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Organic processes and technological change – an economic perspective

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Abstract - This paper reviews characteristics of the organic-based chemical industry in relation to the role which innovation plays in its prosperity. The influence of its international economic and business environment is crucial in this respect and will continue to dominate developments in the future.

KEY POSITION OF ORGANIC CHEMICAL INDUSTRY IN ECONOMIC ACTIVITY

The organic chemical industry occupies a unique place in economic activity and the satisfaction of human needs and desires. What other industry can claim to have done so much for improving health, satisfying vital needs and improving standards of living? Chemistry has a fundamental impact on human life and is the mainstay of modern civilisation, whether in securing food supplies and other basic needs, in controlling once deadly diseases, or in improving the quality of life at home and at work. The indispensable advantages bestowed by the chemical industry are frequently taken for granted or ignored in drawing attention to some of its less desirable consequences.

The chemical industry is not designed narrowly around its own specific products as is the case for example with the motor car industry or the computer industry. It is instead primarily an enabling industry concerned with processes and with materials and products which are in turn used by other industries to make their products (e.g. rubber and plastics for cars), or to improve or substitute more traditional products (e.g. textiles, packaging, medicines, buckets). The chemical industry has expanded into and revolutionised other industries, changed the way many things are made and drastically altered their characteristics.

Chemistry and the chemical industry are thus deeply embedded in a broad spectrum of economic activities and make essential contributions to many other product-oriented industries. In a typical industrialised country the chemical industry, narrowly defined, may only account for about 5% of gross national product and may only employ 1% of the national workforce, but in terms of the downstream industries which in some way or other depend on it, it can have a strategic impact on perhaps 40% of the total economy.

The importance of the chemical industry thus exceeds by far its own boundaries. Indeed it is debatable what the boundaries of the chemical industry actually are, as chemical processes and the skills of chemists become essential in more and more industries, for example microelectronics.

DRIVING FORCES BEHIND THE HISTORICAL SUCCESS OF CHEMICAL INDUSTRY

From the end of the last century until the early 1970's the chemical industry demonstrated almost continuous growth. A hundred years ago it dealt chiefly in a few basic inorganic chemicals needed by other expanding industries, such as soda ash for textiles, paper and glass manufacture, bleach for textiles and paper, and caustic soda for soap. Dyestuffs were the only significant commercial organic chemicals. The subsequent growth of the chemical industry, which has occurred at a rate many times that of the growth of the gross world product, has been dominated by the products of organic chemistry, ranging from pharmaceuticals and agricultural chemicals to man-made fibres, plastics and other polymers.

In achieving its record of growth and prosperity the chemical industry has depended on two of its important characteristics, the ability to innovate in new directions, and the flexibility to adapt readily to the changing economic, political and commercial circumstances in which it operates.

Let us look more closely at the role that innovation has played in the past. Some of the major organic chemical inventions of the last fifty years or so are listed in Table 1. The timescale from an initial discovery or invention to successful commercial production can be ten years or more, and a further five to ten years may elapse before the new business created is making a significant contribution to the industry's profits. The period of very rapid growth of the chemical industry after the second world war was based on the industry's 'golden age' of major innovation in the 1930's and 1940's and the successful exploitation of the opportunities they created. The resulting stream of new processes and new products enabled the industry to create major new markets and to penetrate and expand existing markets with improved, lower cost products. The list of major innovations in Table 1 also shows a disturbing feature to which I shall return later, namely the drying up of the stream of major inventions in the 1950's and 1960's.

TABLE 1 Some major organic chemical inventions

1930 - 1940	Polystyrene
	Perspex
	Nylon
	Polyvinyl chloride
1940 - 1950	Polyethylene
	Polyurethane
	Penecillin
	DDT
	Selective weed killers
	Epoxy resins
	Polyester
1950 - 1960	Polypropylene
1960 - 1970	?
1970 - 1980s	Biotechnology

The chemical industry is multi-disciplinary in terms of the skills needed to develop inventions into major successful innovations. Chemical research and development need to be complemented by the skills of the physicist and biologist for example, and the chemical engineer, marketing and financial experts must all work with them as a team to transform an invention into a successful innovation. The chemical industry has a good record of managing innovation in this respect.

