These can then be regarded as molecular systems, all the components of which must be carefully matched. Use of such a system permits a set of properties to be varied within rather broad limits by tailoring the blend of components.

For example *(Fig. 7)* neutralized polyacrylic acid can be adapted simply by adjusting the molecular weight to such different fields of application as dispersion and flocculation, e. g. for water treatment purposes, as a raw material for detergents, or as a thickener for establishing the proper viscosity in cleansing agents. This principle of optimizing a molecular system has also become extremely important in the finishing of textiles and leather, in electroplating, in the printing sector, and in the design of new polymeric materials, an application with particular significance for the future. Some recent developments in this area hold great promise for the future.

Products have emerged in recent years in this field, offering combinations of unusual properties that cannot be duplicated with conventional materials *(Fig. 8)*. Examples of such properties are increased temperature resistance, toughness, strength, dimensional stability, low flammability, corrosion resistance, specific optical properties, or electrical conductivity. In the case of conventional organic polymers, advantage is taken of only about 5 % of

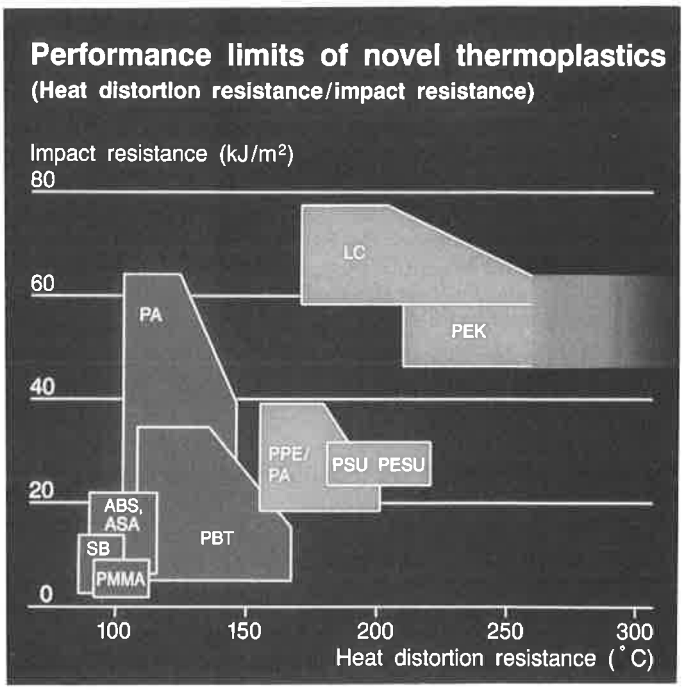

FIGURE 8. - *Performance limits of novel thermoplastics (heat distortion resistance/impact resistance).*

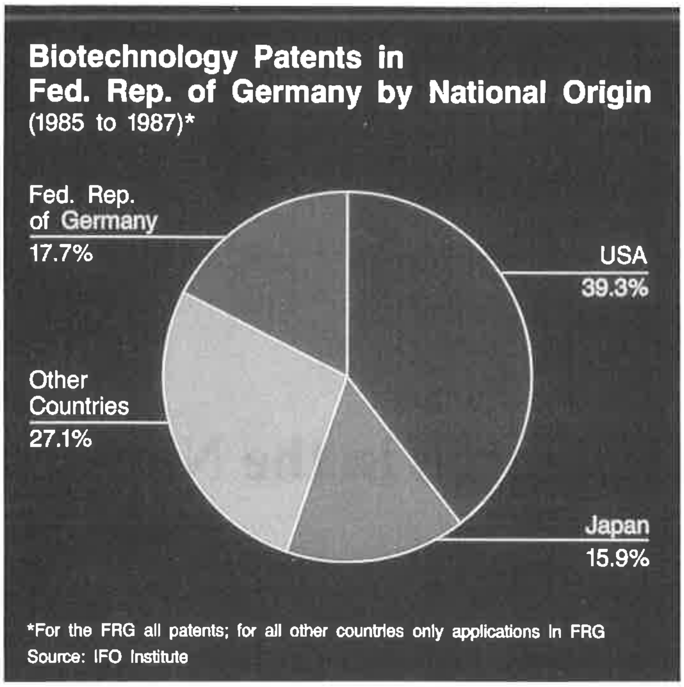

FIGURE 9. - *Biotechnology patents in Federal Republic of Germany by national origin (1985 to 1987).*

