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.

ICI Corporate Research and Technology, Mereside, Alderley Park, Macclesfield, Cheshire SK10 4TG (UK).

One way of doing this might be to list last year's "Queen's Awards" for Technology. In the chemical field these are as follows :

Laboratory diagnostics (Amersham/Birmingham University).

- Lubricant for steel rolling (Croda).
- Organometallics for semiconductors (Epichem/RSRE).
- Ceftazidine antibiotic (Glaxo).
- Genetic fingerprinting (ICI/Lister Institute).
- Membrane electrochemical cell (ICI).
- Low NO_x combustion system (N.E. Int. Combustion).
- Plasma mass spectrometry (VG/NERC).
- Screen printing emulsions (Sericol).
- Retrovir (AIDS drug) (Wellcome).

An interesting list covering a wide range. Interesting also in the wide range of sciences besides chemistry which were involved. Indeed, in surveying the prospects for "chemical research in the nineties" it is frankly impossible to consider chemistry alone. In science its borders with physics, biology and engineering are becoming hazy and in commerce very little money is made by chemistry alone, albeit most areas have a key chemical component.

Moving now to a quick review of UK chemical research. May we first look at the whole massive area of interaction between chemistry and biology. This is, of course, a very lively field in both academy and industry and one in which there is a strong UK tradition - Crick Watson's DNA, Cesar Milstein's monoclonal antibodies, Jimmy Black's beta-adrenergic and histamine blockers and the like. It is also an area of huge commercial significance. On the positive side the pharmaceutical and agrochemical businesses are amongst the most profitable and on the negative side most environmental concerns centre on the unwanted biological effects of chemicals. In our own Company ICI spends just over half of its £ 600 M research budget in biological areas.

Others will consider pharmaceutical research in detail later at this symposium, but one is bound to mention that this area flourishes in the UK. Most pharmaceutical multinationals have a research laboratory in the UK and three of the top five drugs - Zantac, Tagamet and Tenormin, were discovered in the UK. Exciting frontier research is being carried out over a wide area but the whole affair is crucially dependent on the excellence of the academic science base in organic chemistry, pharmacology, molecular biology and clinical medicine, and there is a great deal of current concern about the erosion of our traditional strength in these subjects.

The Agrochemicals business is another key part of the UK chemical industry. There are of course fewer large companies in our country than there are in pharmaceuticals, but the four world largest agrochemical companies are all European and most of them carry out research in the UK. The area is naturally hugely important to us as an exporter. The research principles are broadly similar to those for pharmaceuticals, but the economics are vastly different. The costs are crucial and toxicological and ecological factors are often rate limiting. Interests in our own company in this field, as with some of our competitors, have now broadened to include research on seeds and on plant breeding.

The pure research areas which underpin the pharmaceutical and agrochemical businesses are in a state of great ferment and excitement in the UK as elsewhere. Advanced synthetic chemistry, molecular biology, protein engineering, enzyme and receptor structure and function, these and many related topics are being intensively studied in academy and in industry. Funding is, by common consent, barely adequate to cover present needs or to allow a confident extrapolation of our past international position.

Outside the biological areas there is increasing interest in our own company and in many others in redirecting their main research thrust from the large tonnage areas to those concerned with specialties, small volume chemicals with higher added value. Although most conventional dyestuff and pigment effects can be readily achieved, there is maintained interest in new chromophores, new dyeing systems and for the use of "coloured" materials in reprographics and in security marking systems. Demands in the electronics industry have brought new research targets for liquid crystals, substances for opto-electronic systems, and organometallics and masking systems for "chip" manufacture. There is growing interest in co-ordination chemistry for hydrometallurgy and corrosion inhibition. New surface active agents are being sought for a wide range of applications in paints, coatings and ceramics, besides their conventional applications in detergency and lubrication.

Many areas of the chemical industry in the UK as elsewhere fit between the large tonnage and the effect chemical scale of production. Research to support these sorts of enterprises and lead them into new areas is active throughout the whole field of materials science - organic and metallic composites, films and fibres for special purposes, membranes, ceramics and, of course, biodegradable substances. The paint and coatings business is demanding research into new polymerisation systems, many of them water based. Even such a traditional field as that of explosives technology is backed by intensive research into new ways of stabilising emulsion and slurry explosives, into new detonation systems and into rock fracture mechanisms which can form the basis of computer based blasting models.

The large tonnage areas of our industry concerned with the production of petrochemicals, polymers, fertilizers and suchlike are obviously hardest hit in any general business downturn. This inevitably reflects in the research effort allocated to support them. However, there are huge targets in chemistry and engineering, stemming from increasing needs for the economical use of energy and feedstocks and from the desire to avoid pollution. Research in catalysis is clearly crucial to virtually all large tonnage chemical production and continues even under the present harsh commercial conditions. In academy there is of course increasing excitement over the new battery of spectroscopic techniques which proffer greater real understanding of the mechanisms of catalyst activity.