Innovation is not confined to the products of the chemical industry. Equally important for growth and profitable business is process-oriented innovation aimed at process improvement. This includes improving technology, making plants more efficient, using cheaper raw materials, and operating continuously on a larger scale. Such improvements reduce costs and improve profit margins or enable prices to be reduced. One of the key aspects of strategic management in the chemical industry is maintaining the appropriate balance in allocating resources between improving the competitive position of existing products by innovation aimed at cost reduction, and more fundamental longer term research aimed at creating entirely new opportunities in the market place.

The past development of the chemical industry has been very capital and cash flow intensive. The industry has a record of relatively large budgets for research and development ranging from more than 10% of sales in pharmaceuticals and agricultural chemicals to 5% in dyestuffs and polymers and to 2% in bulk and basic chemicals. Many of course would argue that these budgets are not large enough.

The capital investment in terms of plant and equipment needed for chemical production is generally high so that altogether large amounts of money have to be tied up in a new venture before any return is obtained. However, the large financial risks associated with innovative developments have not deterred the chemical industry from innovation-based growth. Instead it has sought to reduce these risks as much as possible by the careful management of new ventures, including the use of detailed procedures for screening and selecting inventions for development, for forecasting and evaluating their commercial potential, and generally for ensuring that a new venture is designed and planned to maximise its chances of commercial success. Chemical industry innovation proceeds in a careful, thorough and deliberate manner, taking full account of all its perceived implications. This can be contrasted for example with the breakneck speed of developments in the microcomputer and software industries at present, where failure is common place but the individual financial risks are much less.

In the past the success of the chemical industry in terms of growth and profitability has in turn smoothed the way for the financing of new innovative ventures. The industry has acted significantly as its own banker by reinvesting profits in new projects. Where external funding has been needed the record of the industry has attracted it without too much difficulty.

The adaptability of the chemical industry is illustrated by its international features. Before the first world war Western Europe and the U.S. between them accounted for about 90% of world chemical production; in the interwar period U.S. domination increased further. However immediately following world war two the situation started to change dramatically, with the rise of chemical industries in Eastern Europe and in Japan as part of their general industrialisation programmes. In more recent years several other countries have started to become significant producers. As a result the positions of the U.S. and Western Europe have been eroded, so that by 1979 between them they only accounted for 54% of world chemical output, and Japan had taken over from Germany as the world's second largest chemical producer, after the U.S.

The market for chemicals is an international one and the export trade is a key feature of the industry. As the major producers, Western Europe and the U.S. also originally dominated the world trade in chemicals. In the interwar years countries became protectionist and erected trade barriers and this resulted in a dramatic decline in the world chemical trade, from 27% of production in 1913 to 15% in 1929 and down to only 11% in 1937. Trade in chemicals only recovered after the second world war in the freer economic environment of the 1950's. Since then the international trade in chemicals has grown much faster than the growth of production and has provided a significant added impetus to the industry in the major exporting regions.

CHEMICAL INDUSTRY SINCE THE MID 1970s

Reference was made earlier to the fact that since the 1950s the emergence of inventions and discoveries with the potential of developing into major innovations leading to entirely new areas of business for the chemical industry has declined. This is not to say of course that invention and innovation have disappeared, but that they have been directed more at process and product improvement in existing areas rather than in opening up entirely new business opportunities. The businesses built on earlier innovations are becoming mature; substitution for more traditional materials and products is well advanced and saturation is being reached in their markets. In these areas the fortunes of the chemical industry now reflect more closely those of its customer industries.

We are all only too aware of the trauma for the industry since the mid 1970s. The postwar period of rapid growth and high profitability had produced an atmosphere of complacency in the industry based on the confident assumptions that supplies of cheap raw materials and energy would continue, that capital would continue to be easily available, and that the continuing expansion of markets and the world economy would persist uninterrupted. Because of the central place of the chemical industry in economic activity its future was therefore guaranteed.