FIGURE 10. - *Fermenter of BASF's projected plant to produce tumor necrosis factor.*

the potential to withstand mechanical stress that is actually present in the chemical bonds. Modern developments like carbon fibers already permit more than 50 % of this potential to be exploited, and the resistance of such materials to stress is increased correspondingly. Further developments are aimed in two directions. First, it is hoped that improved production techniques will minimize the occurrence of weak spots that reduce product strength. Second, even more advantage is to be taken of the potential residing in chemical bonds, permitting the elimination, for example, of extreme anisotropic behavior with respect to physical properties (e. g. graphite layers in carbon fibers) through chemical cross-linking of adjacent layers. Because of the leading position Germany has attained in plastics technology - both as a science and in production and application - Germany is expected to play a crucial role in helping to shape the future. The situation looks rather different, however, in another sector currently undergoing dramatic changes and promising to bring substantial improvements in the conditions of life, namely biotechnology.

The use of biotechnology is as old as mankind itself. Microorganisms have always played a part in alcoholic fermentation and in the preparation of sourdough or cheese. Specific microorganisms have been selected, now and in the past, on the basis of the effectiveness of their adaptation to the processes in question.

Recently, genetic engineering has provided us with methods for obtaining more rapidly than in the past very high levels of synthetic performance from microorganisms. The secret is discriminate modification of the target organism's genetic information. On the one hand this makes it possible to prepare substances more economically than by the methods of conventional chemistry, but it also opens the way to products obtainable only by this route.

Knowledge in the field of genetic engineering is growing at a tremendous rate, and Germany as well as Europe as a whole are far from setting the pace. A look at the origin of biotechnological patents in Germany *(Fig. 9)* shows that the domestic share is rather low. Whereas German basic research in this field has caught up with the international standard, industrial research suffers from the society's uncertainties about the new technology. To the high level of basic research such research institutions as the Society for Biological Research (GBF) and the German Cancer Research Center contribute as well as the newly installed gene centers in Berlin, Heidelberg, Cologne, and Munich. The expenditures for basic *and* applied biotechnological research are estimated at 250 Mio DM each. Another 820 Mio DM are spent on biological and biomedical basic research. This compares to the 4.5 bn DM of fundings by the US administration alone. In the period from 1989-1994 the budget of the Research Ministry foresees total expenditures of 1.7 bn DM for biotechnological research.

In Germany the main obstacle for biotechnology, especially genetic engineering must be seen in society's acceptance of the new technology. Their refusal by sections of the public may be due in part to the fact that the public and political debates have failed to draw a sufficiently clear distinction between genetic engineering on the one hand and reproductive biology with all its ethical, moral, and legal ramifications, on the other. It is therefore a welcome development that the Genetic Engineering Act came into force in July 1990. After Denmark, Germany is the world's second country to regulate genetic engineering by a special law. Binding legal parameters now circumscribe genetic engineering research and the construction and operation of plants based on genetic engineering processes. Nevertheless, this act and the regulations associated with it still do not guarantee that approval proceedings will advance smoothly. The public hearings that are mandated at safety review stages 2-4 are still subject to the influence of "refusal experts". A recent study showed, however, that such important products as tissue plasminogen activator (tPA), erythropoiethine (EPO), or interleucine-2 could be produced under the new act under safety stage one, which means without disclosure and public hearing.

We are optimistic now that pictures, like the *figure 10*, belong to the past. It shows the fermenter of BASF's projected plant to produce tumor necrosis factor, a mediator of the immune system. The fermenter has a volume of 200 liters and, alongside it, you can see the stack of documents prepared for obtaining official approval for production before the Genetic Engineering Act came into force.