Concern for the environment and for the avoidance of chemical pollution has led to many research based new activities. In ICI, for example, we have developed CFC alternatives and devised a modest scale electrochemical cell for the local production of chlorine. Johnson Matthey have achieved considerable technical and commercial success with their automotive exhaust catalyst systems. The need for greater production efficiencies and concern for plant safety has provided a greater stimulus for research in chemical engineering. Interests in process intensification are leading to the design of new types of extraction systems, heat exchangers and the Higee distillation process. Growing interest in biochemical processes has induced a new range of challenges for the chemical engineer.

Virtually all that I have said is not peculiar to UK, but is true of the chemical industry and the research which underpins it in virtually every country. May I close by making a few remarks about a problem which, though common to many countries, is particularly acute in the UK at present. The problem concerns the academic science base which underpins our whole industry. Although, as must be obvious from my earlier remarks, we depend on a wide range of sciences, perhaps we might concentrate, as indeed the title of our symposium bids us, on chemistry.

Anyone who has talked to UK academics in recent years can be in no doubt that most of them are unhappy. After about 30 years of continuous expansion, university funding has now levelled off. Indeed the provision made for inflation is held to be inadequate. There are now about 50 universities and 30 polytechnics in the UK where chemistry is taught to degree level. Clearly the UK is too poor to afford a wide ranging properly equipped research department for every university where a subject is taught to degree level. A great deal of stratification is now taking place and indeed some few departments of chemistry are either closing or merging with others. For some years, to add to academic misery, chemistry student numbers were falling. Happily these seem now to have levelled off. In the UK a high proportion, currently about a third, of chemistry undergraduates stay on for PhD research, but quite a few of the others, not unreasonably, leave chemistry and science altogether. Happily, alongside the unhappiness of most of the university research community, there seems to be a growing interest in new ways of teaching the subject and in providing a wider range of course options.

For the last ten years my own job in ICI has been to foster interactions with universities, especially in research. This is a delightful occupation in the sense of being favoured thermodynamically. Our industry has always had close and fruitful interactions with the academic research community and, with due modesty, I think I can claim that ICI has always been a leader in this sort of activity. Interactions between academy and industry are now seen to be of growing importance and are being vigorously encouraged, especially in UK. One driving force stems from the realisation that much of our national wealth stems from the practice of advanced science and technology, much of it originating in universities. Another less praiseworthy aim of governments in furthering this sort of activity is their desire for industries to pay a larger proportion of academic research costs. I feel very strongly about this and only by a massive exercise in self-discipline can I restrain myself from speaking about it at great length. Suffice it to say that the desire for academic researchers to earn more of their own support funding from industry will inevitably lead to their neglecting the longer term curiosity driven research which industry rarely does itself but which is crucial for its long term prosperity. This government inspired trend is yet another example of the current obsession with short term thinking which in my view is the dominant problem in science in the UK.

By international standards the UK does have some of the best systems for encouraging academic-industrial interaction and these often catalyse changes which, as I mentioned earlier, are thermodynamically favoured. Our Research Councils, pre-eminently the Science & Engineering Research Council (SERC) have played a leading role in this. A substantial proportion of all SERC funded PhD students, currently about one-third, are working on topics of industrial interest and have an industrial as well as an academic research supervisor. At a higher level SERC fund, jointly with industry, a substantial number of co-operative research awards for postdoctorals.

They also provide special facilities for industrial scientists at their synchotron, neutron and computer laboratories. In an attempt to make best use of specialist university facilities a series of Interdisciplinary Research Centres (IRCs) have been set up between different university departments and these frequently involve industrial partners. Our Department of Trade and Industry has also set up a series of industrial collaborative programmes at universities under their LINK scheme.

I hope this short review has given you a quick picture of chemical research in our country, I hope, whatever our problems, we are seen as a force to be reckoned with in the future. Virtually all of the topics I have mentioned and indeed most of our current problems are common to many countries.

May I close with another problem which, though widespread, is particularly acute in the UK at the moment, that of science teaching in schools. As in virtually all countries the sciences, especially the physical sciences, are less popular with children. In the UK a new national curriculum is being set up in which all children in state schools are taught some science until the age of 16. However, there is an acute and growing shortage of physics, chemistry and maths teachers and many children are taught by those who have not studied these subjects themselves at university or college. The whole problem is compounded for us in the UK by the disappointingly small proportion of young people who stay on for education at university level.

All of us who have had long happy careers in science should naturally be concerned that those following us should have a comparable opportunity for enjoying science and, if need be, making this a basis for a career. Those of us in industry, especially the chemical industry, meet everyday fascinating examples of the application of science. Surely displaying these to young people alongside the classical examples of academic science can only make the subject more attractive to those with any inclination towards it. In our own company, as in many others in the UK, we are giving high priority to work of this sort and to supporting the careers, rewards and conditions of those teaching the next generation.