Those happy days ended with the oil price hike of 1973 and the repercussions which followed. Not only did the raw material and energy costs of the industry shoot up, but the general economic recession which was also triggered severely affected the chemical industry's markets as well. The optimistic expectations of the early 1970's, that the growth of the 1950s and 1960s would inevitably continue, disappeared in the hard reality of the new situation. The 10% annual growth rate of the 1960s declined to 5% in the 1970s and touched zero at the beginning of the 1980s. Fortunately there are now signs that it is beginning to recover.

Since the mid 1970s the industry has been grappling with urgent problems of short term cash flow and profitability which have resulted from rising costs and lower real product prices, and from over-capacity through previous market expectations disappearing. Expenditure on research and development actually declined during the 1970s and was in any case concentrated on cost reduction projects to improve the profitability of existing businesses.

The industry is now emerging from this period, during which its immediate problems have dominated longer term strategic planning. The moves towards rationalisation and improved productivity which have been taking place should enable more attention to be paid once more to laying the foundations for the industry's long term growth and prosperity.

CREATING CHEMICAL INDUSTRY'S FUTURE

There are two facets to the future of the chemical industry. One relates to the future of existing business and the other, in the longer term, relates to the generation of completely new business areas. The latter is very dependent on the former since the resources needed for long term innovation have to be generated by current business.

The industry is beginning to recover from the shake-out of the last thirteen years. The demand for what are now mature products should follow the trends of general economic activity and hopefully this implies at least modest growth. However the need for more

energy-efficient and cost-effective processes will continue. The implication for raw materials sources is a major field of activity and is being discussed elsewhere at this Symposium. In the next round of capital investment substantially more efficient processes are needed than the established ones. Significant changes are likely to come from altogether new approaches rather than from attempts to modify existing processes. As well as the need for operating cost reduction there is also pressure to find ways of reducing capital costs. In the future straightened circumstances of the industry capital will continue to be in short supply and therefore available funds must be used as effectively as possible. Process intensification, leading to the design of smaller, cheaper plants for the same output, is already receiving increasing attention. There is thus a very real need for innovative activity relating to existing business areas to continue and to increase, in order to recover and maintain their profitability in the present and future environment which is so different from that in which they originally developed.

If the chemical industry is ever to resume a rate of growth greater than that related to its existing product range this will depend on the generation of new business areas through successful major long term innovation, as has happened in the past. The process of innovation, from invention to successful new business, is a long one and, because of the recent disappointing performance of the industry in this respect, there is also some catching up to be done, which implies even greater resources and effort should be made available for this purpose.

In what directions should this effort be made? There are many experts at this Symposium who are better qualified than I am to make such predictions but I will venture a few general suggestions which relate to the economic circumstances of the industry. The era of innovative large tonnage products forming the basis of new profitable businesses is probably gone for good. The high cost of such development and the risks and uncertainty involved would not be justified by the relatively small margins which such products could earn on the investment needed. Major successful innovation in the future will instead be directed at small volume, high added value products which are less dependent on raw material and energy costs and less capital intensive in their production.

One major area of promise into which the chemical industry is already moving is of course biotechnology. In this it is following its previous tradition of combining the skills of the chemist with other disciplines in order to expand the chemical industry into new areas. Considerable resources are being devoted to research and development in biotechnology, and especially in molecular biology and molecular genetics. This is a good example of an area where innovation is directed at the high added value specialty products referred to earlier. Initial efforts appear to be directed towards the cost-effective synthesis of vaccines, antibiotics and other pharmaceutical products. There is also the potential in the future for spawning other new products, new processes and new businesses in areas such as food production, and also based on wholly novel approaches to other types of organic synthesis. The potential for biomass as a cost-effective renewable resource for a range of bulk chemicals is illustrated by just two examples of innovations which could revolutionise the situation, and agriculture as well. These are the possibility of genetically transferring the ability to fix nitrogen to a variety of crops, and the genetic optimisation of photo-synthesis.

Chemistry and chemists, if not the chemical industry, will also continue to extend their roles in other areas of manufacture. There is a considerable amount of chemistry involved for example in the production of micro-electronic components or in building a nuclear power station, but these are not usually regarded as part of the chemical industry. These roles involve placing relatively small numbers of atoms or molecules with precision and keeping them where they belong, whereas the chemical industry is conventionally regarded as dealing with the controlled annual production of around 10^{35} or more similar molecules reliably and economically.