The new methods of biotechnology open up bright opportunities for medicine, food production and environmental protection.

Therefore it is not this technology where managers have to worry about whether it is the right one or not. But in many respects the ongoing developments arising from new knowledge involve a problem of the coming decade for research management. At the end of our century we are going to make use of a whole series of pioneering results which have sprung up from research efforts in the last two decades. Let me mention only a few of them : advanced ceramics, membrane technology, electronic materials, composites, high heat resistant thermoplastics, biotechnology, use of renewable resources, new forms of energy and so on. Thus it will be indeed a great task for leaders in state and industry to choose the right technologies, to support these adequately and not to dissipate scarce resources.

B.W. Langley

UK Chemical Research in the Nineties

Chemical research in the UK flourishes but at the moment, as in many other places, it is not having an easy time.

The industrial revolution began in the UK and with it the first large scale chemical industry. Alas we have now seen the relative decline of most of our large manufacturing industries and that based on chemistry remains the most obviously successful exception. The UK is a small country, not very affluent, but it still has a good science base and is a good place in which to conduct R & D, especially for the chemical industry. Indeed most of the chemical multinationals have a research laboratory in the UK. However, there is far too little industrial R & D in other areas, and we have too few technically advanced home-based customers. At the moment there is excessive concern with the short-term, both in academy and industry, and as a result our science base is eroding.

Chemistry is one of the oldest and best known sciences and one which, by any standard, has been conspicuously useful. If we are looking at the prospects for future research, it is as well to ask what are the future growth points ? How exciting is the subject itself ? What parts are likely to be most useful ? For me these questions were most crisply answered in the National Academy of Sciences 1985 report "Opportunities in Chemistry" (The Pimentel Report). This gave as the dominant intellectual frontiers - kinetics, theory, catalysis, materials, synthesis, life processes and analytical methods. It listed as the main social benefits, more food, better health, new materials, more energy, new processes, a cleaner environment, economic competitiveness and greater national security.

All of this is true of chemistry everywhere. If we are to review chemical research specifically in the UK, perhaps we may look first at the position of the UK chemical industry. It is large and important, fifth in the world league. It is the third largest manufacturing industry in the UK and the only one with a continuing and substantial export/import balance (over £ 2000 M). As everywhere the public is largely unaware of it except as a source of "pollution". In total there are about 2000 chemical companies dominated by about ten who do most of the research, and all of these ten are multinationals. Our own company, ICI, is the largest in the UK and fifth largest in the world.

Production by percentage of the gross added value is as follows :

Pharmaceuticals	28
Organics	17
Specialties (for industry and agriculture)	17
Soaps and toiletries	9
Resins, plastics, rubber	7
Paint, varnish, ink	6
Dyes, pigments	5
Inorganics	5
Specialties (house and office)	4
Fertilisers	2

When considering research prospects, gross added value is not as important as profitability. Statistics for this are not so readily available, but those for some parts of ICI from the 1989 Annual Report are as follows :

	World turnover (£ M)	Profit (%)
Pharmaceuticals	1330	30
Paints	1630	6
Polymers and petrochemicals	3000	14
Explosives	410	12
Agrochemicals and seeds	1340	11
Fertilisers	940	- 1

Those for other companies working in these fields are probably broadly similar. From the research standpoint the key fact is that most of the more profitable areas are crucially dependent on new products or new processes. The UK Chemical Industries Association listed those areas which they thought should receive research priority - electronics and opto-electronics, advanced materials, health care, agriculture and food, safety and environmental control, energy, and the supporting areas in analysis, biotechnology, surface science and catalysis. Again, no surprises from the Pimentel Report. Virtually all of these research areas are being vigorously pursued in the UK at the moment in academy and industry - not all of course with equal enthusiasm nor with equally successful outcomes.

Before surveying some of the topics being examined in research it may be interesting to look at some current research successes.

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