The management of successful innovation and of business development has already become more difficult in recent years and this trend is likely to continue. In some sectors such as fibres, plastics and petrochemicals a major factor for successful business is a detailed understanding of international politics and the control of finance and markets by governments, coupled with the ability to expand, contract, merge and generally adapt as necessary. Management must also know their processes and products in great technological detail so that they can fine tune them to international market perceptions.

The uncertainties of the future in terms of economic trends, markets, inflation, currency movements, etc. have to be recognised and allowed for in development and in investment decision making. The economic evaluation techniques of the previous era now appear simplistic and inadequate as bases for decision-making in the face of these continuing uncertainties. More thorough analysis of competition, strengths, weaknesses, and the investigation of a wide range of possible scenarios is needed, coupled with a strong faith that, come what may, the chemical industry has a worthwhile future and the first priority is to ensure a substantial stake in that future.

WORLD PERSPECTIVE FOR CHEMICAL INDUSTRY

The patterns of world chemical production and trade are changing, as referred to earlier, and these trends are likely to continue at an increasing rate. Rapidly industrialising countries such as India and Brazil are expected soon to become substantial chemical producers and other developing countries will follow. Chemical output in the third world is growing at a faster rate than in the present major chemical producing countries. Although they are starting from a smaller base, their absolute expansion may amount to about a quarter of the world increase in chemical production by the end of the century.

Developments in the third world are tending to concentrate on bulk commodity chemicals, especially where these can be related to local sources of raw materials. As new or alternative raw materials come into economic use (e.g. coal, biomass) they will stimulate chemical industry growth in new geographical regions. Complementary to this the older industrialised chemical producers (Europe, U.S., Japan) are moving away from commodity chemicals and towards high added value specialty products of an innovative nature, based on new or advanced technology. Country and company rationalisation of production is already occurring under strong economic pressures for more efficiency in production. This growing pattern of rationalisation and specialisation has to be accompanied by further growth in world trade in chemicals, growth in both magnitude and complexity. This in turn requires political and economic conditions for free trade and stable currencies.

There is also another facet to this further internationalisation of the chemical industry which may turn out to be the most important of all in terms of technological change. Almost all the knowledge, expertise and knowhow for innovation in the chemical industry, in products, processes and equipment, originate from research, development and design activities in the traditional chemical producing regions of Western Europe, the U.S. and more recently Japan. This situation is likely to continue for many more years, at least until the emerging chemical industries in other regions are technologically and financially strong enough to support their own research, development and associated activities on a sufficiently large scale. Thus the importance of the technology transfer of chemical industry expertise from its originators in the traditional chemical producing countries to potential users on a world scale should grow considerably as chemical production expands in other regions.

By analogy with the computer industry this expertise dimension of the chemical industry is sometimes called 'chemical software' as contrasted with 'chemical hardware'. It covers the whole range of knowledge, expertise and knowhow which is potentially marketable within the chemical industry. Examples are given in Table 2.

TABLE 2 Examples of potentially marketable chemical software

Information from	Other expertise and knowhow
Fundamental research	Product support services
Analytical research	Technical marketing information
Product research	Process Licensing
Process research	Process & equipment design & engineering
Product development	Instrumentation and process control
Process development	Computerised operation

Just as the computer software industry is expanding to be greater in value than the computer hardware industry, so the value of the chemical software business is becoming an increasingly important aspect of the chemical industry's exports from Western Europe, the U.S. and Japan. If the computer industry analogy is able to be taken further, it may also be significant that the price of computer software has tended to rise while that of computer hardware has come down.

Bearing in mind that for many years most new chemical industry developments will be based on technology originating in existing centres of research and development, this invisible trade in technology transfer is likely to be exploited to the full as it is beneficial to both the originator and receiver industries.

CONCLUSION

The main business of this Symposium is new technology relating to various aspects of organic chemistry. What I have tried to do is to provide a view of the chemical industry, as the user of this technology, in its economic and business environment and to indicate some of its problems and potential. The range and implications of the developments being discussed at this Symposium are very encouraging in terms of providing major innovations which are the lifeblood of the chemical industry in ensuring its future growth and prosperity.